

The Impact of Transport Infrastructure on Productivity, Employment Center Growth, and Land Values in the Seoul Region

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Declaration

I, Jae Kwang Lee, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

Transport infrastructure investment has been a pillar of urban and regional development strategies as well as a key policy tool for economic growth in the European Union, the United States, China and many other countries. It has also been regarded as one of the key planning tools for tackling a range of urban and regional issues. However, the link between transport infrastructure investment and economic performance remains unclear. Debates regarding the magnitude of the effects of transport infrastructure investment on economic performance have been ongoing for decades, and it is still unclear how and to what extent transport infrastructure investment leads to increased economic performance and economic development. This knowledge gap makes it difficult draw any reliable conclusion about the impact of transport infrastructure investment and makes it difficult for policy makers to evaluate transport infrastructure projects. In addition, little is known about the economic effects of transport infrastructure at the micro level. In the present research, sophisticated statistical and spatial methods have been used to better understand and analyse the impact of transport infrastructure on economic performance.

This research aims to provide reliable empirical evidence regarding the effect of transport infrastructure on three aspects of economic performance: productivity, employment centre growth and land values. The objective of this research is to (1) develop empirical strategies for the three analyses and create various accessibility measures and spatial variables, (2) investigate the link between transport-induced economic effects and firm productivity, (3) examine the relationship between transport-induced labour accessibility and the growth of employment centres and (4) explore the impact of rail transit investment on residential and commercial land values.

The results reveal that transport infrastructure is influential in promoting productivity, employment centre growth and land values. Specifically, (1) transport-induced workforce accessibility is positively related to firm productivity, (2) transport-induced labour accessibility is a determinant of job growth in employment centres and (3) the completion of rail transit leads to positive yet modest proximity and accessibility effects on residential and commercial land in the vicinity of rail stations as well as on land in the wider neighbourhood of rail stations. Transport infrastructure can lead to an

increase in economic performance and economic development. The economic effects of transport infrastructure include more than just time-saving benefits. It not only reduces travel costs but also increases productivity, land values and job growth in employment centres. The spatial extent of the economic effect of transport infrastructure is not confined to the area near the transport network but can extend to the wider neighbourhood beyond the vicinity of the transport network.

Impact Statement

Transport infrastructure is a cornerstone of urban and regional development strategies. Despite its importance, it remains unclear whether transport infrastructure improves economic performance. The present research has sought to fill this knowledge gap in the literature by investigating three aspects of economic performance in relation to transport infrastructure. Its key finding is that transport infrastructure is important in promoting land values, firms' productivity and employment centre growth, which suggests that transport infrastructure can improve economic performance and economic development. These findings can be beneficial to researchers and planners within academia who are interested in the debates on the link between transport infrastructure and economic performance.

The benefits outside academia are twofold. First, policy makers who seek to develop more refined public policy regarding transport infrastructure investment can benefit from the results of the present research. Policy makers emphasise an effective transport policy to keep the economy vibrant in times of recession and to stimulate economic growth through job creation. An effective public policy is underpinned by empirical evidence that indicates how the policy will affect its main beneficiaries. The present research provides robust empirical evidence, upon which public policy may be based, regarding how and to what extent transport infrastructure investment improves economic performance.

Second, the analytical tools and methods developed in the present research can be beneficial in professional practice when the costs and benefits of a transport infrastructure project are evaluated. A professional practice precisely evaluates the costs and benefits of a transport infrastructure project to determine whether it is beneficial to its stakeholders and society. The exact evaluation of a transport infrastructure project requires accurate analytical tools and methods to obtain precise measures of its feasibility. The present research provides several key analytical tools and methods developed in the process of analysis, ranging from a method for measuring travel costs to one for estimating firm productivity in relation to transport infrastructure.

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Abbreviation

BRT: Bus Rapid Transit
CBD: Central Business District
CPI: Consumer Price Index
DID: Difference-in-difference Model
FAR: Floor Area Ratio
GIS: Geographical Information System
GMM: Generalized Method of Momentum
ICT: Internet and Communication Technology
KLDC: Korea Land Development Corporation
KS: Kolmogorov Smirnov Test
KSIC: Korea Standard Industrial Classification
KTX: Korea Train Express
LED: Light-Emitting Diode
LIDA: Local Industrial Development Act
LISA: Local Indicator of Spatial Correlation
LRT: Light Rail Transit
LTE: Long-Term Evolution
MLTM: The Ministry of Land, Transport and Maritime Affairs
NASA: National Aeronautics and Space Administration
NGII: The National Geographic Information Institute
OLS: Ordinary Least Square Regression
SCR: the Seoul Region
SGMP: Seoul Growth Management Policy
SMRPA: Seoul Metropolitan Area Readjustment Planning Act
TFP: Total Factor Productivity
VIF: Variance Inflation Factor

1. Introduction

Transport infrastructure investment has been a key policy tool for economic growth and is a pillar of urban and regional development strategies in many countries. It has also been a significant planning tool for addressing a range of urban and regional issues and developing the spatial economy. Political leaders and decision makers in the EU, US and China have placed great emphasis on providing adequate transport infrastructure as a means of promoting economic development, reducing disparities and congestion, and facilitating territorial cohesion. In 2011, President Barack Obama announced an investment plan that included an infrastructure package worth over \$60 billion that sought to reduce carbon pollution, strengthen the economy, and make transportation easier for American families (Whitehouse, 2016). Similarly, President Xi Jinping of China in 2014 announced a transportation investment plan to promote low-carbon, intelligent development and create a modern, comprehensive transport system. The ultimate aim is to support the national 'One Belt, One Road' strategy to integrate Beijing, Tianjin, Hebei and the Yangtze Economic Belt into one large region. In the EU, over 28% of the European Regional Development Fund (ERDF) and Cohesion Fund were devoted to infrastructure investment in the period between 2007 and 2013. About €76 billion in the ERDF budget was allocated solely to transport infrastructure (European Commission, 2008).

It remains unclear, however, whether an enormous investment in transport infrastructure increases economic performance or delivers economic development. The results of theoretical and empirical analyses of the outcomes of transport infrastructure investments are mixed, making it difficult to draw any convincing conclusions about the impact of transport infrastructure and making it hard for policymakers to evaluate transport infrastructure projects (Crescenzi & Rodríguez-Pose, 2012; Funderburg, Nixon, Boarnet & Ferguson, 2010; Leduc & Wilson, 2012; Redding & Turner, 2015). It remains unclear how and to what extent transport infrastructure investment leads to an increase in economic performance and economic development.

The current debate demands better, more convincing empirical evidence to guide policymakers in making decisions about transport infrastructure investment. Reliable evidence on the extent to which transport infrastructure influences the spatial economy

can aid the assessment of the costs and benefits of implementing transport infrastructure projects.

Problem Statement

Decision makers in cities and regions in the world are increasing budgets for transport infrastructure development to address serious issues in urban and regional areas, such as congestion, deteriorating urban areas, spatial disparities, rising unemployment and falling economic growth (Asian Development Bank [ADB], 2017). The accessibility provided by transport infrastructure helps people to secure jobs, gives access to various services, and allows businesses to interact with customers and producers. Yet, it is not simply the case that all investment in transport infrastructure will automatically bring about benefits. In fact, sub-optimally planned transport infrastructure can have negative impacts on the economy and on society.

Decision makers' concern about transport infrastructure investment is whether or not it is cost-effective as a strategy for making better cities and regions. A key issue here is the economic effects that transport infrastructure investment can provide, although other social and environmental effects of transport infrastructure are also considered crucial factors. These economic benefits essentially determine the viability of transport infrastructure investment. Therefore, it is important to obtain empirical evidence for these economic effects in order to guide decision makers in planning transport and making the right decision on transport infrastructure investment.

The economic effects of transport infrastructure are twofold: user benefits and wider economic benefits (Vickerman, 2007). User benefits directly arise from reduction in travel costs due to the provision of transport infrastructure (De Palma, Lindsey, Quinet & Vickerman, 2011a), whereas wider economic benefits indirectly stem from a change in the spatial distribution of economic activities due to transport infrastructure improvement (Graham, 2007a). The related literature suggests that the impact of transport infrastructure improvement is wide ranging, so that understanding its contribution to economic performance requires both user benefits and wider economic benefits (productivity and investment/employment) to be assessed (Venables, Laird & Overman, 2014).

Nevertheless, less attention appears to be paid to the wider economic benefits of

transport infrastructure at the micro level, especially in the Asian context. Most existing studies on the economic effect of transport infrastructure are at the macro level and have mainly focused on the user benefits of investment in transport infrastructure. Only a handful of studies have been conducted to explore the wider effect of transport infrastructure improvement on firm productivity. In addition, the existing literature provides little evidence about the wider economic benefits (productivity and employment) of transport infrastructure at the micro level in the Asian context. This gap in the literature requires the development of a framework to evaluate transport projects by exploring their wider economic effects. Further studies are also needed to assess the user benefits of transport infrastructure investment in the Asian context.

Existing studies have tended to rely on relatively simple accessibility indicators to capture the economic effects resulting from transport infrastructure. The quality of accessibility indicators is a crucial factor for transport analysis, because it is directly linked to how accurately the economic effects induced by transport infrastructure are captured. Yet, only a few studies have used the actual transport network to measure travel costs between locations. Thus, there is a need to develop more advanced accessibility indicators for spatial analysis.

Research Objective

The current study aims to explore the effects of transport infrastructure on economic performance at the micro level, using the Seoul region in South Korea, one of the largest metropolitan area in the world, as a case. This will provide empirical evidence of the micro-level economic effects of transport infrastructure investment in the Asian context, which is currently lacking in the literature. The study focuses on both user benefits and wider economic benefits of transport infrastructure improvement to fill the gap in the literature. Specifically, the current study investigates three aspects of economic performance: productivity, employment and land values. The work is organized around the classification of the effects of transport infrastructure presented by Venables et al. (2014). The study also aims to develop more advanced accessibility indicators to better capture the economic effects resulting from transport infrastructure.

I contribute to the debate by providing empirical evidence of both user benefits (land values) and wider economic benefits (productivity and employment growth) of transport

infrastructure improvement. The current study will be essential for decision makers who are considering investment in transport infrastructure as a tool to address urban and regional issues and a strategy for economic growth and integration.

I focus on developing empirical strategies and then applying them to the case of the Seoul region to explore how and to what extent transport infrastructure impacts firm productivity, employment centre growth and residential and commercial land values. With these objectives, three research questions are posed: (1) How and to what extent are transport-induced economic effects related to the productivity of manufacturing firms in the Seoul region?; (2) How and to what extent is transport-induced labour accessibility related to the growth of employment centres in the Seoul region?; (3) How and to what extent does rail transit investment affect residential and commercial land values?

Research Structure

The rest of this research thesis is structured as follows: Chapter Two reviews the literature relevant to the research topic. Starting with a basic introduction to the characteristics of transport infrastructure, it discusses methods of measuring its capacity and its economic effects. Following that general discussion of the effects of transport infrastructure, the chapter offers theoretical arguments for the three analysis chapters, presenting theories relevant to each of the research questions. The chapter concludes with a summary of previous empirical evidence for the individual analysis chapters.

Chapter Three introduces the case area, the Seoul region, and justifies its selection. It provides background information on the area's population and employment and on the transport infrastructure network in the region. This chapter also describes the methodology and data used in this thesis. It offers a rationale for the use of a quantitative approach and the way to interpret the findings obtained from a series of regression analyses. The analytical tools used for analysis are also introduced, together with the specific techniques and models employed in the analysis chapters.

The next three chapters explore the three research questions individually. Chapter Four investigates the relationship between transport-induced economic effects and a firm's productivity, aiming to provide evidence of how and to what extent firm's productivity is

determined by transport-induced economic effects. Using the actual transport network and a disaggregated dataset, it constructs a measure of workforce accessibility to capture the economic effect generated by transport infrastructure. It creates instrument variables to correct for the endogeneity of the benefits of accessibility and develops a two-stage empirical approach in which various regression models are used to assess the degree to which firm's productivity changes in relation to variations in transport-induced workforce accessibility. It also tests for how the productive effects vary by manufacturing sub-sectors with diverse production features.

Chapter Five examines the relationship between transport-induced labour accessibility and the growth of employment centres, aiming to provide evidence of how and to what extent transport-induced labour accessibility affects job growth in employment centres. It also analyses how and to what extent the growth of employment centres is determined by factors such as employment density, industrial growth and access to transport facilities. The clusters of employment in the Seoul Region are identified using a disaggregated dataset, and measures of absolute and relative labour accessibility and access to transport facilities are constructed on the basis of the actual transport network. This chapter develops a panel model for the growth of employment centres as a function of population, employment, access to transport facilities, labour accessibility and industrial growth.

Chapter Six investigates the impact of rail transit investment on residential and commercial land values, aiming to provide evidence of how and to what extent land values vary by diverse types of land use in relation to rail transport infrastructure investment. It also analyses how the accessibility benefits vary by lands at different price levels. Measures of proximity and accessibility are constructed to capture changes in both proximity to rail stations and job accessibility before and after the completion of Seoul Metro Line 9. Three types of regression model are applied to analyse the dynamic relationship between rail transit, land use, various characteristics of land and land values. Specifically, this chapter tests for the presence of neighbourhood effects resulting from the completion of rail transit investment in addition to its proximity effects. It then examines the degree and spatial extent of both the proximity and neighbourhood effects and investigates how these effects vary with diverse types of land use and how they are associated with residential and commercial land values at various price levels. The chapter provides policy implications drawn from

these results.

Finally, Chapter Seven concludes this research paper by summarizing its findings and addressing several implications for transport and planning policies. The findings of the three analysis chapters are summarized to generate overarching evidence of the economic effects of transport infrastructure. The chapter also considers several implications that may contribute to the factors that are considered when making and implementing transport and planning policies and offers recommendations for further research and describes several limitations of the research.

2. Literature Review

This thesis turns to reviewing theories and empirical evidence relevant to the three research questions. Starting with a general discussion of the features of transport infrastructure, the current chapter presents methods for measuring transport infrastructure and its economic effects. Two types of economic effects in relation to transport infrastructure are discussed: user benefits and wider economic benefits. I first provide an overview of the impact of transport infrastructure and factors involved in its provision.

Then, three strands of the literature related to the three analysis chapters are reviewed. The first section reviews theories on the link between transport-induced economic effects and firms' productivity, discussing in detail the mechanism by which firms and workers benefit from transport infrastructure improvements. This is followed by a review of previous empirical studies. The second section provides a theoretical discussion on the link between transport-induced labour accessibility and the growth of employment centres, with a review of previous empirical studies. In the last section, the link between transport infrastructure investment and land values is discussed. A summary of the empirical evidence is presented at the end of this chapter.

First, I provide an overview of the impact of transport infrastructure and factors involved in its provision. This overview situates this thesis in the debate on the effect of transport infrastructure investment. The impact of investment in transport infrastructure is normally grouped into three types, as shown in Figure 2-1, according to whether it is associated with economy, with the environment, or with society. Distributional impact can be grouped together with the social impact.

These three impacts are influenced by various factors involved in the provision of transport infrastructure, such as the macro-economic condition, political and cultural context, planning strategy, and the level of technology. To some extent, these factors are not static but dynamic, interacting with the current situation in the location of transport infrastructure projects. As those factors influence potential impacts of transport infrastructure projects, the validity of transport infrastructure projects is to some extent determined by a change in those factors. For example, if economic and political conditions favouring transport infrastructure investment are established, a

transport infrastructure project would be likely to gain permission from decision makers. Yet, since the factors may change over time, whether transport infrastructure investment is viable or not may change accordingly.

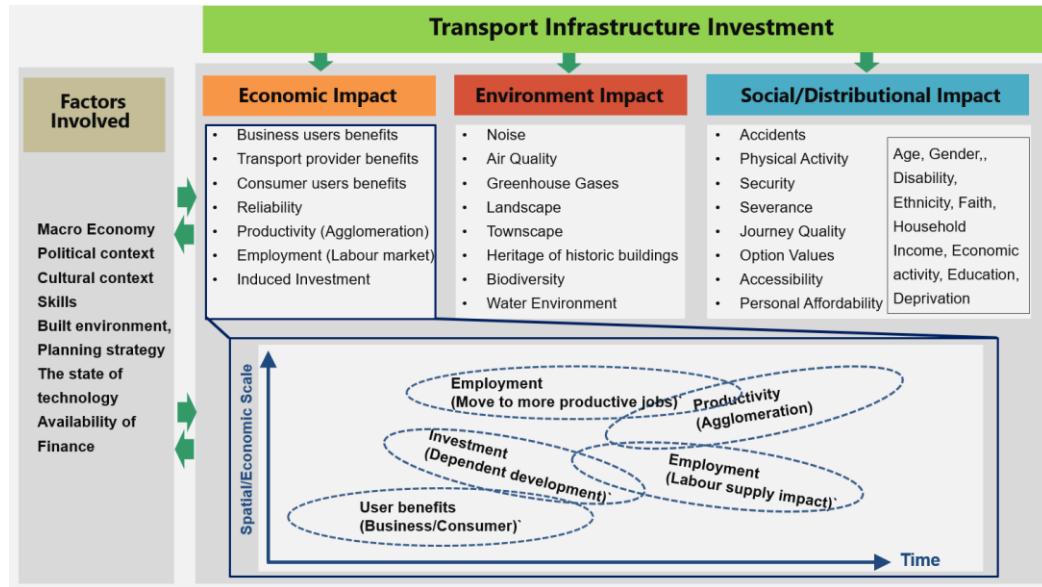
In general, seven items can be considered as the economic impacts of transport infrastructure investment, as presented in Figure 2-1. These items are largely separated into user benefits, such as business user benefits and consumer user benefits, and wider economic benefits such as productivity, employment and induced investment.

These economic impacts are time and spatial/economic scale specific, as shown in the graph at the bottom of the diagram in Figure 2-1. Some economic benefits tend to take place at small spatial/economic scale in the short term rather than at large economic scale in the long term. For example, user benefits typically take place immediately after transport infrastructure investment, which means these economic benefits tend to be short term. Also, the spatial extent of user benefits tends to be moderate (small to medium) compared to other economic effects. By contrast, employment and investment economic effects take place at the medium spatial/economic scale in the medium term. Productivity and employment effects are the largest in terms of the spatial and economic scale and these effects tend to take place in the long term.

The thesis presented here focuses on the economic impacts of transport infrastructure, although its environment and social impacts are considered essential in the evaluation of transport projects. Using Venables' classification, both user benefits and wider economic benefits (productivity and employment effects) are covered in separate analysis chapters.¹ User benefits (land values) are explored in Chapter Six and the productivity and employment effects are examined in Chapter Four and Five, respectively.

¹ Venables' classification of the economic effects of transport infrastructure is user benefits, productivity effect and investment/employment. For the investment/employment category, this thesis focuses mostly on the employment effect.

Figure 2-1. The Impacts of Transport Infrastructure Investment



Source: the author

Transport infrastructure investment affects the real incomes of individuals as well as those of regions and the country. The impacts are largely grouped into three elements according to whether they are associated with welfare, gross domestic product (GDP) or both as shown in Figure 2-1 (Department for Transport [DfT], 2018; Venables et al., 2014). Gross domestic product measures the value of marketable output and is often used as an indicator of economic health in a given area. Many welfare gains are counted in GDP, but some are not. Business user benefits have GDP impact through improving productivity in the economy, but they also have a welfare impact.

Figure 2-2. Transport Infrastructure Impacts, Welfare, and Gross Domestic Product

Welfare	Welfare & GDP	GDP
<ul style="list-style-type: none"> Social Impact Safety Impact Environment Impact Leisure/Commuting User-benefits 	<ul style="list-style-type: none"> Business User-benefit Imperfect competition <ul style="list-style-type: none"> Agglomeration Labour market effect (tax wedge) Dependent development 	<ul style="list-style-type: none"> Labour market effect (net of tax)

Source: the author

2.1. The Characteristics of Transport Infrastructure

This section begins by discussing transport infrastructure features as quasi-public goods (Section 2.1.1). This is followed by a discussion of the ways in which the capacity and stock of transport infrastructure can be measured (Section 2.1.2). Section 2.1.3. provides a discussion of the measure of accessibility as a tool for evaluating the effects of transport infrastructure projects.

2.1.1. Transport Infrastructure as Quasi-Public Goods

Public goods are defined as products or services that all people enjoy in the sense that each individual's consumption does not subtract from any other individual's consumption of the same good (Samuelson, 1954, p. 387). Specifically, goods that have all of the following characteristics are regarded as pure public goods: non-rivalry in consumption, non-excludability, and non-rejectability (Barr, 1993). An example of public goods are the defence and health services in the UK. Goods that have some, but not all, of these characteristics are considered quasi-public goods.

Transport infrastructure can be classified as a quasi-public good, because it is characterised by non-excludability and non-rivalry in consumption. Travel services provided by transport infrastructure are available to all consumers who are willing to travel via the infrastructure and such services are nearly unlimited as long as they are well maintained by the service provider. The feature of non-rivalry in consumption refers to the idea that commuters do not need to care about the initial construction costs for the transport infrastructure, because they only have to pay the fee for the service as they use it.

That said, transport infrastructure can be excludable and rival in certain circumstances. For example, if travellers have to buy a ticket or pay a toll, the infrastructure is excludable. If they have assigned train seats, other travellers cannot use these seats, making the infrastructure rival. Whether transport infrastructure is excludable and rival can differ, depending on locations and countries. In some countries where travellers do not have to buy a ticket for public transport, transportation is non-excludable. In the same way, transport infrastructure is non-rival in some cities or regions where train seats are not assigned.

Because of the aforementioned characteristics of transport infrastructure, a sufficient level of public transport infrastructure is unlikely to be supplied by the private sector. Public transport infrastructure cannot be provided as exclusive bundles of products for each customer and individuals' preferences for the public transport infrastructure are scarcely revealed enough to give private entrepreneurs signals for business opportunities. Historical records show that the public sector has been a key player in providing transport infrastructure in most cases (Taylor, 1951), although a large amount of transport infrastructure was provided by the private sector in Britain in the 19th century.

The fact that the private sector tends to work inefficiently in transport infrastructure development also points to a key role of the government in providing public transport infrastructure. Especially, the non-excludability of public goods discourages the private sector from investing in transport infrastructure development as public goods, because opportunities to make a profit from transport infrastructure are, by and large, slim for the private sector (Cullis, Jones & Jones, 2009, pp. 45-70). For this reason, the government intervenes in the transport infrastructure provision to correct for inefficiencies in the market system. Decisions on how much, when and where to provide public transport infrastructure are determined by either the public sector or public-private partnerships (Siemiatycki, 2009). Given that transport infrastructures are mainly supplied by the public sector, decisions are not made at an individual level but rather at the societal level. This is the point at which planning involves the provision of public transport infrastructure.

Yet, the inefficiency of the private sector is not the only reason for the public sector's intervention in the provision of public transport infrastructure. The public sector also develops transport infrastructure to build better cities and societies. It puts a great deal of effort into delivering transport infrastructure that can give communities and businesses more economic and social opportunities. Transport infrastructure is an essential part of comprising cities and communities, together with other valuable elements, such as policy, culture, housing, land use and environment.

2.1.2. Methods for Measuring Transport Infrastructure

Transport infrastructure is typically measured by two methods that are based on

different units of measurement: physical and monetary units (Rietveld & Bruinsma, 2012). When transport infrastructure is measured as physical units, it is evaluated by either its capacity or its stock. Physical units are probably the simplest way to assess transport infrastructure in the form of figures and are thus frequently used in research. For example, the total length of the railway system is widely used to demonstrate its capacity to transport passengers and products.

Monetary units, by which the capacity of transport infrastructure is represented in terms of monetary values, are also used to evaluate transport infrastructure. The amount of capital invested in building transport infrastructure is a typical means of measurement for this category. Note that it is important for this unit to be discounted to the present value because of depreciation. Compared to physical units, measurement based on monetary units allows different transport infrastructure projects to be compared because they can be assessed with the same monetary unit.

While both physical and monetary units are useful for evaluating the capacity or stock of transport infrastructure, they tend to have several limitations in accounting for the differences in the characteristics of transport infrastructure. For example, the total length of transport infrastructure does not explain whether it is in operation. Also, the capacity of transport infrastructure for the same length may differ due to its condition and features, such as single tracks or double tracks. Similarly, transport infrastructure costs may differ by cities and regions. When transport infrastructure projects with different construction costs are measured in monetary units, they may produce biased outcomes.

Table 2-1. Regions with the Highest Motorway Density in Europe

Rank	Regions	Length of motorways (km)	Land area (km ²)	Motorway density
1	Bremen	80	419	191
2	Zuid Holland	362	2805	129
3	Utrecht	177	1382	129
4	Noord-Holland	296	2664	111
5	Wien	43	395	109
6	Hamburg	81	755	107
7	Noord-Brabant	492	4913	100

8	Limburg	213	2148	99
9	Comunidad de Madrid	783	7967	98
10	Saarland	240	2569	93
11	Berlin	77	892	86
12	Prov. Viaams-Brabant	175	2102	83
13	Zurich	138	1661	83
14	Gelderland	393	4968	79
15	Prov. Antwerpen	220	2796	79
16	Prov. Hainaut	284	3775	75
17	Flevoland	103	1413	73
18	Nordwestschweiz	139	1859	71
19	Liguria	375	5416	69
20	Prov. Liege	266	3844	69

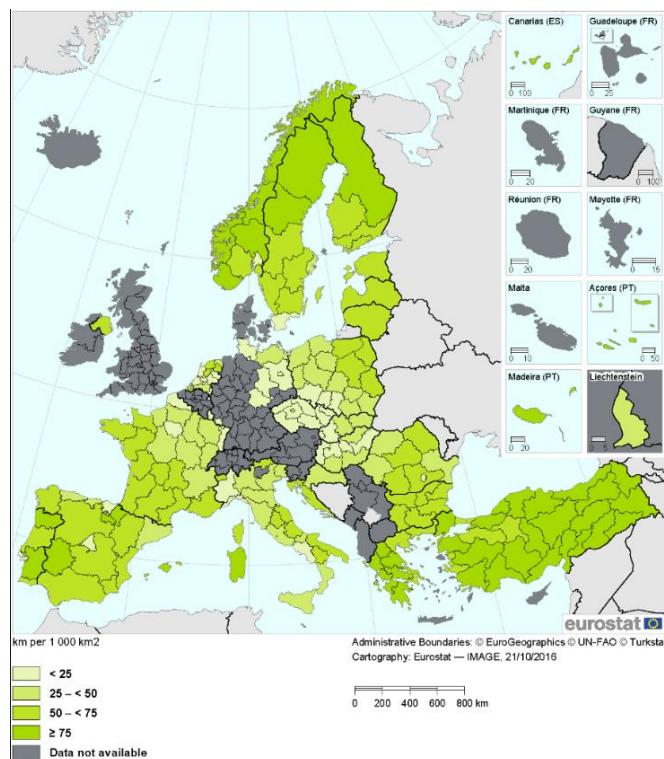
Source: Eurostat (2014)

Another way to measure the capacity and stock of transport infrastructure is via the density of transport infrastructure (Rietveld & Bruinsma, 2012). One of the advantages of this measurement is that it enables the standardisation of the capacity of transport infrastructure such that transport infrastructure projects can be mutually compared. Since each transport infrastructure project needs to be standardised, two types of standardisation techniques are normally used for the density-based measurement: standardisation by area and by population. Table 2-1 shows the case in which density units are used to measure motorway transport infrastructure in Europe. In a similar vein, Figure 2-3 shows the case in which the density of railways is used to measure rail transport infrastructure. I use European map and statistics simply because it is better suitable to explain how the density measure can be used in the measurement of transport infrastructure.

The three measurements of transport infrastructure mentioned above may be useful for representing the level of transport infrastructure stock as well as the degree of changes in the stock. However, these measurements have some limitations in that they do not account for both the quality and characteristics of transport infrastructure. Also, to a certain extent, the accuracy of these measurements is subject to how the spatial distribution of socio-economic activities is considered and how the spatial structure of transport infrastructure is taken into account in the measurement (Rietveld & Bruinsma, 2012). Further, while these measurements can represent the capacity of transport

infrastructure, they have little relevance to how transport infrastructure impacts a firm's productivity, employment centre growth and land values. For these reasons, the measure of accessibility has instead been used to evaluate the impact of transport infrastructure development in the transport literature.

Figure 2-3. Railway Density in European Regions



Source: Eurostat (2016)

2.1.3. The Concept of Accessibility

2.1.3.1. Accessibility Measures

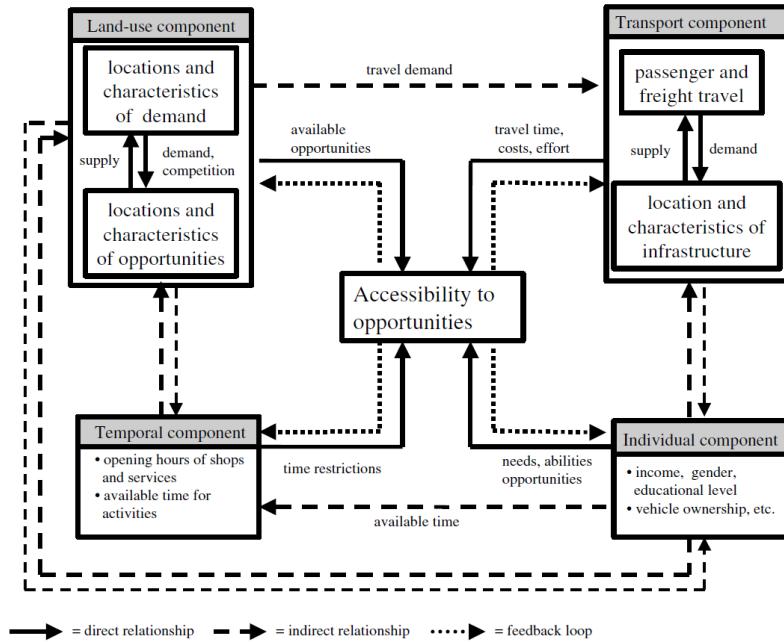
Accessibility is normally defined as the potential for opportunities for interaction in a spatial location, although it has various meanings depending on its purpose and condition (Hansen, 1959; Martellato, Nijkamp & Reggiani, 1998). In the area of transport and planning, the use of accessibility can be traced back to the time at which transport planning began to gain in popularity as an important academic subject (Batty,

2009). The concept of accessibility was proposed in Hansen (1959) seminal work, 'How Accessibility Shapes Land Use', which positioned accessibility as a central idea for the transport and planning fields.

The concept of accessibility has been widely used in many academic areas, such as transport planning, economic geography and urban planning, as it offers researchers a convenient way to evaluate the effects of transport infrastructure projects (Vickerman, Spiekermann & Wegener, 1999). Compared to the physical and monetary measures, the accessibility measure is regarded as a more precise tool in terms of accounting for various perspectives on transport infrastructure.

The concept of accessibility may be specific depending on the various perspectives taken by the measure, such as the type of users and the purpose of trips. In the literature, there are four components that matter with respect to the perspective of accessibility measures: the land-use component, transportation component, temporal component and individual component (Geurs & van Wee, 2004). These four components are linked to each other as shown in Figure 2-4, and they interact with each other in shaping the level of accessibility to opportunities. The locational characteristics of opportunities and the extent to which they are spatially distributed determine both the number of passengers and the amount of freight. The land-use component is concerned with the temporal component, such as time restrictions for activities, whereas the transportation component relates to the individual component, such as income and car ownership.

Figure 2-4. The Link between Components of Accessibility



Source: Adapted from (Geurs & van Wee, 2004)

The measure of accessibility is largely grouped into four accessibility measures, depending on both the purpose of the measure and its focus: infrastructure-based accessibility (Ewing, 1993), location-based accessibility (Martín & Reggiani, 2007), person-based accessibility (Kwan, 1998) and utility-based accessibility (Halden, 2003; Mogridge & Parr, 1997).²

Infrastructure-based measures are often used to analyse the service level of transport infrastructure, such as the average speed on the road and rail network and the level of congestion. Location-based measures analyse the level of accessibility to economic opportunities or amenities distributed spatially. One example of this measure is the number of jobs accessed within 30 minutes at a micro-geographical location. Person-based measures are used to explore the level of activities that individuals can participate in at a certain time, such as the time budget for activities. Utility-based measures analyse the benefits that individuals obtain from access to spatially distributed socio-economic potentials. Note that these accessibility measures can be

² Geurs and van Wee (2004) provided the latest review of the four perspectives in regard to accessibility.

used alone or in combination with one another. For example, a combination of infrastructure-based measures and utility-based measures is often used in studies that seek to evaluate the impact of transport infrastructure projects (Geurs & van Wee, 2004). Of these measures, location-based measures are closely relevant to the research question, as the accessibility measure developed in this study measures the level of access to the labour force and to jobs distributed across the region.

2.1.3.2. A theoretical Basis on Accessibility Indicators

Accessibility indicators used in this research are partly based on a model of trade that explains how each area is affected by a change in the regional matrix of area-to-area trade costs (Donaldson & Hornbeck, 2016). The region consists of a number of areas that generate positive or negative influence on other areas. Interacting goods, markets and factor markets, these areas have direct or indirect impacts. A change in trade costs is the key to these impacts to occur, and, under several standard assumptions, the extent of all these impacts are reflected in an area's market access. An area's market access increases when trade costs with other areas become cheaper. This normally occurs when the population in that other areas increases.

In the literature, market access has been also called an index of accessibility (Vickerman et al., 1999), market potential (Harris, 1954) and effective density (Graham, 2007b). A general form of market access is interchangeable with an accessibility indicator proposed by Hansen (1959), which a weighted sum of activities discounted by travel cost.

2.2. Transport Infrastructure and Economic Effects

This section reviews different types of effects that transport infrastructure development may have on society. In Section 2.2.1., a general overview of the effects of transport infrastructure is provided as well as how these effects can be classified by type. The following sections focus on the direct and indirect economic effects of transport infrastructure.

2.2.1. The Effect of Transport Infrastructure by Type

The way in which transport infrastructure impacts society can be divided simply into temporary and non-temporary effects (Rietveld & Bruinsma, 2012). Temporary effects are concerned with the demand side of the economy because they create jobs by promoting temporary construction works for transport infrastructure projects. Job creation directly leads to an increase in workers' income and thus increased levels of consumption. The government often use this temporary effect to create short-term economic effects on the local economy, although employment for the temporary construction work is likely to come from other uses.

The government's main purpose to build transport infrastructure is to make better societies and businesses, yet those temporary effects often influence the government's transport and employment policies. The government's purpose of building transport infrastructure is more concerned with non-temporary effects of transport infrastructure. In addition, transport infrastructure demands a large amount of investment in its operation and maintenance, which subsequently leads to temporal effects on the related sectors and jobs. According to the Highways Agency 2014 report, expenditures on capital improvement and maintenance amount to around £2,200 million (Highways Agency, 2014).

On the supply side of the economy, only non-temporary effects are involved in transport appraisal, because temporary effects do not exist, as shown in Table 2-2. Most of the effects that can be expected from the provision of transport infrastructure fall into this category, ranging from the economic effects of transport infrastructure to its spatial effects to its environmental effects.

Table 2-2. Temporary and Non-Temporary Effects of Transport Infrastructure

	Temporary effects	Non-temporary effects
Demand side	Construction effects	Operation and Maintenance

Supply side	-	Economic effects (Productivity, Land values, Employment), Spatial effects, Environmental effects, Equity effects
-------------	---	--

Source: Adapted from (Rietveld & Bruinsma, 2012)

Transport infrastructure development affects both the environment and the social value of individuals and communities (Banister & Button, 2015). The environmental effect often occurs during the construction of transport infrastructure, creating road congestion and air pollution. A well-known example of the environmental effect are CO₂ emissions linked to road traffic. In addition, transport infrastructure development improves the quality of people's lives by giving them more time to spend on various pursuits, such as leisure, learning and networking.

Transport infrastructure also contributes to Gross Domestic Product (GDP), i.e., the total value of goods and services produced in the economy, by making changes to the performance of economic activities (Eddington, 2006). GDP effects can be attributed to a reduction in travel costs caused by transport infrastructure improvement. For example, transport infrastructure allows more workers to obtain access to jobs by reducing transport costs between the home and workplace. Also, transport infrastructure generates changes to the behaviour of firms such that they are encouraged to create more goods and services. The ways in which transport infrastructure impact the economy are further discussed below, where they are classified into user benefits and wider benefits (externalities).

2.2.2. User benefits of Transport Infrastructure

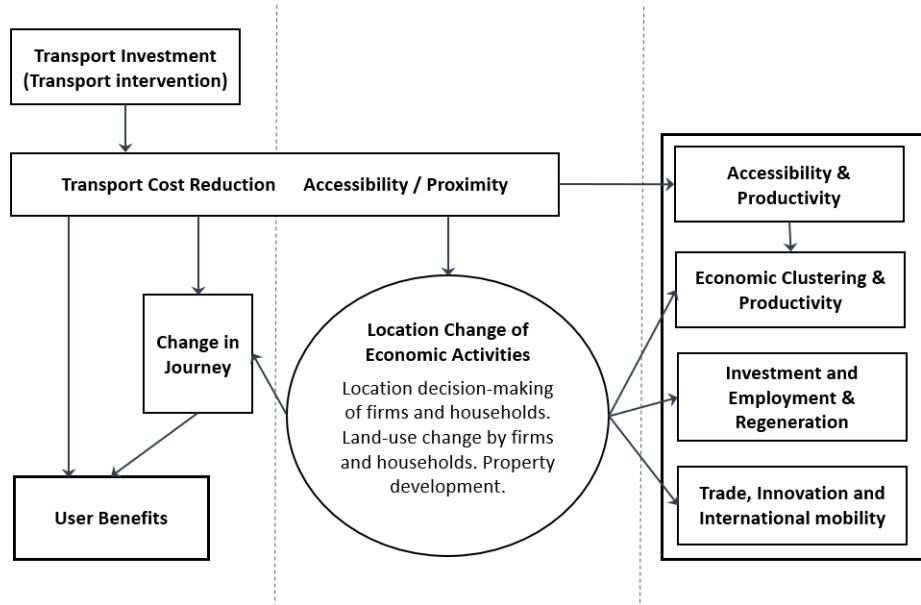
Investment in transport infrastructure decreases travel costs between origins and destinations and thus lowers travel costs related to commuting and shipping (user benefits). Accordingly, economic actors that use the transport infrastructure benefit from the lowered travel costs, which is often called user benefits (De Palma et al., 2011a; Venables et al., 2014). The travel cost savings first go to users who commute via the newly built transport infrastructure, because it allows them to save time and money.

This is regarded as a major economic effect directly expected from most transport infrastructure projects, although the extent of the user benefits depends on various conditions (Roberts, 1987). For firms, reduced travel costs decrease production costs, because costs linked to input factors, such as raw material shipment, can be lowered by the reduction in travel costs. For example, new road infrastructure that connects manufacturing firms to new ports of entry for raw materials is likely to provide firms with economic benefits.

Transport infrastructure development also leads to a change in transport network routes because lowered travel costs affect the matrix of the transport network. The centrality of locations changes as a result of new transport infrastructure. The shortest route from home to work may also change, which would most likely give commuters the motivation to alter their personal work routes. In this regard, transport infrastructure development results in the creation of a number of new routes alongside the existing infrastructure. But, altered routes provide benefits only to users, generating no net economic or social gains.

To a large extent, the user benefits arising from lowered travel costs lead to changes in the behaviours of firms and households in relation to their location in the transport network, including both location changes for firms and land-use changes (Jara-Díaz & Friesz, 1982). Location changes are transformed into wider economic effects through spatial dynamics, parts of which lead to route changes while other parts are concerned with economic factors, such as productivity and investment, as shown in Figure 2-5 (Venables et al., 2014). For example, the completion of new rail transit may bring about changes in the centrality of locations in the network: Some locations become more valuable in terms of access to resources. Responding to these changes, firms that seek competitiveness are likely to relocate their facilities in favour of either saving costs for production or increasing business opportunities. In a similar manner, workers are likely to move to an area where they can increase job opportunities and enjoy a range of amenities (Fujita, Krugman & Venables, 2001).

Figure 2-5. The Effects of Transport Infrastructure



Source: Adapted from (Venables et al., 2014)

The user benefits of transport infrastructure projects are normally measured by a cost-benefit analysis (CBA) that both predicts the costs and benefits of transport infrastructure and compares them with each other (Quinet & Vickerman, 2004). In CBA, changes in traffic flows are predicted before the construction of transport infrastructure, and a transport demand model is frequently used to obtain estimates regarding new travel demands and costs caused by new transport infrastructure development. Changes in users' travel costs are also measured with an economic model that considers the speed and capacity of transport infrastructure projects (Halden, 2003). For example, it has been shown that the travel-time savings of the Crossrail project in London may reach 21% of the total user benefits (Buchanan, 2007), while the time-saving benefits of the planned high-speed rail line between London and the West Midlands have been predicted to be over one-half of the total user benefits (DfT, 2012).

2.2.3. Wider Benefits of Transport Infrastructure

Investment in transport infrastructure may lead to wider benefits (externalities) in addition to user benefits, which can be separated into productivity effects, economic clustering effects, and investment and employment effects (see Figure 2-5). The way

in which these economic effects are promoted by transport infrastructure investment is not the same as that for user benefits. Economic benefits are an outcome formulated by the interaction between transport infrastructure improvement and spatial elements (Venables et al., 2014').

As discussed in previous sections, transport infrastructure improvement leads to a reduction in travel costs and subsequent changes to the behaviours of both firms and households in relation to their location in the transport network. A change in proximity to economic activities is the major driver for firms and households to decide where they will be located in the network. These spatial changes are the fundamental catalyst for wider benefits to occur (Venables et al., 2014). For example, households are likely to be located closer to jobs to reduce travel costs, while firms are likely to relocate their facilities to areas that bring advantages in regard to resources and their use.

Transport infrastructure improvement also enhances the productivity of firms and workers, increasing the efficiency with which they use input factors in production. Improved transport infrastructure especially increases workers' mobility, which in turn accelerates their productivity in relation to communicating with people and searching for resources. For firms, improved transport infrastructure enables them to find better-matched workers in the labour market. More detailed discussions on these topics will be presented in later sections.

In addition, increased proximity between economic activities impacts their economic performance at local, regional and national levels. Interactions between economic activities are promoted better in dense and large urban and regional areas, as agglomeration economies are enhanced by better connection to each other. The prominent example of this is the relationship between transport infrastructure and urban growth (Garcia-Mila & McGuire, 1992). The presence of transport infrastructure is a necessary condition for cities or employment centres to grow and function. In addition, transport improvement leads to changes in the level and distribution of investment and employment, which consequently provokes a shift in the spatial pattern of employment and income in urban and rural areas.

2.3. Transport-induced Economic Effects and Firms' Productivity

This section discusses the theoretical basis for the research question: 'How and to what extent are transport-induced economic effects related to the productivity of firms in the Seoul region?'. This question is explored in Chapter Four. The first section provides a discussion on the theoretical link between transport infrastructure and productivity. This is followed by a section that discusses the underlying mechanism of transport-induced economic effects, focusing on the role of transport infrastructure in promoting a spatial environment in which firms can operate in a more productive way.

2.3.1. Transport Infrastructure and Productivity

This section touches on the theoretical link between transport infrastructure and productivity. Transport infrastructure development indirectly leads to a change in firms' productivity by altering their locational centrality and spatial behaviours in relation to production (Graham, 2007a; Venables, 2007).

Conceptually, this linkage between transport infrastructure and productivity can be separated into two processes: agglomeration economies that enable both firms and workers to be more productive, and transport infrastructure improvement that promotes the spatial environment in which the agglomeration economies are stimulated.

A key theoretical basis for the link between transport infrastructure and productivity is concerned with agglomeration economies, which are considered productive advantages arising from the spatial concentration of firms and people (Graham, 2007a). These productive advantages are considered the main source for the formation of various types of cities because they allow such cities to be more productive in making goods and services than unclustered cities (Duranton & Puga, 2004). Firms and workers tend to be more productive when they are spatially clustered, and most innovation tends to take place in such spatial settings. Because of the importance of agglomeration economies in the formation of cities, they have been considered the key theoretical notion in several streams of research, such as transport planning, regional science and new economic geography (Combes, Duranton & Overman, 2005).

The ways in which firms benefit from being clustered in a dense area have been one of

the main research subjects in the literature (Diego, 2010; Eberts & McMillen, 1999). Accordingly, some mechanisms of agglomeration economies have been identified: sharing, matching and learning. The mechanism of sharing is concerned with a reduction in travel costs which enables firms to share the variety of intermediates, suppliers and goods needed in production. Matching is concerned with spatial settings that facilitate matches between jobs and job-seekers in a more efficient way. The lower the cost for matching between jobs and workers, the more both firms and workers benefit from economic advantages in relation to production. Learning is the mechanism by which both firms and workers benefit from economic advantages through a process of knowledge exchange among actors with different types of information and expertise in large cities.

Another key theoretical basis for the link between transport infrastructure and productivity is concerned with the ways in which transport infrastructure development facilitate the spatial formations in which agglomeration economies are fostered (Venables, 2007). Transport infrastructure improvement reduces travel costs between places, which in turn promotes the denser areas in which firms are clustered. For example, new motorways and rail transit may transform previously geographically scattered firms into a closer network, forming a new cluster of firms at a larger scale.

The degree of agglomeration economies is determined by three factors: increasing returns in economic activities, accessibility to economic opportunities and the size of the labour market (Puga, 2010b; Vickerman, 2008). The latter two factors are associated with transport infrastructure. Transport infrastructure improvement plays a key role in accessibility to economic opportunities simply because workers' mobility is partly governed by travel costs, which vary depending on the level of transport services provided. If transport costs are high, then the mobility of firms and workers will be to some extent restricted, and thus the intensity of agglomeration economies will become less significant, with the other two factors remaining unchanged.

For the size of labour market, transport infrastructure improvement leads to an increase in the market's spatial range, providing workers with more opportunities for diverse jobs as well as various opportunities linked to consumption (Venables, 2007). The expanded labour market enables more participation by people who are willing to work because a reduction in travel costs leads to a decrease in the spatial friction between firms and workers. In addition, transport infrastructure improvement also brings benefits to

workers who already have jobs because they have a greater capacity to move across the area at the same travel cost. Because of an enlarged labour market, more and diverse job opportunities become available to existing workers (Graham, 2007a).

A good example of this benefit is Crossrail in London. According to the project's impact study, the construction of Crossrail is expected to generate a GDP of £47.1 billion by 2026 in the best-case scenario, as shown in Table 2.3 (Bhasin & Buchanan, 2007). While the labour market impacts of Crossrail differ in the three scenarios, its impact on the relocation of workers to more productive jobs is the most considerable in terms of the amount of the GDP contribution.

Yet, the construction of Crossrail might not achieve the goal of contributing to the GDP as expected in the best-case scenario. A major reason for this is the fact that the arrival of Crossrail does not directly lead to creation of new jobs in the area. Its main role in the labour market is to expand the scope of spatial economies functioning and by doing so to increase the chances of matches between firms and workers. New jobs to be created are complicatedly related to other factors such as policy, built environment, culture and planning.

Table 2-3. Crossrail Impact on Welfare and GDP

Benefits	High Scenario		Mid Scenario		Low Scenario	
	Welfare (£m)	GDP (£m)	Welfare (£m)	GDP (£m)	Welfare (£m)	GDP (£m)
Business time savings	4847	4847	4847	4847	4847	4847
Commuting time Savings	4152		4152		4152	
Leisure time savings	3833		3833		3833	
Increase in labour force participation		872		872		872
Move to more productive jobs	46165		29919		19625	

Source: Adapted from (Bhasin & Buchanan, 2007)

2.3.2. Mechanism for Productive Effects of Transport Infrastructure

2.3.2.1. Micro-Foundation of Transport-induced Productive Advantages

A primary socio-economic effect of transport infrastructure is the proximity effect (De Palma et al., 2011a). Transport infrastructure basically supports an environment in which economic actors are tightly clustered. It encourages face-to-face contacts and communications among economic actors in a city, enabling them to travel around the city at lower travel costs. Transport infrastructure also allows workers and firms to obtain access to various amenities, resources and economic opportunities. The larger the size of the city, the more considerable the role of transport infrastructure in supporting contacts and communications among firms and workers (Melo, Graham, Levinson & Aarabi, 2016). In large cities in which jobs and workers are unevenly distributed, those who live far from workplaces, for example, can benefit considerably from transport infrastructure improvement.

The actual channel through which transport infrastructure improvement leads to an increase in productive advantages is concerned with the micro-foundation of agglomeration economies (Graham, 2007a). To some extent, productive benefits result from the sharing mechanism of agglomeration economies, based upon the idea that 'a localized industry gains a great advantage from the fact that it offers a constant market for skill' (Marshall, 1890, p. 271). Specifically, skilled workers are one of the key factors in production, and thus it is natural for firms to ensure a certain level of accessibility to the labour pool. To some extent, the level of workforce accessibility is determined by travel costs simply because of the physical distance between homes and workplaces (Fujita et al., 2001). For example, if the travel costs are high, then the number of workers available to firms would decrease. Transport infrastructure improvement leads to a reduction in travel costs, which in turn increases the number of workers available to firms. In other words, the spatial range from which the labour pool is accessed by firms improves due to transport infrastructure improvement.

The other theoretical argument for transport-induced productive advantages is grounded on the matching mechanism of agglomeration economies, which accounts for labour market efficiency (Venables, 2007; Venables et al., 2014). Transport infrastructure improvement increases opportunities for available jobs to be matched by job-seekers by expanding the spatial range in which economic activities take place.

The size of the labour market also increases because of transport infrastructure improvement. The expansion of economic activities brings more firms and workers into the urban economy, improving the chances of matches between producers and consumers. Labour market efficiency enhances as matches between available jobs and job-seekers become less expensive in the expanded labour market. The urban agglomeration model provides a specific account of how the labour market is linked to the chance of matches, adopting a definition in which the number of job matches is a function of search friction comprising the number of available jobs and the number of job-seekers (Petrongolo & Pissarides, 2001).

2.3.2.2. Venable's Theoretical Model

The link between transport infrastructure and productive advantages can be further understood by reviewing Venable's model,³ which provides a theoretical account of a change in workers' wages in relation to a reduction in travel costs when transport infrastructure improvements are made in urban areas (Venables, 2007). The foundation of the model rests on the notion that the spatial concentration of economic activities is the source of productive advantages to workers and firms, which has been revealed by a number of empirical studies that have reported that the doubling of a city's size leads to an increase in the productivity of firms and workers (Duranton & Puga, 2004; Eberts & McMillen, 1999). In the model, transport infrastructure investment is the driving factor in the spatial agglomeration of workers, and it extends the spatial extent to which firms and workers can interact. The greater the spatial extension transport infrastructure investment allows, the more firms and workers receive productive benefits from both reduced travel costs and the enlarged labour market.

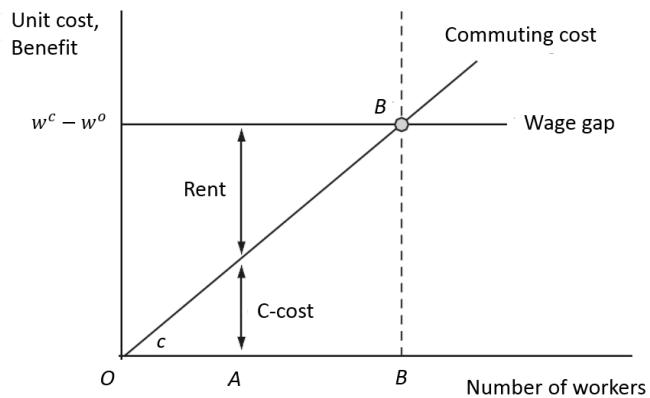
It is worth taking a closer look at how Venable's model works to gain a better understanding of the link between transport infrastructure and productivity. The two diagrams presented below demonstrate the mechanism by which workers' benefits change with a reduction in travel costs. In Figure 2-6, the size of the labour market (the size of the city) is defined at point B. The closer a worker is to the city centre, the higher the level of rent,⁴ as decided by both the commuting cost and the distance between

³ For simplicity, the model was formulated based on a monocentric urban structure.

⁴ In this model, other factors remain equal because rent and travel costs consume a large part of

w^c and w^o .

Figure 2-6. Urban Equilibrium

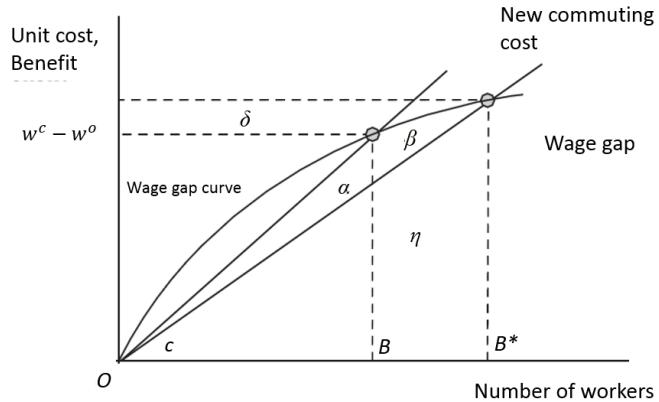


Source: Adapted from (Venables, 2007)

Figure 2-7 demonstrates how workers benefit from transport infrastructure investment. It can be observed that transport infrastructure investment basically results in a reduction in travel costs, and this time-saving benefit shifts the slope of commuting cost downwards on the diagram. Since this allows workers to commute farther with the same commuting cost, the spatial scope of the labour market increases from B to the point of B^* . The growth of the city's size generates direct savings in terms of travel costs and extra output from new city workers. Net benefits are represented as the areas of $\alpha + \beta$, which are attributed to both direct cost savings and extra output from new city workers.

workers' spending.

Figure 2-7. Net Gain from Transport Improvement with Endogenous Productivity



Source: Adapted from (Venables, 2007)

Aside from the direct economic benefits, workers receive indirect productive benefits from agglomeration economies because they promote a spatial formation in which workers have more access to jobs but at the same travel costs. This increased productivity is not the product of a constant relationship to a city's size but rather to a closer relationship, such that it can be expressed as a concave curve on the diagram. The number of productive benefits for workers is represented as an area of δ , which can be referred to as an increase in workers' wages.

In sum, transport infrastructure investment results in direct time-saving benefits as well as indirect productive benefits, which are represented as an area of $\alpha + \beta + \delta$ on the diagram. The fundamental reasoning for these benefits directly arises from a reduction in travel costs and indirectly arises from the spatial formation promoted by transport infrastructure investment. This theoretical understanding provides significant implications for an exploration of the link between transport-induced economic effects and firms' productivity.

2.3.3. Empirical Evidence on the Impact of Transport Infrastructure on Productivity

In the theoretical section, the relationship between transport infrastructure and productivity was discussed in two parts: agglomeration economies and transport infrastructure. Applying the same configuration to this empirical review section, I first

reviewed empirical studies on agglomeration economies, after which I reviewed empirical studies relevant to the impact of transport infrastructure on productivity. This way of reviewing empirical studies corresponds to the way in which empirical studies on the link between transport infrastructure and productivity have evolved across several areas of studies, such as transport, new economic geography and planning.

With regard to the presence of agglomeration economies in urban and regional areas, an extensive number of empirical studies have been conducted to ascertain whether productive advantages of the spatial concentration of economic activities actually exist as presented in the theories of agglomeration economies (Fujita & Thisse, 2002). Most of these studies have tended to focus on measuring the magnitude of agglomeration economies in order to verify the presence of productive advantages arising from the spatial concentration of economic activities (Rosenthal & Strange, 2004). For example, Ciccone and Hall (1996) estimated how country-level employment density impacts aggregate state productivity. They made their case in the context of the US, reporting that a change in the density of employment accounts for over 50% of the change in labour productivity. Ciccone (2002) conducted a similar analysis to that for the US using European data and detected agglomeration effects which were only slightly smaller than those in the US. Brülhart and Mathys (2008) confirmed the presence of significant agglomeration effects for Europe at the aggregate level.

The literature has recently reached the conclusion that the spatial concentration of economic activities is positively linked to productivity (Eberts & McMillen, 1999). While the degree to which firms and workers benefit from being clustered varies, empirical findings accepted in the literature suggest that doubling a city's size increases productivity in the range of 3–8% (Rosenthal & Strange, 2004).⁵ This is broadly consistent with Melo, Graham, and Noland (2009) report that agglomeration economies do matter with respect to firms' productivity, controlling for other characteristics of firms, industries and countries. They showed that China and Sweden have relatively low values of 0.013 and 0.018, respectively, for the magnitude of agglomeration economies, whereas the UK has the highest value of 0.083. In summary, there is broad consensus on the positive effects of agglomeration economies on firms' productivity in empirical

⁵ Transforming these figures into the elasticity of productivity with respect to city size, they are in the range of 0.05 to 0.11.

studies.

Alongside the proliferation of empirical studies, theoretical discussion on how the agglomeration of population and employment work at the micro level is related to the generation of productive benefits has received much attention from researchers, some of whom have attempted to unpack the underlying mechanism of agglomeration economies, which remained unclear (Duranton & Puga, 2004). Two theoretical papers distinctively contributed to the development of the micro-foundation of agglomeration economies and were based on Marshall's work on the source of agglomeration economies (Duranton & Puga, 2004; Puga, 2010b). According to these studies, agglomeration economies that bring about productive advantages are promoted by three mechanisms: sharing, matching and learning.

Recent studies in the literature have focused on firm- and plant-level data, on the basis of the idea that firms are more productive when they are located in larger and denser areas (Henderson, 2003; Martin, Mayer & Mayneris, 2011). Henderson (2003) estimated the plant-level production function for machinery and high-tech industries using panel data. It was found that in high-tech industry, the number of plants in the same industry enhances productivity. Similar evidence was found by Martin et al. (2011), who estimated the effects of the spatial agglomeration of economic activities on productivity at the plant level using longitudinal French firm data. The researchers measured urbanisation economies with inter-industry employment at the administrative level. They showed that French plants benefit from both urbanisation and localisation economies, but that the impact of urbanisation economies was minimal.

Combes, Duranton, Gobillon, Puga, and Roux (2009) and Combes, Duranton, Gobillon, and Roux (2010) also analysed the effects of agglomeration economies using longitudinal French firm data. They measured agglomeration economies with both employment density and market potential at the employment area level. They showed both that firms are more productive in large cities and that the density of employment at the local level improves firm-level productivity.

Most studies in the literature have relied on city- or region-based measure to study the effects of agglomeration economies. The quantification of agglomeration economies has been mainly carried out by identifying employment density at the administrative level. Yet, cities and regions are not necessarily confined by administrative boundaries because they, in fact, communicate with areas outside the boundaries. In this regard,

the spatial scope over which agglomeration may materialise can be extended by transport infrastructure investment that reduces travel costs and facilitates the movement of the labour force, goods and information. And yet, many studies on transport infrastructure have been developed separate from studies on agglomeration economies.

The spatial aspect of transport infrastructure has recently become an important research subject in the literature on agglomeration economies. Several studies have examined the role of transport infrastructure in promoting agglomeration economies, claiming that the transport dimension has been relatively ignored in the estimation of productive advantages arising from agglomeration economies (Holl, 2012). This is echoed in Eberts and McMillen (1999), who pointed out that the spatial aspect of transport infrastructure has typically been omitted from the literature on agglomeration studies.

However, recent studies have formulated important links between transport infrastructure investment and agglomeration economies. Venables (2007) provided a theoretical model for the relationship between transport infrastructure investment, agglomeration economies and productivity. Transport infrastructure investment basically reduces travel costs and increases the potential for interaction and access to resources, such as the labour force, ideas and goods, forming a more clustered way of economic functioning. This subsequently promotes agglomeration economies and facilitate productive benefits to economic actors. Building on Venables (2007) theoretical model, Graham (2007a) developed a regression model for the relationship between agglomeration economies, productivity and transport investment that was intended to investigate the impact of the density of economic activities on the productivity of the UK economy. The model tested the existence of agglomeration externalities that arise from transport investment but are not included in transport appraisals. It was found that transport investment increases urban densities and induces positive externalities.

Index for Agglomeration Economies

In these studies, the measure for agglomeration economies was key to studying their impact on firm-level or plant-level productivity. Most of these studies used an

accessibility-type index to consider spatial externalities, an alternative to city or region measures based on population and employment densities. This index can incorporate the concept of distance decay into the measurement of agglomeration economies, better representing spatial proximity (Melo et al., 2016). Several names have been proposed for the index — an index of accessibility (Vickerman et al., 1999), market potential (Harris, 1954), effective density (Graham, 2007b) and market access (Donaldson & Hornbeck, 2016). A theoretical basis of these measures is in trade theory.

Using the measure of market potential and effective density, a few studies have analysed firm-level productivity. Combes et al. (2010) constructed the measure of market potential, defined as a distance-weighted sum of the density of other areas, and estimated elasticities of local total factor productivity with respect to agglomeration. Lall, Shalizi, and Deichmann (2004) used a measure of market potential determined by the distance from market centres near the plant as well as its size and density. They found that market accessibility is an important determinant of plant-level productivity. However, the majority of these studies relied on accessibility measures based on physical distance without accounting for the role of the real transport network. Yet, the travel costs between locations are based on travel times in the actual transport network. Also, transport investment promotes interactions between economic actors by reducing travel costs, and therefore affects their productivity. This perspective is not considered in the measure of market potential.

To date, few studies have used accessibility measures based on travel times derived from actual transport networks. As of 2019, only seven studies are available in the literature (Donaldson & Hornbeck, 2016; Gibbons, Lyytikäinen, Overman & Sanchis-Guarner, 2019; Graham, 2007a; Holl, 2012; Martín-Barroso, Núñez-Serrano & Velázquez, 2015; Néchet, Melo & Graham, 2012; Rice, Venables & Patacchini, 2006). Néchet et al. (2012) investigated the link between transport-induced agglomeration effects and productivity in different industry sectors. Agglomeration economies were captured by accessibility measures that considered driving times derived from the actual road transport network. Néchet and colleagues showed that industry sectors receive different levels of transport-induced agglomeration effects, and that the effects are larger for business services. Martín-Barroso et al. (2015) analysed the impact of accessibility on firms' productivity in the Spanish manufacturing industry. The measures of accessibility to workers and commodities were constructed based on actual road

transport networks. They showed that accessibility is a key determinant of firms' productivity.

On the other hand, the transport literature has long explored the question of whether transport infrastructure investment leads to economic performance (Fernald, 1999; Gramlich, 1994; Haughwout, 2002). The subject has attracted much attention in recent decades. The focus of these studies has been on how transport investment impacts economic outcomes at the macro or regional level (Melo et al., 2009). A reduction in travel costs resulting from transport infrastructure improvements is a key mechanism related to these studies, because travel costs play a key role in determining locations (Alonso, 1964; Fujita & Thisse, 2002). Another mechanism relevant to these studies is that transport infrastructure improvements lead to a reduction in firms' input costs and an increase in factor productivity. Also, transport investment can lower production and distribution costs and therefore bring about scale effects, increasing the level of competition (Baldwin & Okubo, 2005; Melitz & Ottaviano, 2008).

The transport literature provides mixed evidence on the link between transport infrastructure and economic performance (Crescenzi & Rodríguez-Pose, 2012; Funderburg et al., 2010; Leduc & Wilson, 2012; Redding & Turner, 2015). The outcomes obtained from previous studies varied depending on the spatial level at which they were explored and the time during which they were conducted. Many earlier studies reported positive economic effects arising from the development of transport infrastructure at the urban level. At the national level, while some previous studies have reported a positive causality between transport infrastructure and economic performance, other studies have also shown that transport infrastructure investment may lead to negative effects on the national economy (Aschauer, 1989).

Previous studies basically differed with respect to the mode of transport. Some studies investigated the economic outcome of road transport infrastructure, whereas others estimated the degree of productivity that rail transport infrastructure produces. In terms of output elasticity, road infrastructure has the largest value, at 0.088. Port and railway infrastructure follow, at 0.068 and 0.037, respectively. The average value for all transport infrastructure is 0.028, which is slightly higher than the estimated value for airports (Melo, Graham & Brage-Ardao, 2013).

Classifying previous studies into countries, most have been conducted in the US and Europe. A relatively small number of studies have investigated other regions, such as

Asia and Africa. The level of development in an area affects the degree of output elasticity of transport, and therefore estimates for transport economic output differ across countries because their levels of development are different (Hansen, 1965). In terms of the output elasticity of transport, studies of Europe yielded the lowest value of 0.039 compared to the US and other countries, which had larger estimated values of 0.069 and 0.083, respectively (Melo et al., 2013).

For the measurement of transport infrastructure, most studies have tended to measure transport infrastructure in monetary terms, mainly because monetary values are easy to collect and compare (Garcia-Mila, McGuire & Porter, 1996). Although monetary values are easy to use, it has been pointed out that they do not reveal how resources have been spent, and it is therefore difficult to distinguish between different types of transport. Some studies have relied on physical units that measure transport infrastructure in length and mileage. As physical units are more homogenous, their estimates of the economic output of transport infrastructure have been more uniform than those derived from monetary units.

Concerning empirical methods adopted in the literature, most studies have used the production function, in which economic output is a function of several input factors, such as labour, capital, education and intermediate inputs. The most common functional form used in the literature is a Cobb-Douglas specification with log transformation (Baltagi & Pinnoi, 1995; Xueliang, 2008). A translog specification has also been used as a more flexible functional form in the literature. In some studies with time series data, vector auto regression models have been applied to obtain future values of variables from a given variable (Sturm, Jacobs & Groote, 1999).

Various econometric estimators have been used to estimate production functions in the literature. The most common estimators used in previous studies are OLS and panel data estimators. OLS estimators were mainly used in earlier studies (Garcia-Mila & McGuire, 1992), whereas panel data estimators have proliferated since the mid-1990s (Cantos, Gumbau-Albert & Maudos, 2005). Recently, some studies have adopted econometric techniques to produce meaningful differences in results, including the generalised method of moments (GMM), arguing that econometric methods can influence the estimates of transport infrastructure economic effects (Boopen, 2006).

Across previous studies, the level of data aggregation differed. Previous studies were largely separated into those that used regional data and those that relied on national

data. Depending on the focus of a study, the estimation for output elasticity differs because of the nature of the transport infrastructure project in question. Some transport investment increases national economic outputs on average, whereas others just relocate economic output from one location to another.

While transport infrastructure investment impacts economic output, it also affects the location of economic activities (Atack, Bateman, Haines & Margo, 2010; Baum-Snow, 2007; Combes et al., 2010; Ghani, Goswami & Kerr, 2015). According to evidence provided by these studies, transport infrastructure induces firms and economic activities into the surrounding area, increasing the density of economic activities at a local level. Further, the level of firms' productivity increases as a result of the increased density of firms (Combes & Gobillon, 2015). When firms are closely clustered, they receive positive agglomeration externalities through the mechanism of knowledge spillover, labour pooling and input sharing. Thus, the geographic extent to which agglomeration economies operate can be extended by transport infrastructure investment, as it reduces travel costs and facilitates the movement of goods, labour force and information.

Most of the empirical evidence in the literature was obtained from studies conducted at the macro or regional level (Straub, 2011). In these studies, the aggregate production function, where expenditures on transport infrastructure are treated as a factor of production, has generally been adopted (Garcia-Mila et al., 1996). The results of these studies were mixed (Crescenzi & Rodríguez-Pose, 2012; Funderburg et al., 2010; Leduc & Wilson, 2012; Redding & Turner, 2015). One reason for this is the endogeneity issue, by which 'transport infrastructure improvement is not randomly allocated but spatially targeted to meet specific economic demands' (Gibbons, Lyytikäinen, Overman & Sanchis-Guarner, 2016, p. 6).

Recently, the literature's focus has been shifting from macro-economic studies to micro-economic analysis (Melo et al., 2009). Few studies have investigated the link between transport infrastructure and firm-level productivity in the literature (Gibbons et al., 2019; Graham, 2007a; Holl, 2012; Lall et al., 2004; Martín-Barroso et al., 2015), although a number of studies have been conducted to estimate the impact of transport infrastructure on economic outcome.

Ghani et al. (2015) examined the impact of transport infrastructure on the organisation and efficiency of manufacturing activities using the case of the national highway

upgrade programme in India. They found that increases in entry rates and productivity in the manufacturing sector were observed in districts within 10 km of the non-nodal sections of highways in comparison with districts farther away. Holl (2016) estimated the effect of highway accessibility on firm-level productivity using a micro-level panel dataset for Spanish manufacturing firms. The distances to the nearest highways were used as an accessibility measure. It was found that access to highways was directly related to firm-level productivity, and that the productivity effect persisted even when controlling for the density of local employment. The results also showed that productive benefits were unevenly distributed across manufacturing sectors.

Until recently, the wider economic effects of transport infrastructure at the firm level was regarded as an intriguing subject in the transport literature. A major motivation for this was the presence of potential productive benefits that can be promoted by transport infrastructure investment. Another motivation came from the fact that the typical approach in the literature does not properly address the physical interaction between workers and firms. In response to these motivations, a growing number of studies have begun to incorporate the element of transport infrastructure into the evaluation of the productive benefits of transport infrastructure in the transport literature (Melo et al., 2009). Holl (2012) investigated the effect of road infrastructure improvement on the firm-level productivity of Spanish manufacturing firms. Based on the idea that transport infrastructure investment improves accessibility to input and output markets, market potential was used as an accessibility measure. Access to resources was measured by travel time through the real transport network. It was found that road infrastructure improvement has positive impacts on firm-level productivity, confirming its wider economic benefits.

2.4. Transport-induced Labour Accessibility and the Growth of Employment Centres

This section discusses the theoretical basis for the research question: 'How and to what extent is transportation-induced labour accessibility related to the growth of employment centres in the Seoul region?', which is explored in Chapter Five. The first section discusses the underlying causes for the emergence of contemporary spatial

structures in which multiple employment centres exist. It also discusses the process of employment and population decentralisation and de-concentration. In the second section, the link between transport infrastructure and spatial structure is discussed, reviewing a simple model of how transport infrastructure relates to the development of spatial structure. It also discusses spatial models for the formation of multiple employment centres. In the last section, the chapter reviews previous empirical studies on the impact of transport infrastructure on the growth of employment centres.

2.4.1. The Spatial Change of Spatial Structure

2.4.1.1. Theoretical Arguments for Concentration and Dispersion

The development and pattern of spatial structure is the product of the complex interaction between the forces for and against the concentration of economic activities (Fujita & Thisse, 2002). The two contrasting forces, working at different spatial scales, are the fundamental cause of both employment and population being concentrated or dispersed, as well as the heterogeneity of the spatial structure in large metropolitan areas. The theoretical arguments for both concentration and dispersion are well formulated to account for the existence of the spatial concentration of firms and people, built on a series of theoretical works.

The most well-known theoretical argument for the spatial concentration of economic activities is agglomeration theory, which explains the productivity advantages for firms and workers when they are clustered in large metropolitan areas (Fujita & Thisse, 2002).

With regard to networked and creative work environments, dense and diverse neighbourhoods provide creative entrepreneurs or workers with more opportunities for casual or formal meetings with other creative workers. Trust and social networks are considered important factors in economic development and political activism, complementing actors with ideas (Jacobs, 1961, 1969). In addition, dense and diverse neighbourhoods are a necessary condition for building trust and social networks among people in the neighbourhood. In Jacobs' discussion on the decline of cities and their neighbourhoods, she states that the 'locality knowledge' of their inhabitants and 'social network' play a crucial role in making the neighbourhoods livable, dynamic and economically prosperous (Jacobs, 1961).

Physical proximity, normally provided by various transportation, is considered in the

literature as another factor that promotes the spatial concentration of populations and firms, although this is still up for debate (Alonso, 1964; Fujita et al., 2001). Physical proximity facilitates a long-standing, stable relationship among people in a neighbourhood, which may ultimately enable them to build trust and make agreements on the common values required to achieve. Being close to other firms is also a crucial factor in building trust among actors and agents, which can be expressed as their willingness to take a chance in doing business with one another (Harrison, 1992). Geographical proximity motivates managers and workers in different firms to have more contacts and interactions, which can in turn provide them with opportunities to learn about potential business partners.

The theoretical argument for dispersion involves a long-standing decrease in transport costs. A reduction in communication and transport costs affects the location choices of both firms and workers. Reduced transport costs expand the extent to which economic activities take place, which in turn increases the size of the city-region area (Mieszkowski & Mills, 1993). To the extent that costs for communication and transport can be reduced, the mobility of firms and workers in a city-region area will increase. In this long-standing trend, firms may be able to make more flexible choices regarding their locations in a city-region area. Reduced costs also affect workers' location choices, enabling them to travel farther to their jobs. As long as their jobs remain at the same location, workers may be able to relocate their homes away from the core of a city, where rent is far more expensive than it is outside the city. Reduced transport costs also allow firms to make more flexible location choices.

The fall in transport costs is derived from three factors: (1) transport technologies, (2) increase in income levels and (3) advances in transport infrastructure. The expansion of the middle class has fuelled a considerable increase in car ownership. Alongside the surge in car ownership, new types of transport infrastructure have begun to appear across cities and regions. Motorways for intra-urban travel are being constructed, as are freeways for inter-urban travel, to meet the surge in the demand for such travel. This construction of new roads is reorienting the existing road networks. In addition, as automobile speeds are increasing due to advancements in automobile technology, motorway networks for higher speed travel are also being constructed to promote more frequent and faster commuting and logistics in and across cities and regions.

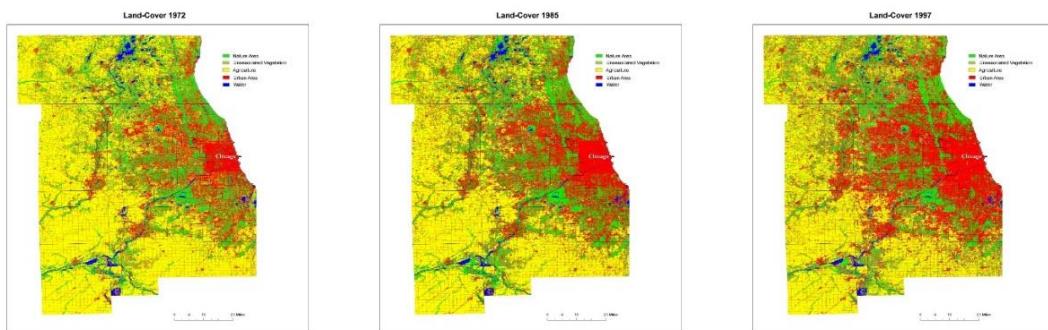
The effect of reduced transport costs on the decentralisation of population and

employment is being reinforced by a revolution in communication technology due to the advent of the Internet (Gillham & MacLean, 2002). The revolution of internet communication technology (ICT) is strengthening the continuous effect of the reduction in transport costs on the decentralisation of employment. As ICT has begun to be adopted in both production and consumption, a number of researchers have envisaged new cities with no physical borders emerging across the world.

2.4.1.2. Multiple Employment Centres in Contemporary Metropolitan Areas

The dynamic tension between centripetal and centrifugal forces working at different levels has manifested in the formation of contemporary urban spatial structures, in combination with social and economic features of urban society and its technological capability (Hall, 1998). The distinctive feature of a contemporary spatial structure is multiple clusters of employment, population and commercial activities emerging outside the CBD in metropolitan areas (see Figure 2-8). As the emergence of multiple concentrations of population and employment is a novel phenomenon, several names for these clusters have been proposed according to their functions and industry compositions, such as multi-core metropolises and edge cities (Hall, 1999; Taylor & Lang, 2004).

Figure 2-8. Employment Decentralisation in Chicago from 1972 to 1997



Source: NASA

While the decentralisation of population and employment has been the general trend in most contemporary metropolitan areas, there has been disagreement in the literature

as to whether the spatial pattern of decentralised metropolitan areas is polycentric or dispersed. Lang and LeFurgy (2003) proposed contrasting notions of edgeless cities and edge cities, arguing that contemporary metropolitan areas may not be characterised as large-scale offices and retail developments that involve a large cluster of employment but rather a bulk of isolated office buildings spread across a vast area without a clear boundary. Gordon and Richardson (1996) contended that contemporary metropolitan areas have progressively moved beyond polycentricity towards a generalised dispersed structure, based on the findings of a longitudinal analysis of changes in the share of employment in sub-centres in the Los Angeles metropolitan region.

The notions of edge cities and edgeless cities have created a contentious debate over which notion better describes a contemporary metropolitan area. Lee (2007) contributed to the debate on whether emerging urban structures can be characterised as edge cities or edgeless cities by investigating changes in the spatial pattern of six metropolitan areas in the US. He concluded that the pattern of employment tends to be dispersed rather than clustered, although whether employment is dispersed or clustered may depend on the way in which agglomeration economies work in regard to employment decentralisation.

Nevertheless, it is evident that metropolitan areas have multiple clusters of employment and population. A number of empirical studies have determined the existence of multiple centres in a metropolitan area (Garcia-López & Muñiz, 2010; McMillen, 2003). Bertaud (2004, p. 9) described the spatial transformation of large metropolitan areas from monocentric towards polycentric spatial structures as follows: "As cities grow in size, the original monocentric structure of large metropolises trends with time to dissolve progressively into a polycentric structure. The CBD loses its primacy, and clusters of activities generating trips are spreading within the built-up area. Large cities are not born polycentric; they may evolve in that direction".

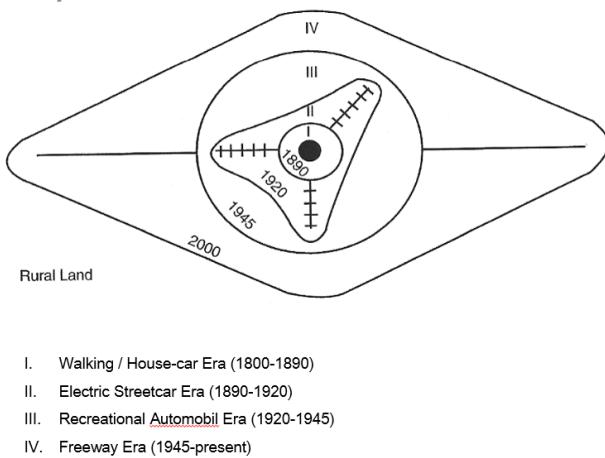
2.4.2. Transport Infrastructure and Spatial Structure

2.4.2.1. Transport Innovation and the Development of Spatial Structure

Transport infrastructure improvement is closely concerned with the development of urban spatial structure. Transport technology available at each phase of urban growth

plays a key role in shaping a distinctive pattern of urban structures (Adams, 1970). The phase of urban growth in western cities has occurred parallel to the phase of transport innovation. Each stage of urban spatial pattern in western cities is dominated by available transport technologies, as illustrated by examples of US metropolises developed over four transportation-related phases (see Figure 2-9).

Figure 2-9. Inter-urban Transport and Urban Growth Pattern.



Taking the example of Boston in the late 1900s, the arrival of electric streetcars opened an era of suburbs, permitting a number of urban dwellers to migrate from the city centre to the city outskirts. This migration brought about the commercial and residential development near electric streetcars' stations, and this transport-orientated development shaped the radial form of urban structures (Warner, 1962). A similar pattern can be found in London due to the opening of the underground railway network in 1863. Residential and commercial development were promoted by increased population at the underground stations, functioning as economic and social foci in the city peripheries.

In Asian cities, the connection between transport innovation and urban form growth holds, although the pattern is slightly different. In the development of urban spatial structures in Asian cities, the causal link between transport innovation and urban spatial growth is subtly different from the western experience in terms of the intensity of

transport innovation playing out in the urbanisation process. This is because Asian cities have experienced rapid and extreme urbanisation where a large number of rural populations have migrated to cities in a very short period of time. Because of the rapid growth in urban spatial structures, the provision of transport infrastructure has often lagged behind, not in parallel with the phase of urban spatial growth that took place in western cities.

2.4.2.2. Spatial Models for Multiple Employment Centres

The evolution of contemporary spatial structures can be understood by reviewing various spatial models that theoretically explain the location choices of households and firms in an urban area. These spatial models incorporate factors and conditions affecting location choices together with the formation of the urban spatial structure (Fujita, 1989; Mills, 1967). In these models, households are distributed across a city as a result of trade-offs between housing rent and commuting cost to the CBD, and population density decreases with distance from the CBD because commuting costs increase.

The monocentric models have often been criticised as less suitable for describing large modern cities or metropolitan areas, which are characterised as a number of sub-centres resulting from a decentralised population and employment (Anas, Arnott & Small, 1998). Specifically, when it comes to the spatial distribution of economic activities, the models give little account of how modern metropolitan areas evolve into dispersed or polycentric spatial structures.

Motivated by the lack of spatial models explaining spatial development in contemporary large cities, Fujita et al. (2001) developed a theoretical framework for the evolution of spatial economic structures from monocentric to polycentric urban structures. They attempted to provide a convincing logic for research questions about how concentrations of employment are shaped and where they are located in relation to one another. With a developed spatial model of multiple regions, they showed that spatial economic structures are the product of interactions among scale economies at the individual firm level, transport costs and factor mobility. They also argued that the tension between centripetal and centrifugal forces in urban areas is the major driver for creating the potential for sub-centres.

2.4.3. Empirical Evidence on Transport Infrastructure and the Growth of Employment Centres

As discussed in the theoretical section, population and employment have been progressively decentralised, changing the location of production and consumption in urban and regional areas over the last several decades. The transformation of spatial structures has provoked a number of studies on various topics regarding what factors affect the formation and growth of multiple centres and how transport infrastructure is related to the locational transition of employment and population.

As the role played by transport infrastructure in job decentralisation occupies the central part of theoretical argument, studies on the link between transport infrastructure and the growth of employment centres have been developed along several strands, which can be largely separated into two categories. Studies in the first category have focused on developing a spatial model that can explain the emergence of multiple employment centres as well as their underlying causes. The majority of earlier studies tended to be based on the monocentric urban model (Fujita, 1989; Mills, 1969; Muth, 1969).

For contemporary large cities or metropolitan areas, several modelling studies have been conducted to develop a fundamental mechanism that can explain the new phenomenon of multiple emerging sub-centres (Fujita et al., 2001). For example, Fujita and Ogawa (1982) focused on two kinds of forces that play out differently in shaping employment centres. They recognised that agglomeration benefits between firms act as a force that pulls employment to the centres, whereas high living costs and congestion push employment outside the centres. They suggested that a spatial model that takes into account the two kinds of external forces could be useful in understanding the new phenomenon of multiple sub-centres.

A more advanced modelling study was developed by Anas and Kim (1996), who focused on a general equilibrium model of a contemporary urban region. Compared to the earlier studies, Anas and Kim's study differed by taking into consideration the dynamics of key economic factors simultaneously, not separately. In the model, the behaviours of firms and consumers are modelled in relation to transport costs to explain the formation of urban spatial structures. The model shows that a high level of traffic congestion may lead to the emergence of multiple sub-centres at the expense of the degree of agglomeration externalities, whereas a high level of agglomeration economies may intensify the concentration of economic activities.

Chen (1996) focused on the level of transport costs, arguing that a polycentric urban form is attributable to a reduction in transport costs. Simulating a model developed for the evolution of urban growth, it was found that a decrease in transport costs brought about more decentralised urban areas, with population, employment and land rent being dispersed. The model also confirmed that both a low level of commuting cost and a high degree of agglomeration economies in the CBD are major factors that give rise to the emergence of multiple sub-centres outside the CBD.

A key message drawn from reviewing the spatial models is that multiple sub-centres are the spatial outcome arising from the process of trading off between transport costs and productive advantages arising from agglomeration economies. The role of transport infrastructure in shaping modern spatial structures is essential, because its development changes the level of access to employment centres.

Recently, the key role of transport infrastructure in shaping urban form has been empirically explored by Baum-Snow, Brandt, Henderson, Turner, and Zhang (2017) who paid attention to the policy question of how infrastructure investments affects local urban form. They developed an econometric model that instruments for both transport infrastructure measure and population growth and includes controls that are correlated with outcomes. Various economic and transport infrastructure data were used, including lights-at-nights data to describe the decentralization of economic activities. They found that radial highways displaced 4% of population reside in the centre to the city outskirt and ring roads displaced additional 20% of population, and radial railroads and ring roads promoted the decentralization of industrial production and its workforce. They also found that radial highway decentralized service sector activity, and ring roads decentralized both service and industrial activities.

Another strand of studies in this category has focused on the formation of employment centres, emphasising finding employment centres to ascertain whether a given area is polycentric (McDonald & McMillen, 1990; Small & Song, 1994). These studies have been mainly conducted in US metropolitan areas in light of their decentralising trends of population and employment since the 1970s. Small and Song (1994) investigated whether monocentric or polycentric urban models fit with the spatial patterns of population and employment of the LA region in 1980. They found that the polycentric models fit statistically better than the monocentric models. McMillen (2003) showed that Chicago's urban structure evolved to be polycentric, with an increased number of

employment centres established outside the traditional centre. They demonstrated the expansion of urban structure by comparing the number of employment centres over 20 years, from 1980 to 2000, finding that it increased from 13 to 32.

Studies in the other category have paid attention to the role of transport infrastructure or accessibility in job location or employment growth at a local level (Blumenberg & Ong, 2001; de Vor & de Groot, 2010; Giuliano, Redfearn, Agarwal & He, 2012; Giuliano, Redfearn, Agarwal, Li & Zhuang, 2007b; Hoogstra & van Dijk, 2004). Less attention has been paid to this field in comparison to studies on the link between transport infrastructure and employment growth at urban and regional levels (Andersson & Karlsson, 2004; Rietveld, 1994). Studies in this category have pursued an understanding of the relation between the presence of transport infrastructure and employment growth to determine the way in which access to transport facilities relates to job opportunities and employment growth. These studies have tended to use regression analysis to assess the determinants of job location and employment growth, controlling for other factors related to employment growth.

Some studies have reported that the presence of transport facilities is positively related to job location and employment growth (de Vor & de Groot, 2010). Blumenberg and Ong (2001) investigated what factors affect welfare participants' relative access to job opportunities. They found that residential location and commuting mode are key factors for welfare participants' access to employment opportunities. Welfare participants' access to employment is significantly reduced in neighbourhoods where public transit is required to travel to work. de Vor and de Groot (2010) investigated the link between the performance of industrial sites, local economic structures and accessibility. They showed that specialisation is not the determinant of employment growth at the site-industry level; rather, access to transport facilities is a key factor for employment growth. Industrial sites that have easy access to highways are likely to grow relatively fast, while sites near harbour areas are likely to have higher performance.

Some studies have focused on service job development at a local level in relation to transport infrastructure, arguing that specialised services tend to develop around transport infrastructure (Carlino & Mills, 1987; Gong & Wheeler, 2002; Ihlanfeldt & Raper, 1990). Gong and Wheeler (2002) explored the spatial distribution and suburbanisation of business and professional services that took place in Atlanta between 1982 and 1997. Regression analysis was carried out to ascertain what factors

were associated with such phenomena. They found that highway access was one of the important determinants of service job location in Atlanta; further, they stated that highway access and well-educated professionals were the underlying factors for the increasing suburbanisation of business and professional services.

Employment redistribution in relation to transport infrastructure has been another subject of interest in this line of studies (Meijers, Hoekstra, Leijten, Louw & Spaans, 2012; Mejia-Dorantes, Paez & Vassallo, 2012). Meijers et al. (2012) investigated the distributive centre–periphery effects of transport infrastructure, aiming to ascertain whether the completion of transport infrastructure leads to the redistribution of employment and population. Using the case of a new tunnel linking a central region with a peripheral region, they found that jobs in the centre have decreased after the opening of the new tunnel, whereas jobs in the non-commercial service sector in the periphery have slightly grown. For population, they found a considerable increase in the population in the centre.

Yet, some studies have reported that the presence of transport infrastructure has either no relation or a weak relation with job location at a local level (Arauzo-Carod, 2007; Deitz, 1998). Arauzo-Carod (2007) explored the location determinants of population and employment at a local level. The author showed that professional groups of residents and employment dictate location patterns. For transport infrastructure, it was found that the presence of transport infrastructure is a less significant factor for population and employment. There may be not a close relationship between transport networks and the distribution of economic activities.

Hoogstra and van Dijk (2004) investigated how the location of a firm influences its performance using an econometric model in which several location characteristics were incorporated, such as population level, spatial specialisation and accessibility. They found that access to highways is not a significant factor for the performance of a firm, as was found in another Dutch study (Meurs, 1993). They concluded that a firm's location affects its performance, but that the effect differs depending on the type of economic activity.

Results in the literature are diverse in terms of the degree of importance on job location and employment growth (Hoogstra & van Dijk, 2004). Depending on the industrial sector, the link between transport accessibility and employment growth varies. Access to transport networks is more important for the manufacturing industry than for the

service and business industries mainly because manufacturing firms tend to be agglomerated in one area. The degree to which access to transport facilities is important also varies depending on the mode of transport (McMillen & McDonald, 1998). The performance and function of transport differs by transport system.

While several empirical studies have been conducted regarding the role of transport in local employment growth and job location, little attention has been paid to employment centre growth in relation to accessibility and transport infrastructure. To the best of my knowledge, only a handful of studies have been conducted so far (Agarwal, 2015; Garcia-López & Muñiz, 2010; Giuliano & Small, 1999). The focus of these studies has been on understanding the process of employment decentralisation and identifying the determinants of employment centre growth. The major method used in these studies was regression analysis, as well as longitudinal employment and population datasets.

For studies on the process of employment decentralisation, Garcia-López and Muñiz (2010) investigated the process of employment decentralisation and de-concentration across municipalities in the Barcelona Metropolitan Region, testing whether employment was moving from polycentricity to dispersal. The regression results showed that employment density always declines with increasing distance to transport infrastructure and the city centre, while a comparison analysis showed that employment centres increasingly influence employment locations. They concluded that a significant part of total employment is still dominated by employment centres, and that new centres have emerged in the periphery.

Concerning studies on the determinants of employment centre growth, the results are mixed regarding whether access to the labour force is a determinant of the growth of employment centres in a metropolitan area. Giuliano and Small (1999) empirically explored the determinants of growth of employment centres using the LA region as a case. They showed that the growth of employment centres has no significant relation with access to the labour force or with access to freeways. They also showed that close proximity to airports is strongly related to employment centre growth. However, Giuliano et al. (2012), who examined the link between employment centre growth and transport network accessibility, showed otherwise. These researchers showed that access to freeway networks positively impacts the growth of employment centres, and that access to the labour force is a determinant of employment centre growth. They also found no significant relationship between proximity to airports and employment centre growth.

They concluded that accessibility still plays a key role in shaping spatial structures in the context of contemporary large cities.

2.5. The Impact of Transport Infrastructure Investment on Land Values

This section reviews theories and empirical evidence relevant to the research question: 'How and to what extent does rail transit investment impact residential and commercial land values?', which is explored in Chapter Six. The first section discusses the theoretical link between transport infrastructure and land values, focusing on the way in which the value of land is determined by demand and supply, and how the demand for land is determined by its various features. In the following section, previous empirical studies on the impact of transport infrastructure on land values are reviewed.

2.5.1. The Link between Transport Infrastructure and Land Values

Land is regarded as one of fundamental factors linked to production. Economic activities normally take place on land and theoretically produce a certain degree of economic surplus; this surplus basically accrues to the land, giving it a certain level of capital value. This capital value is used to measure the economic surplus and welfare produced by economic activities on land (Dobb & Dobb, 1975).

Typically, two measures have been used to capture economic surplus and the welfare of economic activities on land; the measures are very similar but have different meanings: one is the price of land based on its exchange value on the market, and the other is the value of land based on its fundamental worth in production. The price of land can be defined as the sum for which the land is exchanged between buyers and sellers on the market. Yet, the price of land between buyers and sellers is likely to differ from the value of land to society. For example, an urban park has an amenity value which is difficult to express as market price because the park's land is not likely to be exchanged on the market.

The value of land is determined by 'the earnings accruing to land in the process of

production' (Willian J. McClocksey, 2009). Due to the complex nature of the economy, it is difficult to determine what land is worth to whom and in what circumstances. Land may be worthwhile to some individuals but not to others in different societies. For this reason, land worth is measured according to the economic earnings or welfare that the land generates in the economy. This is because land is one of the major production factors in the economy together with capital and labour (Vickrey, 1999). The earnings accruing to land are expressed in two ways: rental value and capital value. Rental value can be converted into capital value through a process of conversion, and vice versa. For land not put into the production process, its value is determined by 'opportunity cost', or the monetary value that the land could produce for the next best alternative use.

The economic earnings of land are determined by its demand and supply. Given that the supply of land in production is to a large extent restricted in urban and regional areas, the demand for land tends to play a key role in shaping its value (Ricardo & Sraffa, 1955). According to Ricardo's theoretical framework, the value of an agricultural plot of land is determined according to the price of crops cultivated on it, since land for agricultural production is fixed. For urban land, Marshall (1890) made a theoretical improvement to Ricardo's theoretical framework with respect to how the value of urban land is shaped. Marshall argued that the value of land is determined by both the price of the commodity produced on it and its various features. The characteristics of and demand for a plot of land are correlated.

The demand for land is determined by a range of land features, such as physical characteristics, neighbourhood characteristics, transport accessibility and attached legal rights (Vickrey, 1999). For example, the bundles of rights attached to a plot of land influence the demand for it because users' decision making depends on their right to sell or lease when putting land on the market for exchange. In the same manner, various features linked to locational features of land affect demand for it, including crime, education, green spaces and a sense of community (Cheshire & Sheppard, 1995). The degree to which land is connected to jobs, workers, and amenities via transport infrastructure is also a key determinant of its value (Banister & Thurstain-Goodwin, 2011).

2.5.2. Location Theory

The notion that transport investment can raise land and property values also relies on the theoretical framework provided by location theory (Alonso, 1964; Muth, 1969). Location theory, which explains the relationship between transport and the location of land, can be grouped into two approaches: one that focuses on the optimal location of land by considering a number of factors, such as transport, and another that examines the relationship between the location and value of the land (Debrezion, Pels & Rietveld, 2007).

The most well-known location theory is the bid-rent model, which can be traced back to an earlier model by Von Thunen that suggests that transport service capacity is the key to reducing costs for transporting agricultural products to the market. Inspired by Von Thunen's agricultural model, Alonso (1964) devised a bid-rent model that explains the relationship between the bid value of urban land use and its accessibility to the CBD. Alonso's bid-rent model assumes a monocentric city in which the CBD has the highest accessibility and the level of accessibility declines linearly as the distance from the core increases. In the model, households and firms are modelled to maximise their utilities and profits, which are determined by the trade-off between the space and accessibility factors. Also, the model assumes that all goods must be traded in the market located in the city centre.

The key assumption of the bid-rent model is that households and firms select the location at which their utilities are maximised, and thus the land price they are willing to pay is higher. Households and firms also trade-off accessibility to the city centre and space. Basically, the level of rent increases as the location nears the city centre because households and firms can save travel costs for transporting goods to the market. Because of this travel cost savings, demand for the most accessible locations is high, stimulating more competition for the location and higher land and property values. As households and firms select the location for which their bid rent outbid those of their competitors, bids theoretically increase until the benefits of travel cost savings become fully capitalised into the land and property values.

2.5.3. Empirical Evidence on the Impact of Transport Infrastructure on Property Values

Much of the debate around the direct benefits of transport investment is centred on the question of how transport infrastructure improvement impacts property values; the debate concerns the theoretical argument that the direct benefits of transport improvement are capitalised in land and property values. A large number of empirical studies have emerged to assess how and to what extent the user benefits of transport infrastructure projects are capitalised in property values

The literature on rail transit value comprises over 100 empirical studies on different types of properties, rail services and contextual locations (Debrezion et al., 2007; Debrezion, Pels & Rietveld, 2011). A key issue tackled in these studies is whether the positive externalities of rail transit outweigh the disadvantages of proximity to rail services, such as nuisance and noise. Most of these studies measured the proximity benefits of rail transit by calculating the distance from a property to a rail station; some also assessed the net effect of rail station proximity on property values (Banister & Thurstan-Goodwin, 2011).

Regarding methodology, the hedonic regression model is primarily used because of its capacity to distinguish the effect of proximity to a rail station from other factors in relation to variations in property values. Since property values are not determined by transport elements alone, factors that may have potential associations with property values are incorporated into an estimation of the impact of rail transit on property values. Factors that describe a property's physical and location characteristics may be considered as essential control variables. The characteristics of transport facilities may also play a key role in determining property values in transport capitalisation studies, including the design features of transit services, parking facilities in rail stations and actual transit ridership levels (Bartholomew & Ewing, 2011; Bowes & Ihlanfeldt, 2001; Cervero & Duncan, 2002).

Concerning the measurement of changes in access to the transport network, it has been pointed out that the measure of proximity to transport networks is the key to determining whether the price effect of transport accessibility on property values is positive or negative (Ahlfeldt, 2011). Earlier studies have tended to rely on relatively simple measures, such as straight distance or approximate time to the closest transport network. While most researchers have recognised the issue regarding the measure of

proximity to transport networks, both inadequate spatial analysis techniques and a lack of high-resolution datasets have discouraged them from using a more sophisticated version of proximity measures. Recently, however, significant developments in spatial analysis techniques and geographical information systems have occurred, with dataset resolution increasing (Geoghegan, Wainger & Bockstael, 1997; Seo, Golub & Kuby, 2014). Ryan (1999) argued that as innovations in spatial technology progress, travel times will be calculated based on transport networks, and more accurate outcomes on the effects of rail transit can consequently be evaluated.

More recently, a gravity-type accessibility measure has been considered as a conceptually improved measure of access to transport networks (Ahlfeldt, 2013). While previous proximity measures have implicitly treated rail stations as the substitute for transport networks, the gravity-type accessibility measure considers the idea that not all rail stations are the same in terms of their centrality within an urban system. For example, some rail stations have an important role in the local economy, whereas others do not.

The majority of empirical studies have focused on residential property, as the impact of transport investment on residential property is directly concerned with household welfare and travel patterns (Deweese, 1976; Efthymiou & Antoniou, 2013; Hess & Almeida, 2007). About the question of whether transport infrastructure projects impact residential property values, a large number of studies have yielded positive results on the various types of transport infrastructure in different cities and at various scales (Agostini & Palmucci, 2008; Pan & Zhang, 2008). Deweese (1976), who investigated the price effects of railway stations on residential property values in Toronto, found that residential property values within a distance of 1/3 mile from rail stations increased. Damm, Lerman, Lerner-Lam, and Young (1980), who examined the extent to which property values responded to the planned Washington Metro, generated findings similar to those of Deweese: The value of residential properties near to where rail stations were scheduled to be built increased in response to the new subway line. Therefore, Damm and colleagues concluded that property values were highly sensitive to proximity to subway stations.

With regard to types of rail transit, the price effects of rail transit differ depending on the transportation type, such as supertrams, bus rapid transit (BRT), high-speed rail and light rail transit (LRT). John (1998) investigated how the supertram in Sheffield affected

housing prices for the period between 1988 and 1993. Rodríguez and Targa (2004) reported that the arrival of the BRT system impacted residential rental values by around 0.16% and 0.22% for a 5-minute walking distance from the station. Hess and Almeida (2007) assessed the impact of proximity to light rail rapid transit on the values of residential properties around stations in Buffalo, New York. Using a hedonic model that accounted for neighbourhood characteristics and accessibility measures, they found that the property values within a one-quarter mile radius of the stations increased by 4–11% of the median value; they also reported that price effect caused by proximity to rail stations were positive in high-income areas and negative in low-income areas.

Recently, thanks to the development of spatial analysis techniques, this line of studies has been able to employ more detailed measurements for variations in proximity resulting from transport improvement, separating the accessibility effect of transport improvement by the distance from each property plot to the transport network node. Researchers have been able to draw a progressive curve of the proximity effect. An example of such an approach is found in Knaap et al. (1996), in which variations in property values around stations of the Westside LRT in Washington, Oregon were observed. The researchers pointed out that proximity to a rail station does not necessarily have a positive effect on property values; indeed, negative effects on amenity occurred in the immediate distance to rail stations due to noise and congestion. Comparing property values before and after the construction of LRT stations, Knaap and others found that property values within 0.5 miles of stations decreased with increasing distance from the stations due to these negative effects but increased in the residential properties between stations.

A relatively smaller number of studies have focused on commercial and industrial properties, showing positive effects of transport improvement on these properties (Cervero & Duncan, 2002; Debrezion et al., 2007; Ryan, 2005; Weinberger, 2001). Cervero (1994) investigated whether commercial properties jointly developed with rail stations performed better than commercial properties alone using a case study of five stations in Washington and Atlanta. Cervero found that jointly developed commercial properties tended to have higher property values, with an average rent of 7–9%. A possible reason for their better performance could be their well-organised development plan, which not only allows better on-site circulation of people and cars but also makes more efficient use of space. Weinberger (2001) examined the actual effect of light rail

transit on the rents of commercial properties in Santa Clara County, California. Comparing access to rail transits with access to highways, it was found that the rents of commercial properties within a half-mile of light rail stations increased by almost 15%; in contrast, highway access had no significant effect on the rents of commercial properties.

The positive effects of proximity to transport networks on commercial property values were supported by Cervero and Duncan (2002), who examined the price effects of proximity to light rail and commuter rail stations as well as proximity to freeway intersections in Santa Clara County, California. They showed that commercial lands near rail stations increased by 23%, while commercial lands in a business district within a quarter-mile of rail stations increased by 120%. Similar results were found in subsequent studies on commercial properties in San Diego conducted by Cervero (2003), who examined the variation of commercial property values near the South Line and East Line rail stations. Cervero found price premiums of 91.1% and 71.9% for commercial properties near Coaster stations and the Mission Valley Line, respectively, showing that the closer commercial properties were to railway stations, the higher their commercial property values. Cervero also concluded that being close to a mixture of shops, offices and well-planned streets tended to create a synergy effect on commercial property values.

The price effect on commercial properties was further extended by Debrezion et al. (2007), who investigated the extent to which new railway stations impacted commercial and residential properties. They found that the effects of new railway stations on commercial properties were 12.2% stronger than those on residential properties within 0.25 miles of the stations – but beyond 0.25 miles, the effects on commercial properties diminished immediately. This finding showed that rail stations might play an important role in attracting commercial activities.

Looking at the previous studies by study location, the majority tended to focus on cases in the US, Canada and the UK (Dubé, Thériault & Des Rosiers, 2013; Gibbons & Machin, 2005). While a number of researchers have recently attempted to examine transport infrastructure in large cities in Asia, published studies for this region are sparse in comparison to western-based studies, limiting our understanding of Asian transport infrastructure projects. Despite the growing demand for transport planning and policies in Asian countries, Asian transport infrastructure projects remain relatively

underexplored from an academic perspective.

Studies for South Korea and China

To the best of my knowledge, studies on rail transit in Asian cities have been conducted for Hong Kong, Shanghai, Seoul, Beijing and Bangkok (Bae, Jun & Park, 2003; Chalermpong, 2007; Hu, 2016). For Seoul, several rail capitalization studies have been conducted with various perspective; some have focused on the impact of upgrading BRT services while others have paid attention to discriminant impact of transit stations on office rents and land values.

Cervero and Kang (2011) explored the land-market effect of upgrading BRT services from regular bus operations to median-land bus services in Seoul, Korea. Multilevel models were used to predict land use changes near BRT corridor as well as land value capitalization. They found that intensification of land use along BRT corridor has been pushed forward by property owners and developers who were prompted by an increase in accessibility due to the substantial upgrading of BRT services. Land use change mainly occurred with single-family residential units being converted to multi-family units and apartments. They also showed that the increased accessibility resulting from the upgrading of BRT services was capitalized into land parcels for condominiums and higher density residential uses, with an average price premium of 10-25%.

Kim (2007) explored discriminant impacts of rail stations on office rents and land values using 731 office properties in Seoul. The author focused on not determining whether rail transit stations influence land values near stations but seeking whether effect of proximity to rail stations are discriminately capitalized by rail stations due to the urban spatial structure. Spatial models with various interactions were used to reveal how both the spatial structure and passenger density interact with distance to rail stations and how these interactions are related to office rents. The author found that the effect of proximity to rail stations decreases with an increase in distance from the CBD and this effect considerably depends on the density of property development near rail stations. It was pointed out that simple hedonic approach, only based on physical walking distance, might have difficulty in measuring exact effect of proximity to rail stations due to factors relating to density and spatial structure.

Bae et al. (2003) examined the impact of a new subway line on residential property

values in Seoul. They found that the construction of the new subway line impacted residential property values even before its opening, which is consistent with the theoretical argument that the effect of railway investment may be capitalised in property values in anticipation of its future benefits.

For China, many studies on the price impact of rail transport infrastructure have recently emerged to explore the phenomenon occurring with rail transport investment taking place in several Chinese cities. Overall, Chinese publications have nearly come to agreement that rail transit investment lead to positive effects on residential property values and these effects diminish with an increasing distance from rail stations (Feng, Li & Zhao, 2011), although a few studies have reported insignificant effect of proximity to rail stations on property values (Hui, Chau, Pun & Law, 2007). Pan and Zhang (2008) examined the impact of rail transit on residential properties in Shanghai and found positive link between rail transit investment and residential property values.

The majority of Chinese studies have focused on residential property values due to the data availability. Only a handful of studies have investigated the link between rail transit and commercial property values (Xu, Zhang & Aditjandra, 2016). Studies on the link between rail transit investment and commercial property values are rare in either international or Chinese publications. Xu et al. (2016) explored the effect of proximity to metro station on commercial property values. They found a 16.7% price premium in commercial properties within 100m distance of metro stations.

Looking at previous studies by cities, Beijing and Shanghai have been the most popular case area in the literature (Pan & Zhang, 2008; Sun, Zheng & Wang, 2015). Recently, the geographical focus of Chinese studies has extended to other Chinese cities apart from Beijing to Guangzhou (Salon, Wu & Shewmake, 2014) ; Wuhan (Xu et al., 2016); Shenzhen (Wang Fuliang, 2014); Tianjin (Sun, Wang & Li, 2016); Xian (Li, 2018); Zhengzhou (Zhang & Jiao, 2019).

With regard to the method used to estimate the price effects of rail transit, a hedonic pricing model has been dominantly used in the Chinese literature as it does in the Western literature (Hui et al., 2007; Pan & Zhang, 2008). Compared to Western publications, various methods have yet been attempted in Chinese publications, apart from spatial autoregressive model and repeat-rental model. Sun et al. (2015) used a repeat-rental model to address the issue of omitted variables often taking place in the estimation using a hedonic model. They found the significance of the missing variable

bias in a hedonic model. It was also found that the price effect of proximity to rail stations is weaker where land supply is more elastic.

There are a few interesting findings in Chinese studies. Zhang, Meng, Wang, and Xu (2014) explored differences in the price effects of three major transits: bus rapid transit (BRT), light rail transit (LRT) and metro rail transit (MRT). They found that MRT has the largest impacts in terms of the spatial extent as well as the increase in property values among the three transit. Liu and Hu (2007) showed that the price effects of rail transit investment vary by time points of a rail project. The effects are mainly large from the announcement of a rail project to its opening. Wang (2009) found that property values decrease gradually with an increase in the distance from rail stations. Zhang, Li, and Duan (2012) showed that accessibility to rail stations is the key factor of the price effects of subway stations.

Inconclusive Results on the link between Rail Transit and Property Value

However, the positive relationship between transport investment and property values is not conclusive. Some studies have reported that proximity to railway stations or highways is an insignificant factor for determining property values (Gatzlaff & Smith, 1993) or has negative effects on property value variations (Landis, Guhathakurta, Huang & Zhang, 1995). Gatzlaff and Smith (1993) showed that proximity to railway stations does not necessarily determine an increase in property values. They reported that the price effect of the Metrorail in Miami, which runs through the downtown area (half to the poorer north, half to the richer south), on property values only occurred in rich areas, not poor areas.

Inconsistent results on the link between proximity to transport networks and property values can be found in recent empirical studies. Ryan (2005) reported the inconsistent influence of access to transport facilities on property values. It was found that access to highway systems was a determinant of commercial property values, whereas access to light railway systems was statistically insignificant. It was also found that access to neither the highway nor the railway system was related to industrial property values. Theebe (2004) clarified that the major source of the negative impacts of transport improvement was noise pollution resulting from traffic activities around airports and railway stations. Theebe estimated the non-linear impacts of noise on property values

and found that the impact of traffic noise reached around 12%.

Most previous studies reported positive effects of proximity to rail transit on property values (Ahlfeldt, 2013; Cervero & Duncan, 2002; Gibbons & Machin, 2005), although some found insignificant or negative results on property values due mainly to negative externalities of transport facilities, such as noise and crime (Bollinger, Ihlanfeldt & Bowes, 1998; Gatzlaff & Smith, 1993). In response to this uncertainty, several studies have been conducted to investigate the reasons why the link between proximity to transport infrastructure and property values remains inconclusive.

Some studies have argued that the inconsistent results may be derived from the fact that previous studies were carried out under different research contexts, i.e., in variable geographical and land-use settings (Duncan, 2011; Hess & Almeida, 2007; Ryan, 1999). Ryan (1999) stated that contradictory results in previous studies might be attributable to complexities in urban and regional development as well as to unpredictable travel patterns. Debrezion et al. (2011) claimed that inconclusive outcomes in the literature were mainly attributable to the heterogeneity of the study contexts, which can be categorised as follows: level of transport services, type of transport infrastructure and neighbourhood characteristics. For example, heavy-rail stations are likely to have higher impacts on property values than light-rail stations because the former provide a higher level of access to economic opportunities, such as more frequent train services, larger geographical coverage and faster train speeds (Cervero & Duncan, 2002).

Other studies have argued that inconsistent results in previous studies were caused by differences in either the method used to estimate the effects of transport infrastructure improvements on property values or the measures used to capture changes in proximity to transport networks (Hess & Almeida, 2007). It has been reported that differences in the estimation techniques applied to explore the price effect of transport improvement may create subtle inconsistencies in the estimated results because each technique is based on different economic principles (Geurs & van Wee, 2004). A qualitative approach mainly relies on techniques based on comparison and observation, whereas a quantitative approach tends to use regression models.

The magnitude of the impact of rail transit investment is not constant across studies (Debrezion et al., 2011). It is therefore difficult to obtain a generalised result from the literature. The main source of this variation is that both the type of rail transit and the

type of properties vary across studies. Recent studies have emphasised that another reason for the varied results may be because the actual effect of rail transit investment is not appropriately captured by the price gradient alone (Billings, 2011; Dubé et al., 2013). Rail transit investment may have secondary impacts on property values in neighbourhoods near to rail stations. Much of the interest in most previous studies was on generating the price gradient. Only a handful of studies considered both the proximity and neighbourhood effects of rail transit together. Few studies have explored these effects for different types of land use in reference to variations in property values.

2.6. Conclusion

The findings from the literature review have a series of implications for the impact of transport infrastructure on productivity, employment centre growth and land values (the three empirical analyses that are pursued from Chapter Four onwards). First of all, a productive effect induced by transport infrastructure is the outcome of spatial processes that can be theoretically separated into two processes: transport infrastructure improvement and agglomeration economies.

In the first process, transport infrastructure improvement facilitates the spatial environment in which firms and workers are clustered in a more effective way by reducing their travel costs. Transport infrastructure development fosters agglomeration economies. This spatial mechanism is well accounted for by Venables' theoretical model, which explains the relationship between transport infrastructure investment, agglomeration economies, and productivity. In the second process, agglomeration economies induced by transport infrastructure bring productive benefits to economic actors through the micro mechanisms of agglomeration economies. Both the sharing and matching mechanisms are involved in this process in which firms and households benefit from the increased spatial concentration of economic activities. These two processes theoretically underpin the analysis of the impact of transport infrastructure on firm productivity in Chapter Four.

Research Gaps filled in Chapter Four

The literature review has identified three research gaps that are filled in Chapter Four. First, few studies on the link between transport infrastructure and productivity have been conducted at the micro level, mainly due to the lack of data availability, compared to the macro and regional levels. Further, the results of these studies are mixed. One reason for this inconclusiveness is endogeneity: transport infrastructure improvement is not randomly allocated but spatially targeted to meet specific economic demands.

Second, looking at study location, few studies have been conducted for Asian countries, compared to for Western countries. A relatively small number of studies have investigated regions such as Asia and Africa. Very few studies have explored the link between transport infrastructure and productivity at the micro level in these regions. This is a clear gap in the research and additional studies are required to increase understanding on the impact of transport infrastructure on productivity at the micro level in the Asian context.

Third, previous studies have tended to rely on a relatively simple accessibility indicator to capture the degree of productive advantages arising from transport infrastructure investment, such as city- or region-based measures and the assumed straight line. Recently, a growing number of studies have started using accessibility-type indicators to capture spatial externalities, such as market potential and effective density, as an alternative indicator. Yet, even in these indicators it has not been common to base travel costs on the actual transport network. Only seven studies have obtained travel costs this way. Additional studies, using improved accessibility indicators need to be done to increase the accuracy of the accessibility measurement and to reduce the inconsistency in the literature.

Research Gaps filled in Chapter Five

The literature review shows that transport infrastructure has long been considered as having a close relationship with the emergence of multiple employment centres. A series of spatial models have been developed in the literature to identify underlying forces and a fundamental mechanism of the emergence of multiple employment centres. A key message drawn from reviewing these models is that multiple employment centres are the spatial outcome arising from a trade-off between travel

costs and productive advantages arising from agglomeration economies.

Two research gaps have been identified in the literature for Chapter Five. First, few studies have thus far explored the growth of employment centres as compared to their emergence. Especially, little is known about how the growth of employment centres is associated with transport-induced accessibility in the context of Asian cities and regions. This is a research gap for which additional research is required.

Second, the few existing studies provide mixed results regarding how transport-induced accessibility affects the growth of employment centres. Some studies have reported that the growth of employment centres has no significant relation with access to the labour force or with access to freeways, whereas others have shown otherwise. Additional research is required to reach a conclusion regarding whether transport-induced accessibility plays a key role in employment centre growth. In addition, accessibility indicators used in previous studies could be further developed by using the actual spatial-decay parameter in the measurement of accessibility, rather than arbitrary values.

Research Gaps filled in Chapter Six

A last point that I have identified in the literature review is the central role of transport infrastructure investment in increasing the value of land. According to the theory, the value of land is determined by the economic earnings accruing to land in the process of production. Given that the supply of land is to a large extent restricted in urban areas, the value of land is determined by the demand for land. Accessibility has a significant impact on this. In addition, the link between transport infrastructure and land values can be explained by the theoretical framework provided by the bid rent model. The bid rent model explains the relationship between the bid value of land use and access to the city centre. Transport infrastructure plays a key role in reducing travel costs for transporting goods to the city centre. An analysis of the impact of rail transit investment on land values is underpinned by this theoretical framework.

Three research gaps have been identified in the literature for Chapter Six. First, previous studies on the link between transport investment and property values is not conclusive. While a large number of studies have found positive effects of transport infrastructure investment on property values, some studies have reported that proximity

to railway stations is an insignificant factor for determining property values or may even have negative effects on property value. One potential reason for this is differences in the research context in which studies were carried out. Another reason is differences in either the method used to estimate the effects of transport infrastructure improvements on property values or the indicators used to capture changes in proximity to transport networks.

Second, disaggregated land uses, such as retail, mixed, and multi-family housing land uses, have been underexplored in the literature. Most previous studies have relied on housing land uses to assess the impact of transport infrastructure investment on property values. While some studies have looked into office land uses, very few studies have attempted to assess the price impact of transport infrastructure investment on other types of land uses. This is a gap in the research and the impact of transport infrastructure investment on land values needs to be studied further.

Third, most earlier studies have tended to rely on a simple proximity indicator to estimate the effect of transport infrastructure investment on land values, paying less attention to wider accessibility effects that might result from that investment. Recent literature argues that investment in rail transit has both direct effects and wider accessibility effects on land plots near stations and their neighbourhoods. While the direct proximity effects are captured by a simple proximity indicator, the wider effects are not appropriately captured by a simple indicator alone. An analysis that seeks to uncover both the proximity and wider accessibility effects of rail transit investment remains a desideratum to provide a more complete picture of changes in land values.

3. Research Methodology

Following the theoretical discussion in Chapter Two, this chapter discusses the research methodology used in this thesis. Section 3.1 provides the research setting, which defines the scope of the research, as well as the unit of analysis. This is followed by Section 3.2. that presents an overview of the data used in this thesis, which is divided into six categories. In Section 3.3., the research method is presented, together with the tools used to interpret and analyse the results.

3.1. Research Setting

3.1.1. Spatial Unit of Analysis

The basic spatial unit of analysis upon which this research is based is the *dong*. The *dong* is the smallest administrative area in Korea, roughly equivalent to a ward in the UK, where the impact of transport infrastructure can be assessed. The reason for choosing the *dong* is that major datasets that need to assess the impact of transport infrastructure are available at the *dong* level. Also, the size of the *dong* is suitable for an investigation of the effect of transport infrastructure, as it is small enough to observe the phenomenon occurring with transport infrastructure and is also large enough to cover the spatial extent of the effect of transport infrastructure.

While the *dong* is the basic spatial unit of analysis, I use different unit of analysis for the three analysis chapters as different research questions are explored in each chapter. The *dong* is used as the spatial unit of analysis in Chapter Four whereas an employment centre identified by the cut-off method is used as the spatial unit of analysis in Chapter Five. In Chapter Six, land plot is the spatial unit of analysis as this chapter explores the variation in land values with respect to a change in proximity to rail station and employment accessibility.

The unit of analysis is a major concern in any spatial research, because a phenomenon occurring in the spatial system can be observed at different levels (Longley, Goodchild,

Maguire & Rhind, 2010). The research outcome may differ depending on the choice of the unit of analysis, as it makes a difference to the extent and the detail of understanding on that phenomenon. For this reason, the unit of analysis should be defined in such a way that it covers the spatial extent of the phenomenon being researched while allowing for a detailed analysis of this phenomenon (Longley et al., 2010). The spatial unit of analysis is interrelated with the scale of analysis and, therefore, it is normally defined in accordance with it.

The definition of the unit of analysis is subject to data availability. It is thus necessary to check whether data is available at the spatial unit chosen, because this availability determines whether spatial analysis can be performed at the chosen spatial unit. The more a disaggregated spatial unit of analysis is used, the more likely it is that the outcome of the analysis is accurate, because the high resolution of spatial data can reveal the phenomenon of research interest in more detail. However, such disaggregated data is not always available. As such, there is a trade-off between the level of spatial disaggregation and the level of detail of the research (Longley et al., 2010).

Taking into account these points, I ran a series of tests to determine the right spatial unit of analysis for this thesis. The unit of analysis that represents the phenomena of research interest of this thesis is the *dong*. In Chapter Six, I set the spatial unit of analysis as a land plot, since the phenomenon of rail transport infrastructure investment can be represented better at this spatial level than at the *dong* level. The effect of rail investment on land values can be more accurately captured at the disaggregated spatial level.

3.1.2. Temporal Scope of Study

The time period between 2000 and 2012 is the temporal dimension of analysis. The temporal scope is selected to cover the time period when the phenomenon under study took place. As noted in Chapter Two, it takes a long time to complete new transport infrastructure projects. It also takes some time for its spatial economic effects to materialise. In this regard, I choose a longitudinal time scope to investigate the spatial economic effects of transport infrastructure rather than a cross-section time horizon. A longitudinal time frame is considered more effective than a cross-sectional time frame

in terms of assessing the economic effect of transport infrastructure, because it allows for observing the phenomenon being researched in more detail. It enables investigating the economic effect of transport infrastructure over time.

The time period between 2000 and 2012 is noted for the rise of information and communication technology (ICT) in production. The development of ICT has brought about a change to the way in which products such as mobile phones, LED, and semiconductors are produced. In addition, between 2000 and 2010, both the road and the rail transport infrastructure network improved significantly.

The three analysis chapters each have their own temporal scope of analysis. For Chapter Four, I set the time period between 2000 and 2012. For Chapter Five, the time period between 2000 and 2010 is set as the temporal scope of analysis. For Chapter Six, I set the time period between 2008 and 2010 as the temporal dimension of analysis. Using different temporal scope of analysis in each chapter is attributed to different research questions being explored in each chapter. For example, in Chapter Six, the research focus is on a short-term effect of rail transit investment rather than its long-term effect. The chapter evaluates an immediate real change in land values before and after rail transit investment during the time period between 2008 and 2010. In Chapter Five, the data availability dictates the temporal scope of analysis, because datasets for employment centre growth are not available for the year of 2011 and 2012.

The definition of the temporal dimension of analysis is also subject to the data availability. For this thesis, the availability of transport network data is the key to defining the scope of analysis, because the transport network data is directly related to the quality of the variables of interest used in the analytical chapters. I use the best available dataset from 2013, when I embarked on this thesis, but the transport network data was not available in the form of a time series (Korea Transport Institute [KOTI], 2013). Because of this limitation, I cannot use the dynamic panel model for firm's productivity in Chapter Four so that I had to devise a solution. I adopted a two-stage econometric approach that allows for obtaining firm's productivity at the first stage and for estimating its association with transport-induced labour accessibility at the second stage. The estimation in the second stage was carried out with a cross sectional data of transport infrastructure network.

3.1.3. Defining Transport Infrastructure and Accessibility

Infrastructure is normally defined as capital that provides public services such as roads, electronic systems, sewage and water systems. Transport infrastructure is defined as capital that provides transport services such as roads, railways, waterways, airports, and seaports (OECD, 2002). This thesis focuses on roads and railways as transport infrastructure, confined to a geographical area in the Seoul region.

As discussed in the literature review, the concept of accessibility has been used in many areas of transport and planning studies. This extended interest in accessibility measures is attributed to advancements in spatial modelling, spatial analysis techniques, and the high resolution of spatial data. While accessibility measures are used to measure a change in the distance to transport nodes, their applicability to evaluating the productive effects of transport infrastructure has only recently been recognised. Several studies have pointed out that accessibility measures can be further developed as an indicator that evaluates transport infrastructure projects (López, Gutiérrez & Gómez, 2008). In this thesis, I further develop the concept of accessibility as an indicator that captures the indirect economic effects of transport infrastructure, applying advanced spatial analysis techniques and using disaggregated spatial datasets. Models and detailed specifications for the accessibility indicators are presented in Section 3.3.

3.2. Research Method

3.2.1. Quantitative Approach

It is essential for any research to choose the right research approach, because the approach governs the procedure followed in the research, from creating a hypothesis to analysing the phenomenon and answering the research questions (Booth, Colomb & Williams, 2009). I selected a quantitative approach as the main research method, based on the nature of the research questions being asked (Barbara, 1993). The choice of a quantitative approach guarantees robust and generalisable evidence on the economic effects of transport infrastructure.

A major reason for choosing a quantitative approach is down to the fact that

researchers who have explored research questions similar to the thesis presented here have relied mainly on a quantitative approach. A qualitative approach may be alternative option as it has several strong points in terms of describing detailed and various aspects of transport infrastructure investment. However, given how research questions similar to mine have been investigated in the literature, a quantitative approach is more reasonable choice for me to choose to explore the economic effect of transport infrastructure.

Specifically, research questions similar to mine have been explored by key author in the field of research, using a quantitative approach. Here are a few examples of previous studies. In Chapter Four, the link between firm's productivity and transport-induced accessibility has been investigated by several researchers who have used a quantitative approach with a panel model and an IV model (Gibbons et al., 2019; Holl, 2012, 2016; Martín-Barroso et al., 2015; Néchet et al., 2012). In Chapter Five, Giuliano et al. (2012) and Agarwal (2015) have explored the link between employment centre growth and labour accessibility by using a quantitative approach with a regression model. In Chapter Six, the link between land values and rail transport investment has been assessed by a number of researchers who have adopted a quantitative approach with various econometric models (Cervero, 2003; Cervero & Duncan, 2002; Debrezion et al., 2011; Duncan, 2011; Gibbons & Machin, 2005; Hess & Almeida, 2007).

Since a quantitative approach has been used to answer for the research questions, a range of statistical models and a large amount of data have been used in this thesis. Different research questions and issues are addressed in the three-analysis chapter, and therefore different statistical and dataset are used. Table 3-1 summarises both statistical models and data against research questions.

A quantitative approach is characterised by testing a research hypothesis formulated on the basis of relevant theories and findings (Creswell, 2013). Quantitative research normally tends to be used to explore closed-ended research questions rather than open-ended ones and focuses more on examining the relationship between the variable of interest and a dependent variable. The research questions of this thesis are closed ended and seek to understand the relationship between the economic effects of availability of transport and a firm's productivity; the link between transport-induced labour accessibility and the growth of employment centres; and the impact of rail transit investment on land values.

In a quantitative approach, it is essential to give a clear account of how the data and its analysis answer the research questions. In accordance with the APA's guideline, I set out the way in which this thesis interprets the estimates obtained from statistical models (American Psychological Association, 2009). The outcomes obtained from statistical analysis are expressed in the form of figures, normally presented in tables or diagrams. These figures contain statistical information confirming or disconfirming the research hypothesis, as well as showing to what extent a variable of interest impacts a dependent variable. Two figures are important to interpret the results: the p-value and the coefficient of a variable.

P-values are defined as the probability of obtaining an effect at least as extreme as the one in the sample when the null hypothesis is true (Wasserstein & Lazar, 2016). A high p-value indicates that the sample provides little evidence to support the null hypothesis, whereas a low p-value suggests that the sample provides enough evidence to reject the null hypothesis. I set the cut-off level for "no effect" at a 0.5 p-value, which means that there is strong evidence against the null hypothesis when the p-value of a variable is smaller than 0.5. For example, in Chapter Six, if the p-value of a variable for accessibility in relation to the variation of land values is lower than 0.5, this would indicate statistically significant effects of accessibility on land values (Rudestam & Newton, 2014).

The coefficient of a variable represents the mean change in the variable for one-unit change in the dependent variable, all other variables remaining unchanged. In other words, the coefficient of a variable refers to the degree to which the variable impacts the dependent variable. Note that the interpretation of the coefficient of a variable can differ depending on the model form selected. In addition, the *R*-squared value shows the performance of a regression model in terms of how it statistically fits the relationship between the variable of interest, independent variables, and a dependent variable. The higher the *R*-squared value, the closer the distance between the fitted line and the data points, meaning that the regression model explains the relationship well.

Table 3-1. Summary of Statistical Models and Data against Research Questions

	Research question	Statistical model	Data
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Chapter four	“How and to what extent are transport-induced economic effects related to the productivity of manufacturing firms in the Seoul region?”	Pooled OLS model Standard panel model IV_DD model with Anderson-Hsiao (AH) estimator Dynamic panel model with the system-GMM estimator IV model with instrument variables	Firm data Firm features Data Data for instrument variables Government policy data Transport network data Household Travel Survey
Chapter five	“How and to what extent is transport-induced labour accessibility related to the growth of employment centres in the Seoul region?”	Regression model	Employment data Population data Geographical data Policy data Transport network data
Chapter six	“How and to what extent does rail transit investment affect residential and commercial land values?”	Multilevel hedonic model Difference-in-difference model Quantile regression model	Land value data Employment data Neighbourhood data Land features data Transport network data

3.2.2. Analytical Tools for the Quantitative Approach

This thesis adopts two widely used analytical tools to answer the research questions: 1) statistical and econometric analysis, 2) spatial modelling and visualisation. An overview of these tools is presented in the following sections and both the specification and detailed usage of these tools is provided in the methodology parts of each analysis chapter.

3.2.2.1. Statistical Analysis

Statistical analysis with a range of econometric models is one of the main analytical tools used in this thesis to answer the research questions. Considering the differences in specific issues addressed in the three analysis chapters, I have developed different statistical and econometric models that are best suited to answer the research questions based on the literature. The details of statistical models are summarized in

Table 3-2.

In Chapter Four, I employ a two-stage empirical approach to explore the link between transport-induced economic effects and a firm's productivity. In the first stage, a simple production function is estimated to obtain the elasticities of a firm's output with respect to the input factors. I use four regression models for this estimation: a pooled OLS model, a standard panel model, an IV-DD model and a dynamic panel model with a system-GMM estimator. A preferred model in this chapter is a dynamic panel model with system-GMM estimator, because it is capable of correcting for several estimation issues. In the second stage of the estimation, I use an IV model to estimate how a firm's productivity responds to a change in workforce accessibility caused by a change in transport infrastructure. I incorporate a series of instrument variables in this IV model to address the endogeneity of productive effects induced by transport infrastructure.

In Chapter Six, I use a difference-in-difference (DID) model to investigate the accessibility effects of rail transit investment on residential and commercial land values. A DID model is widely known as a quasi-experimental research approach to infer the causal relationship between policy changes and subsequent outcomes. I also use a quantile regression model to investigate the hypothesis that the accessibility benefits of rail transit investment are not constant across lands at different price levels.

In addition, I present simple descriptive statistics for variables used in the three analysis chapters. Descriptive statistics are useful to understand the structure and characteristics of the dataset used in each chapter. Four statistical figures of variables are presented in descriptive statistics, namely the minimum value, the maximum value, standard deviation, and the mean. Alongside these statistical figures, I discuss possible implications and inferences that can be derived from them.

Table 3-2. Summary of Statistical Models

	Dependent variable	Statistical model	Study period
Chapter four	Firm's total output (Firm's productivity)	Pooled OLS model Standard panel model IV_DD model with Anderson-Hsiao (AH) estimator Dynamic panel model with the system-GMM estimator	The years between 2000 and 2012

		IV model with instrument variables	
Chapter five	A change in the number of jobs	Regression model	The years between 2000 and 2010
Chapter six	Residential and commercial land values	Multilevel hedonic model Difference-in-difference model Quantile regression model	The years between 2008 and 2010

3.2.2.2. Spatial Analysis and Visualisation

Spatial analysis and visualisation are the other main analytical tools used in this thesis to answer the research questions. These two tools play an essential part in capturing the interaction between the spatial structure and the transport infrastructure. These spatial techniques are also used to determine how spatially economic activities are shaped and distributed across an area, and what sort of relationship this distribution of economic activities has in relation to changes in accessibility.

For visualisation methods, I use two techniques: thematic mapping and the interpolation method. Thematic mapping techniques are used to visualise spatial variation and patterns of variables (Burrough, McDonnell, McDonnell & Lloyd, 2015). Thematic mapping can be classified into three types, depending on the number of variables involved in the mapping procedure. Maps with univariate thematic mapping show the spatial distribution of a single variable while bivariate thematic maps show the spatial distributions of two variables. I focus on choropleth mapping as it enables showing statistical data in predefined spatial units such as countries and municipalities. In terms of how the maps are interpreted by readers, I group variables by a certain numerical range, based on numerical differences in lightness. Thematic mapping techniques are used in all three analysis chapters of this thesis. For example, the level of workforce accessibility is mapped to visualise its spatial pattern across the Seoul region, with the classification legend for the numerical intervals between classes.

The interpolation technique is used to show changes in spatial variables and their relations with other socio-demographic variables, displaying the continuity and variability of variables in the sample. Interpolation techniques are in some sense similar to thematic mapping techniques in that the spatial morphology and characteristics of variables are mapped, but they differ in that interpolation techniques are more

specialised in visualising a change in spatial variables such as a change in population density.

For spatial analysis, I use a range of spatial analysis techniques embedded in ArcGIS for spatial modelling, including spatial editing, network analysis, and data integration. For example, network analysis is most frequently used to determine the spatial pattern of commuting flows and to calculate the level of commuting flows between origins and destinations in the Seoul region (Environmental Systems Research Institute [ESRI], 2015).

Aside from spatial analysis techniques, I also create spatial variables feeding into the visualisation process. This is done by either joining new spatial information with the existing spatial variables or simply appending them to the existing tables. For example, in Chapter Six, a table that contains the characteristics of land plots is joined to a table with the level of proximity to public rail transportation, based on the matching values found in the two tables.

3.3. Accessibility Indicators

In the thesis presented here, an accessibility indicator is used as a key means of capturing the economic effects of transport infrastructure on productivity, employment centre growth and land values. The literature tells that access to both the labour force and employment by transport infrastructure is the source of economic benefits (Graham, 2007a; Venables, 2007). Since the access to the labour force and employment changes due to transport infrastructure investment, it is essential to capturing both labour and employment accessibility using an effective method.

Despite the important role of accessibility indicators, previous studies have tended to largely depend on a simple accessibility indicator such as an assumed straight line between locations. This has often been the source of inconclusive results for the price effect of rail transit investment (Hess & Almeida, 2007). A key limitation of a simple accessibility measure is that it is only capable of capturing a change in distance to transport facilities but is not capable of capturing a change in wider effects of transport infrastructure.

To address the limitation of previous accessibility indicators, I develop more advanced accessibility indicators in which I improve both the quality and accuracy of accessibility indicators in four aspects. The quality of accessibility indicators is a crucial factor for any spatial analysis, because it is directly linked to how accurately economic effects induced by transport infrastructure are captured. Detailed explanations on the four improvement to accessibility indicators are presented in the following sections.

3.3.1. Accessibility as Productive Effects of Transport Infrastructure

Accessibility indicators developed in this thesis is based upon the theoretical notion discussed in Chapter Two. The key point is that transport infrastructure improvement expands the spatial boundary of economic activities, enabling firms and workers to interact with each other in a more clustered space. Transport infrastructure improvement thus promotes the spatial interaction between firms and the workforce. This causes an increase in the level of efficiency in production, reduces the cost involved in the interactions, and results in an enlargement of the labour market, improving the chances of matches between firms and workers and the quality of these matches (Combes & Gobillon, 2015; Venables et al., 2014).

Based on the aforementioned theoretical notion, I construct a series of accessibility indicators for the three analysis. The accessibility indicator proposed by Hansen (1959) is used as a base for those accessibility indicators. Hansen's accessibility indicator has been widely adopted in studies in urban planning, geography, and transport planning as the standard indicator of accessibility (Ahmed, Petzold, Kabir & Tomson, 2006; Shen, 1998; Vickerman et al., 1999; Wilson, 1974).

To develop more advanced accessibility indicators, I make improvement to Hansen's accessibility indicator in four aspects. This improvement is mainly intended to increase the accuracy and quality of accessibility indicators. First, I improve the way to measure travel costs from using a straight line between locations to calculating travel costs between origins and destinations based on the actual transport network. Second, I take into account commuters' preference for transport mode in the measurement of travel costs. Third, I estimate a simple spatial interaction model to use the actual spatial-decay parameter in the calculation of accessibility indicators. Lastly, I incorporate the notion that workers compete for job opportunities in the region and in the same manner, firms

compete for skilled workers in the region.

With the improvements mentioned above, I construct accessibility indicators for each chapter. The details of accessibility indicators developed are summarized in Table 3-3. The details of equations are provided in the section of research strategy in each chapter.

Table 3-3. Summary of Accessibility Indicators

Accessibility Indicators		Equations and Description
Chapter four	Transport-induced Workforce accessibility indicator	$AC_i = \sum_j \frac{L_j(D_i \cdot e^{-\alpha \cdot T_{ji}})}{\sum_m D_m \cdot e^{-\alpha \cdot T_{jm}}}$ <p>A given area's relative potential for workers in the Seoul region</p>
	Proximity indicator	Network distance to international airport and high-speed rail stations
Chapter five	Transport-induced Absolute labour accessibility indicator	$ACC_i = \sum_j L_j e^{-\alpha T_{ij}}$ <p>A given area's absolute potential for the labour force in the Seoul region</p>
	Transport-induced Relative labour accessibility indicator	$RACC_i = \sum_j L_j (D_i \cdot e^{-\alpha \cdot T_{ji}} / \sum_m D_m \cdot e^{-\alpha \cdot T_{jm}})$ <p>A given area's relative potential for the labour force in the Seoul region.</p>
	Proximity measure	Network distance to the nearest rail station
Chapter six	Absolute employment accessibility indicator	$ACC_i = \sum_j E_j e^{-\alpha T_{ij}}$ <p>A given area's absolute employment potential in Seoul</p>
	Relative employment accessibility indicator	$RACC_i = \sum_j (E_j \cdot e^{-\alpha \cdot T_{ij}} / \sum_m D_m \cdot e^{-\alpha \cdot T_{jm}})$ <p>A given area's relative employment potential in Seoul</p>

3.3.2. Measurement of Real Travel Cost

As mentioned previously, I make improvement to the way of measuring travel costs using the actual transport network. The way to measure travel costs between origins and destinations directly influence the accuracy of accessibility indicators. Most previous studies have tended to use a simple accessibility indicator based on an assumed straight line between locations (Combes et al., 2010; Fally, Paillacar & Terra, 2010; Hering & Poncet, 2010; Mion & Naticchioni, 2009). While a simple accessibility indicator may be easy to use in practice, it may not be suitable for studies investigating the economic effect of transport infrastructure. Travel costs measured by an assumed straight line are very different from those measured based on actual transport network. Also, a change in travel costs is not captured by an assumed straight line between locations when transport infrastructure investment is made.

To address the limitation of accessibility indicators in previous studies, I use the actual transport network to calculate travel times between origins and destinations. I expect that this might increase the accuracy of accessibility indicator considerably, and this improvement might make a significant difference in the outcome in this or similar studies. To my best knowledge, only seven studies have explored the link between transport infrastructure and firm-level productivity using accessibility indicators based on real transport network (Donaldson & Hornbeck, 2016; Gibbons et al., 2019; Graham, 2007a; Holl, 2012; Martín-Barroso et al., 2015; Néchet et al., 2012; Rice et al., 2006).

3.3.3. Consideration of Multiple Travel Modes

I also make key improvement to the measurement of travel costs by taking into account travel modes selected by commuters. A couple of travel modes are normally available to commuters and only one travel mode is chosen by commuters in favour of travel cost savings as they can't select multiple travel modes at the same time. For example, commuters who care for cost savings are likely to choose public transportation over cars as travel costs for public transportation are likely to be lower than those for cars although there are some exceptional areas where this is not applied.

Few studies have considered the role of travel modes in the measurement of travel

costs in the literature. The mode of transport chosen may significantly influence travel costs between origins and destinations because travel costs by cars are very different from those by public transportation. Not taking this into account in the calculation of workforce accessibility indicators might overestimate the level of workforce accessibility and thus result in an outcome that is biased towards the productive benefits of transport infrastructure. Even though significant influence of travel modes on the measurement of travel costs, they have received less attention in most previous studies.

To address the limitation of the way to measure travel costs between location, I take into account commuters' choice of travel modes in the measurement of travel costs. I formulate a simple travel model that can include the choice of travel modes in the measurement of travel costs. The model considers two key travel modes following the literature: public rail transit modes and automobile modes (de Palma, Lindsey, Quinet & Vickerman, 2011b). The specification of a simple travel model is shown in Eq. 3-1. Public rail transit modes involve three steps of travel: walking from home to rail stations, traveling by rail, and walking from rail stations to workplaces. Automobile modes comprise only travel by car. Using this travel model, I calculate the minimum travel times for the two travel modes and then compare them with each other to obtain the shortest travel time for the commuting route.

Equation 3-1. Travel Model

$$T_{ij} = \min\left(\frac{D_{ij}}{V_{car}}; \frac{D_{iso}}{V_{walk}} + \frac{D_{sosd}}{V_{train}} + \frac{D_{sdj}}{V_{walk}}\right)$$

where T_{ij} is the minimum travel time between zone i and zone j. For automobile modes, D_{ij} is the distance between zone i and zone j by a car with a velocity of V_{car} . For public rail transit modes, D_{iso} is the distance from zone i to the nearest rail station. D_{sosd} is the distance from the rail station in zone i to the rail station in zone j, and D_{sdj} is the distance from zone j to the nearest rail station.

3.3.4. Estimation of Spatial-decay Parameter

Another important factor that affects the accuracy of accessibility indicators is a spatial-

decay parameter that explains the way in which commuters respond to a change in commuting distance. A spatial-decay parameter represents how far workers are willing to travel to workplaces, indicating the degree of spatial friction caused by the distance from home to work. Most previous studies have tended to use arbitrary values as a spatial-decay parameter, not taking into account how actually workers respond to a change in commuting distance in the real world.

To address the limitation of accessibility indicators in previous studies, I estimate a simple spatial interaction model based on the gravity-type model in order to obtain the spatial-decay parameter for the Seoul region (Graham & Melo, 2011).⁶ I use household travel survey that provides key information on the pattern and behaviour of household travel in the region. Using an estimate spatial-decay parameter for the Seoul region considerably reduces that arbitrariness used in previous accessibility indicators. I expect that this might increase the quality of accessibility indicators significantly and contribute to an increase in the accuracy of the outcome of this research.

The specification of a spatial interaction model for commuting trips is shown in Eq. 3-2, where the commuting trips are a function of the size of economic activities at both origin and destination. The scale parameter k is added to measure the relationship between the number of commuting trips and the size of economic activities at both origins i and destinations j . To incorporate a travel-cost sensitivity function into the model, I employ a negative exponential function in accordance with the literature (Reggiani, 2004; Wilson, 1967). I focused on commuting trips only, because they are more relevant to the study of the productive effects of transport infrastructure than other types of trips such as shopping or school trips. Also, in the Seoul region, commuting trips make up over 60% of trips from home.

Equation 3-2. Spatial Interaction Model for Commuting Trips in the Seoul Region

$$T_{ij} = k O_i^{\beta_1} D_j^{\beta_2} \exp(-\alpha d_{ij}) \quad i, j = 1, \dots, N$$

⁶ Spatial interaction modeling has a long history, tracing back to the gravity-type modeling. Since then, it has been developed into popular modeling for spatial analysis, employing the entropy theory and the utility maximization approach.

where T_{ij} is the number of commuting trips between origin i and destination j ⁷; O_i is the size of the population at each origin; D_j is the number of jobs at each destination; d_{ij} is the spatial distance between the centroids of origins and destinations. The commuting data comes from the housing travel survey that provides key information on the pattern of household travel and its behaviour in the region, such as the purpose of travel, the number of trips made for each travel purpose, and the travel costs between origins and destinations.

3.3.5. Consideration of the Demand and Supply Side of Accessibility

In the thesis presented here, I use the relative accessibility indicator in addition to both the absolute accessibility indicator and proximity indicator. The absolute accessibility indicator is accepted by many researchers in various strands of literature relating to geography, transport and planning. Nonetheless, there is criticism of the absolute accessibility's handling the spatial distribution of economic opportunities, which is the 'demand side' of accessibility measurement — the competition for available economic opportunities — is not taken into account while the 'supply side' of accessibility measurement is considered.

It may be close to the reality to consider the demand for the available opportunities because the demand is not uniformly distributed across the area and the available opportunities are not infinite. Each of the available opportunities is not for only one opportunity seeker at any moment in time. There is always competition for the available opportunities in the real world. Because economic opportunities exist in locations in which various levels of demand potential are attached to, accessibility to each set of economic opportunities is partly determined by the demand potential for the location of the economic opportunities.

To apply this concept of the demand side to accessibility indicators, I develop the relative accessibility indicator that incorporates both the supply and demand potentials

⁷ The spatial units for origins and destinations are set as *dongs* (the smallest administrative areas) in this thesis.

in the measurement of accessibility. Based on the accessibility indicators presented by Shen (1998), I articulate this concept in the form of equation. A brief specification for this accessibility indicator is shown in Eq. 3-3 in which the supply potential is in the numerator of the equation whereas the demand potential is in the denominator of the equation. More details on the accessibility equations are presented in the section of research strategy in each analysis chapter.

Equation 3-3. Relative Accessibility Measure for Land Plots

$$RACC_i = \sum_j (E_j \cdot e^{-\alpha \cdot T_{ij}} / \sum_m D_m \cdot e^{-\alpha \cdot T_{jm}})$$

where E_j refers to employment opportunity in dong j. T_{ij} refers to the travel time between dong i and j, while T_{jm} represents the travel time between dong j and m. D_m is the numerical value of the workforce⁸ in m.

3.4. Data

Many datasets are used in this thesis and they can be classified into six categories: employment and population data, government policy data, transport data, property data, firm data, and other spatial and neighbourhood data. I have collected these datasets from various sources such as the Statistics Office of Korea, the Korean Land Registry, the Korean Ministry of Construction and Transportation, and the National Transport Database. Data used in this thesis is summarised in Table 3-4, together with various sources for the data. The details of data are provided in each analysis chapters.

In terms of the quality of data, there has been a significant improvement in recent years. This improvement is mainly attributed to the recent development of ICT. Innovation in ICT has increasingly enabled scientists and technicians to overcome many technical

⁸ Labour force, in this study, is defined as the population whose age falls between 15 and 64.

hurdles and obstacles that hinder the gathering of high-quality data. For example, the development of smartphones and LTE telecommunication has enabled researchers to trace information on people's behaviour and mobility at the micro level.

In addition, data has become more detailed and accurate because more researchers demand high-quality data that allow them to study complicated problems. Society has become more complex and diverse and issues and problems in society have consequently become more complicated, which requires more advanced methods and datasets to resolve them.

Responding to the growing demand for high-quality data, the Statistics Office of Korea made an improvement to socio-economic and spatial data in three aspects (Opendata Strategy Council, 2013): the resolution of spatial data, the features of data, and the access to data. Firstly, the resolution of spatial data improved considerably, allowing researchers to study the phenomenon of social and economic activities taking place at the disaggregated level and to explore them more accurately. For example, the household travel survey contains several attributes of households, such as income and demographic data. In addition, access to data improved significantly since the public information act came into effect. A large amount of public government data is now available to the public through a user-friendly website.

Table 3-4. Summary of Data and Data Source

	Data type	Spatial scale	Data source
Chapter four	Firm output	Firm level	The Korean Micro-Data Database
	Firm characteristics	Firm level	The Korean Micro-Data Database
	Instrument variables	<i>dong</i> level	Various primary sources
	Government policy	<i>dong</i> level	The Korean Ministry of Land, Transport and Maritime Affairs
	Transport network	<i>dong</i> level	Korean National Transport Database
	Household travel survey	<i>dong</i> level	The Korean Ministry of Land, Transport and Maritime Affairs
Chapter five	Population	<i>dong</i> level	The Statistics Office of Korea
	Employment	<i>dong</i> level	The Statistics Office of Korea
	Locational features	<i>dong</i> level	The Korean Ministry of Land, Transport and Maritime Affairs
	Transport network	<i>dong</i> level	Korean National Transport Database

	Household travel survey	<i>dong</i> level	the Korean Ministry of Land, Transport and Maritime Affairs
Chapter six	Land values	Land plot level	The Korean Land Registry
	Land physical features	Land plot level	The Korean Land Registry
	Neighbourhood and contextual features	<i>Jipgyegu</i> level	The Statistics Office of Korea
	Transport network	Land plot level	Korean National Transport Database

Data Management

This research involves a number of statistical and graphical procedures works with a large amount of data collected and generated. To ensure the quality of these works, I have devised a simple procedure to manage this data and to keep statistical and graphical analyses aligned. The management of the datasets is closely connected with the methodological approach, as well as the selection of computer programs. This sub-section discusses the computer programs used in this thesis.

For statistical and econometric analyses, I used STATA 13.0, MATLAB, and R 3.2.5. as statistical software. One reason for this choice is that they provide a range of functionalities suitable for statistical analysis in this research. STATA is a statistical program that provides a range of regression models suitable for various research purposes (Rabe-Hesketh & Skrondal, 2012). Compared to Stata, R provides a range of functionality linked to the visualisation of variables and statistical computations, as well as a programming-type syntax environment for regression analysis (Lander, 2013).

For the spatial and geographical works, I used an ArcGIS software package, as it provides a range of functions and tools required to handle various spatial analysis for this thesis (Kennedy, Dangermond & Goodchild, 2013). ArcGIS is one of the most commonly used software packages in the field of spatial analysis. It is equipped with Geography Information System (GIS) technologies that can investigate the interactions between spatial nodes and their economic potentials. In addition, ArcGIS is compatible with a range of third-party applications used in the process of spatial data analysis.

4. Transport-induced Economic Effects and Firm Productivity

4.1. Introduction

This chapter explores the link between transport-induced economic effects and the productivity of manufacturing firms in the Seoul region for the time period between 2000 and 2012, addressing the research question: 'How and to what extent are transport-induced economic effects related to the productivity of manufacturing firms in the Seoul region?'.

There are many studies about whether transport infrastructure development leads to economic outcomes and about the extent and spatial scope of these economic benefits. This is because transport infrastructure gathers a lot of attention from political leaders who are eager to keep the economy vibrant in times of recession and to stimulate economic growth with job creation. Most previous studies have tended to look at the economic benefits due to time saved, hypothesizing that transport infrastructure development leads to a reduction in travel costs and thus increases economic performance. Yet, the time-saving benefits decrease considerably, especially in dense urban areas, although time is of increasing value to business and leisure. Reliable and robust evidence on the issue is thus essential for policy makers and stakeholders to allow them to make better decisions on transport infrastructure development.

More importantly, the link between transport infrastructure and economic outcome is not conclusive (Crescenzi & Rodríguez-Pose, 2012; Funderburg et al., 2010; Leduc & Wilson, 2012; Redding & Turner, 2015), especially in terms of how and to what extent transport infrastructure results in an increase in productivity, the key to economic growth. One of reasons for the inconsistent results is the fact that aside from the time-saving benefits, transport infrastructure is likely to lead to the spatial environment where firms are clustered closer together and interact with the resources in a more efficient way. A recent theoretical study stresses the role of transport infrastructure in stimulating

the spatial mechanism in which firms interact with workers at lower costs (Venables et al., 2014). The current literature pays less attention to this indirect productive benefit of transport infrastructure (Banister & Berechman, 2000; Fujita & Thisse, 2002; Vickerman, 2008).

In terms of the spatial scope, the majority of studies have been conducted at the national and regional level (Graham & Melo, 2011; Hensher, Ellison & Mulley, 2014). Only a handful of studies have examined the variation of productivity in relation to transport infrastructure at the firm level (Holl, 2012; Martín-Barroso et al., 2015; Melo et al., 2016; Néchet et al., 2012). There is a lack of empirical studies about how transport infrastructure impacts a firm's productivity (Gibbons et al., 2019). In addition, there is limited understanding of how the productive benefits of transport infrastructure differ by sub-sectors in the industry. Relatively little attention has been paid to how individual sub-sectors respond to changes in the level of transport-induced accessibility (Martín-Barroso et al., 2015). I argue that a disaggregated analysis by sub-sector may provide detailed empirical evidence that can be useful to understand the link between transport infrastructure, accessibility, and a firm's productivity.

In terms of the accessibility measure, previous studies have tended to rely on city or region-based measures or a straight line to study the productive effects of transport accessibility, a simple and conventional measure (Melo et al., 2009). These measures are however not capable of capturing the indirect productive benefits of transport infrastructure. An advanced measure of accessibility needs to be developed to analyse the impact of transport infrastructure on a firm's productivity. Previous studies have also paid less attention to the reverse causality between economic outcome and transport infrastructure, which may be a reason for the inconsistent results (Melo et al., 2013). An appropriate approach that can correct for estimation issues is necessary to obtain unbiased results for the productive impacts of transport infrastructure.

With regard to research methodology, I made two improvements in the assessment of the productive benefits resulting from transport infrastructure. First, following the literature, I developed a two-stage econometric model that can single out changes in a firm's productivity that relate to transport-induced workforce accessibility. In the model, several econometric techniques are applied to address a number of issues in the estimation of a firm's productivity, such as the endogeneity of spatial economic benefits and the simultaneous bias of the input factors. Second, I developed a measure of

workforce accessibility that captures the level of the productive effects caused by transport infrastructure, using advanced spatial techniques.

The remainder of this chapter is structured as follows. Section 4.2 discusses the construction of the measures relating to access to the workforce. Section 4.3 develops an empirical strategy to examine the link between transport-induced economic effects and a firm's productivity. Based on the conceptual model of a firm's production, a two-stage empirical approach is developed, for which a series of econometric models, including a dynamic panel model, are employed. In Section 4.4, data used in the current chapter is presented. Section 4.5 provides the results obtained from exploratory analyses and descriptive statistics for variables used in this chapter. In Section 4.6, the main results of the regression analysis are presented. Section 4.7 provides a number of policy implications. Section 4.8 concludes this chapter with a summary of the research findings.

4.2. Workforce Accessibility

In this chapter, the economic effects of transport infrastructure are captured. Following the literature, I use an accessibility indicator that measures the level of access to the labour force based on the transport network, rather than the conventional city-based measure and straight line measure. While these measures are simple and easy to generate, it is not capable of incorporating transport infrastructure and therefore does not account for the interaction between economic activities and transport infrastructure.

The accessibility measure used in this chapter is based upon a theoretical notion discussed in the literature that transport infrastructure improvement may spatially extend firms' access to the labour force and enlarge the labour market (Graham, 2007a; Venables, 2007). It embraces the concept that the subsequent enlarged labour market may increase spatial interactions between firms and the workforce and bring about economic benefits to economic actors. I improved the accessibility measure to ensure the theoretical concept is well reflected in the measure. The quality of the accessibility measure is a crucial factor for analysis, because it is directly linked to how accurately the economic effects induced by transport infrastructure are captured.

4.2.1. Workforce Accessibility as Productive Benefit of Transport Infrastructure

To develop a more advanced measure of accessibility, I first conceptualize workforce accessibility indicators, based on the theoretical arguments discussed in Chapter Two. The key point is that transport infrastructure improvement expands the spatial boundary of economic activities, enabling firms and workers to interact with each other in a more clustered space. Transport infrastructure improvement thus promotes the spatial interaction between firms and the workforce (Graham, 2007a; Venables, 2007). This causes an increase in the level of efficiency in production, reduces the cost involved in the interactions, and results in an enlargement of the labour market, improving the chances of matches between firms and workers and the quality of these matches (Combes & Gobillon, 2015; Venables et al., 2014).

Based on this theoretical notion, I construct an indicator of workforce accessibility for the Seoul region. For a basic model, I build upon the accessibility indicator proposed by Hansen (1959) in his seminal paper. Hansen's accessibility indicator has been widely adopted in studies in urban planning, geography, and transport planning as the standard indicator of accessibility (Ahmed et al., 2006; Shen, 1998; Vickerman et al., 1999; Wilson, 1974).

I make some improvements to Hansen's accessibility indicator to increase the accuracy and quality of accessibility indicators. First, I improve the way of measuring travel costs from using a straight line between locations to calculating travel costs between origins and destinations based on the actual transport network. Second, I consider commuters' preference for transport mode, which is not considered in Hansen's accessibility measure. Third, I use the actual spatial-decay parameter for the Seoul region by estimating a simple spatial interaction model. Lastly, I incorporate the notion that firms compete for workers in the region, which is not taken into account in Hansen's accessibility measure.

The accessibility indicator formulated in this chapter has some advantages over previous indicators based on city or region in the literature. First, it is capable of accounting for the combined effect of economic activities, which is one of key aspects of this chapter in examining the spatial-economic effects of transport infrastructure.

Second, it considers the commuter's perception of travel cost by using the estimated spatial-decay parameter (Condeço-Melhorado, Tillema, de Jong & Koopal, 2014). In addition, it considers individual preferences by incorporating a simple spatial model that accounts for commuters' preference for travel modes.

Third, it incorporates the 'demand side' of accessibility measurement in together with its 'supply side' to take into account the notion that firms compete for skilled workers. The accessibility indicator developed in the current chapter captures a given area's relative potential for workers in the Seoul region. The competition between firms for available workers is taken into account by incorporating the demand side of accessibility measurement.

Firms require skilled workers supplied on the labour market because skilled workers are one of key factor in firm production. The availability of skilled workers is finite, and they are actually in short, so that firms compete for the skilled workers. In addition, the spatial distribution of firms is not uniform. Skilled workers are surrounded by firms with various levels of demand for those workers. Each worker is not for only one firm at any moment in time. Multiple firms (the demand side) compete for skilled workers to ensure their productivity. This demand potential influences the amount of potential for workers, and access to workers is partly determined by the demand potential for the location of the labour potential.

Considering these conditions, I develop a relative accessibility indicator that incorporates both the supply and demand potentials, based on the accessibility indicators presented by Shen (1998). The demand side of accessibility measurement is in the denominator in Eq. 4-1, whereas its supply side is in the numerator in the equation. The weighted sum of the number of potential workers accessible from each origin (supply potential) is divided by the weighted sum of the number of potential employments for those workers (demand potential). A specification for the workforce accessibility indicator is shown in Eq. 4-1.

Apart from firms' competition for workers, the relative accessibility indicator also incorporates probability of choosing to work in a given area (*dong i* in Eq. 4-1). I use the concept of theoretical probability in the measurement of accessibility to include the workers' probability. From the standpoint of workers, they may have multiple chances to work in various areas; they might work in the surrounding areas or they may choose to work in a given area (*dong i*). These multiple chances can be expressed as

probability for them to choose to work in a given area or in other areas. Using the concept of theoretical probability, this can be articulated.

In the literature on Mathematics, theoretical probability of some event is calculated by the number of favourable outcomes divided by the total possible outcomes. Applying this to the current case, probability of workers' choosing to work in a given area (*dong i*) is equal to the number of employments in a given area divided by the total number of employment potential.⁹ Thus, I include the number of jobs in a given area (D_i) in Eq. 4-1 to consider the workers' probability in the measurement of relative accessibility.

Equation 4-1. The indicator of workforce accessibility¹⁰

$$AC_i = \sum_j \frac{L_j(D_i \cdot e^{-\alpha \cdot T_{ji}})}{\sum_m D_m \cdot e^{-\alpha \cdot T_{jm}}}$$

where AC_i is the level of relative access to the workforce in dong i. L_j refers to the workforce in dong j. T_{ji} refers to travel times between dong i and j, whereas T_{jm} stands for travel times between dong j and m. α is a spatial-decay parameter for commuting trips in the Seoul region that reflects the degree to which commuters change their travel behaviour based on changes in the cost of commuting, which is discussed

⁹ The probability of workforces' working in a given area can be expressed as follows:

$$P(\text{Working in a given area}) = \frac{\text{The number of employments in a given area}}{\text{The total number of employment potential}}$$

¹⁰ I also construct the same accessibility indicator but based on the calculation of the pre-improvement distribution of labour force (year 2000). This accessibility indicator only explains changes in travel times due to transport network improvement.

The Fixed Indicator of Workforce Accessibility

$$FAC_i = \sum_j \frac{L_j(D_i \cdot e^{-\alpha \cdot T_{ji}})}{\sum_m D_m \cdot e^{-\alpha \cdot T_{jm}}}$$

in the following section. D_i and D_m are the total number of jobs in *dong* i and m, respectively. This accessibility indicator is interpreted as access to the net labour force in the region.

The numerator in Eq. 4-1 indicates the number of potential workers expected by firms located in *dong* i (the potential supply of the workforce), which is determined by the weighted sum of the workforce in all destinations in j that can be reached from origin i via a means of transportation. The denominator denotes the number of employments in *dong* m that refers to the demand potential for the workforce.

The measure of workforce accessibility is made specific by its temporal dimension. To some extent, the level of workforce accessibility is governed by the number of commuting trips occurring simultaneously, which varies by time of day. The volume of commuting trips is normally the largest during the rush hours of the day and the smallest in the middle of night. As such, the productive effects of workforce accessibility may vary by a given temporal dimension. I focus on the average commuting flow in the daytime on weekdays for the temporal dimension of the accessibility measure.¹¹

For the workforce in the accessibility measure, I focus on the working-age population, defined by the World Bank as between 15 and 64 years old (World Bank, 2015). The working-age population represents the characteristics of labour market rather than the total population because the population under 14 and over 65 is unlikely to be working. Using the working-age population is also advantageous to capture the uneven distribution of the workforce. This is because, to some extent, the labour market is segmented in terms of the proportion of the working-age population. The amount of the working age population is high in some districts in urban areas whereas it may be relatively low in some districts such as business centers or commercial streets.

4.2.2. Measuring Travel Costs

The accuracy of any workforce accessibility measure is in part dependent upon the precision with which travel costs between origins and destinations are measured. I make two improvements over the existing measurements in this respect. First, I

¹¹ The average numbers of commuting trips occurring during the daytime on weekdays are used for this calculation.

improve the way to measure travel times between origins and destinations. Unlike previous studies where travel costs are calculated based on an assumed straight line between origins and destinations (Combes et al., 2010; Fally et al., 2010; Hering & Poncet, 2010; Mion & Naticchioni, 2009), I use the actual transport network to calculate travel times between origins and destinations. To my best knowledge, only seven studies have explored the link between transport infrastructure and firm-level productivity using accessibility indicators based on real transport network (Donaldson & Hornbeck, 2016; Gibbons et al., 2019; Graham, 2007a; Holl, 2012; Martín-Barroso et al., 2015; Néchet et al., 2012; Rice et al., 2006). This improvement might make a significant difference in the outcome in this or similar studies, because travel costs measured by the straight lines are very different from those measured based on actual transport networks. Also, the assumption of straight lines between origins and destinations does not reflect a change in travel costs when a transport infrastructure investment is made.

My other improvement lies in how commuters' choice of travel modes is accounted for in the measurement of travel costs. Travelers normally choose their travel modes from several transport modes available, favouring cost savings. For example, travel costs for public transportation are likely to be lower than those for cars in most cases. Few studies have considered this point, but the mode of transport chosen may significantly influence travel costs between locations. Not taking this into account in the calculation of workforce accessibility measures might overestimate the level of workforce accessibility and thus result in an outcome that is biased towards the productive benefits of transport infrastructure.

To take into account commuters' choice of travel modes, I formulated a simple travel model that considers two key travel modes following the literature: public rail transit modes and automobile modes (de Palma et al., 2011b). The specification of a simple travel model is shown in Eq. 4-2. Public rail transit modes involve three steps of travel: walking from home to rail stations, traveling by rail, and walking from rail stations to workplaces. Automobile modes comprise only travel by car. Using this travel model, I calculate the minimum travel times for the two travel modes and then compare them with each other to obtain the shortest travel time for the commuting route.

Equation 4-2. Travel Model

$$T_{ij} = \min\left(\frac{D_{ij}}{V_{car}}; \frac{D_{iso}}{V_{walk}} + \frac{D_{sosd}}{V_{train}} + \frac{D_{sdj}}{V_{walk}}\right)$$

where T_{ij} is the minimum travel time between zone i and zone j. For automobile modes, D_{ij} is the distance between zone i and zone j by a car with a velocity of V_{car} . For public rail transit modes, D_{iso} is the distance from zone i to the nearest rail station. D_{sosd} is the distance from the rail station in zone i to the rail station in zone j, and D_{sdj} is the distance from zone j to the nearest rail station.

To solve the travel model specified, I used ArcGIS software that provides the key functions required to perform a spatial analysis of the relations between links and nodes on the digitized map of the Seoul region. I created a layer for the actual transport network of the Seoul region on the workspace of ArcGIS. With this layer, I calculated travel times between origins and destinations in the Seoul region for the two travel modes and then constructed a table for the minimum travel times for all pairs of possible commuting routes.

4.2.3. Spatial Interaction Model

The quality of workforce accessibility measures also depends on a spatial-decay parameter. This parameter represents how far workers are willing to travel to workplaces, indicating the degree of spatial friction caused by the distance from home to work. The accuracy of the accessibility measure is directly linked to whether the spatial-decay parameter accurately reflects the distance workers travel for work. The literature shows that parameters obtained from travel surveys may provide a better representation of the travel behaviours of commuters in the real world, as opposed to using arbitrary values that have been used in previous studies (Geurs & van Wee, 2004). This study partly reduces that arbitrariness by applying an estimated spatial-decay parameter for the Seoul region to the construction of workforce accessibility measures.

I obtained the spatial-decay parameter for the Seoul region by estimating a simple

spatial interaction model based on the gravity-type model (Graham & Melo, 2011).¹² I focused on commuting trips only, because they are more relevant to the study of the productive effects of transport infrastructure than other types of trips such as shopping or school trips. Also, in the Seoul region, commuting trips make up over 60% of trips from home.

The specification of a spatial interaction model for commuting trips is shown in Eq. 4-3, where the commuting trips are a function of the size of economic activities at both origin and destination. The scale parameter k is added to measure the relationship between the number of commuting trips and the size of economic activities at both origins i and destinations j . To incorporate a travel-cost sensitivity function into the model, I employ a negative exponential function in accordance with the literature (Reggiani, 2004; Wilson, 1967).

Equation 4-3. Spatial Interaction Model for Commuting Trips in the Seoul Region

$$T_{ij} = kO_i^{\beta_1}D_j^{\beta_2} \exp(-\alpha d_{ij}) \quad i, j = 1, \dots, N$$

where T_{ij} is the number of commuting trips between origin i and destination j ¹³; O_i is the size of the population at each origin; D_j is the number of jobs at each destination; d_{ij} is the spatial distance between the centroids of origins and destinations. The commuting data comes from the housing travel survey that provides key information on the pattern and the behaviour of household travel in the region, such as the purpose of travel, the number of trips made for each travel purpose, and the travel costs between origins and destinations.

I transform Eq. 4-3 into a logarithmic form to handle situations where a non-linear relationship exists between the independent and dependent variables (Benoit, 2011).

¹² Spatial interaction modeling has a long history, tracing back to the gravity-type modeling. Since then, it has been developed into popular modeling for spatial analysis, employing the entropy theory and the utility maximization approach.

¹³ The spatial units for origins and destinations are set as *dongs* (the smallest administrative areas) in this thesis.

In addition, a set of explanatory variables that describe the features of origins and destinations is incorporated in the model to control for any spatial heterogeneity. The specification of the transformed spatial interaction model is shown in Eq. 4-4.

Equation 4-4. The Logarithmic Form of the Spatial Interaction Model

$$\log T_{ij} = k + \beta_1 \log O_i + \beta_2 \log D_j + \alpha d_{ij} + \varepsilon_{ij}$$

where O_i is the size of the population at each origin; D_j is the number of jobs at each destination; d_{ij} is the spatial distance between the centroids of origins and destinations. The parameter k is a scaling factor that generalizes the model by measuring the link between the commuting flow and the size of origin and destination; β_1 is a parameter for the relationship between the outflow of commuting trips and the size of opportunities at origins, and β_2 is a parameter for the relationship between the inflow of commuting trips and the size of opportunities at destinations; α is the spatial-decay parameter.

4.3. Research Strategy

The research strategy is separated into five parts. First, I formulate a production function that describes the relationship between a firm's production, the input factors, and transport-induced workforce accessibility. Second, I highlight several issues that may be involved in the estimation of a firm's productivity in relation to transport-induced workforce accessibility. Third, following the literature, a two-stage empirical approach that can address the estimation issues is formulated. Fourth, a regression model for the effect of workforce accessibility improvement on firm productivity is developed, which can address the endogeneity of targeted transport policy and unobserved fixed effect, based on a first-difference model with instrument variables. Lastly, instrument variables are created to correct for the endogeneity of transport-induced productive benefits in the two-stage approach.

4.3.1. Empirical Model Development

Based on the conceptual model outlined in Appendix A, I formulate a regression model for firm production to account for the relationship between firm output, the input factors, and transport-induced workforce accessibility, following an empirical approach used in previous studies (Levinsohn & Petrin, 2003; Van Beveren, 2012). The specification of a regression model is shown in Eq. 4-5, allowing for the presence of scale coefficients of variables on the right-hand side. These coefficients capture the influence of the input factors on the firm output.

Equation 4-5. Production Function of Firm Output

$$Y_{pit} = A_{pit} K_{pit}^{\beta_k} L_{pit}^{\beta_l} M_{pit}^{\beta_m}$$

where Y_{pit} is the output of firm p , in location i at time t ; K_{pit} , L_{pit} , and M_{pit} stand for firm inputs (capital, labour, and intermediate), respectively. A_{pit} is the level of production efficiency that firm p experience in location i at time t , including the level of transport-induced workforce accessibility. While the three input factors are observable, production efficiency is difficult to observe and the measure of productivity is thus adopted to capture this. Taking the natural logarithm of Eq. 4-5, I transform it to a linear production function, as shown in Eq. 4-6.

Equation 4-6. Log-transformation of Production Function

$$y_{pit} = \alpha_{pit} + \beta_k k_{pit} + \beta_l l_{pit} + \beta_m m_{pit}$$

β_k is the coefficient of the capital input with respect to the total output and β_l and β_m capture the values of the output elasticities with regard to labour and intermediate

inputs, respectively. α_{pit} is the logarithm of the efficiency level of firm p in location i at time t. I attempt to estimate Eq. 4-6 to examine the portion of firm output that is explained by both the input factors and non-input factors, including the level of transport-induce workforce accessibility. However, due to the distinctive nature of workforce accessibility, the estimation of Eq. 4-6 suffers from several issues which may lead to estimation bias. I discuss possible estimation issues and the corresponding solutions to these issues in the following section.

4.3.2. Estimation Issues

As pointed out in previous studies, several issues may arise in the estimation of the production function, which is likely to result in biased estimates (Graham., Melo, Jiwattanakulpaisarn & Noland, 2010). These issues mainly stem from both the unique nature of the productive benefits of transport infrastructure and the heterogeneity of input factors involved in production. These issues can be categorized into three types: unobserved characteristics of firms, the simultaneity of the input factors, and the endogeneity of transport-induced productive effects. It is essential to devise appropriate techniques to correct for such estimation issues to obtain unbiased results. Below, each estimation issue is presented in detail, with the corresponding approaches to counter for them (Combes & Gobillon, 2015).

4.3.2.1. Unobserved Characteristics of Firms

The most widely reported estimation issue is a potential bias arising from unobserved characteristics of firms. The idea of unobserved heterogeneity originates from the fact that a firm's output is not fully accounted for by its observable characteristics. For example, a firm's organization structure may impact its output, but is difficult to observe. Bias caused by unobserved heterogeneity has frequently been reported in previous studies (Matas, Raymond & Roig, 2015).

To address the issue of unobserved characteristics of firms, I consider a panel model with the fixed effect as the base model for the analysis. A number of previous studies have shown that a possible estimation bias caused by unobserved heterogeneity can be corrected by using a panel model (Melo & Graham, 2014). Since many observations

over time are required for the use of the panel model, I draw upon a dataset with around 295,000 observations of manufacturing firms.

4.3.2.2. Simultaneous Bias of Input Factors

Another estimation issue is the simultaneity of the input factors, especially when firms make changes to the arrangement of the input factors in production (Levinsohn & Petrin, 2003). One of any firm's goals in business is to maximize their profits and firms may thus make a series of decisions about input factor endowment in response to their business performance. When firms anticipate changes in expenses on capital and intermediate inputs, they are likely to make changes to the arrangement of input factor endowment, which is likely to result in a positive correlation between the input factors in the production function.

A standard approach to this issue is to use the dynamic generalized method of moments (GMM) with lagged values of the endogenous variables as instruments (Arellano & Bond, 1991). One advantage of using the system GMM is that it allows for additional moment condition where the error term is not correlated with explanatory variables (Arellano & Bover, 1995; Blundell & Bond, 1998).

4.3.2.3. Endogeneity of Transport-induced Productive Benefits

Another issue in the estimation of productive effects induced by transport infrastructure is the endogeneity of accessibility benefits, which may result from reverse causality between the improved productivity and the spatial agglomeration of economic activities (Graham & Van Dender, 2011). If transport infrastructure leads to an increase in a firm's productivity, this improved productivity is likely to alter the spatial landscape of firms and facilitate spatial clustering. Firms tend to move to where they can benefit the most. This reverse causality may lead to overestimation of the productive benefits induced by transport infrastructure.

The key question linked to this endogeneity issue is whether the productive benefits can be separated from the reverse effects caused by the improved productivity of economic actors. A solution to this issue is to use long-lagged values of explanatory variables to instrument their current value (Combes, Duranton & Gobillon, 2008;

Combes et al., 2010; Mion & Naticchioni, 2005; Rice et al., 2006). I incorporate a series of instrument variables in the model to correct for the source of endogeneity of transport-induced workforce accessibility. More details on instrument variables are provided in Section 4.3.4.

4.3.3. Two-Stage Empirical Approach

To address the aforementioned estimation issue, I adopt a two-stage empirical approach to explore the relationship between transport-induced workforce accessibility and firm productivity, following the empirical approach used in production studies (Van Beveren, 2012). In the first stage, I estimate Eq. 4-7 to obtain the elasticities of output with regard to the input factors to calculate the firm total factor productivity (TFP). The aim of the first stage is to acquire the portion of the firm output that is not explained by the input factors but may be explained by the level of efficiency in production, including productive effects resulting from transport-induced workforce accessibility. Equation 4-7 is estimated by using several regression models, such as a pooled OLS model, a standard panel model with fixed effect, an IV-DD model with the AH estimator, and a dynamic model with the system-GMM estimator.

Equation 4-7. Estimation for Firm-level Productivity

$$\ln(A_{pit}) = y_{pit} - \beta_k k_{pit} - \beta_l l_{pit} - \beta_m m_{pit}$$

In the second stage, I regress the firm-level TFP, obtained from the first-stage estimation, on transport-induced workforce accessibility and the firm's characteristics. I focus on analysing the relationship between the firm-level TFP and the level of transport-induced workforce accessibility. The coefficient of transport-induced workforce accessibility reveals the degree of transport-induced workforce accessibility in relation to the firm's TFP. The specification of the model used in the second stage is shown in Eq. 4-8. The practical benefit of this two-stage approach is that the firm's TFP derived from the first stage estimation can be used to evaluate productive benefits resulting from transport-induced workforce accessibility directly at the firm level

(Ackerberg, Lanier Benkard, Berry & Pakes, 2007).

Equation 4-8. Model of the Link between Workforce Accessibility and Firm Productivity

$$\ln(A_{pi}) = \alpha_{pi} = \beta_0 + \delta_c \ln(AC_i) + \gamma_x \ln(X_{pi}) + \varepsilon_{pi}$$

where AC_i indicates the level of transport-induced workforce accessibility in location i ; δ_c is the coefficient of interest that reveals the effect of transport-induced workforce accessibility on firm productivity, which can be interpreted as a percent change in firm productivity for one percent change in the level of transport-induced workforce accessibility; X_{pi} refers to a vector of variables accounting for the firm characteristics; γ_x is the coefficients of these variables with respect to the firm productivity. In the estimation of Eq. 4-8, I use the IV model to address the endogeneity of workforce accessibility.

4.3.4. First-Difference Model with Instrument Variable

In addition to the two-stage approach, I develop a regression model that estimate the average effect of transport-induced workforce accessibility improvement on firm productivity. A key difference from the two-stage approach is that first-difference approach incorporates a change in accessibility induced by transport infrastructure and analyse its association with a change in firm productivity over time. The first-difference approach can be articulated as a model that has a component that measures a change in transport-induced workforce accessibility of the location i in which firm p is sited. A specification of a basic regression model for this approach is as follow.

Equation 4-9. Model of the Effect of Accessibility Improvement on Firm Productivity

$$y_{pit} = \alpha_0 + \beta AC_{it} + \gamma' I_{pit} + \mu_{pi} + \tau_t + \varepsilon_{pit}$$

where y_{pit} refers to log of the output of firm p , in location i at time t ; AC_{it} captures the level of transport-induced workforce accessibility in location i at time t ; I_{pit} represents firm inputs (capital, labour, and intermediate). μ_{pi} represents the unobserved time-invariant productivity components of firms, which means the model includes firm fixed effects. μ_{pi} denotes year-specific unit invariant components that is a general change that influence all firms and locations in a given year, such as macro shocks, which indicates that the model includes time fixed effects.

The coefficient of interest is β in Eq. 4-9, the effect of workforce accessibility on firm productivity. OLS estimates of β are likely to be biased when unobserved firm fixed effects μ_{pi} are correlated with accessibility. Particular conditions for this bias include the following cases; 1) more productivity can be found in dense places, and travel distances are shorter in dense places; 2) more productivity can be induced by more efficient transport system, such as faster connection and high-speed transport system (Gibbons et al., 2019).

I firstly eliminate the endogeneity induced by unobserved components of accessibility to control for fixed-time firm effects by differencing the data over time. A specification for this first-difference model is as shown in Eq. 4-10.

Equation 4-10. First Difference Model of the Productive Effect of Accessibility

$$\Delta y_{pit} = \beta \Delta A_{it} + \gamma' \Delta I_{pit} + \delta_t + \Delta \epsilon_{pit}$$

where Δ denotes time-differencing, and therefore ΔA_{it} captures changes in transport-induced workforce accessibilities in location i ; ΔI_{pit} captures changes in the inputs of firm p sited in location i . β is the coefficient of interest that considers a change in workforce accessibility due to a change in transport infrastructure network and reveals the effect of workforce accessibility improvement on firm productivity. γ' reveals the influence of firm inputs on the variation in firm productivity.

The estimates obtained from Eq.4-10, yet, are likely to be biased if transport policy is endogenous to the productivity trends in the targeted locations (i.e. new transport infrastructure is targeted at places based on their productivity trends. This case leads

to creating correlation between changes in accessibility ΔA_{it} and changes in the time varying unobservables for unit p $\Delta \varepsilon_{pit}$. To deal with this, I exploit instrument variables that account for the pattern of transport infrastructure network in the region. As will be mentioned in the following section, I use variables for transport network density in the years of 1899, 1930 and 1960.

4.3.5. Instrument Variables

It is well known that choosing an appropriate instrument for the endogenous variable is not an easy task, because valid instrument variables should meet two requirements: relevance and exogeneity (Combes & Gobillon, 2015). In other words, instrument variables need to be correlated with the endogenous variable instrumented for but should not be related to the residuals of the main regression (Combes & Gobillon, 2015; Néchet et al., 2012).

To choose instrument variables appropriate to the research presented, I reviewed various variables used as instrument in the literature. The most common instrument variables used in previous studies are long-lagged values of the endogenous variables or other “past” variables to instrument for its present values, which has been common in the literature since Ciccone and Hall (1996). Many studies have used this type of instrument variables (Combes et al., 2008; Mion & Naticchioni, 2005; Rice et al., 2006).

Apart from the long-lagged variables of the endogenous variables, various variables have been used as instrument in previous studies, such as total land area (Ciccone, 2002), geological data (Combes et al., 2010; Rosenthal & Strange, 2008) and natural factors (Glaeser & Gottlieb, 2009). Some studies have used time-lags in the context of GMM estimators (Holl, 2012). For instrumentation for current value of accessibility, previous studies have tended to use the following variable as instrument: previous value of accessibility (Holl, 2012; Martín-Barroso et al., 2015), historical transport network (Holl, 2016), population in previous years, distance to the city centre and distance to rail stations (Néchet et al., 2012).

Instrument Variables for the Two-stage Approach

Based on the literature, I reviewed various variables as potential candidates for

instrument in this research, such as distance to the city centre, distance to Han river, distance to rail station, the size of a given area, population size, historical transport network, employment size, employment density and lagged values of workforce accessibility. I constructed a set of these variables and tested for whether they are valid as instrument.

Having tested those caudate variables, I finally selected the following variables as instrument. These instrument variables are used for the two-stage approach. First, a lagged value of workforce accessibility was chosen as main instrument variable to isolate productive effects of the current workforce accessibility. This approach is similar to the dynamic panel data estimators of Arellano and Bond (1991), as those estimators make use of appropriate lagged values of endogenous regressors to identify the model. Lagged values are less likely to be influenced by current shock.

Second, adding to the lagged value of workforce accessibility, I include some variables to improve the efficiency of the IV estimator. I use the size of a given area (the *dong*) as instrument, based on the idea that economic activities area concentrated in *dongs* with smaller area and therefore the level of workforce accessibility is high in these *dongs*. The size of *dongs* does not change in response to firm productivity. I also use weighted average of areas of surrounding *dongs*, based on the idea that having more areas on average will add to workforce accessibility. Further I include weighted average of urbanized areas of surrounding *dongs* because having urbanized areas nearby will increase the level of workforce accessibility. This idea comes from the fact that urbanized areas differ with areas in that the latter simply explains the size of a certain area while the former describes the quality of a given area. Incorporating these two variables in the model, I take into account both the size and quality of the surrounding area.

Lastly, distance to rail station was selected as instrument because close proximity to transport node will increase the level of access to workforce. This variable was used as instrument in previous study on French firm productivity (Néchet et al., 2012). In addition, the pattern of transport infrastructure network in 1960 was selected to deal with the endogeneity of targeted transport policy, given that current economic performance doesn't affect past transport policy decisions. The fundamental issue in transport-induced productive study is the endogenous concern that transport policy is endogenous to the productivity trends in the targeted locations. In other words,

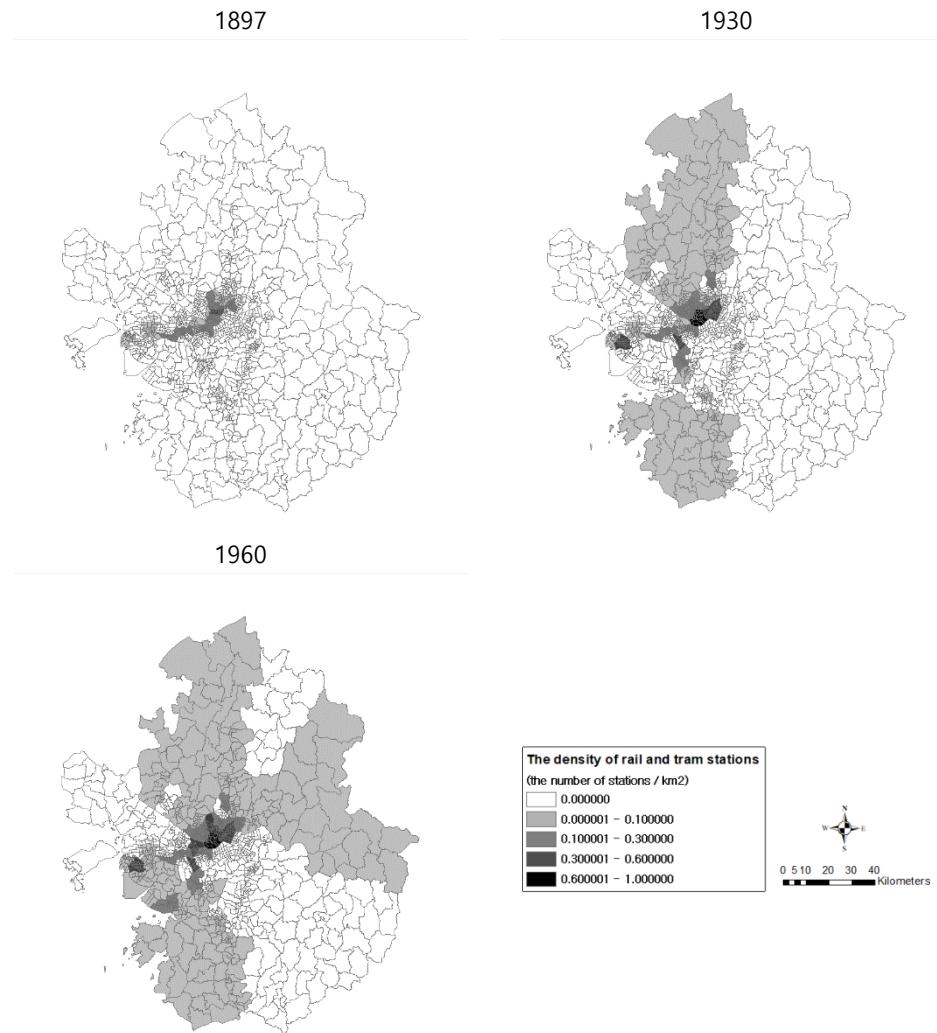
transport policy improvements are not randomly allocated, but are targeted to meet specific economic demands. This fact will produce biased estimates of the productive effects of transport improvements, implying that the error term is correlate with the accessibility change. The instrument variables chosen is used to deal with this endogenous issue. Yet, these variables are incorporated in the model, together with the lagged value of workforce accessibility, because those variables have little explanation for policy relating to area-specific advantages such as downtown that is more productive for non-transport related reasons.

Instrument Variables for the First-Difference Approach

For the first-difference approach, I include instrument variables that can deal with the endogenous issue arising from the targeting of transport policy. I generated three instrument variables taking account of the development of the transport infrastructure network, based on the idea that major economic activities tend to be established either near the nodes of transportation or along with the transport network. The density of rail and tram stations is surveyed at the municipality level for the years of 1897, 1930, and 1960 and is used to capture the spatial pattern of transport infrastructure development in the early period of spatial growth in the Seoul region. Figure 4-1 shows the three instrument variables created to account for the lagged values of transport-induced workforce accessibility.

In addition, I instrument changes in transport-induced workforce accessibility with the workforce accessibility indicator that is based on the calculation of the pre-improvement distribution of labour force (year 2000). As specified in Eq. 4-1, the change in workforce accessibility could result from changes in the spatial distribution of labour force, or changes in transport infrastructure network. These changes might be correlated with each other, which may lead to bias in the estimation of the productive effect of workforce accessibility improvement induced by transport infrastructure improvement. Thus, an actual change in workforce accessibility is instrumented by “the fixed accessibility indicator” based on the spatial distribution of labour force in pre-improvement year.

Figure 4-1. Development of Railway Infrastructures as Instrument Variables



4.4. Data

The current analysis draws upon four main sets of data collected from various sources: firm data, transport infrastructure network data, government policy data household travel survey data, and household travel survey data.

Firm data is mainly used to estimate the elasticities of workforce accessibility with respect to firm productivity. Firm data is comprised of firm output, firm characteristics, and firm inputs. Firm output is used as dependent variable of production models and

both firm inputs and firm characteristics are incorporated in the models as independent variables.

Firm data was collected from the Micro-Data Database (MDDS) maintained by the Statistics Office of Korea. This database is constructed based on a survey of the manufacturing industry. The survey, called the Census of the Mining and Manufacturing Sector, is carried out on an annual basis by the central government for every firm with more than five employees. Data resulting from the survey is processed to create a database of manufacturing firms. The survey contains detailed information on manufacturing firms such as firm age, its ownership, the number of employees, the amount of capital invested in production, the amount of fixed assets and firm total output

Transport infrastructure network data is the key data upon which the current analysis relies because it is used to construct accessibility indicators that capture the productive effects arising from transport infrastructure improvement. Transport network data is also used to describe the transport infrastructure network geographically, delineating roads and railways on a digital map. In addition, with transport infrastructure data, I can undertake an accurate measurement of the actual rail and road transport infrastructure, which ultimately leads to an increase in the quality of the studies. I collected transport infrastructure network data from the Korea National Transport Database, which consists of two features: nodes and links. "Nodes" refers to stations, intersections or stops in the rail and road transport network, while "links" refers to the railways and roads connecting these nodes on the network.

Government policy data is used to account for its relationship with firm economic activities or output. It is normally accepted that government policies and regulations play a key role in the formation of economic activities and it is thus useful to consider the implementation of policies and regulations in exploring the economic effect of the transport infrastructure on firms' economic activities (Agarwal, 2015). Some policies may promote the establishment of new firms and households whereas others may regulate firms' economic activities in a certain location. I take into consideration the Seoul Growth Management Policy (SGMP) to account for its relationship with a firm's location choice and its economic output. The Seoul Growth Management Policy was established in the 1980s as part of the Seoul Metropolitan Area Readjustment Planning Act (SMRPA) that intended to curb dramatic increases in employment and population within Seoul. I collected the policy data from the Korean Ministry of Land, Transport

and Maritime Affairs (MLTM).

The household travel survey is used for the estimation of the spatial-decay parameter for the Seoul region. Using travel costs data extracted from the survey, a simple travel interaction model is estimated to reflect the way in which commuters respond to a change in the commuting distance. The household travel survey contains key information on the pattern and the behaviour of household travel in the region, such as the purpose of travel, the number of trips made for each travel purpose, and the average distance between origins and destinations. The survey is a part of the Korean National Travel Survey (KNTS), which investigates detailed information on the travel pattern and behaviour of several types of travel in South Korea. Household travel surveys for municipalities in the region have been carried out for the years of 2002, 2006, and 2011. I collected the household travel survey data from the Korea National Transport Database for the year of 2011, the latest travel survey available, to generate a series of variables related to household travel patterns and behaviour.

In addition, the current chapter draws upon spatial and locational data that is used to generate independent and instrument variables. Several digitised maps for the Seoul region are collected from the National Geographic Information Institute (NGII) and the Spatial Geographic Information Service, maintained by the Statistics Office of Korea. They are comprised of multiple files of administrative boundaries at the different spatial levels for 2000, 2005, 2010 and 2012. I also collected geographical locations of rail and metro stations between 1897 and 2012 from various sources, such as the Korea Railroad Corporation and Seoul Metro, which are used to generate a series of instrument variables to address the issue of endogeneity.

4.5. Exploratory Analysis

This section examines the results obtained from both exploratory analyses and descriptive statistics. First, the spatial-decay parameter for the Seoul region is estimated using a simple travel interaction model (Section 4.5.1). Second, travel times between all the centroids of spatial units in the region are calculated. The levels of workforce accessibility for all spatial units in the Seoul region are measured and the results are presented in the form of a diagram (Section 4.5.2). Lastly, Section 4.5.3.

provides the descriptive statistics of the variables used in this chapter.

4.5.1. Results of the Travel Interaction Model

The spatial-decay parameter for the Seoul region is estimated to reflect the way in which commuters respond to a change in commuting distance. The simple travel interaction model specified in Eq. 4-4 is used to obtain the estimated value. The smaller the value of a spatial-decay parameter, the fewer commuters respond to changes in the commuting distance. Drawing upon the household travel survey data for the Seoul region, I estimate a simple spatial interaction model to reveal the spatial-decay parameter for the Seoul region.

Table 4-1 presents the results obtained from the estimation of a simple travel interaction model. The estimated spatial-decay parameter for the Seoul region is -0.0267, which means there is a reduction in the commuting flow by 2.67% for one additional kilometre. In other words, commuters will reduce their trips from home to work by 2.67% if the distance between their home and their workplace increases by one kilometre. Compared to spatial-decay parameters in previous studies, the spatial-decay parameter of -0.0267 falls within the normal range. For example, the spatial-decay parameter for the average intra-commuting trips in UK cities is -0.0168 (Graham & Melo, 2011).

Table 4-1. Results of the Spatial Interaction Model

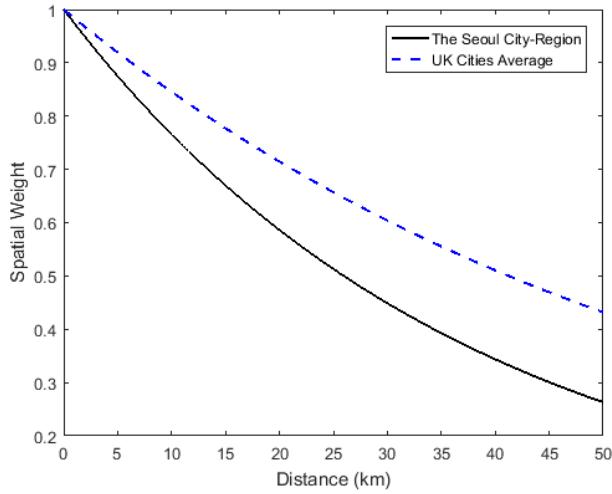
Variables	Spatial interaction model	
	Coefficient.	S.E.
Constant	0.9788***	0.05474
Log of population in origin	0.0312***	0.00495
Log of employment in destination	0.3260***	0.00291
Travel cost (km)	- 0.0267***	0.00027
R-squared		0.1013
Adjusted R-squared		0.1013
Number of Observations		185737

The coefficient of the population is positive and statistically significant, pointing to its positive effects on the extent of the commuting flow in the Seoul region. The coefficient of employment is also positive, indicating that the number of jobs available at a destination is also a determinant of the number of commuting trips in the region. In terms of magnitude, the number of jobs at destinations has a larger effect on the volume of commuting flow than the population in origins. This may be because the distribution of jobs is largely unbalanced across the region, which may increase the extent of commuting flow between homes and workplaces.

Figure 4-2 presents the graph of the estimated spatial-decay parameter for the Seoul region together with that for UK cities to provide a simple comparison. The region's spatial-decay parameter is displayed on the graph in a solid black line, while UK cities' parameter is shown in a dotted blue line. Figure 4-2 shows that the black solid line is slightly steeper than the blue dotted line, indicating that the value of the region's parameter is larger than that of UK cities on average. In other words, commuters in the Seoul region tend to be more sensitive to a change in the commuting distance than those in UK cities.

The difference in commuters' perception of the commuting distances may be due to the differences in the level of transport services provided in the areas. Most UK cities are frequently served by various transport services such as tram, underground, and bus, which means that people can easily access key places in the cities. The difference also stems from the fact that local and central governments in the UK manage these transport services in a coordinated manner. The most common example of this is London, which has a long history of railway development and management.

Figure 4-2. Spatial-decay Parameter for the Seoul Region and UK Cities



4.5.2. The Measurement of Workforce Accessibility

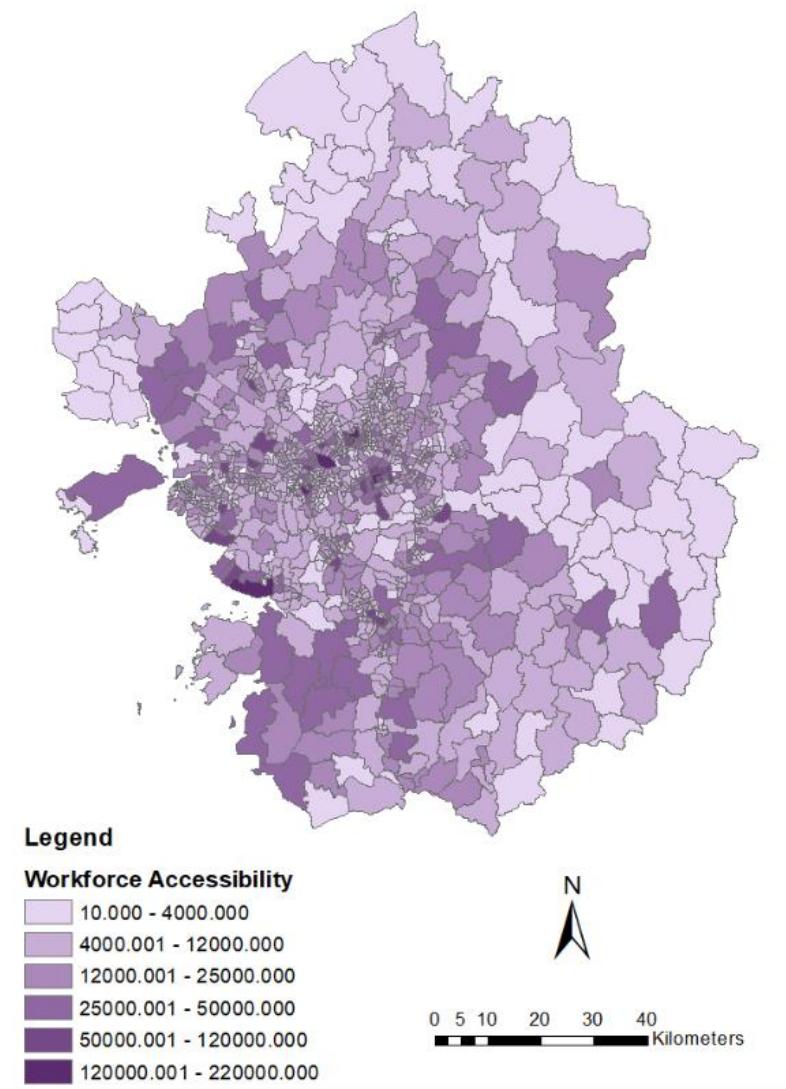
Using Eq. 4-1, I measure the level of workforce accessibility for all spatial units in the Seoul region for 2010. For the spatial-decay parameter, I use the value of -0.0267, estimated in the previous section. For the travel costs in the measure, I use the shortest travel time between origins and destinations, based on the actual transport network.

Using these two elements, I construct the measures that capture the level of workforce accessibility for all spatial units in the Seoul region for 2010. The level of workforce accessibility measured is mapped in Figure 4-3, presented at the *dong* level. Workforce accessibility is coded in six domains defined in advance based on its statistical distribution, ranging from the lowest range between 0 and 4,000 to the highest range between over 120,000. Overall, the level of workforce accessibility is high at the peripheries of the region, with a central area of the region showing the highest level of workforce accessibility. In Seoul, the level of workforce accessibility is high in the traditional city centre and two sub-centers located in the south of Seoul, demonstrating their hierarchical importance in the Seoul region.

Figure 4-3 provides interesting spatial patterns of workforce accessibility in the Seoul region. The levels of workforce accessibility between Seoul and a 20-kilometer radius of the Central Business District (CBD) are by and large lower than those beyond a 25-

kilometer radius of the CBD, which indicates that workforce accessibility is relatively high on the peripheries of the region. This higher level of workforce accessibility may be the result of population growth, the provision of transport infrastructure, and the interaction between the two. The size of the population residing beyond a 25-kilometer distance of the CBD has increased considerably due to a combination of migration to the Seoul region and migration from the core of the region toward its peripheries. This coincides with transport infrastructure development connecting newly developed residential locations to jobs, although transport infrastructure development lagged slightly behind population growth on the periphery of the Seoul region.

Figure 4-3. The Level of Workforce Accessibility in the Seoul Region



4.5.3. Descriptive Statistics

Table 4-2 presents the descriptive statistics of variables used in this chapter, which shows relative changes in the input factors to the trend of firms' output during 2000 and 2012. The average output of manufacturing firms in the Seoul region increased by about 33.4% over the study period. Compared to firms' output, the three input factors show a contrasting pattern for the same period. The number of workers involved in production declined by about 37.9% on average, suggesting that the role of labour in the production process tended to decrease. By contrast, the average amount of both capital and intermediate inputs climbed by about 7.3% and 44.2% for the same period, respectively.

In terms of firms' ownership structure, private firms make up 99.6% of manufacturing firms in the sample. Of these, 33.2% are owned by individual investors and 66.4% by commercial corporations. Non-commercial corporate bodies own just 0.4% of manufacturing firms in the sample. Changes in firm ownership over the study period show an interesting pattern in that the proportion of firms owned by individual investors decreased considerably. By contrast, the corresponding figures for firms owned by commercial corporations increased by 31.4%. The main reason for this restructuring may be the increasing competition between manufacturing firms in the region.

Table 4-2. Descriptive Statistics for Variables Used in the Regression Model

Variables	Definition	2000 – 2012			
		Mean.	S.D.	Min.	Max.
In output	Log of the total output of firms' production (million KRW 2005 prices)	7.840	1.302	-0.258	17.406
In labour	Log of the total amount of labours in production (persons)	3.026	0.772	0	10.290
In capital	Log of the amount of tangible fixed assets (million KRW 2005 prices)	6.206	1,930	-0.503	16.938
In intermediate	Log of the amount of direct intermediate inputs (million KRW 2005 prices)	7.098	1.659	-0.489	16.43
Finance	Dummy variable. 1: if financial liquidity is flexible, 0 otherwise. Specifically, variable is 1 if firm has paid-in capital by issuing shares of its common or premium stocks.	0.116	0.3204	0	1

Firm-type	Dummy variable. 1: if a firm is owned by an individual investor, 2: if a firm is owned by commercial corporation, and 3: if a firm is owned by non-commercial corporation body	1.671	0.476	1	3
Firm-age	Years after firm's birth	12.455	9.010	1	87
the Seoul Growth Management Policy	Dummy variable. 1: if a firm is located in growth management area, 0 otherwise.	0.131	0.377	0	1
In workforce accessibility-SCR	Log of relative workforce accessibility measure for the Seoul region	10.316	0.949	7.134	12.218
In workforce accessibility-Seoul	Log of relative workforce accessibility measure for Seoul	13.544	0.8393	9.5279	14.764
Rail station density 1899	IV1: Rail and tram station density in 1899	2.97e-07	8.02e-07	8.81e-09	0.00002
Rail station density 1930	IV2: Rail and tram station density in 1930	5.32e-06	1.77e-06	8.81e-09	0.00002
Rail station density 1960	IV3: Rail and tram station density in 1960	6.81e-07	1.85e-06	8.81e-09	0.00002
In proximity-to-station	IV4: Log of the distance to the nearest rail or tube stations	9.899	0.601	6.077	11.205
In the area of <i>dong</i>	IV5: Log of the area of a given <i>dong</i>	14.789	1.553	12.120	19.324
In weighted average of the areas of surrounding <i>dongs</i>	IV6: Log of the weighted average of the sum of the areas of the surrounding <i>dongs</i>	15.457	1.414	12.837	18.903
In weighted average of the urbanized areas of surrounding <i>dongs</i>	IV7: Log of the weighted average of the sum of the urbanized areas of the surrounding <i>dongs</i>	14.940	1.099	12.780	18.466

4.6. Main Results

This section examines the main results obtained from the two-stage approach. The main results are presented in four parts. The first part estimates the values of the output elasticities with regard to capital, labour, intermediate inputs (Section 4.6.1). With these output elasticities, the second part calculates the level of productivity of manufacturing firms and generates a dependent variable for the main production model (Section 4.6.2). The third part estimates the regression model of Eq. 4-8 to explore the relationship between transport-induced workforce accessibility and firm productivity for the manufacturing industry and for disaggregated manufacturing sub-sectors (Section 4.6.3). The last part estimates the effect of workforce accessibility improvement on firm

productivity to investigate how and to what extent transport-induced economic effects are related to firm productivity in the Seoul region (Section 4.6.4).

4.6.1. Productivity Analysis of the Input Factors

Table 4-3 provides the results obtained from the estimation of the contribution of the input factors to a firm's output. I consider four types of regression models, ranging from a pooled-OLS model to a dynamic panel model with the system-GMM estimator. All models work well to explain the relationship between a firm's output and the three input factors. The overall performance of these models is good in terms of the *R*-squared scores, which are overall high at around 0.90 in all models.¹⁴ F-tests also reveal that, statistically, all models fit well with the sample. For a dynamic panel model, an χ^2 -test is carried out to evaluate whether the models fit with the sample. The tests show that the test results are statistically significant.

The results of the OLS regression model, presented in column (1), show that the coefficients of the three input factors are all positive and the output elasticity with regard to intermediate inputs is the largest among the input factors, amounting to 0.57. This indicates that a firm's output would increase by 0.57% for additional percent increase in the amount of intermediate inputs. In column (2), a standard panel model with a fixed-effect estimator is applied to the estimation to control for the unobserved characteristics of firms. The results show a similar pattern to that in the OLS estimation, although the coefficients of the three variables are slightly different from those in the OLS estimates. This suggests that the OLS estimates are likely to be upward biased because the OLS estimation does not address the issue of unobserved characteristics of firms.

The estimates obtained from a standard panel model may be still upwardly biased if the complexity of the simultaneous interaction linked to the arrangement of the input factors is not properly accounted for in the estimation. Column (3) reports the results of the IV model with the Anderson-Hsiao (AH) estimator. Instrument variables are generated, derived from the lagged values of both the dependent and independent variables, and they are incorporated into the model to correct for the simultaneous bias

¹⁴ For dynamic panel models estimated in column (4), the Arellano-Bond test score is used instead of the *R*-squared score to determine the model's fitness.

of the input factors. The coefficients of the three input factors, again, are positive and statistically significant.

In column (4), I apply a dynamic panel model with a system-GMM estimator to address several estimation issues involved in the previous estimation. It instruments the current values of independent and dependent variables as well as their first differences.¹⁵ Using Arellano and Bond (AB) tests, the validity of the dynamic panel model is checked to ensure it does not violate the assumption that no autocorrelation exists in the idiosyncratic error (Arellano & Bond, 1991). The AB tests show that the results in column (4) meet the condition of no autocorrelation. I therefore prefer the dynamic panel model with the system-GMM estimator.

Table 4-3. The Result of Production Model for the Manufacturing Industry

	(1)	(2)	(3)	(4)
	Pooled-OLS Model	Standard Panel Model	IV-DD Panel Model	Dynamic Panel Model
	OLS	FE	AH	GMM
In labour	0.4517*** (0.0036)	0.3245*** (0.0018)	0.2210*** (0.0028)	0.2185*** (0.0054)
In capital	0.0388*** (0.0009)	0.0420*** (0.0006)	0.0299*** (0.0011)	0.0261*** (0.0019)
In intermediates	0.5700*** (0.0022)	0.5415*** (0.0008)	0.4814*** (0.0013)	0.4683*** (0.0054)
constant	2.1209*** (0.0090)	2.6684*** (0.0072)	0.0046*** (0.0008)	1.3666*** (0.0681)
R-Squared	0.9121	0.9100	0.9334	–
F-statistics Test	36692.0***	47485.3***	–	–
Anderson-Rubin Wald χ^2 Test	–	–	171089***	38417.7***
Arellano-Bond Test				
1 st order	–	–	–	-39.792***
2 nd order	–	–	–	1.1246
3 rd order	–	–	–	–
Lagged variables	N	N	Y	Y

¹⁵ In total, 85 instrument variables are generated. The estimation with many instrument variables easily leads to an overload of computer memory. For this reason, I limit lagged values for instruments to t-2, as suggested by Roodman (2009).

Dynamic effect	N	N	N	Y
Instrument variable	N	N	Y	Y
Number of Observation	295657	295657	142762	175454
Number of instruments	–	–	19	85

Notes: Robust standard errors are reported in parentheses. Coefficients are significant at the 1%, 5%, and 10% level, which are expressed by *, **, and ***, respectively.

Similar results hold for the estimation of the dynamic panel estimation, which shows that the coefficients for labour, capital, and intermediate inputs are positive and statistically significant, as in the previous estimates. Of the input factors, the amount of intermediate inputs is most significantly related to a firm's output, demonstrating the importance of raw materials and intermediate inputs in making final products in the manufacturing industry. The amount of labour comes second in terms of impact on a firm's output, confirming that labour is an essential factor in a firm's production. The amount of capital has least impact on a firm's output. This is because the durability of production facilities and equipment is relatively high, which means that investment in these items is not required as long as they continue to operate normally.

Overall, the results of the four regression models show that the three input factors are determinants of a firm's output, despite slight differences in the magnitude of output elasticities with regard to the input factors. All three input factors are positive and statistically significant. These results are consistent with a large body of empirical studies in the literature (Bartelsman & Dhyrmyes, 1998; Chen & Guariglia, 2013; Disney, Haskel & Heden, 2003). The results are also in accordance with the findings in studies examining the productivity of Korean firms, indicating that capital, labour, and intermediate inputs are the determinants of the output of manufacturing firms in Korea (Oh, Heshmati & Lööf, 2014).

Table 4-4. The Result of the Production Model for Manufacturing Sub-sectors

Variables	The whole sectors	Food production	Beverage products	Tobacco	Textile except apparels
					(1)
<i>In</i> labour	0.2185***	0.1181**	0.2572	0.0329	0.1980***

	(0.0054)	(0.0512)	(0.3263)	(0.0657)	(0.0504)
<i>ln</i> capital	0.0261*** (0.0019)	0.0408 (0.0351)	0.0433** (0.1394)	0.0799 (0.0611)	0.0289** (0.0131)
<i>ln</i> intermediates	0.4683*** (0.0054)	0.4150*** (0.0616)	0.4224*** (0.1143)	0.5338*** (0.0829)	0.5428*** (0.0640)
Constant	1.3666*** (0.0681)	1.8981** (0.9231)	1.6033** (0.6689)	-0.6237 (1.8415)	2.3585** (0.6746)
Number of Observation	175454	2011	104	182	1919
Number of instruments	85	40	31	29	23
Anderson-Rubin Wald χ^2 Test	38417.7***	217.98***	332.34***	88.97***	307.44***
Arellano-Bond test					
1 st order	-39.792***	-3.4044**	-1.8872*	-3.1624**	-3.0023**
2 nd order	1.1246	0.4887	0.3186	-0.2078	1.6331
	Apparel and Accessories (5)	Luggage and Footwear (6)	Wood products (7)	Paper and paperboard products (8)	Printing (9)
<i>ln</i> labour	0.13837** (0.06648)	0.1104*** (0.0232)	0.14196 (0.09614)	0.2264*** (0.02477)	0.3952*** (0.0289)
<i>ln</i> capital	0.05627** (0.02470)	0.0454*** (0.0091)	0.04203** (0.01785)	0.01650 (0.01254)	0.0368*** (0.0111)
<i>ln</i> intermediates	0.47383*** (0.07111)	0.5737*** (0.0277)	0.58026*** (0.06160)	0.42571*** (0.02437)	0.2654*** (0.0121)
Constant	1.4337** (0.46763)	2.4029*** (0.3898)	1.0629* (0.59272)	0.03278 (0.21875)	0.5538** (0.3931)
Number of Observation	2318	4086	805	6208	6425
Number of instruments	23	44	23	59	44
Anderson-Rubin Wald χ^2 Test	1228.38***	966.14***	524.24***	7511.30***	1825.43***
Arellano-Bond Test					
1 st order	-3.9461***	-5.1244***	-3.708***	-9.3116***	-12.361***
2 nd order	-0.86117	-0.8278	0.9320	0.8275	-0.1597

Notes: Robust standard errors are reported in parentheses. Coefficients are significant at the 1%, 5%, and 10% level, which are expressed by *, **, and ***, respectively.

Table 4-5. The Result of the Production Model for Manufacturing Sub-sectors (Continued)

Refined Petroleum Products 19	Chemicals and chemical	Pharmaceutic als, Medicinal Chemicals	Rubber and Plastic Products	Non-metallic Mineral Products
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	products ¹⁶				
	(10)	(11)	(12)	(13)	(14)
<i>ln</i> labour	0.1702** (0.0436)	0.2506*** (0.0429)	0.1369*** (0.0291)	0.2847*** (0.02809)	0.1575*** (0.04619)
<i>ln</i> capital	0.0924*** (0.0231)	0.0340** (0.0164)	0.0278** (0.0100)	0.0371*** (0.00902)	0.05464* (0.02983)
<i>ln</i> intermediates	0.5027*** (0.0486)	0.5377*** (0.0392)	0.5789*** (0.0371)	0.49142*** (0.02918)	0.4463*** (0.07253)
Constant	1.0997** (0.5627)	2.090*** (0.3736)	1.4287** (0.4235)	1.6389*** (0.46905)	1.9533*** (0.6007)
Number of Observation	1030	3332	2968	7696	1393
Number of instruments	41	48	41	76	42
Anderson-Rubin Wald χ^2 Test	760.06***	948.24***	1089.7***	7806.28***	273.79***
Arellano-Bond test					
1 st order	-3.6631***	-5.3307***	-4.5638***	-9.9217***	-3.1559**
2 nd order	-0.0852	-0.7696	-1.6435*	0.9664	1.1979
	Basic Metal Products	Fabricated Metal Products	Computer and Communication Equipment	Precision and Optical Instruments	Electrical equipment
	(15)	(16)	(17)	(18)	(19)
<i>ln</i> labour	0.1262*** (0.0282)	0.1745*** (0.0158)	0.1813*** (0.0332)	0.1580*** (0.0301)	0.1480*** (0.0152)
<i>ln</i> capital	0.0558*** (0.0101)	0.0103* (0.0061)	0.0184* (0.0160)	0.0079	0.0175** (0.0052)
<i>ln</i> intermediates	0.5465*** (0.0271)	0.5808*** (0.0193)	0.4720*** (0.0301)	0.5682*** (0.03580)	0.5047*** (0.0170)
Constant	1.0802** (0.3612)	2.1461*** (0.2728)	0.9824*** (0.2528)	0.7201*** (0.2018)	1.9778*** (0.2471)
Number of Observation	5802	13269	7175	4639	13627
Number of instruments	51	64	50	41	71
Anderson-Rubin Wald χ^2 Test	1046.8***	3356.8***	2316.3***	2956.7***	3244.3***
Arellano-Bond test					
1 st order	-6.5169***	-6.572***	-7.5012***	-6.6828***	-8.7387***
2 nd order	0.5317	-0.3189	0.6988	0.8493	-0.7308

Notes: Robust standard errors are reported in parentheses. Coefficients are significant at the 1%, 5%, and 10% level, which are expressed by *, **, and ***, respectively.

¹⁶ Chemical products in this category does not include pharmaceuticals, medicinal chemicals

Table 4-6. The Result of the Production Model for Manufacturing Sub-sectors (Continued)

	Other Machinery products	Motor Vehicles and Trailers	Other Transport Equipment	Furniture	Other manufacturin g
	(20)	(21)	(22)	(23)	(24)
<i>In</i> labour	0.15629*** (0.01155)	0.2866*** (0.0425)	0.1565*** (0.0221)	0.3001*** (0.0350)	0.1750*** (0.0307)
<i>In</i> capital	0.01594*** (0.00381)	0.0704*** (0.0189)	0.0193** (0.0060)	0.0205* (0.0110)	0.0279** (0.0128)
<i>In</i> intermediates	0.61295*** (0.01477)	0.5254*** (0.0367)	0.6106*** (0.0285)	0.4487*** (0.0263)	0.4460*** (0.04371)
Constant	0.56432*** (0.08642)	1.3898*** (0.3505)	0.9664*** (0.2471)	1.2195*** (0.2939)	1.1074*** (0.21216)
Number of Observation	25623	2370	5593	6524	3368
Number of instruments	86	47	46	44	48
Anderson-Rubin Wald χ^2 Test	22973.33***	1409.3***	2510.1***	2897.8***	1489.38***
Arellano-Bond test					
1 st order	-13.676***	-3.763***	-6.481***	-9.1066***	-6.2267***
2 nd order	-1.1978	-1.0061	-1.391	0.6020	1.115

Notes: Robust standard errors are reported in parentheses. Coefficients are significant at the 1%, 5%, and 10% level, which are expressed by *, **, and ***, respectively.

Using a dynamic panel model with the system-GMM estimator, I further examine how capital, labour, and intermediate inputs contribute to firm output in manufacturing sub-sectors in the Seoul region.¹⁷ The results are shown in Tables 4-4 – 4-6. All models for the manufacturing sub-sectors pass the χ^2 -test at the 1% level. For the presence of autocorrelation in the first-differenced error, none of the models show signs of serial correlation at the second order.

In all dynamic panel models for the manufacturing sub-sectors, the estimated results show the expected signs with positive coefficients, except for several models with small sample sizes such as Tobacco. I suspect that the small number of observations may be the source of such difference in the estimates. Overall, capital, labour, and intermediate inputs are positively associated with firm output, suggesting that these

¹⁷ According to KSIC, the manufacturing industry in South Korea consists of 24 manufacturing sub-sectors, ranging from food production to electrical equipment.

input factors are determinants of a firm's output for the manufacturing sub-sectors as they are for the whole manufacturing industry.

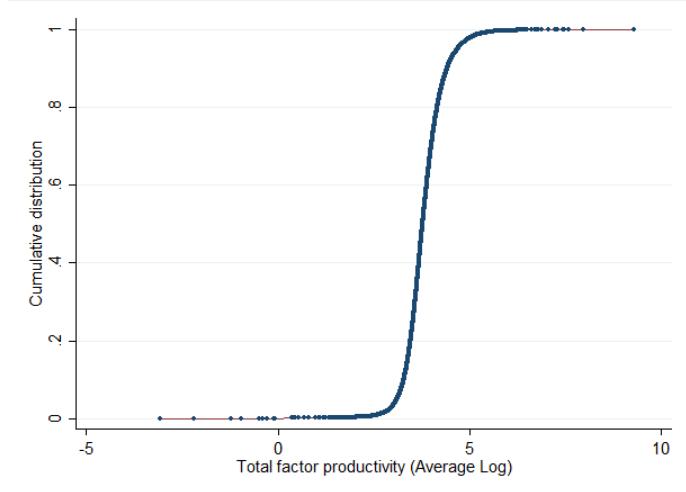
The estimated results show some interesting patterns. It is observed that the coefficients of capital, labour, and intermediate inputs vary across manufacturing sub-sectors. The differences in the coefficients are mainly attributed to the way in which they use the input factors in production. For example, the coefficient of labour tends to be higher in manufacturing sub-sectors that require labour-intensive activities for final products, such as furniture, printing, and rubber. In a similar vein, the coefficient of intermediate inputs tends to be higher in manufacturing sub-sectors that consume raw materials in production, such as machinery, metal, and transport equipment.

4.6.2. Calculation of Total Factor Productivity

The average elasticities of firm output with respect to the input factors are obtained from the estimates in the previous section. These elasticities are essential to the calculation of the TFP of manufacturing firms. With these elasticities, I isolate the amount of firm output not explained by the input factors and create a dependent variable for the main production model specified in Eq. 4-8.

Figure 4-4 shows the cumulative distribution of the average TFP of manufacturing firms in the Seoul region. Productive distribution is concentrated in the middle of the graph and spreads out at the bottom and top end. This indicates that manufacturing firms in the sample are dominated by firms with an average TFP value between 3 and 6. The average TFP values of manufacturing firms in the Seoul region is 3.81 in the logarithmic form. The highest TFP value of manufacturing firms is around 9.30 while the lowest TFP value is around -3.07.

Figure 4-4. TFP Distribution of Manufacturing Firms in the Seoul Region



I perform additional graphic analyses to highlight TFP differences between firms operating in different time periods and firms with different characteristics. I also conduct Kolmogorov-Smirnov (KS) tests to supplement the interpretation of graphical analyses statistically. The KS test provides statistical assessments on the gap between two productive distributions.

Figure 4-5 clearly shows that TFP in manufacturing firms improved over the period between 2000 and 2012. Firms operating in 2012 had a productive distribution to the right of those operating in 2000, indicating that TFP distribution of firms in 2012 was higher than that of firms in 2000. The result of the KS test confirms the growth of TFP in manufacturing firms over the study period. The estimated value of the KS test is statistically significant at the 1% level.

The productivity distribution of firms with financial management capability lies to the right of the productivity distribution of firms with no financial management, indicating that the former has a higher impact on TFP than the latter. Figure 4-6 demonstrates how TFP distribution varies by firms' financial management capability. The dominance of firms with financial management in terms of TFP distribution is also supported by the KS test, which is statistically significant at the 1% level.

The cumulative distribution of productivity also varies by a firm's ownership. Figure 4-7 compares between firms owned by individual investors, commercial corporations, and non-commercial corporate bodies. Firms owned by commercial corporations overall

have the highest productivity among the three groups, although their productive distribution intersects at the top end. By contrast, firms owned by individual investors have the lowest productivity with a highly significant value of KS test. The productive distribution of firms owned by individual investors lies far left of the others. These results suggest that a firm's ownership matters in determining the level of its productivity, demonstrating that it is important to consider a firm's ownership in the estimation of TFP.

Figure 4-5. TFP distribution by firm's age

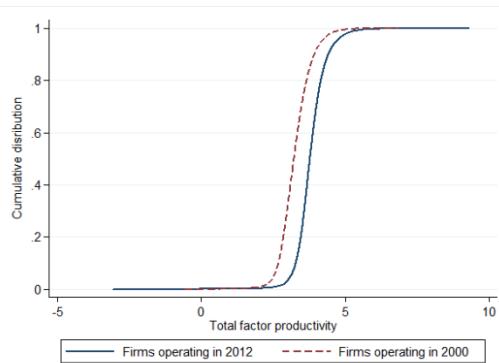


Figure 4-6. TFP distribution by firm's finance

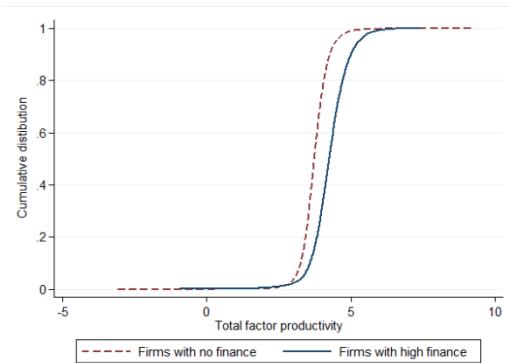


Figure 4-7. TFP distribution by firm's ownership

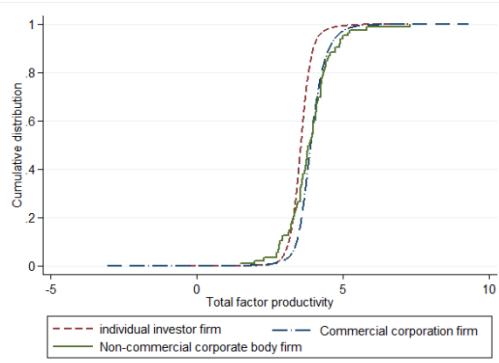
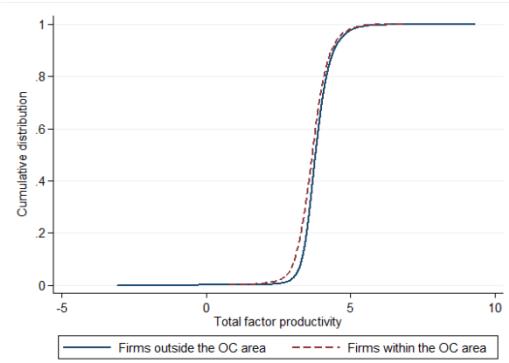


Figure 4-8. TFP distribution by firm's location



4.6.3. Transport-induced Workforce Accessibility and Firm Productivity

4.6.3.1. Transport-induced Workforce Accessibility in the Manufacturing Industry

This section discusses the second stage of the approach, which presents the estimated results for how and to what extent transport-induced workforce accessibility is related to firm productivity. Firms' TFP is used as a dependent variable for the estimation. The indicator of transport-induced workforce accessibility is used to capture the level of productive effects induced by transport infrastructure. Table 4-7 shows the estimated results of the IV model for the entire manufacturing industry. The estimated result of the panel model is also presented for the purpose of comparison.

The coefficients of variables included in the models are shown with standard errors and statistical significance levels. At the bottom of the table, the statistical values of tests for instrument identification and the number of observations is presented. All models work well to explain the relationship between a firm's productivity, its characteristics, and transport-induced workforce accessibility.

The results of the panel model are reported as a benchmark in column (1). In this model, the indicator of workforce accessibility is included as an independent variable to test to what extent firm productivity is solely explained by transport-induced workforce accessibility. The coefficient of transport-induced workforce accessibility is positive and statistically significant at the 1% level, pointing to a positive relationship between transport-induced workforce accessibility and firm productivity. Its magnitude is 0.0523, which means that firm productivity would rise by 0.0523% for one additional percent increase in transport-induced workforce accessibility. The estimates for transport-induced workforce accessibility on firm productivity may have been upward biased to some extent, because an increase in productive benefits resulting from transport-induced workforce accessibility might lead to a change in the density of economic activities, which may cause a potential bias in the estimates. For this reason, I turn to the IV model with instrument variables to address the endogeneity estimation issue.

The estimated results of IV models are reported in columns (2) – (5). In all models, standard errors are clustered at the *dong* level as workforce accessibility varies at this level. In Column (2), I include a lagged value of workforce accessibility as instrument. The coefficient of workforce accessibility is found positive and strongly statistically

significant. In Column (3), I add three instrument variables relating to the average size of a given area and the weighted average of the size of the surrounding areas. The results are very similar to those in Column (2).

In Column (4), instead of the area-related instrument variables, instrument variables relating to transport network are added to deal with the endogeneity of targeted transport policy. This model shows the coefficient of workforce accessibility of 0.0329, indicating that increasing the level of workforce accessibility by 1% would raise firm productivity by 0.0329%, all else being equal. In Column (5), I include all instrument variables. This model yields similar results to those in Column (2) – (4), with an elasticity of workforce accessibility of 0.0352.

Table 4-7. Estimated Results for the Effect of Workforce Accessibility on Firm Productivity in the Seoul Region

	(1)		(2)		(3)		(4)		(5)	
	OLS		IV		IV		IV		IV	
	Coef.	s.e.								
<i>In Workforce Accessibility</i>	0.0523***	(0.0029)	0.0343***	(0.0039)	0.0345**	(0.0146)	0.0329**	(0.0155)	0.0352**	(0.0141)
Control variables										
Industrial location policy	–	–	-0.088***	(0.0085)	-0.088***	(0.0222)	-0.088***	(0.0218)	-0.088***	(0.0221)
Firm's finance condition	–	–	0.338***	(0.0095)	0.338***	(0.0172)	0.338***	(0.0172)	0.338***	(0.0172)
<i>In Firm age</i>	–	–	0.126***	(0.0034)	0.126***	(0.0053)	0.126***	(0.0052)	0.126***	(0.0053)
Commercial corporation	–	–	0.293***	(0.0065)	0.293***	(0.0104)	0.293***	(0.0105)	0.293***	(0.0103)
Non-commercial corporation bodies	–	–	0.311***	(0.0513)	0.311***	(0.0865)	0.311***	(0.0864)	0.311***	(0.0865)
Constant	3.2787***	(0.0340)	2.961***	(0.0408)	2.959***	(0.144)	2.975***	(0.154)	2.952***	(0.140)
Instruments										
Accessibility in 2000	N		Y		Y		Y		Y	
The area of <i>dong</i>	N		N		Y		N		Y	
Weighted average of the areas of surrounding <i>dongs</i>	N		N		Y		N		Y	
Weighted average of the urbanized areas of surrounding <i>dongs</i>	N		N		Y		N		Y	
Distance to rail station	N		N		N		Y		Y	
Transport network in 1960	N		N		N		Y		Y	
Clustering standard errors	-		YES		YES		YES		YES	
Number of observations	26721		26721		26721		26721		26721	
R-squared	0.094		0.215		0.215		0.216		0.215	
Instrument identification										

Under-identification test (Kleibergen-Paap M statistic)	-	2.614	12.845**	20.190***	23.348***
Weak-identification test	-	4.1e+04***	1.1e+04**	1.4e+04***	7442.715*
Cragg-Donald Wald F statistic	-	44.574***	14.516**	24.043***	11.887*
Kleibergen-Paap Wald F statistic	-	0.000	9.947*	4.022	10.144*
Over-identification test					
Hansen J statistic	-				

Notes: Robust standard errors are reported in parentheses. Coefficients are significant at the 1%, 5%, and 10% level, which are expressed by *, **, and ***, respectively.

In total, six instrument variables are incorporated into the IV model to correct for the endogeneity of workforce accessibility. To ensure the validity of instrument variables used in the IV model, I perform three statistical tests to evaluate how accurately the endogeneity of workforce accessibility is identified by the selected instrument variables.

The results of the Kleibergen-Paap LM statistics test show that IV models (3) – (5) are correctly identified, rejecting the null hypothesis that the model is under-identified. Similarly, the results of Cragg-Donald Wald statistics also confirm the identification of the IV models. The statistical values of Cragg-Donald statistics are higher than critical values of the minimum eigenvalue defined by Stock and Yogo (2005), which rejects the null hypothesis of weak identification of instruments in all models. The results for the Hansen J test of overidentifying restrictions show that the null hypothesis of instrument exogeneity cannot be rejected for results in models (2) and (4). For models (3) and (5), the null hypothesis can be rejected at the 5 percent level but not at the 1 percent level, suggesting that cautious interpretation needs for these results.

The estimated results reported in columns (2) – (5) show that the coefficients of transport-induced workforce accessibility range from 0.0329 to 0.0352. The results show that transport-induced workforce accessibility is positively and significantly related to firm productivity in the manufacturing industry, as found in the OLS estimates, yet its magnitude is lower than the estimates in the OLS. Of those results, I prefer the estimated result in column (4), where the null hypothesis that the over-identifying restrictions are valid cannot be rejected at the 1 percent level.

As for variables controlling for a firm's heterogeneity, they show the expected signs with statistical significance. A firm's age is found to have positive impacts on its productivity. The older the manufacturing firm, the higher its efficiency in production, which is in line with the learning-by-doing argument made by Jovanovic and Nyarko (1996).

A firm's financial management capability is positively related to its productivity. Of the firm's characteristics, its financial management capability has the largest impact on its productivity. The coefficient of a firm's management capability is 0.338, which means that a 33.8% increase in a firm's productivity is expected when it has financial management. This finding is consistent with previous studies where the relationship between firms' financial management and their productivity was found to be positive (Chen & Guariglia, 2013; Nucci, Pozzolo & Schiavardi, 2005).

The industrial location policy is found to affect a firm's productivity. Firms located within the

area of the Seoul Growth Management Policy (SGMP) perform about 8.5% less than firms outside the SGMP area in the region, all other variables being equal. The coefficient of this variable is statistically significant at the 1% level and its significance is found in all models. These results show that industrial policy has some potential to change the demand for and supply of economic activities by regulating the level of economic activities in the region

As for firms' ownership, ownership by individual investors is found to have a lower impact on a firm's productivity than ownership by commercial or non-commercial corporation bodies. This may be due to the fact that firms owned by commercial or non-commercial corporation bodies are more likely to have a better management strategy, better marketing capability and specialized knowledge on production that may give them an advantage in production (Dana, 2004). This is also in line with the argument that a lack of understanding of management may be disadvantageous to a firm's efficiency (Dunning, 2013).

4.6.3.2. Transport-induced Workforce Accessibility in Manufacturing Sub-sectors

Table 4-8 shows the results obtained from the IV model estimations for disaggregated manufacturing sub-sectors. The IV model specified in the previous section is used to estimate the elasticity of firm productivity with respect to transport-induced workforce accessibility. Specifically, I use two IV models for each manufacturing sub-sector; one with both a lagged value of accessibility and instrument variables relating to transport network, one with all instrument variables. The former is the preferred model in the previous estimation for the entire manufacturing industry. In all models, standard errors are clustered at the *dong* level.

The estimated results for manufacturing sub-sectors are reported in columns (1) – (5). The results obtained from the IV models for manufacturing sub-sectors show that the coefficient of workforce accessibility is positive and statistically significant, indicating that transport-induced workforce accessibility is positively related to firm productivity in manufacturing sub-sectors, except for a few sub-sectors such as chemical. Transport-induced workforce accessibility is a key determinant of firm productivity for manufacturing sub-sectors. The results confirm that the link between transport-induced economic effects and firm productivity holds at the disaggregated industrial levels.

The validity of instrument variables used in IV models is tested using three statistical tests. The results of the Kleibergen-Paap LM statistics test show that all IV models are correctly

identified except for model (4) and (5), rejecting the null hypothesis that the model is under-identified. As for weak identification of instruments, the results of Cragg-Donald Wald statistics are significant in all IV models, which rejects the null hypothesis of weak identification of instruments. Hansen J test of overidentifying restrictions show that the null hypothesis of instrument exogeneity cannot be rejected for results in most model, except for model (4) and (6).

Table 4-8. Estimated Results of the Productive Effect of Workforce Accessibility by Manufacturing Sub-sectors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Textile		Metal		Computer & ICT		Plastic		Chemical	
	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)
<i>In Workforce Accessibility</i>	0.0395*** (0.0108)	0.0388*** (0.0109)	0.0390** (0.0138)	0.0393** (0.0132)	0.0515** (0.0247)	0.0482* (0.0266)	0.0414 (0.0278)	0.0476* (0.0238)	0.0241 (0.0171)	0.0208 (0.0182)
Control variables										
Industrial location policy	0.0334 (0.0420)	0.0337 (0.0421)	-0.136*** (0.0358)	-0.136*** (0.0358)	-0.203*** (0.0406)	-0.199*** (0.0426)	-0.00624 (0.0716)	-0.0127 (0.0719)	-0.264*** (0.0660)	-0.259*** (0.0674)
Firm's finance condition	0.180*** (0.0503)	0.181*** (0.0504)	0.327*** (0.0379)	0.327*** (0.0379)	0.365*** (0.0329)	0.365*** (0.0329)	0.260*** (0.0387)	0.260*** (0.0387)	0.294*** (0.0442)	0.294*** (0.0442)
<i>In Firm age</i>	0.116*** (0.00991)	0.116*** (0.00986)	0.131*** (0.00997)	0.131*** (0.00998)	0.112*** (0.0158)	0.112*** (0.0157)	0.123*** (0.0136)	0.123*** (0.0136)	0.152*** (0.0189)	0.153*** (0.0188)
Commercial Corporation	0.330*** (0.0248)	0.330*** (0.0248)	0.273*** (0.0163)	0.273*** (0.0163)	0.145*** (0.0345)	0.145*** (0.0345)	0.285*** (0.0154)	0.285*** (0.0154)	0.304*** (0.0371)	0.304*** (0.0371)
Non-commercial Corporation	-	-	0.191 (0.343)	0.191 (0.343)	0.125* (0.0581)	0.119* (0.0593)	-1.012** (0.338)	-1.008** (0.340)	-0.123 (0.196)	-0.126 (0.196)
Constant	2.851*** (0.108)	2.857*** (0.109)	2.919*** (0.153)	2.916*** (0.147)	2.946*** (0.275)	2.982*** (0.293)	2.880*** (0.291)	2.818*** (0.253)	3.072*** (0.170)	3.104*** (0.183)
Instruments										
Accessibility in 2000	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
The area of <i>dong</i>	N	Y	N	Y	N	Y	N	Y	N	Y
Weighted average of the	N	Y	N	Y	N	Y	N	Y	N	Y

areas of surrounding <i>dongs</i>										
Weighted average of the urbanized areas of surrounding <i>dongs</i>	N	Y	N	Y	N	Y	N	Y	N	Y
Distance to rail station	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Transport network in 1960	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Clustering standard errors	YES	YES	YES	YES						
Number of observations	1013	1013	4788	4788	2593	2593	2382	2382	951	951
Adj. R-squared	0.300	0.300	0.212	0.212	0.215	0.215	0.210	0.210	0.201	0.201
Instrument identification										
Under-identification test (Kleibergen-Paap LM statistic)	12.652**	21.287**	9.801*	11.517	3.806	15.750*	13.704**	16.347*	14.893*	14.893*
Weak-identification test Cragg-Donald Wald F statistic	912.02***	477.49***	3447.0***	1869.1***	2202.9***	1147.0***	1345.4***	745.981*	468.54***	468.54***
Kleibergen-Paap Wald F statistic	64.084***	35.970***	42.274***	20.849***	36.626***	26.777***	26.321***	11.614*	42.919***	42.919***
Over-identification test Hansen J statistic	2.883	4.323	4.848	14.659*	2.934	20.875**	4.600	9.766	9.171	9.171

Notes: Robust standard errors are reported in parentheses. Coefficients are significant at the 1%, 5%, and 10% level, which are expressed by *, **, and ***, respectively.

The estimated results show that different manufacturing sub-sectors receive different levels of productive benefits resulting from workforce accessibility. In column (1), the coefficient of workforce accessibility for the textile sector is 0.0395, which is roughly similar to the industry average found in the previous estimation. It indicates a 0.0395% increase in firm productivity for a 1% rise in the level of workforce accessibility in the textile sector. Similar results can be found in the metal sectors, which receive productive benefits of 0.039% in response to a 1% increase in the level of workforce accessibility.

The estimated results for the computer and ICT sector, shown in column (3) provide interesting implications for the link between firm productivity and transport-induced workforce accessibility. The coefficients of workforce accessibility in this sector is 0.0515. The magnitude of this coefficient is higher than the average coefficient in the manufacturing industry as a whole. This indicates that production activities in this sector is more sensitive to a change in transport-induced workforce accessibility than other manufacturing sub-sectors. The large productive benefit that computer & ICT sector receives can probably be attributed to its unique feature in production. The sector requires advanced technology and complicated assembly procedures to make final products.

Looking at the link in more detail, transport infrastructure provides firms in manufacturing sub-sectors with physical access to high-skilled workers who have specific qualifications for such production work, and it reduces the search friction between firms and workers, increasing the spatial extent to which firms and workers interact with each other. The extended labour market provides firms with productive benefits by improving the quality of the matches. Thus, the level of transport-induced workforce accessibility matters considerably to the variation of productivity in firms in manufacturing sub-sector. The finding highlights that the magnitude of transport-induced workforce accessibility depends on what kinds of production are carried out by workers who can be accessed by transport infrastructure. A firm's production feature, thus, may be one factor considered in decisions on the development of transport infrastructure.

A key message derived from the estimated results is that features in production affect the degree of productive effects induced by workforce accessibility. The productive benefits induced by transport-induced workforce accessibility are not the same for all manufacturing sub-sectors, but the level of these benefits varies depending on their

production characteristics. The production features in manufacturing sub-sectors are different from each other and they have become more heterogeneous over the last decades. Some manufacturing sub-sectors have adopted advanced communication and production technologies to make final products more attractive, whereas others remain more traditional.

As for the control variables included in the model, all variables behave as they do in the estimates for the whole manufacturing industry, although the coefficients of these variables are slightly different. The coefficients of a firm's age, its financial management capability, and its ownership are positive at the statistically significant level, which confirms that these factors are relevant to variations in firm productivity.

4.6.4. The Effect of Workforce Accessibility Improvement on Firm Productivity

This section discusses the results obtained from the estimation of regression models for the effect of workforce accessibility improvement on firm productivity, which directly addresses the research question of 'how and to what extent are transport-induced economic effects related to the productivity of manufacturing firms in the Seoul region?'. Log of firm output is used as a dependent variable for the model, and the indicator of transport-induced workforce accessibility is used as capturing a change in the level of productive benefits arising from a change in transport infrastructure network.

Table 4-9 reports the results for FD regression model of Eq. 4-10, showing the impact of transport infrastructure improvement on firm productivity. Unlike IV model estimations in Table 4-7, those reported in Table 4-9 provide estimated results regarding how and to what extent a change in workforce accessibility affects the variation in firm productivity in the manufacturing industry. A key difference between those estimates is that the latter use a change in workforce accessibility in estimating the impact of transport-induced workforce accessibility on firm productivity.

The result for the basic FD regression model is reported in Column (1), whereas those for FD models with instrument variables (FD-IV) are reported in Column (2) – (10). In all models, standard errors are clustered at the *dong* level as workforce accessibility varies at this level. The basic FD model yields the baseline results regarding the impact of a change in workforce accessibility on firm productivity. In this model, the indicator of workforce accessibility is included along with variables for firm inputs to evaluate how

firm productivity is explained by these variables without instrument variables. The magnitude of the coefficient of transport-induced workforce accessibility is 0.1572 with statistical significance, pointing to a positive relationship between a change in transport-induced workforce accessibility and firm productivity.

The estimates obtained from the basic FD model, yet, are likely to be upward biased because those does not address the endogenous issue arising from targeted transport policy. If this is the case, a change in workforce accessibility is correlated with a change in unobservable error terms. For this reason, I turn to the FD-IV model with instrument variables to correct for the endogeneity pf targeted transport policy and changes in both labour force distribution and transport infrastructure network, which causes a potential bias in the estimates.

The estimated results of FD-IV models are reported in Columns (2) – (10). The coefficients of a change in transport-induced workforce accessibility are found positive and statistically significant as found in the FD estimates, yet its magnitude is lower than the estimates in the FD. I incorporate instrument variables into the FD-IV model. In Column (2), I include a variable for the 1899 transport network density as instrument. The coefficient of workforce accessibility change is found positive and statistically significant, with the magnitude of 0.1293.

In Column (3), I add variables for the 1930 and 1960 transport network densities as instruments. This model yields estimates with the lower coefficient of a change in workforce accessibility. In Column (4), industrial fixed effect is applied to the IV model, with the fixed accessibility indicator¹⁸ included as instrument. In Column (5), all variables for the transport network densities are included, whereas some of these instrument variables are taken away in Column (6) and (7). The magnitude of the coefficients of a change in workforce accessibility are found between 0.050 and 0.060 in these models. In Column (8) and (10), industrial fixed effect is not applied while time fixed effect is applied. Instrument variables for the transport network densities and the fixed accessibility indicator. The coefficient of workforce accessibility change is 0.0452 in model (9), indicating that increasing the level of workforce accessibility by 1% would raise firm productivity by 0.0452%, all else being equal.

¹⁸ This accessibility indicator is basically the same as workforce accessibility indicator specified in Eq. 4-1. But it is calculated based on the pre-improvement distribution of labour force (year 2000), which means that only changes in travel times due to transport network improvement is accounted for in the indicator.

Table 4-9. Estimated Results for the Effect of Workforce Accessibility Improvement on Firm Productivity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	FD	FD-IV	FD-IV	FD-IV	FD-IV	FD-IV	FD-IV	FD-IV	FD-IV	FD-IV
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
	(s.e.)	(s.e.)	(s.e.)	(s.e.)	(s.e.)	(s.e.)	(s.e.)	(s.e.)	(s.e.)	(s.e.)
<i>ln</i> Workforce Accessibility	0.1572*** (0.0190)	0.1293* (0.0676)	0.0722* (0.0436)	0.0635** (0.0311)	0.0600** (0.0260)	0.0576** (0.0256)	0.0511* (0.0299)	0.0498* (0.0267)	0.0452* (0.0271)	0.0439* (0.0259)
<i>ln</i> Capital	0.0508*** (0.0043)	0.0307*** (0.0038)	0.0323*** (0.0035)	0.0315*** (0.0033)	0.0316*** (0.0033)	0.0316*** (0.0033)	0.0318*** (0.0033)	0.0330*** (0.0034)	0.0319*** (0.0033)	0.0331*** (0.0034)
<i>ln</i> Labour	0.3096*** (0.0174)	0.3619*** (0.01888)	0.3618*** (0.0187)	0.3598*** (0.0188)	0.3598*** (0.0188)	0.3598*** (0.0188)	0.3597*** (0.0188)	0.3618*** (0.0187)	0.3597*** (0.0188)	0.3618*** (0.0187)
<i>ln</i> Intermediate	0.6399*** (0.0145)	0.5770*** (0.0176)	0.5783*** (0.0174)	0.5766*** (0.0174)	0.5767*** (0.0173)	0.5767*** (0.0173)	0.5769*** (0.0173)	0.5788*** (0.0174)	0.5770*** (0.0173)	0.5789*** (0.0174)
Instruments										
Transport network 1899	-	Y	Y	Y	Y	N	N	Y	Y	N
Transport network 1930	-	N	Y	N	Y	Y	N	Y	Y	Y
Transport network in 1960	-	N	Y	N	Y	Y	N	Y	N	Y
Accessibility fixed in 2000	-	N	N	Y	Y	Y	Y	Y	Y	Y
Firm Fixed Effect	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
Time Fixed Effect	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
Industry Fixed Effect	-	N	N	Y	Y	Y	Y	N	Y	N
Clustering standard errors	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
Number of observations	13206	13206	13206	13206	13206	13206	13206	13206	13206	13206
R-squared	0.9357	0.8378	0.8393	0.8421	0.8422	0.8422	0.8422	0.8394	0.8422	0.8394
Instrument identification										

Under-identification test (Kleibergen-Paap LM statistic)	-	31.880***	43.561***	41.287***	44.310***	25.406***	13.542***	43.863***	41.396***	25.194***
Weak-identification test	-	311.695**	200.22***	523.142**	360.42***	479.10***	921.09**	379.28***	419.48***	499.17***
Cragg-Donald Wald F statistic										
Kleibergen-Paap Wald F statistic	-	11.279**	25.558***	11.243**	22.232***	29.582***	10.075**	23.448***	25.652***	29.710***
Over-identification test										
Hansen J statistic	-	0.000	8.022*	0.958	6.122	2.886*	0.000	8.107*	3.497	4.040

Notes: Robust standard errors are reported in parentheses. Coefficients are significant at the 1%, 5%, and 10% level, which are expressed by *, **, and ***, respectively.

Three statistical tests are carried out to evaluate the validity of instrument variables used in the FD-IV models. The statistical values of these tests show how accurately the endogeneity of workforce accessibility is identified by the selected instrument variables. The results of these tests are presented at the bottom of the table. All models work well to explain the relationship between firm productivity, firm inputs, and a change in transport-induced workforce accessibility.

The results of the Kleibergen-Paap LM statistics test show that FD-IV models (2) – (10) are correctly identified, rejecting the null hypothesis that the model is under-identified. As for the weak identification of the FD-IV model, the results of Cragg-Donald Wald statistics are significant in all FD-IV models, rejecting the null hypothesis of weak identification of instruments. The results for the Hansen J test of overidentifying restrictions show that the null hypothesis of instrument exogeneity cannot be rejected for results in FD-IV models (2) - (10), except for models (3), (6) and (8). For the latter models, the null hypothesis can be rejected at the 5 percent level but not at the 1 percent level, suggesting that cautious interpretation needs for these results.

The estimated results reported in columns (2) – (10) show that the coefficients of a change in transport-induced workforce accessibility is positive and statistically significant, indicating that transport-induced workforce accessibility is a determinant of firm productivity in the manufacturing industry. Of those results, I prefer the estimated result in column (5), where the statistical significance is relatively high and the null hypothesis that the over-identifying restrictions are valid cannot be rejected at the 1 percent level. The coefficient of workforce accessibility improvement is 0.0600, indicating that increasing the level of workforce accessibility by 1% would increase firm productivity by 0.060%.

The estimated results show that transport-induced workforce accessibility leads to an increase in firm productivity. This is because the provision of transport infrastructure improves connectivity between firms and workers in the spatial economy, strengthening the level of agglomeration economies. The ways in which firms and workers access economic activities change because of transport infrastructure and this affects the degree to which they receive productive benefits arising from agglomeration economies. In other words, transport infrastructure improvement extends the spatial extent of the labour market, thickening the spatial interaction between firms and the labour force, which increases firm productivity. The locational centrality of firms shifts because of transport infrastructure, altering the way in which firms access resources. For example,

costs for recruitment may decrease and hence the costs for high-quality matches. For workers, transport infrastructure improvement alters their residential locations relative to jobs and changes the way in which they access jobs. The search friction for jobs decreases in accordance with the changed residential locations and therefore both the amount and quality of job matches improves. In these manners, transport infrastructure brings about an increase in firm productivity by changing the spatial environment where firms make products.

This improvement in productivity through agglomeration economies is an indirect benefit that firms receive from transport infrastructure in addition to an increase in factor productivity resulting from travel-cost savings linked to the input factors such as transport costs for raw materials. As such, the productive benefit found in the IV model can be viewed as an additional impact of transport infrastructure on a firm's productivity. This confirms that transport-induced workforce accessibility is a key determinant of firms' productivity in the manufacturing industry in the Seoul region. This reveals that the level of firms' productivity is closely related to the spatial environment, which is itself shaped by the interaction between transport infrastructure and the spatial labour market in the region. In other words, the indirect productive benefits of transport infrastructure are another key factor that may be taken on board in the debate about transport infrastructure investment, in addition to its direct travel-cost saving benefits.

It is worth comparing the results of the IV models with those found in other studies. While many studies have explored firms' productivity in relation to transport infrastructure, a handful of studies are comparable to my study because they differ in both the research focus and the geographical scope of analysis. To the best of my knowledge, the findings in three previous studies can be compared with those presented in this chapter. Néchet et al. (2012) found an estimated value of 0.023 for French manufacturing firms in the megacity region of the Paris basin, which is lower than the estimated results obtained from this study. For Spanish manufacturing firms, Martín-Barroso et al. (2015) reported an estimated value of 0.059, which is similar to the estimated result found in this research. Holl (2012) found an estimated value of 0.042 for Spanish firms, which is slightly lower than the estimate of this study. Given that the estimated value of the FD-IV model is 0.0600, the result of this study is largely in the range of elasticities of transport-induced productive benefits reported in previous studies. That said, possible caveat in the aforementioned comparison is that the accessibility indicator used in this research is slightly different from those in previous studies.

To qualify the results, it is worth identifying the reasons for the differences between the estimate in this study and those in previous studies. The first reason for the difference between the estimated results is probably linked to the use of different measures in capturing the level of workforce accessibility. The choice of accessibility measures is directly concerned with the extent to which the productive benefits induced by transport infrastructure are captured. The degree of transport-induced economic effects is likely dictated by the choice of accessibility measures. The second reason may be related to different statistical models used in previous studies. Some studies have relied on a relatively simple model with cross-sectional datasets, not accounting for the statistical bias arising from the endogeneity issue. Others have used a two-step approach to address the endogeneity issue with longitudinal datasets (Holl, 2012).

The dissimilarities in the estimates of previous studies may be partly attributed to the distinctive characteristics of individual labour markets, although this argument needs further analysis in future studies. The productive outcome induced by transport infrastructure is likely to differ depending on the vitality and quality of the workforce in the labour market. The local unemployment rate is one example of this, because it is concerned with how firms benefit from being close to the workforce. Cities and regions with a higher unemployment rate are likely to have a loose relationship between a firm's productivity and access to the workforce. As an example of the impact of the quality of the workforce on a firm's productivity (Moretti, 2004), workers with several years of training are likely to be more productive than workers who have just graduated college.

4.7. Policy Implications

The results presented in this chapter have several interesting policy implications for planning and transport. First, the results of the travel interaction model show that the number of commuting trips is determined by both the size of the population in origins and the number of jobs at destinations, with the latter having a greater effect. This finding suggests that jobs are unevenly distributed across the region and this might be the reason why commuters are sensitive to changes in the commuting distance. Policy makers may consider journey-to-work patterns in evaluating transport infrastructure projects. The fact that jobs are not uniformly distributed across the region may be a key

factor for policy makers to keep in mind in formulating a policy for transport infrastructure. Also, an important policy objective may be addressing potential issues resulting from long distances between homes and workplaces.

Second, the main results obtained from the FD-IV models provide important policy implications for transport infrastructure investment. The results show that transport-induced workforce accessibility improvement is positively statistically related to the variation in firm productivity in the manufacturing industry. This finding highlights that transport infrastructure improvement fosters agglomeration economies by bringing firms and workers closer to other economic agents, making changes to the way in which firms and workers access economic activities. The spatial interactions between firms and workers, induced by transport infrastructure, increases the level of efficiency in production. This finding suggests that transport infrastructure investment can provide productivity benefits to stakeholders, in addition to time-saving benefits. Policy makers may target a transport-planning policy in such a way that the spatial agglomeration is fostered and the spatial interactions between firms and workers is better facilitated across the area where it is developed. It may be an effective option for policy makers to develop practical guidance for transport infrastructure projects.

Third, the results obtained from the disaggregated analysis for manufacturing sub-sectors provide a key policy implication. The results show that transport-induced workforce accessibility is positively related to firm productivity in disaggregated manufacturing sub-sectors, suggesting that the link between transport-induced workforce accessibility and firm productivity is positive even at the disaggregated industry level. It is also shown that the productive benefits induced by transport infrastructure are not the same for all manufacturing sub-sectors. The level of productive benefits induced by transport infrastructure differs across the different manufacturing sub-sectors. This finding suggests that the degree to which manufacturing sub-sectors benefit from transport-induced workforce accessibility depends on their different features in production. The magnitude of transport-induced workforce accessibility is closely related to the way that final products are produced. For example, computer & ICT sector requires workers who can manage advanced technology and complicated assembly work to make final products. Transport infrastructure connects firms with workers with skills for such production work and reduces the search friction between firms and workers. Policy makers may want to consider the characteristics in production when formulating transport-planning policies. They may consider the unique features in production together with the potential effects

of transport infrastructure at the disaggregated level.

Fourth, the results obtained from the IV model provide several policy implications for industrial complexes and business districts. The results show that firm productivity is also determined by the industrial location policy and the firm's own characteristics, such as its age, ownership, and financial management capability. The findings suggest that understanding firms' characteristics may be important for the development of transport infrastructure in relation to construction of an industrial complex or a business district. Policy makers may be interested in developing a planning policy for transport infrastructure development that considers firms' characteristics and industrial location policy.

Finally, the empirical findings presented in this chapter contribute to the debate on whether transport infrastructure development is worth the money. Overall, the findings suggest that transport infrastructure improvement leads to productive benefits to stakeholders in addition to time-saving benefits. Transport-induced workforce accessibility improvement has positive impacts on firm productivity. This does not, yet, necessarily indicate that any construction of transport infrastructure automatically brings about such productive benefits. As far as such productive benefits are concerned, policy makers may be interested in taking two sufficient conditions on board in transport infrastructure development. It may be crucial for transport infrastructure projects to ensure enough of an increase in the level of workforce accessibility to change both the spatial interactions between firms and workers and the way in which firms and workers access economic activities. It may also be important to take into account the diverse features in production in terms of how these characteristics interact with a change in the level of workforce accessibility.

4.8. Conclusion

This chapter has explored the link between transport-induced economic effects and firm productivity, addressing the research question: 'How and to what extent are transport-induced economic effects related to the productivity of manufacturing firms in the Seoul region?'. A novel feature compared to previous studies is that I constructed a measure of workforce accessibility that improves travel costs measurement and considers the aspect of commuters' choice of travel modes. A spatial interaction model

is also estimated to obtain the actual spatial-decay parameter for the Seoul region. A distinctive feature is that I developed a research strategy to analyse variations in firm productivity in relation to a change in transport-induced workforce accessibility. A two-stage econometric model is constructed to address estimation issues involved in the estimation of firm productivity such as the simultaneity of the input factors and the endogeneity of workforce accessibility. In addition, FD-IV model is constructed to address endogeneity of targeted transport policy and unobserved firm effect.

The results obtained from the travel interaction model show that both the size of the population in origins and jobs in destinations are determinants of the number of commuting trips, with the latter having larger effects than the former. This finding implies that jobs are unevenly distributed across the Seoul region, which might be one of the reasons that commuters are sensitive to a change in the commuting distance. A simple comparison analysis between the Seoul region and UK cities shows that commuters in UK cities tend to be less sensitive to a change in the commuting distance than those in the Seoul region. This is mainly because of the differences in the level of transport services provided in the areas.

Based on the results obtained from the dynamic panel model, I show that firm output is determined by three input factors, capital, labour, and intermediate inputs. This finding is in line with a number of previous studies. Firm output is affected most by the amount of intermediate inputs, indicating that raw materials and intermediate inputs are important in the production of manufacturing firms. The amount of labour is the second most influential in terms of its impact on firm output. The degree to which the three input factors impact firm output varies slightly across manufacturing sub-sectors. For example, the coefficient of labour is higher in manufacturing sub-sectors that require labour intensive activities such as furniture and printing. The differences in the coefficients is attributed to the way in which manufacturing sub-sectors use the input factors in production.

Based on the results obtained from the FD-IV models, I show that transport-induced workforce accessibility improvement is positively related to manufacturing firms' productivity with an average elasticity of 0.0600 for the overall manufacturing industry, indicating that increasing the level of workforce accessibility by 1% would raise firm productivity by 0.0600% on average. The link between firm productivity and transport-induced workforce accessibility can be explained by the way transport infrastructure improvement strengthens the level of agglomeration economies to the extent firms and workers increase connectivity and productivity. In other words, transport infrastructure

improvement extends the spatial extent of the labour market, improving the way in which firms and workers access economic activities, which increases their productivity. Both the matches between job search and recruiting and qualities thereof become better as transport infrastructure reduces the search friction. The finding suggests that the improvement in firms' productivity is an indirect benefit resulting from transport infrastructure in addition to the direct benefits of travel-cost saving. The finding contributes to the debate, claiming that indirect productive benefits of transport infrastructure may be taken on board together with direct time-saving benefits.

Comparing the results obtained from the FD-IV models with those found in previous studies, only a handful of studies are comparable. For French manufacturing firms, Néchet et al. (2012) found an estimated value of 0.023, which is lower than the estimated results obtained from this research. For Spanish manufacturing firms, Martín-Barroso et al. (2015) found an estimated value of 0.059, which is similar to the estimates of this study. The estimated result of this research is largely in the range of elasticities of transport-induced productive benefits reported in previous studies. The slight dissimilarities in the estimates among previous studies may be attributed to the use of different methods and accessibility measures, as well as to the distinctive characteristics of the labour markets explored in previous studies. The choice of accessibility measures directly influences the extent to which the economic benefits induced by transport infrastructure are captured.

Based on the results obtained from the IV models, I show that transport-induced workforce accessibility is positively related to firms' productivity in disaggregated manufacturing sub-sectors, which confirms that the link between transport-induced economic effects and firm productivity is positive even at the disaggregated industry level. I also show that the level of transport-induced economic effects differs across diverse manufacturing sub-sectors. The productive benefits induced by transport infrastructure are not the same for all manufacturing sub-sectors. Different manufacturing sub-sectors receive different levels of transport-induced productive benefits. For example, the estimate for the textile sector with respect to workforce accessibility is 0.0395, whereas the same value for the metal sector is 0.0390, which means a 0.039% increase in firm productivity for a 1% rise in the level of workforce accessibility.

Based on the results obtained from the IV models, I show that diverse features in manufacturing production affect the degree to which manufacturing sub-sectors benefit from transport-induced workforce accessibility. The magnitude of transport-induced

workforce accessibility is closely related to the way production is carried out. The coefficient of workforce accessibility in Computer & ICT sector is higher than the average coefficients of workforce accessibility in the manufacturing industry. This larger productive benefit is determined by how production is carried out in the sector, where advanced technology and complicated assembly procedures are required to make final products. Transport infrastructure functions as a means of connecting firms to workers with skills for such production work and reducing the search friction between firms and workers, improving the interactions between them. The extended labour market provides firms with productive benefits by either increasing the chances of matches between job search and recruiting or improving the quality of the matches.

Based on the results obtained from the IV models, I show that firm productivity is also determined by its age, ownership, financial management capability, and the presence of the industrial location policy. The older the manufacturing firm, the higher its efficiency in production, because firms' productivity improves as with experience. A firm's financial management capability is positively related to its productivity, with the largest impact among the firm's characteristics. To a certain extent, firm productivity increases when it has financial management for production. As for firms' ownership, firms owned by commercial or non-commercial corporation bodies perform better than ones owned by individual investors. The former is likely to have more capabilities to compete in the market than the latter. With regard to the industrial location policy, firms located outside the growth management area perform better than those located within the area. The demand for and supply of firms' business activities are affected by the government's spatial policy which regulates the level of economic activities.

5. Transportation-induced Labour Accessibility and the Growth of Employment Centres in the Seoul Region

5.1. Introduction

This chapter explores the relationship between transportation-induced labour accessibility effects and the growth of employment centres in the Seoul region for the time period between 2000 and 2010, addressing the research question: 'How and to what extent is transportation-induced labour accessibility related to the growth of employment centres in the Seoul region?'. This issue is important because the rise and fall of employment centres are concerned with the formation of urban spatial structure, the degree of development density at a local level, and the level of property and land values in the real estate market.

Few studies have explored the relationship between transport-induced labour accessibility and job growth in an employment centre in the context of a metropolitan area (Giuliano et al., 2012). Only a few empirical studies have systematically examined such a relationship over time. Also, empirical studies have provided mixed results on the link between labour accessibility and the growth of employment centres. Giuliano and Small (1999) examined the determinants of employment centres in the LA metropolitan area and found that access to the labour force was not associated with the growth of job centres, although industry composition and proximity to an international airport are associated with job growth. On the contrary, Agarwal (2015) and Giuliano et al. (2012) reported that labour accessibility has significant impacts on the growth of employment centres, all else being equal. Our understanding of the role of transport-induced labour accessibility in employment centre growth is less clear.

This study improves the discussion by proposing the implementation of more sophisticated accessibility measures for the link between transport-induced labour accessibility and employment centre growth. Most previous studies have tended to rely on a simple accessibility measure (Giuliano & Small, 1999). The focus of these studies

was on ascertaining how jobs in an employment centre vary using a simple measure of distance to the nearest transport network. A simple accessibility measure may be useful for understanding and capturing the value of absolute location within the transport network.

However, a simple accessibility measure may not be capable of capturing the potential that transport-induced labour accessibility may provide, because it does not capture the value of relative location. High levels of accessibility generally tend to reduce the travel costs of the interaction, which makes a certain location more attractive. Yet, within the transport network, the levels of attractiveness of locations may be relatively different depending on the distribution of workers and consumers. The transport network provides a set of potential origins and destinations where various activities take place and diverse interactions are generated. This wider scope of network accessibility is not appropriately accounted for by a simple accessibility measure, such as distance to the nearest freeway entrance. In this regard, I argue that an indicator of accessibility that can capture such a value of relative location should be used for this analysis.

The objective of this chapter is to provide empirical evidence on the impact of transport-induced labour accessibility on employment centre growth to better support urban and transport policies for employment centre management. I focus on the relationship between the level of transport-induced labour accessibility and a change in jobs in employment centres. For the data used in this chapter, I used the actual transport network of the Seoul region and the Korean Census to construct a measure of labour accessibility and to test the determinants of the growth of employment centres in the Seoul region. A household survey for the Seoul region that contained the spatial pattern of various types of travel was also used to construct an accurate measure of labour accessibility.

In terms of research strategy, this chapter applies three analytical steps to examine the link between transport-induced labour accessibility and the growth of employment centres. I first identify the spatial concentration of employment in the Seoul region. In the next step, I construct the measure of labour accessibility for each spatial unit of analysis. Lastly, I estimate a panel model for the growth of employment centres, with various control variables included.

The analysis presented in this chapter adds to the literature that investigates the emergence and growth of multiple employment centres in a metropolitan area, which is theoretically established but lacks empirical evidence to support the theoretical

arguments (Agarwal, 2015; Padeiro, 2013). The key contribution of this analysis to the discussion is empirical, providing supporting evidence for the theoretical arguments

The remainder of this chapter is organised as follows. The next section develops the research strategy, which consists of three phases, the first of which defines employment centres used in this chapter and provides a method for identifying them in the context of the Seoul region. The second phase constructs a regression model for the growth of employment centres in relation to a change in labour accessibility. Section 5.3. outlines the data used in this chapter in more detail, with a series of dependent and independent variables included in the regression model. Section 5.4. presents the exploratory results. The first part shows employment centres on a map alongside the transport network in the Seoul region and presents their brief characteristics and descriptive statistics. In the second part, labour accessibility for the Seoul region is measured, and summary statistics are provided. Section 5.5 evaluates the results obtained from a panel model for the growth of employment centres in the Seoul region. In the next section, policy implications are drawn from the results of the regression analysis. Finally, this chapter concludes with a summary of findings and recommendations for future research.

5.2. Research Strategy

The research strategy in this chapter consists of three phases. The first phase starts with the justification for the use of employment centers as the subject of analysis. It then defines employment centres that represent a polycentric spatial structure and identifies those centres in the context of the Seoul region. In the second phase, a measure of labour accessibility is constructed that captures the degree to which the labour force can be accessible to employment centres via a transport network. Lastly, I construct a statistical model that examines changes in the level of labour accessibility in relation to job growth in an employment centre, outlining the dependent and independent variables incorporated in the model.

5.2.1. Definition of Employment Centres

Justification for the Use of Employment Centers

In this chapter, employment centres are used as the subject of analysis of the impact of transport-induced labour accessibility on job growth. Employment centres are often called 'clusters' in the literature as they are geographically concentrations of firms and industries. In the theory, clusters are the source of urban and regional economic development, playing a key role in stimulating productive advantages (Porter, 1998). The logic underpinning this theory is that clusters are the source of agglomeration economies that firms receive from being located in close proximity to concentrations of firms and people.

Because the important role of employment centres in the urban and region's economic growth, many studies have paid attention to multiple centres of employment as the research subject. Some previous studies have explored the formation of multiple employment centres as they exhibit a distinctive feature of contemporary urban and regional spatial structure (McMillen, 2003). Others have focused on the underlying mechanism for the emergence of employment centres (Anas & Kim, 1996; Chen, 1996).

In studies on multiple employment centres, a change in travel costs has been regarded as a key factor of affecting the emergence of multiple employment centres, together with productive advantages arising from agglomeration economies. The role of transport infrastructure in shaping multiple clusters has been found essential as its development changes the level of access to employment centres. Yet, less attention has been paid to the growth of employment centres in relation to transport-induced accessibility, compared to the emergence of employment centers.

I focus on employment centres, because they are a key part of urban and regional economic development. Their contribution to the economic growth of urban and regional areas is significant. Also, little is known about how accessibility induced by transport infrastructure is related to the growth of employment centres. While the link between transport infrastructure and the emergence of employment centres has been uncovered, its relationship with the growth of employment centres is still not conclusive.

That said, there might be a question for the rest part of the Seoul region in regard to the changes in transport-induced accessibility, which might originate from the fact that an analysis on employment clusters in the Seoul region does not uncover the whole picture of how changes in accessibility are related to the economic growth of the region. Responding to this question, I perform an additional analysis for the whole Seoul region

to explore how changes in accessibility are related to a change in the number of jobs in the region. I expect that the results for the entire region may provide useful information on the link between changes in transport-induced accessibility and the economic growth of the Seoul region.

Definition of Employment Centers

It is conventional knowledge that employment centres are the spatial cluster of employment or of a population, but defining them from the heterogeneous spatial distribution of economic activities is no easy task. It is thus an essential priority for this chapter to define the employment centres in the Seoul region.¹⁹ Properly defining employment centres is the key to identifying them because doing so governs the number of employment centres, their sizes and their boundaries (Anas et al., 1998).

For this reason, several studies have explored the topic of employment centres in different urban contexts across the world. Some studies have focused on how to define employment centres theoretically, stating that the level of employment density may be used to delineate the boundary of employment centres. Other studies have been more interested in identifying the number of employment centres in practice, applying theoretical arguments to changing urban structure from monocentric to polycentric spatial structure (McMillen & Lester, 2003; Small & Song, 1994).

Following the long tradition in the literature, I characterise employment centres as areas with higher employment density, establishing the level of employment density as an essential indicator for the boundary of employment centres. In the literature, a couple of indicators have been used to characterise the spatial concentration of economic activities in urban and regional areas. The density of population and employment has been used by many previous studies to describe the spatial concentration of economic activities (McMillen, 2003; Small & Song, 1994). Aside from population and employment, other indicators have also been tested to characterise employment centres, recognising various aspects of employment centres, such as the total amount of floor space of office and retail developments (Cervero, 1989; Cervero & Duncan, 2002). While these alternative indicators may be useful, employment density has been regarded as a key indicator to describe the formation of the spatial concentration of economic activities

¹⁹ Yet, it is not the scope of this thesis to develop a way to find employment centres, as a line of studies regarding this issue have already been conducted (see McMillen (2001) for more information).

(Giuliano & Small, 1991; McDonald, 1987).

The basic spatial unit of analysis upon which this research is based is the *dong*. This spatial unit represents the smallest administrative area in Korea, roughly equivalent to a ward in the UK. Determining the unit of analysis is a major concern in spatial research because any phenomena that occur in the spatial system can be observed at different levels, consequently affecting the viewpoints taken towards them in distinct ways (Longley et al., 2010). The research outcome may differ depending on the choice of the unit of analysis, as it affects both the extent and detail of understanding of relevant phenomena. For this reason, the unit of analysis should be defined in a way that spatially covers the spatial extent of the phenomenon of research interest as well as its high level of detail (Longley et al., 2010). The spatial unit of analysis is basically interrelated with the scale of analysis and is therefore normally defined in accordance with the scale of analysis.

In this analysis, employment centres are defined as a cluster of employment at the *dong* level, where the impact of transport infrastructure on the number of jobs could be assessed. This spatial unit for employment centres is more disaggregated than that used in previous studies, where various employment centres were identified in terms of areas ranging from 105 acres to 17,949 acres. The average area of employment centres used in this chapter is 2623.7 acres. This definition of employment centres allows one to capture changes in the level of a transport infrastructure network at a sufficient spatial resolution and therefore brings greater accuracy to investigating the link between a change in the level of labour accessibility resulting from transport infrastructure and employment centre growth.

In addition, the use of disaggregated employment centres allows this chapter to address the limitations of previous studies, where the impact of transport infrastructure was not properly addressed due to the large size of the employment centres defined. For example, the average size of an employment centre in the LA region is around 8 square kilometres, where it takes travellers around two hours to walk from one side of the centre to the other (Agarwal, 2015). It is well known that the accessibility effect resulting from the transport infrastructure network diminishes sharply as the distance increases (Ahlfeldt & Wendland, 2013). As such, changes in the level of labour accessibility are likely to be captured at a finer spatial unit. Also, recent empirical studies have tended to focus more on high-resolution data, which allow for the investigation of employment changes at a fine level (Padeiro, 2013).

5.2.2. Method for Identifying Employment Centres

To delineate employment centres in heterogenous urban areas, I use the cut-off method proposed by Giuliano and Small (1991). The cut-off method is one of the most commonly used methods in the literature because of its straightforward but robust means of identifying employment centres (Agarwal, 2015). Although decisions made about the cut-off criteria are often criticised due to their lack of a statistical basis, the cut-off method remains one of the most powerful tools for the identification of economic activities. It also allows for the use of local knowledge to identify the spatial variation of employment. Given that there is no available general method that can be applied to any city, using local knowledge in the process of identifying employment centres is essential, as cities and regions have unique spatial development trajectories relevant to the emergence of employment centres. In this regard, cut-off methods informed by detailed local knowledge of the spatial context of an area have a strong point.

It is argued that the identification of employment centres is not as straightforward as has been suggested in theoretical work because clusters of employment activities vary by density and scale (McMillen & McDonald, 1998). The complex nature of the spatial concentration of employment is the source of ongoing research towards the development of a general method for employment centre identification. Note that it is not the intention of this study to develop a new approach but rather to focus on making the most of existing approaches to map out the spatial concentration of employment in the Seoul region.

The Seoul region is typified by wide deviations in both employment density and size. The density of employment in Seoul is relatively higher than that in areas outside Seoul mainly because of the green belt around the city. I thus establish two cut-off criteria for the two areas, Seoul and outside of Seoul, depending on the extent to which employment is concentrated. This type of approach was used by Giuliano and Small (1999), who studied employment centres in the LA region. I set the 20-15 criteria for Seoul, which refers to a minimum total employment of 20,000 jobs and 15 jobs per acre for the minimum employment density. These criteria are higher than the standard used in Giuliano, Redfearn, Agarwal, Li, and Zhuang (2007a), because Seoul is characterised as a denser urbanised area. Using specific knowledge about Seoul's employment and population, I found that the 20-15 criteria was the most suitable standard for identification. For areas outside Seoul, I set the 10-10 criteria, meaning a

minimum total employment of 10,000 jobs and 10 jobs per acre for the minimum of employment density. The number of employment centres identified depends on the cut-off criteria, which researchers determine according to the spatial context of a given area: the more generous the cut-off standard, the more employment centres will be identified.

In addition to the cut-off method, I also employ the spatial clustering method to improve the quality of the identification process, but I only use it to remove outliers from the identified candidates of employment centres. A spatial clustering method is based on statistical techniques that might be effective in discerning a certain spatial concentration of employment from the heterogeneous areas of economic activities. The strong point of the spatial clustering method is that employment centres can be identified based on statistical significance by using advanced statistical techniques, such as kernel density and local indicators of spatial correlation (Leslie, 2010; Riguelle, Thomas & Verhetsel, 2007). As mentioned in previous sections, current approaches to identifying employment centres have their pros and cons. As such, it may be more effective to use the two methods together, in which the spatial clustering method is complementary to the cut-off method, rather than applying the cut-off method alone to the Seoul region.

The statistical technique used for the spatial clustering method is the Local Indicator of Spatial Association (LISA). While several statistical techniques are available for the spatial clustering method, LISA is a widely used and scientifically verified technique in the literature (Anselin, 2005). LISA calculates the Local Moran's I for each spatial unit and estimates its statistical significance. A typical specification for LISA is shown in Eq. 5-1, and this equation can be solved using ArcGIS software. In the evaluation process of LISA, several indicators are generated, such as an indicator of spatial correlation, an indicator of statistical significance and an indicator of spatial clustering. I use the indicator of spatial clustering, which measures the degree to which spatial units in a region are clustered. More specifically, I use this indicator to filter out outliers from the cut-off method results.

More specifically, I use the LISA to identify employment centers more effectively in addition to the cut-off method. The cut-off method is useful for identifying an area that has a certain level of total employment and employment density, but it is not capable of identifying whether the area is clustered with other areas. I use the LISA to address this point where previous studies have not paid attention to. Specifically, I test whether the identified area is clustered with other areas using the indicator of spatial clustering provided by LISA and remove outliers from the identified candidates for employment centers.

Equation 5-1. Local Indicator of Spatial Association (LISA)

$$I_i = \frac{\sum_{j=1}^n w_{ij} (z_i - \bar{z})(z_j - \bar{z})}{s_z^2 \sum_{j=1}^n w_{ij}}$$

where, z is the original value of x in a standardized form, w_{ij} is a matrix of the spatial weight.

In summary, I primarily use the cut-off method to identify employment centres in the heterogeneous urbanised area in the Seoul region. I set two respective cut-off criteria for Seoul and the outlying region because of their differences in terms of both urban development trajectory and the level of geographic scale. With these cut-off criteria, I first single out preliminary employment centres using the cut-off method, and subsequently apply the spatial clustering method with LISA to these employment centres to statistically remove outliers from the identified employment centres. Using the identification method for employment centres, I identify employment centres in the Seoul region for two points in time: 2000 and 2010. As mentioned, I use different cut-off standards, applying the 20-15 standard for Seoul and the 10-10 standard for the surrounding region.

5.2.3. Measuring Transport-induced Labour Accessibility

In this chapter, it is essential to construct a variable that captures the level of transport-induced labour accessibility in order to explore how access to the labour force impacts the growth of employment centres in the Seoul region. I construct a measure of labour accessibility that can capture the degree to which employment centres receive access to the labour force. Two types of accessibility measures are constructed at the *dong* level, one to capture the potential of the total labour force that can be accessed via the transport infrastructure network, and the other to capture the potential of the relative labour force that considers competition between employment centres.

The first accessibility indicator is named the absolute labour accessibility measure, and this measure captures a given area's total labour force potential in the Seoul region. The absolute labour accessibility is equivalent to the potential for spatially distributed

labour opportunities that may be reached from a given employment centre via a means of transportation. In the calculation procedure, the level of absolute labour accessibility is calculated by the weighted sum of potential workers discounted by travel time. The basic assumption for this measure is that potential workers influence employment centres, but this influence declines exponentially with increasing distance from the employment centres. A specification for this accessibility measure is shown in Eq. 5-2.

For potential workers considered in the measurement of accessibility, I focus on workers over 15 but under 64 years of age, i.e., the working-age population according to the World Bank. The working-age population is widely used and accepted as a proxy for the labour force, and it represents the characteristics of the labour market better than the total population.

Equation 5-2. Absolute Indicator of Labour Accessibility

$$ACC_i = \sum_j L_j e^{-\alpha T_{ij}}$$

where L_j refers to the labour force in *dong* j, T_{ij} refers to travel time between *dong* i and j, and α is the spatial decay parameter. The travel time is calculated based on travel time from the centroid of *dong* i and the centroid of *dong* j. The spatial decay parameter reflects the degree to which commuters' travel behaviour changes according to travel distance or time, and it is measured by the degree to which commuters' travel behaviour is deterred as travel distance or time increases. Absolute labour accessibility, in this chapter, is interpreted as access to the total labour force in the Seoul region.

The second indicator is named a relative labour accessibility indicator and captures a given area's relative potential for the labour force in the Seoul region. The accessibility indicator incorporates the concept of both the 'demand side' of accessibility measurement and its 'supply side'. The notion that employment centres compete for labour force is taken into account by incorporating the demand side of accessibility measurement.

Labour force is supplied on the labour market and is demanded by firms in employment centers. The availability of skilled labour force is not infinite. In some sense, they are in short, and thus employment centers compete for the skilled labour force. In urban and

regional areas, employment centres that seek for potential labour force are not spatially uniformly distributed and each labour force is not for only one employment centre at any moment in time. Employment centres (the demand side) compete for potential labour force (the supply side). Various levels of demand potential exist around labour force, and thus this demand potential influences levels of the amount of potential labour force. Access to the labour force is partly determined by the demand potential for the location of the labour force

Considering the aforementioned condition, the 'demand side' of accessibility measurement is incorporated in a relative accessibility indicator, together with the 'supply' side. Based on the accessibility indicator presented by Shen (1998), I articulate this concept in the form of equation, which is shown in Eq. 5-3. The demand side of accessibility is in the denominator of the accessibility indicator, whereas its supply side is in the numerator. The difference between absolute and relative labour accessibility indicators is that the relative labour accessibility indicator considers competition between employment centres for the labour force.

I also incorporate the concept of theoretical probability in the measurement of accessibility to consider labour force's chance to choose to work in a given employment centre. From the perspective of labour force, they may have multiple chances to work in various areas; they may choose to work in a given employment centre or in other surrounding employment centers. There is probability for them to choose to work in a given employment centre. This can be articulated by using the concept of theoretical probability.

In the literature on Mathematics, theoretical probability of some event is equal to the number of favourable outcomes divided by the entire possible cases. Applying this to the current case, probability of labour force's choosing to work in a given employment centre is equal to the number of employments in a given employment centre divided by the total number of employment potential.²⁰ For this probability to be considered in the measurement of accessibility, I incorporate the number of employments in a given employment centre (D_i) in the equation of the relative accessibility indicator.

For the temporal dimension of the labour accessibility indicator, I focus on the average

²⁰ The probability of labour force's working in a given area can be expressed as follows:

$$P(\text{Working in a given area}) = \frac{\text{The number of employment in a given area}}{\text{The total number of employment potential}}$$

number of commuting trips that occur during the daytime on weekdays. This is because the number of commuting trips tends to be the largest during the rush hours of the day on weekdays and smallest during the middle of the night on weekends.

Equation 5-3. Relative Indicator of Labour Accessibility

$$RACC_i = \sum_j L_j (D_i \cdot e^{-\alpha \cdot T_{ji}} / \sum_m D_m \cdot e^{-\alpha \cdot T_{jm}})$$

where $RACC_i$ is the level of relative access to the labour force in *dong* i. L_j denotes the labour force in *dong* j. T_{ji} refers to travel time between *dong* i and j, whereas T_{jm} stands for travel time between *dong* j and m. The spatial decay parameter for relative accessibility indicator, α , is the same as that for absolute accessibility indicator. D_i and D_m represent employment in *dong* i and m, respectively. This accessibility is interpreted as access to the net labour force in the region.

On the right side of the equation, the numerator refers to the potential labour force supply, whereas the denominator refers to the number of employments in *dong* m that indicates the demand potential for the labour force. The numerator indicates the number of potential workers likely to be hired by firms located in *dong* i. The number of potential workers expected by firms located in *dong* i is determined by the weighted sum of the labour force in all destinations j that can be reached from origin i by the minimum-cost route via the transport network between i and j.

For the decay coefficient for the two accessibility indicators, I make use of the spatial decay coefficient estimated in Chapter Four. As presented in Section 4.3., I obtain the spatial coefficient for the Seoul region by estimating a simple travel model (see Section 4.3. for more details). Given that the estimated spatial coefficient represents the actual travel behaviour of commuters, I use the estimated value of -0.0267 for α in the two accessibility measures.

To improve the quality of an accessibility indicator, I modified the indicator of labour accessibility in three areas, adding the benefit of a high-resolution transport network, incorporating various datasets available in relation to travel behaviours and developing a simple travel model for commuting behaviours.

The improvement to the accessibility measure is first made to the measurement of travel costs. I calculate the travel cost between origins and destinations based on the actual transport network and calculate travel times with respect to the average speeds of respective travel modes. This is done to reflect actual interactions between firms and workers. Previous studies tended to use accessibility measures based on straight distances between origins and destinations, with no consideration for the actual transportation system, due to the absence of detailed data for travel times (Hensher, Truong, Mulley & Ellison, 2012). While the use of straight distances for travel costs is often acceptable, a simple distance measure may not be reliable at a metropolitan scale, in which a myriad of transport infrastructure is connected.

Second, I use the spatial decay parameter for the Seoul region, which is estimated by a simple spatial interaction model. A spatial decay parameter is directly linked to the quality of labour accessibility in that it refers to how far workers are willing to travel to workplaces. The measure of labour accessibility basically captures interactions between firms and the labour force, and therefore it is important to determine whether the spatial decay parameter accurately reflects the spatial extent across which workers would travel to workplaces. I focus on commuting trips rather than whole trips because the former is more relevant to the source of productive effects induced by transport infrastructure than other types of trips.

Lastly, I make an improvement to the way travel modes of commuters are measured in the construction of labour accessibility. It is common for commuters to select their travel modes based upon which offer the greatest savings in travel costs. This point has rarely been considered in constructing accessibility measures because of the complexity of commuters' choices regarding travel modes. A couple of approaches to modelling such choices are documented in the transport literature; however, these approaches were developed in isolation from studies on accessibility measures (de Palma et al., 2011b). I construct a simple travel model to account for a traveller's choice between two travel modes: automobile and rail transport.²¹

5.2.4. Regression Model for the Growth of Employment Centres

In the third phase of the research strategy, I develop a statistical model to evaluate the

²¹ For simplicity, these two major travel modes are considered, since commuting by bicycle is minimal

relationship between the growth of employment centres and changes in the level of labour accessibility promoted by transport infrastructure, for the time period between 2000 and 2010. I start by constructing a conceptual model for the growth of employment centres. The growth of employment centres can be posited as a function of the indicator of labour accessibility, changes in the number of jobs in the four major industries in an employment centre, and a set of control variables that may be related to the growth of employment centres. I formulate a conceptual model for employment centre growth as shown in Eq. 5-4. In the equation, ΔE is a dependent variable that refers to a change in the number of jobs in employment centres over the study period. ΔA refers to a change in absolute and relative labour accessibility, which is the variable of interest in this analysis.

Equation 5-4. Conceptual Model for Employment Centre Growth

$$\Delta E = (\Delta A, S, D, L, \Delta I_s)$$

where, ΔA is changes in absolute and relative labour accessibility

S is a vector that captures the size of employment in employment centers

D is a vector that captures the density of employment and population in employment centers

L is a vector that captures locational attributes of employment centers in the Seoul region

ΔI_s is changes in the number of employments in industries in employment centers (a: manufacturing, b: retail, c: service and d: communication)

As defined in the specification presented in Eq. 5-4, variation in the number of jobs in an employment centre is determined by a change in the level of labour accessibility and by several independent variables. These independent variables are carefully selected based on related theories and empirical studies and are classified into four categories: the size of employment centres, the employment and population densities of employment centres, a change in the number of employees in industries in employment centres, and locational features of employment centres.

In the first and second categories of independent variables, the size and density of both population and employment in an employment centre are included. The size of employment centres is a determinant of their economic growth, as economic actors in the centres may benefit from the productive advantages of their spatial concentration. According to agglomeration theory, the size of employment centres may bring about two contrasting outcomes, either positive growth or negative growth, depending on the

degree of the spatial concentration of economic activities (Fujita et al., 2001). In this regard, large employment centres are likely to grow faster than small ones, as the former likely benefit more from agglomeration economies than the latter. Large employment centres, however, may grow slower or decline if the diseconomies of the spatial concentration of economic activities outweigh the possible productive benefits. Employment centres with more jobs may thus experience negative growth due to adverse effects, such as congestion, land scarcity or pressure on public services. For population and employment density in centres, a similar theoretical argument can be applied. High-density employment centres are likely to grow faster than low-density centres, as dense employment centres are more likely to receive productive benefits from agglomeration economies.

In the third category of independent variables, locational characteristics of employment centres are included. First, the proximity to the economic core of the region may be a determinant of the growth of employment centres due to its positive benefits. According to the theory, the level of proximity to the city centre is closely connected to opportunities for economic activities and amenities (Glaeser, Kallal, Scheinkman & Shleifer, 1991). In this regard, employment centres closer to the core of the region may benefit from the positive effects of urbanisation economies and may therefore grow faster than those farther from the core. Yet, proximity to the core of the region may bring about negative effects that could hinder the growth of employment centres. Whether the benefits of urbanisation economies contribute to the growth of employment centres in part depends on the degree to which the negative effects of proximity to the core offset the positive effects.

I incorporate more locational variables to account for whether access to regional and international markets impacts the growth of employment centres (Chen & Hall, 2012; Giuliano & Small, 1999; Kasarda, 2000). Variables of proximity to international airports and high-speed railway stations are included. For these variables, digital information on their locations was collected from various sources, such as websites and digitized maps. The exact locations of airports and high-speed railway stations are mapped to calculate the travel distance from the centroids of employment centres.

For the fourth category of independent variables, the growing performance of major industries in an employment centre is incorporated. The job growth of these industries may be a determinant of overall job growth in an employment centre (Henderson, 1997). This is because employment centre growth is, in large part, attributable to the degree to which its industries grow. Employment centres with fast-growing industries are

likely to grow faster than centres with slow or shrinking industries, all else being equal. The share of industry sectors is also related to employment centre growth. The larger fast-growing industries comprise the economy of employment centres, the faster job growth in these centres will increase, and vice versa. Four industries account for the majority of economic growth in the Seoul region – manufacturing, retail, communication and service. I consider these four industries in the estimation of employment centre growth.

Note that other independent variables have been reviewed but were not incorporated in the current model, for two reasons. One is that some variables have been found to be insignificant in the growth of employment centres in previous studies. For example, the literature suggests that local and central government policies may be relevant to employment centre growth either by promoting the growth of employment centres through tax reduction and investment in public services or by preventing employment growth by limiting economic activities that risk environmental destruction. I decide not to include a set of control variables related to local government policies because the link between government policies and employment centre growth was determined to be insignificant by Agarwal (2015).

The other reason for not including certain variables is because they are highly correlated with variables already incorporated in the model. Since the inclusion of highly correlated variables may cause multicollinearity among predictors, these variables are excluded from the model (Wooldridge, 2013). For example, it has been reported that amenities are a determinant of a firm's location choice (Glaeser & Gottlieb, 2006). In this study, variables for amenities that describe schools and public services in employment centres are highly correlated with proximity to the centre of Seoul because the amenities themselves tend to be concentrated in the core of Seoul. Therefore, the inclusion of these variables in the model would likely generate a multicollinearity bias in the estimation, which should be avoided to obtain the unbiased results.

Multicollinearity is likely to increase the possibility of overinflating the standard errors of the coefficients, which means that statistical significance of the coefficient may be unreliable when multicollinearity occur among the predictors (Wooldridge, 2013). To address the multicollinearity issue in the estimation of employment centre growth, I devise two solutions. One is to test for multicollinearity among the variables included in the model and exclude those with high correlation figures. Multicollinearity is tested by the variance inflation factor (VIF), which evaluates the degree to which an estimated coefficient varies in relation to the correlation of the predictors (Kennedy, 2008). The

other solution involves estimating three sets of statistical models with different variables, excluding those which are highly correlated with each other.

The specification of regression model to be estimated is shown in Eq. 5-5. The dependent variable in the model is a change in the number of jobs per square kilometre in an employment centre i for time period t , denoted as ΔY_{it} . As discussed in the conceptual model, a change in the number of jobs in an employment centre is determined by five vector variables, which are denoted as ΔA_{it} , S_{it-1} , D_{it-1} , L_i , and ΔI_{it} .

Equation 5-5. A Regression Model for the Growth of Employment Centres

$$\Delta Y_{it} = \delta_0 + \beta \Delta A_{it} + \gamma S_{it-1} + \theta D_{it-1} + \alpha L_i + \lambda \Delta I_{it} + \varepsilon_i$$

where ΔA_{it} captures changes in absolute and relative labour accessibilities. S_{it-1} stands for a vector that captures the size of employment in an employment centre at the initial period $t-1$. D_{it-1} represents a vector that captures the density of both employment and population in an employment centre at the initial period $t-1$. These lagged variables account for the initial condition of each employment centre which might influence its growth. L_i is a vector that captures locational characteristics of an employment centre in the region. ΔI_{it} refers to a vector that captures changes in the number of jobs in four major industries: manufacturing, retail, service and communication.

β , γ , θ , α and λ are coefficients to be estimated and ε , is an error term. β is the coefficient of interest, which reveals the effects of changes in absolute and relative labour accessibility on changes in the number of jobs in employment centres. This coefficient can be interpreted as a unit change in employment centre growth for one unit change in either absolute or relative labour accessibilities. More specifically, β means the degree to which access to the total labour force influences employment centre growth when it is estimated for absolute labour accessibility. For the case of relative labour accessibility, β indicates the degree to which access to the net labour force influences employment centre growth as it considers both the supply and demand side of accessibility. Including the notion that employment centres compete for skilled workers. I expect the coefficients β would be significant and has a positive sign, if

changes in the number of jobs in employment centres benefit from both absolute and relative access to the labour force in the region. γ , θ , α and λ reveal the influence of each independent variable on a change in the number of jobs in employment centres.

5.3. Data

I draw upon four sets of data collected from various sources: the transport infrastructure network for the Seoul region, employment and population data, household travel survey data, and several digitized maps of the Seoul region.

I collected the transport infrastructure network data from the Korea National Transport Database. The transportation data contain information on both road and rail transport infrastructure networks, which consist of two main features: nodes and links. Nodes represent stations, intersections and stops in the rail and road transport network, while links represent railways and roads that connect the nodes on the network. This transport infrastructure network was primarily used to generate the absolute and relative measures of labour accessibility.

The household travel survey for the Seoul region was collected from the Korean National Transport Database. The survey provides specific information on the spatial pattern of various types of travel as well as details about travel behaviours in the Seoul region, such as the purpose of travelling, the number of trips made for each travel purpose and the average distance between origins and destinations. I used the household travel survey to generate the measure of labour accessibility.

Employment and population data were collected from the Korean Census, maintained by the Statistics Office of Korea. The census provides population information about age, sex, location and nationality. Since the spatial unit of analysis is the *dong*, the collected employment and population data are compiled at the *dong* level for the years 2000 and 2010. Both the number and density of employment and population are used to capture the agglomeration effects of the spatial concentration of economic activities in employment centres.

Two digitized maps for the Seoul region were collected from the Spatial Geographic Information Service, maintained by the Statistics Office of Korea. The maps consist of shape files of administrative boundaries for 2000 and 2010 at the *dong* level. The

household travel survey was obtained from the Korean Transport Authority and contains both orientations and destinations of commuters as well as the number of commuters. These datasets are integrated as either dependent variables or control variables and then fed into the regression models.

5.3.1. Spatial and Temporal Dimension

The spatial unit of analysis discussed in this chapter is the *dong*, which is the smallest type of administrative neighbourhood in South Korea. Any changes in the boundaries of *dongs* in the study period were corrected via the *jipgyegu*, which is the smallest census tract in South Korea, equivalent to the super output area in the UK. The boundaries of the *jipgyegu* remained the same over the study period, and therefore information collected via the *Jipgyegu* could be used to assess changes in employment and population over time.

Since a *dong* consists of several *jipgyegu*, employment and population in a *dong* can be obtained by tracking changes in total employment and population in the *jipgyegu*. The definition of a *dong* in 2000 is used as the baseline spatial unit. The total number of *dongs* used for this study is 1,108, which cover the entire Seoul region except for negligible *dongs* located on islands. For example, Muui-dong in Gyeonggi province is excluded from the spatial scope of this analysis because it is an island and is therefore not connected to the mainland by a road transport network.

I define the study period between 2000 and 2010 as the temporal dimension of analysis discussed in this chapter. The economic growth rate in the Seoul region in the 2000s was not as rapid as it was in the 1980s, when the national economy grew by around 10%. While the rise of the heavy manufacturing industry was the main driver of the rapid economic growth experienced in the 1980s, the study period between 2000 and 2010 marked the rise of the information and communication technology (ICT), retail and service industry, all of which are becoming a more significant part of the economy in the Seoul region. This is thus a significant period in that the number of employees in the retail, service and communication industries has risen in the Seoul region while, at the same time, the decentralisation of employment has accelerated, forming new clusters of these industries and strengthening the existing spatial concentration of employment.

The other reason for choosing the time period between 2000 and 2010 is attributable

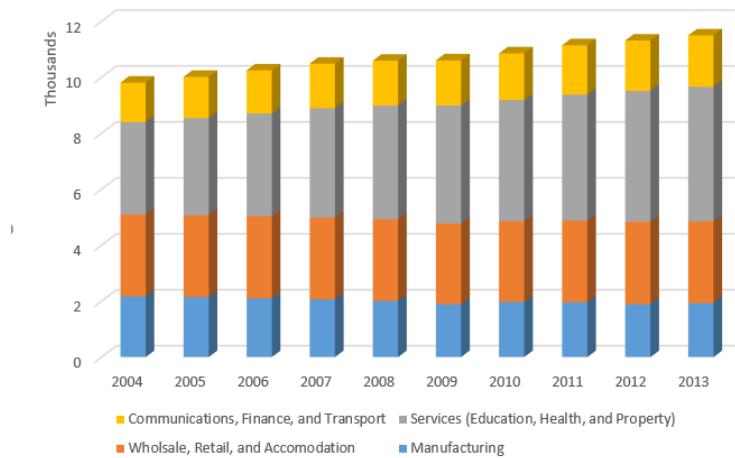
to the limited availability of transport network data and the lack of reliable employment data at the *dong* level. For a longitudinal analysis, it is essential to track changes in transport networks over a prolonged period of time, but data for both the rail and road transport networks before 2000 were not available. In addition, because of the rapid economic growth of the Seoul region, its spatial boundary has considerably changed since the 1960s, resulting in subsequent changes to administrative boundaries in the area. As such, employment data at the *dong* level over a long time period are likely to be unreliable unless changes to administrative boundaries are considered. 10-year study period is sufficient for exploring the phenomenon of research interest and is within the temporal range used in previous studies, i.e., from 10 to 15 years (Giuliano et al., 2012).

5.3.2. Dependent Variable

I use the number of jobs per square kilometre in an employment centre as a dependent variable to explore the growth of employment centres in relation to changes in the level of access to the labour force via transport infrastructure. I focus on the absolute figure of job growth rather than the growth ratio of employment centres because the former is better suitable for a regression model used in the analysis as dependent variable. The growth ratio of employment centres may be straightforward, but it does not allow for controlling for the heterogeneity of unobserved characteristics.

Employment data were collected from the Korean Census, which contains various information on employment, such as the number of jobs by industry classification and the number of jobs by location. These employment data are compiled at the *dong* level in order to fit the spatial unit of analysis outlined in this chapter. The data are also organised for the two time periods of 2000 and 2010, and then geocoded on the digital map. Figure 1 shows changes in employment by industry from 2004 to 2013. The total number of jobs in the Seoul region increased over the last decade. While the number of jobs in the manufacturing industry declined by 11.7% during this period, the number of jobs in the service and communication industries noticeably increased by 40.5% and 30.4%, respectively.

Figure 5-1. Employment Change in the Seoul Region



5.3.3. Control Variables

According to the empirical specification presented in Eq. 5.3, a change in the number of jobs are determined by a set of control variables apart from a change in labour accessibility. These control variables are largely separated into three categories: economic effects of agglomeration economies, the number of employments in industries, and access to major transport facilities.

Four control variables fall into the category of agglomeration economic effects: the size of employment, the density of employment, the size of the population, and the centrality of employment centres in the Seoul region. Employment and population data at the *dong* level are mainly used for constructing a series of variables related to the size and density of economic activities in a given area. These datasets were collected from the Korean Census and the Statistics Office of Korea.

The first control variable is the size of an employment centre that relates to the level of productive advantages arising from agglomeration economies. The benefit of agglomeration economies is one of the important productive sources used by firms to run a business. Given that firms benefit from the productive advantages of agglomeration economies, the size of an employment centre may affect their performance and therefore the economic growth of the centres. In this sense, large employment centres may grow faster than small centres, but they may grow slowly or even decline if the positive effects of agglomeration economies are offset by their diseconomies.

The second control variable is the density of an employment centre, the theoretical

foundation of which is based on agglomeration economies. This control variable is more reflective of the business condition in which firms are situated, such as land costs and land availability. The variable is also connected to the diseconomies of agglomeration economies. A high-density employment centre would increase congestion, whereas a low-density employment centre would have room to grow.

I also include a variable for the size of the population²² to account for agglomeration advantages derived from population changes. As with the variable for employment size, the variable for population size demonstrates that employment centres with a large population may grow faster than those with a small population.

The fourth control variable is the locational centrality of an employment centre in the Seoul region. Given that urbanisation economies work at the regional level, the growth of employment centres may be subject to the overall growth of regional economies, which means that proximity to the core of the region is important to the growth of employment centres. It has been hypothesised that employment centres located closer to the core of a region may grow faster than those located farther away. The locational centrality of employment centres is also associated with negative effects of urbanisation economies, such as congestion and high rent.

For the category of growth of industrial sectors, I consider the growth of each industry in an employment centre. The growth of an employment centre may be influenced by job changes driven by industrial performance. An employment centre with fast-growing industries may grow faster than a centre with slow or shrinking industries.

In addition, I include a set of locational variables related to transport facilities in order to account for their influence on changes in jobs within an employment centre. Based on a recent theoretical argument that the economic growth of employment centres may be in some way connected with global and national economies, I consider access to transport facilities that connect international and regional markets (Giuliano & Small, 1999; Kasarda, 2000).

²² Population density is highly correlated with population size. Since the size of a population accurately represents the possible relations between population and employment growth, I chose population size over population density as a control variable for population.

5.4. Exploratory Results

The exploratory results are presented in two subsections. The first subsection shows the identified employment centres in the Seoul region and briefly outlines their characteristics by presenting their descriptive statistics. In the second subsection, the absolute and relative labour accessibilities are measured for the Seoul region for the two time periods of 2000 and 2010. Then, the summary statistics for labour accessibilities are provided.

5.4.1. Exploratory Results on Employment Centres

Using the identification method for employment centres defined in the section on research strategy, I identify employment centres in the Seoul region for the two time periods of 2000 and 2010. As the distribution of employment is not constant across the Seoul region, two different cut-off standards are applied as explained in the research strategy section. In total, 136 employment centres²³ are identified at the municipality level for 2000 and 2010. These centres are mapped in Figure 5-2 to illustrate the spatial context in which they are situated, along with the borders of the municipalities and the major transport infrastructure in the Seoul region.

Looking at the identified employment centres in Seoul, most tend to be concentrated in three major areas: the CBD, Gangnam and Yeongdeungpo. The CBD is located in the north of Seoul, while the other two are located in the south of Seoul. Apart from these employment centres, some employment centres are located in recently growing areas, such as Guro, Shin-chon and Song-pa. Note that these employment centres were not observed in Seoul in 2000 but were identified in 2010.

Concerning Gyeonggi and Incheon provinces, the majority of employment centres identified are concentrated in Gyeonggi province, many of which tend to be located close to the motorway and railway networks. The largest employment centre in Gyeonggi province is Pyeong-taek, which hosts a couple of large industrial complexes. By contrast, a relatively small number of employment centres are identified in Incheon. Overall, many employment centres are located in Seoul at the municipality level, except for several industrial complexes constructed along with transport nodes in Gyeonggi

²³ These employment centres are defined at the *dong* level, and thus their numbers are probably higher than those defined in previous studies (McMillen & Lester, 2003).

province.

Looking at the trajectory of the identified employment centres, they experienced both a rise and fall in jobs between 2000 and 2010. Most employment centres in 2000 remained stable up to 2010, excluding five which lost employment considerably during the study period. These employment centres were largely located in inner Seoul. Overall, most employment centres gained a number of jobs during the study period, while 17 centres lost jobs, especially in inner Seoul.

Figure 5-2 shows an interesting spatial pattern of employment centres as well as their locational characteristics. The identified employment centres largely tend to be located close to the transport infrastructure network in the Seoul region, including railway stations, motorway ramps and interconnected local and regional transport networks. This may indicate that proximity to the transport network is associated with the formation and development of employment centres. By contrast, some employment centres tend to be situated near harbours and marine infrastructure. These centres are specialised in industries that export products made from raw materials imported via harbours, such as the steel and automobile industries.

It is also observed that the size of employment centres varies in terms of the total number of jobs. Larger employment centres tend to lie in and around Seoul, and the largest employment centre is found in south-eastern Seoul, in Yeoksam-dong, with around 120,000 jobs. The second- and third-largest employment centres are also located in Seoul, with more than 100,000 jobs. By contrast, employment centres outside Seoul are by and large small- and medium-sized in terms of the number of jobs, except for several employment centres in Gyeonggi province. The smallest employment centre is Simgok-dong in Gyeonggi province, with only about 10,000 jobs.

In terms of employment density, employment centres in the Seoul region vary. Employment centres with a high job density tend to be located in Seoul, as shown in Figure 5-2, whereas those outside Seoul tend to have low and medium employment density due mainly to their employment size. For example, Myung-Dong is the densest employment centre, with approximately 306 jobs per acre in 2000 (362 jobs per acre in 2010).

Figure 5-2. Employment Centres in the Seoul Region

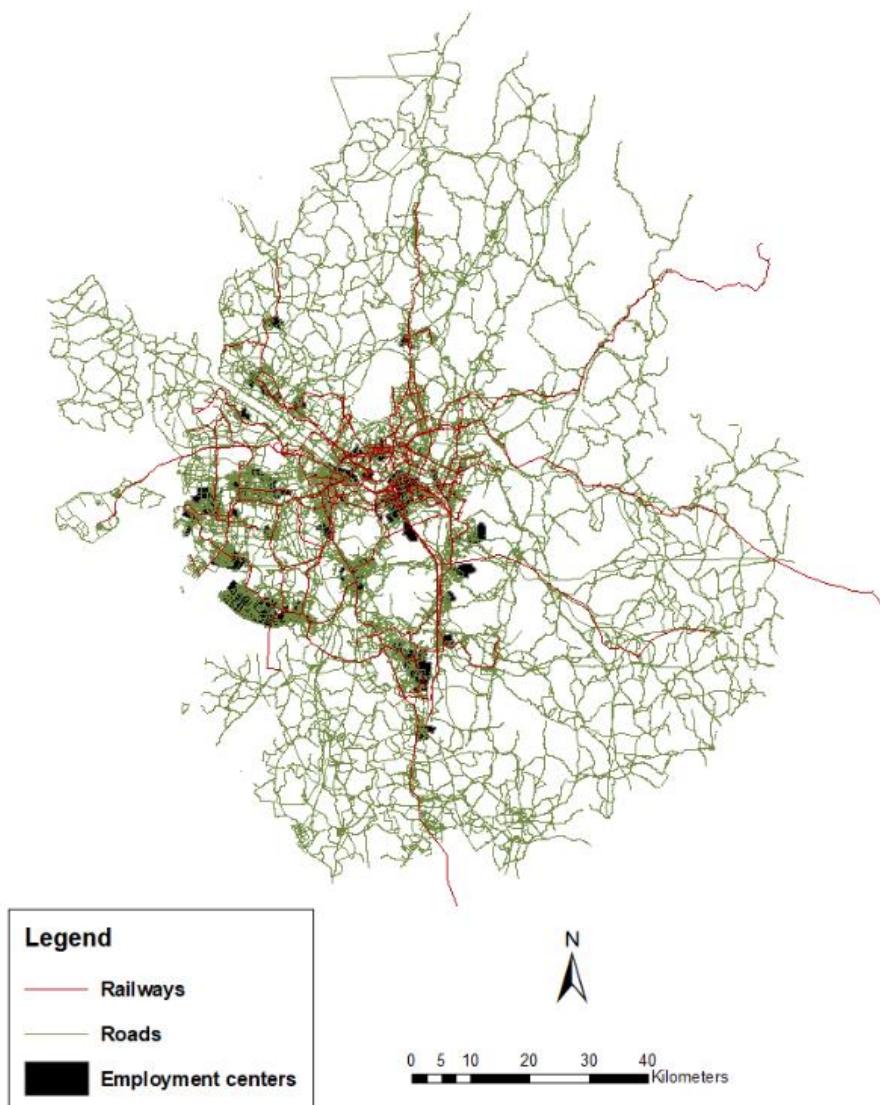


Table 5-1 shows descriptive statistics for identified employment centres in order to provide some understanding of their characteristics as well as their growth trajectory. During the study period between 2000 and 2010, employment centres in the Seoul region grew by 33.2% on average. While this is not as high as the growth rate in the 1980s, when Korea's economy grew even faster, it is still nearly two times higher than the average growth of the region for the time period. This shows that employment centres in the Seoul region tend to grow at a higher rate than less concentrated areas

of employment, which is in accordance with the theory that a higher density of economic activities may promote interactions between firms and workers and subsequently accelerate the economic production of goods and services (Fujita et al., 2001; Puga, 2010a; Rosenthal & Strange, 2004).

Looking at employment centres within and outside Seoul, the difference in the growth rate between these centres shows an interesting feature regarding the spatial development of the Seoul region. Employment centres outside Seoul have a 10% higher growth rate than those within Seoul. This may indicate that both economic development and investment in industries tended to be focused on the clusters of employment outside Seoul during the study period. The high growth rate in employment centres outside Seoul may point to the possibility of an underlying force that attracted jobs and promoted business in these centres, one which worked well during the time between 2000 and 2010. This may imply that the economic role of employment centres outside Seoul strengthened during the study period, although a large part of the economy is still dominated by employment centres within Seoul.

In addition, the high growth rate in employment centres outside Seoul may indicate the possibility that the decentralisation of economic activities in the Seoul region has taken place in a way that has formed a polycentric spatial structure. The literature tells us that the decentralisation of population and employment could occur in either a polycentric or dispersed spatial form, depending on the spatial context of the urban and regional areas (Lee, 2007). Economic activities in the Seoul region have been increasingly decentralised towards its peripheries. Considering that the key economic arena of the Korean economy has been in Seoul, the growing number of jobs in employment centres outside Seoul may be indicative of a changing geography in terms of the spatial pattern of economic activities. It can be said that the Seoul region assumed a polycentric spatial development pattern at least for the time between 2000 and 2010. This argument is confirmed by the difference in the growth rate between employment centres within Seoul and those in the whole region. The growth rate of employment centres outside Seoul outperformed that of the whole region nearly two-fold, which means that the spatial geography of economic growth in the Seoul region is not uniform. This indicates that the Seoul region did not experience dispersed spatial development at least for the time between 2000 and 2010.

Table 5-1. Selected Characteristics of Employment Centres

Name	Avg. Area (m ²)	Employment Density (Jobs /m ²)		Employment growth (%)
		2000	2010	
Employment centers in Seoul	1,677,102	0.0203287	0.0266121	30.9
Employment centers outside Seoul	3,084,692	0.0053161	0.0074888	40.9
Gyeonggi	3,237,008	0.0051273	0.0076674	49.8
Incheon	2,619,280	0.0058929	0.0069431	17.8
Centers in Total	10,618,082	0.0122704	0.0163474	33.2
The total region	10,806,850	0.0040967	0.0049582	21.1

The average density of employment centres within Seoul is 20,329 jobs per square kilometre for 2000 and 26,612 jobs per square kilometre for 2010. The density of employment centres within Seoul is four times higher than that outside Seoul on average, which means that centres within Seoul tend to have more economic activities and interactions between firms and workers than those outside Seoul. The higher density of employment centres within Seoul is mainly attributable to both higher job concentrations in the area and the smaller size of the area. The average size of Seoul's employment centres is around 1.6 square kilometres, which is nearly one-half that of centres outside Seoul.

5.4.2. Descriptive Results of Labour Accessibility

In this section, the two types of labour accessibility, absolute and relative labour accessibility, are measured. First, using a simple travel model, I calculate travel times between the centroids of all *dongs* in the Seoul region for 2000 and 2010. Considering a commuter's choice of travel modes, I obtain the shortest travel time between origins and destinations. The total number of combinations between origins and destination is about 1.2 million observations.

With the calculated travel costs, I construct the measures of both absolute and relative labour accessibility for the Seoul region for the period of 2000 and 2010. Figure 5-3 shows the absolute labour accessibility for 2000 and 2010 compiled at the *dong* level. The level of labour accessibility is coded in seven pre-defined domains, ranging from

the lowest domain (from 0 to 15,000) to the highest domain (over 1,800,000). For the year 2000, Seoul has a higher level of labour accessibility than other parts of the region. Not surprisingly, Seoul's city centre has the highest level of absolute labour accessibility. This result corresponds to the high density of transport infrastructure facilities in the city centre, which has been provided for many decades.²⁴

For the time between 2000 and 2010, the level of labour accessibility for the Seoul region improved overall in absolute terms. While the overall spatial patterns of labour accessibility are similar between 2000 and 2010, a considerable change in the level of labour accessibility occurred in the south of the region. In particular, Gangnam, located in the south of Seoul, gained a high level of labour accessibility, becoming nearly equivalent to the city core, although the city centre still had the highest labour accessibility in 2010. The level of labour accessibility in employment centres in the south of the Seoul region rose higher in comparison to that in the north of the region. This is mainly because of transport infrastructure improvements made to connect employment centres in the south of the region to Seoul. Employment centres connected via motorways or railways tend to have a higher level of labour accessibility than those that are not connected.

²⁴ In this analysis, both road and rail transport infrastructure networks are taken into account. It is worth noting that the first electric railway was constructed in the city centre in 1899. Since then, underground and railway networks have been considerably extended from the city centre towards the city outskirts.

Figure 5-3. Labour Accessibility in the Seoul Region in 2000 and 2010.

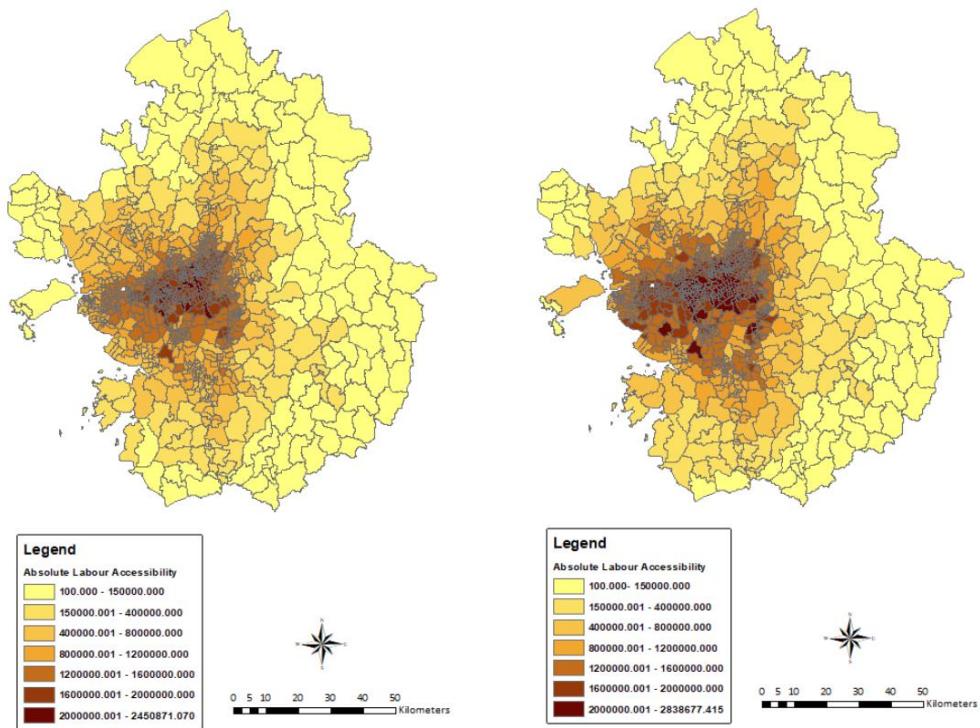


Table 5-2 provides descriptive statistics for the level of labour accessibility for 2000 and 2010. The statistical figures for both the Seoul region and employment centres are separately presented in the table in order to compare them with each other. The first column in the table shows that the mean of labour accessibility for employment centres is higher than that for the whole region for 2000 and 2010. This indicates that employment centres may have higher access to workers via transport infrastructure than in other parts of the region and implies that economic actors in employment centres are likely to have higher benefits than those outside employment centres. It also points to the spatial heterogeneity of labour accessibility across the Seoul region, considering that the level of labour accessibility differs across the region.

A similar pattern for the level of labour accessibility is found in the minimum value. The identified employment centres have a much higher level of minimum labour accessibility than that of the Seoul region, which means that basic access to workers may be reduced outside employment centres in the region. It can be said that the minimum value points to the degree to which workers can be accessed in the area via the

transport infrastructure network. As such, the figures show that the employment centres basically have better access to the labour force via the transport infrastructure than the whole Seoul region.

Table 5-2. Labour Accessibility in the Total Seoul Region and Employment Centres

		Mean	Minimum	Maximum	S.D.
2000	The Seoul region	1044625	2772.7	2204480	527351.2
	Employment centers	1370610	282864.2	2202643	392862.1
2010	The Seoul region	1230356	2885.0	2582628	575959.2
	Employment centers	1603650	377238.9	2569196	376474.7

Overall, the descriptive statistics show a modest but major improvement in the level of labour accessibility in employment centres in the Seoul region over the study period between 2000 and 2010. The level of labour accessibility increased by around 17.0% during the study period. The provision of transport infrastructure made across the Seoul region may be the major reason for this increase in the level of labour accessibility. Given that employment centres grow on average during the study period, this may suggest a link between the growth of employment centres and an increase in the level of labour accessibility. This is supported by a difference in the standard deviation of labour accessibility between 2000 and 2010, as well as by a decrease in the standard deviation for employment centres and an increase in the standard deviation for the Seoul region. I will discuss this in more detail below, with regression models estimated.

5.5. Regression Results

This section examines the results obtained from the regression models. The results consist of two sub-sections, one of which presents the results for descriptive statistics for the variables included in the model, while the other evaluates the results obtained from the regression model for the job growth of employment centres as well as for the job growth of the entire Seoul region.

5.5.1. Descriptive Statistics

Table 5-3 presents descriptive statistics for variables included in the regression model in order to provide a useful understanding for the statistical analysis. Alongside the minimum and maximum values of the variables, the mean and standard deviation of the variables are summarised for the employment centres identified. It is observed that the standard deviation of a variable for employment density is high, and that the difference between its minimum and maximum values is stark, which may indicate that employment density varies across employment centres in the Seoul region. For a variable for employment change, the standard deviation of employment change is high, suggesting that a change in the number of jobs in employment centres differ from each other in the Seoul region. Employment centres in the region tend to be diverse in terms of employment density and job growth.

The average distance from employment centres to the CBD is 19.7 kilometres, and the standard deviation of the distance to the CBD is relatively small, which may suggest that employment centres are broadly distributed across the Seoul region. By contrast, the mean and standard deviation of the distance to an international airport and high-speed rail stations are relatively high, which suggests that they are located in key spatial nodes in the region. In other words, their locations are not dispersed but located in major places, such as important interconnections for the local and regional transport network. This may indicate that access to the international and regional economics from local areas in the Seoul region are disproportionate.

For descriptive statistics for the absolute labour accessibility, the difference between the minimum and maximum values is large. This may suggest that employment centres in the region differ in the level of transport infrastructure provided for access to the labour force. Some employment centres are likely to be served by a high level of transport infrastructure network, whereas others may not. This does not mean that employment centres in the region are not connected with a labour force pool, but it does imply that the degree to which employment centres get access to the labour force is variable. While some employment centres are relatively well connected to potential workers in the region via transport infrastructure, other employment centres may have less interaction with potential workers in the region.

Descriptive statistics for the relative labour accessibility show a somewhat different picture from those for absolute labour accessibility. Its minimum and maximum values are much lower than those for absolute labour accessibility. The minimum value of the

relative labour accessibility is negative, which means that some employment centres may have less access to the labour force because of competition between employment centres for skilled workers. These simple statistics indicate the existence of competition for the labour force among employment centres.

Table 5-3. Descriptive Statistics of Dependent and Independent Variables

Name	Description	Mean	S. D.	Min.	Max.
ΔEmp	A change in the number of jobs in an employment centre	7053.8	10205.9	-6682	84428
Den2000	Employment density in 2000	12270.4	13406.8	50.6	76593.9
Popden2000	Population density in 2000	12916.3	8269.639	16.25409	34921.3
DistCBD	Distance to the CBD (Meters)	19740.4	574.8	51838.47	12170.1
ΔManuEmp	Jobs change in manufacturing industry	-1199.4	3550.5	-25216	13630
ΔRetailEmp	Jobs change in retail industry	164.8	2323.6	-9965	14140
ΔServiceEmp	Jobs change in service industry	4062.6	4301.8	-613	32759
ΔCommEmp	Jobs change in communication industry	1615.1	3842.6	-266	26807
DistAirport	Distance to international airport (Meters)	72144.3	15936.5	42208.3	106288.4
DistHSrail	Distance to the closest high-speed railway station (Meters)	12091.9	7277.6	436.1	32054.3
ΔAccAbsolute	Change in absolute labour accessibility	264863.3	116685.8	80108.3	830486.1
ΔAccRelative	Change in relative labour accessibility	5123.7	17022.1	-34946.3	130714.8

The mean values for a job change in industries demonstrate the trajectory of industrial development between 2000 and 2010. The manufacturing industry in employment centres lost around 1,200 jobs on average during the study period, whereas the service and communication industries in employment centres gained around 4,000 and 1,600 jobs for the same period, respectively. These changes may be indicative of a subtle but important change in the industrial structure in the Seoul region. In fact, the service industry grew considerably as the consumer economy started to take an important part in the economy. The communication industry also advanced as ICT became more important to economic activities in production and consumption. This does not

necessarily mean that the manufacturing industry started to fall apart, but rather indicates that the manufacturing industry is evolving into one that utilises more advanced technology but reduces the amount of labour in production.

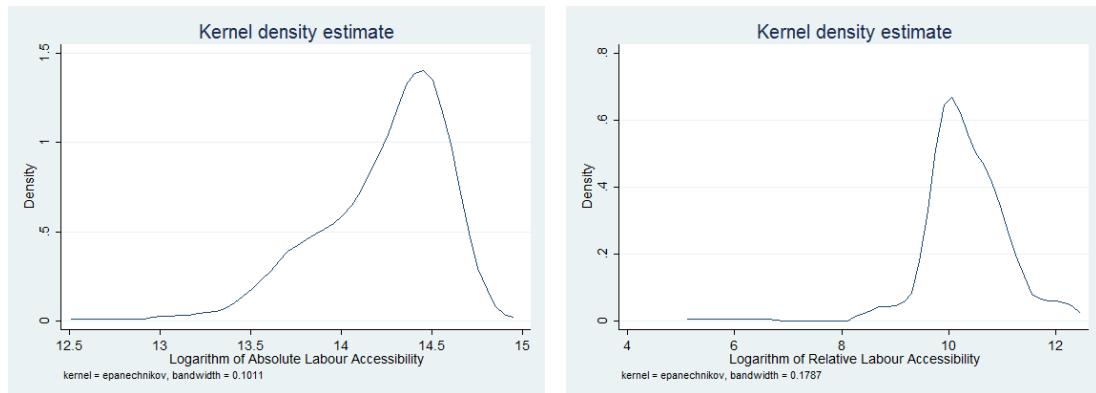
Kernel Density Estimation

Figure 5-4 illustrates the underlying density of both absolute and relative labour accessibility for the identified employment centres in the Seoul region using kernel density estimation²⁵ (Silverman, 1986). The estimation of kernel density for labour accessibility shows how dense employment centres are on a certain level of labour accessibility. The estimated density of absolute labour accessibility is shown in the diagram on the left side, whereas the corresponding figure for relative labour accessibility is shown in the diagram on the right side of the figure. The horizontal axis refers to the logarithm value of labour accessibility, whereas the vertical axis stands for the density in employment centres corresponding to the given value of labour accessibility.

For absolute labour accessibility, most employment centres fall under the range of the logarithm of labour accessibility, between 13.5 and 14.8. This suggests that employment centres in the Seoul region are not very different from each other in terms of the level of absolute labour accessibility. The distribution of absolute labour accessibility in employment centres is not widespread but rather relatively concentrated in a certain range. Absolute labour accessibility is defined as the total workers discounted by distance. To a certain extent, the estimated result shows that employment centres are overall connected to a potential labour force pool via transport infrastructure in the Seoul region. This is in accordance with the fact that most employment centres in the Seoul region are more or less served by the transport network, which connects to a major economic power plant in the country.

²⁵ Kernel density estimation is a nonparametric approach used to estimate the probability density function of a random variable.

Figure 5-4. Kernel Density Estimates for the Level of Labour Accessibility.



For relative labour accessibility, the estimated densities of employment centres are distributed at a slightly wider scope of relative labour accessibility than absolute labour accessibility, ranging from 8 to 12. This suggests that employment centres in the Seoul region are different from each other in terms of the level of relative labour accessibility. In other words, the Seoul region has employment centres with a diverse level of relative labour accessibility. Given that competition between employment centres is considered in the measure of relative labour accessibility, the level of competition may be a key factor that accounts for such a difference in the density among employment centres. The result indicates that the degree to which employment centres reaches the labour force via the transport infrastructure is subject to the level of competition for workers in the Seoul region.

5.5.2. Regression Model Results

The regression model specified in previous section tests for the relationship between the level of transport-induced labour accessibility and a change in the number of jobs in employment centres, controlling for other variables that might be related to a change in the number of jobs in an employment centre. The employment centres identified are the unit of analysis in the regression model, and the dependent variable for the model is the number of jobs. The absolute and relative indicators of labour accessibility are incorporated into the model as key variables of interest.

I establish three different sets of regression models to address the issue of multicollinearity, ranging from a base model to a model with full variables. For the base

model, I only include the set of control variables outlined in Section 5.3. I then add variables for labour accessibility and variables for proximity to transport facilities. I also organise models for both employment centres and the whole Seoul region to compare the estimated results with each other. Model 1-3 are estimated for employment centres, whereas Model 4-6 are estimated for the whole Seoul region. The estimated results for employment centres are presented in Table 5-4, whereas the results for the Seoul region are presented in Table 5-5.

Table 5-4 presents the estimated results obtained from regression models for employment centre growth (Model 1-3). I organise three sets of regression models for employment centres to determine clearly how variables are related to the dependent variable. The absolute and relative labour accessibility indicators are included in Model 2 and 3. Model 2 evaluates how these indicators are related to a change in the number of jobs in an employment centre. In Model 3, variables for proximity to transport facilities are added to assess the association of these variables to the growth of employment centres. *R*-squared scores for all three models are relatively high, at around 0.95, indicating that the overall performances of all three models are good in terms of explaining the growth of employment centres in the Seoul region.

Estimates for Absolute and Relative Labour Accessibility

In Model 2, the estimated results show that the level of absolute accessibility is found positive and statistically significant at the 1% level. This indicates that absolute labour accessibility is related to a change in the number of jobs in an employment centre. The magnitude of the coefficient of absolute labour accessibility is around 0.0055, which means that for one-unit change in the level of absolute labour accessibility, the number of jobs in employment centres would grow by 0.0055 units.

The estimated results suggest that access to the total labour force is one of determinants of employment centre growth. Increasing the level of access to the total labour force would increase the number of jobs in employment centres. The higher the level of access to the total labour force, the more the number of jobs in employment centres will grow. This can be interpreted as having more access to the labour force brings benefits to employment centres in terms of job growth. Specifically, the levels of both production and consumption can rise due to an increase in access to the total labour force, and therefore firms in employment centers can benefit from growing economic activities.

These findings suggest that access to the total labour force is key to the growth of employment centre even in an urbanized area where a number of populations is concentrated. Intuitively, an urbanized area already has a high population density and therefore access to the total labour force may not be an important factor in employment growth. However, it turns out that absolute labour accessibility still has significant effects on the growth of employment centres in the context of the Seoul region.

For relative labour accessibility, the estimated results show that the coefficient of relative labour accessibility is positive and statistically significant at the 1% level, suggesting that access to the net labour force is also one of the determinants of the growth of employment centres, together with the absolute labour accessibility. Increasing the level of access to the net labour force will increase the number of jobs in employment centres. For one-unit change in the level of relative labour accessibility, the number of jobs in employment centers would grow by 0.276 units.

As mentioned in the previous section, the relative accessibility considers the 'supply' side as well as the 'demand' side of accessibility together, which in turn refers to the net access to the labour force. As such, the positive magnitude of the coefficient of relative labour accessibility indicates that the number of jobs in an employment centre is positively related to access to the net labour force. This is consistent with the findings in a previous study that investigated the growth of employment centres in the LA region in relation to changes in access to the labour force (Giuliano et al., 2012).

Compared to absolute labour accessibility, the magnitude of the coefficient of relative labour accessibility is high, which suggests that access to the net labour force is slightly more important regarding a change in the number of jobs in an employment centre. This might be due to the fact that the extent to which employment centres receive access to the amount of labour force is concerned with the supply of labour force as well as the demand for labour force.

Firms in employment centres compete for labour force with firms from other employment centres, and therefore it can be said that the labour force, in some sense, is not always ubiquitous to firms in employment centres because skilled or wanted workers tend to be always in short supply. Because of the competition between firms, the net labour force available to firms may be different from the total labour force around firms. In this regard, labour accessibility is more relevant to job growth in an employment centre when competition for the labour force is taken into consideration.

The estimated results for relative labour accessibility also point to the presence of

competition for the labour force between employment centres in the Seoul region. Many employment centres have been established in the suburbs of Seoul, and the growth of these employment centres has brought about a growing tension with traditional employment centres over workers and customers. For example, Gangnam, a sub-centre developed in the 1970s, has become the second-largest employment centre in Seoul, attracting a number of headquarters and service companies that were once located in the CBD. In recent years, Pangyo has been developed at the periphery of the Seoul region as new employment centres specialised in the ICT and bio-medical industries have been developed.

A key finding obtained from the estimated results is that both absolute and relative labour accessibility are determinants of the growth of employment centers, although the magnitude of the coefficient of relative labour accessibility is higher than that of absolute labour accessibility. Access to the net labour force is of more importance when it comes to job creation in employment centers mainly because it considers both the 'demand' side and 'supply' side of accessibility. Yet, access to the total labour force is still a key factor for the growth of employment centers.

Table 5-4. The Estimation Results for Employment Centres²⁶

	Model 1		Model 2		Model 3	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Constant	1970.0*	(1015.8)	1192.9	(880.6)	-2218.5	(1354.2)
Den2000	0.00168	(0.0267)	0.0317	(0.0209)	0.0366**	(0.0205)
Popden2000	-0.0540*	(0.0302)	-0.0514**	(0.0236)	-0.0584**	(0.0233)
DistCBD	-0.00815	(0.0266)	-0.0287	(0.0218)	-0.0628**	(0.0236)
ΔManuEmp	0.643***	(0.0916)	0.346***	(0.0778)	0.326***	(0.0755)
ΔRetailEmp	1.449***	(0.127)	0.488***	(0.143)	0.477***	(0.139)
ΔServiceEmp	1.135***	(0.0843)	0.728***	(0.0788)	0.714***	(0.0775)
ΔCommEmp	1.142***	(0.0932)	0.768***	(0.0826)	0.779***	(0.0803)
ΔAccAbsolute	–	–	0.0055**	(0.0018)	0.0066***	(0.0018)
ΔAccRelative	–	–	0.270***	(0.0291)	0.268***	(0.0282)
DistHSrail	–	–	–	–	0.0791**	(0.0327)
DistAirport	–	–	–	–	0.0401**	(0.0134)

²⁶ Independent variable for the size of employment is separately estimated because its correlation with other variables. When the variable is incorporated into the model, I found the model becomes unstable. Thus I present separate estimated results for the relationship between the size of employment and a change in the number of jobs in an employment centre in Appendix C.

R-squared	0.931	0.958	0.961
Observations	136	136	136

Notes: * denotes significance at the 10 percent level; ** denotes significance at the 5 percent level; *** denotes significance at the 1 percent level.

Estimates for Employment Concentration and Proximity to Transport Facilities

In Model 3, the estimated results show that the density of an employment centre at the initial period is found statistically significant and positive, which indicates that the formation and growth of employment centres are related to productive advantages arising from the concentration of economic activities. This is consistent with the findings in a number of previous studies, which reported that the positive advantages of employment agglomeration operate at the sub-city–region level (Fujita et al., 2001; Giuliano & Small, 1999). The positive coefficient of employment centre density suggests that the productive benefits of employment clusters outweigh the disadvantages of employment agglomeration, such as congestion. This means that the number of jobs in employment centres is likely to continue to grow to the point at which the positive advantages are cancelled out by the disadvantages.

The magnitude of the coefficient of employment density is 0.0366 in Model 3, which means that for one additional unit increase in employment density, the number of jobs in an employment centre would grow by 0.0366 units. The estimates for employment density confirm that productive benefits arising from the agglomeration of dense employment may be the underlying force for the emergence and growth of the spatial concentration of employment in the Seoul region.

With regard to spatial development of the Seoul region, the estimates of the density of an employment centre cast doubt on the old debate regarding whether the Seoul region is polycentric with multiple clusters of employment or a dispersed, edgeless area. The Seoul region has long experienced the decentralisation of both employment and population over several decades, mainly due to the tension between centripetal and centrifugal forces. The positive coefficient of the density of an employment centre indicates that the decentralisation of employment has not been formed with dispersed areas of employment but rather with some clusters of employment. This finding is consistent with those of previous studies that explored the emergence of employment concentrations outside the city centre and investigated the characteristics of

employment centres (Anderson & Bogart, 2001; Forstall & Greene, 1997).

In contrast to the spatial concentration of employment, the concentration of population is found to have a negative impact on a change in the number of jobs in an employment centre. The coefficient of population density in the year 2000 is negative and statistically significant, which suggests that the denser the population in employment centres becomes, the less the centres will grow. This estimated result demonstrates that population agglomeration is different from employment agglomeration in relation to a job change in an employment centre.

The differences in the estimates between employment concentration and population concentration may be attributed to the trajectory of spatial development which the Seoul region experienced regarding the decentralisation of both employment and population. In the context of the Seoul region, the decentralisation of population has been more phenomenal than employment decentralisation mainly because of both rural migrations into the region and the government's policy of relocating the population outside of Seoul. For this reason, the density of population in employment centres is quite high – high enough to create disadvantages of agglomeration. High population density basically creates congestion and pollution in an area, causing increased pressure on public services and land availability in the location, which can ultimately make the location less attractive to firms and thereby lead to a decline in employment centres.

The relative locational benefits of employment centres in the region are tested by a variable capturing the distance to the CBD. The coefficient of this variable reveals that proximity to the city centre is statistically significant and negative, suggesting that being close to the city centre is related to the growth of employment centers in the context of the Seoul region. To some extent, the city centre plays a key role in promoting the economy of an employment centre in the region. Having good communication with the city centre is one of key factors for employment centers to grow in the context of the Seoul region.

The estimated results also show that a change in the number of jobs in major industries in an employment centre is an important determinant of the growth of employment centres. The four major industries are taken into account in the estimation. It is shown that the all four industries have positive impacts on a change in the number of jobs in an employment centre, which suggests that the number of jobs in industries in an employment centre leads to job creation in that centre. The higher employment in industries in an employment centre, the higher jobs in that centre.

While all these industries are positively related to the growth of employment centres, the degree to which each industry contribute to job creation in the centres varies depending on the different trajectories each industry took during the time between 2000 and 2010. The communication industry has the highest impacts on job growth in an employment centre. The service industry is the second-most influential industry. The manufacturing industry has the lowest impact on employment centre growth. The coefficient of the manufacturing industry is 0.326, which is about half of the communication industry. This suggests that the communication industry is likely to increase the number of jobs almost two times more than the manufacturing industry does when it comes to investing in industries for job creation.

The variation in the coefficient of each industry on employment centre growth is closely related to the growth trajectory of each industry during the study period. The manufacturing industry is the dominant industry in the Korean economy. Its employment has grown significantly since the 1960s, when the government started to establish the nation's industrial base. Yet, the 2000s was a period of slow growth for the manufacturing industry in terms of the number of jobs in the Seoul region.

The retail sector underwent a restructuring process in the period between 2000 and 2010. There was a significant institutional change in the way in which wholesale and retail shops provided customers with goods and services. Also, because of the rise of large-scale shopping malls and supermarkets, many small-scale retail shops closed or went bankrupt. While the number of small-scale retail shops was reduced, the total number of employees in the retail industry increased because of the increasing number of independent retail businesses.

The coefficient of distance to an international airport is found statistically significant and positive, indicating that being away from an international airport is related to the growth of employment centres in the context of the Seoul region. This is a somewhat surprising result given that the world economy is becoming increasingly integrated and international airports are becoming gateways for the international transport network. Yet this result is partly in line with findings in a previous study that showed that whether employment centres near airports have good performance depends on the rise and fall of industries nearby (Giuliano et al., 2012).

The positive coefficient of distance to an international airport is partly attributed to the industrial structure of the Korean economy, which mainly comprises the manufacturing industry, including the automobile, shipbuilding, petroleum and steel industries,

although service and knowledge-based industries are developing. Most manufacturing industries, by nature, tend to prefer locations in which a large number of workers are available and, at the same time, intermediate inputs are available at a low cost. As such, an area near an international airport may not be the best location for manufacturing firms in comparison to an area with cheap rent and easy access to many partner companies, such as industrial complexes at the periphery of the Seoul region. This result is consistent with observations for the area near Incheon International Airport, which show that few economic activities are in operation, although various urban and industrial developments are on schedule (Incheon Free Economic Zone [IFEZ], 2015).

The estimated results also show that the coefficient of distance to the closest high-speed railway station is found statistically significant and positive, which means being away from a high-speed railway station is related to job growth of employment centres in the context of the Seoul region. This result may be attributed to a firm's location choice in the Seoul region. As discussed, the Korean economy is dominated by the manufacturing industry, which prefers an area with low rent and easy access to both the labour force and intermediary goods over an area with high rent and narrow space. As such, an area near a high-speed railway station may not be suitable for many manufacturing firms, although it may fit for some services and knowledge-based firms (Chen & Hall, 2012).

The Korean Train Express (KTX) opened its doors to the public in 2005 as a means of fast transport between the capital region and the rest of the country. The arrival of the KTX had knock-on effects on various industries, and the retail and service industries benefited from an increase in pedestrian footfall in areas around high-speed railway stations. However, it has been argued that its spatial economic impacts have not been fully realised in industries as much as expected (Chang & Lee, 2008). This may be a possible explanation for the coefficient of distance to a high-speed railway station obtained from the estimation.

The estimated results for distance to a high-speed railway station provide an interesting view on the unbalanced spatial development in the Seoul region. The estimated relationship between distance to a high-speed railway station and the growth of employment centres may be a sign of a loose connection between the economic growth of the Seoul region and regional economic growth. In other words, there is a possibility that the Seoul region does not communicate well enough with regional areas in the country in terms of jobs and economic growth. This result is manifested in the spatial pattern of economic development in South Korea, which shows that economic activities

are disproportionately distributed across the country. Over 60% of all economic activities in the country are concentrated in the Seoul region, while only about 40% are distributed across about 90% of the country (The Statistics of Korea, 2016).

Estimated Results for the Entire Seoul Region

In addition to the estimation for employment centers, I conduct an analysis of job growth in the entire Seoul region regarding transport-induced labour accessibility. As the entire Seoul region includes the identified employment centers as well as the rest of an area in the region, I expect the estimates for the Seoul region may provide additional implications for policy for job growth in the region. The estimated results for the Seoul region may show different picture of how transport-induced labour accessibility influences a change in the number of jobs in the region that the estimation for employment centres do not cover.

Table 5-5 presents the estimated results obtained from regression models for the entire Seoul region (Model 4-6). I use the same variables tested in the previous models in order to compare the estimates for the Seoul region with those for the identified employment centres. As does with employment centres, I construct three separated models to address the issue of multicollinearity. Starting with essential variables for the growth of employment in Model 4, I incorporate the absolute and relative accessibility indicators and variables for proximity to transport facilities in Model 6. The focus of the analysis is on changes in the level of both absolute and relative labour accessibility and their associations with job growth in the Seoul region.

The performances of Model 4-6 are as good as those of Model 1-3. R-squared scores of Models 4-6 are high, indicating that the variation in the number of jobs in the region is well explained by the variables incorporated in the models. Of these three models, Model 6, in which variables for the indicators of labour accessibility and variables for distance to transport facilities are added, has the highest R-squared score.

Table 5-5. The Estimated Results for the Whole Seoul Region

	Model 4		Model 5		Model 6	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Constant	349.0**	(118.5)	231.3**	(107.4)	7.409	(177.9)
Den2000	0.0440***	(0.00819)	0.0762***	(0.00660)	0.0770***	(0.00660)

Popden2000	-0.0194***	(0.00318)	-0.0191***	(0.00251)	-0.0189***	(0.00252)
DistCBD	-0.000546	(0.00259)	0.00211	(0.00207)	-0.00341	(0.00350)
ΔManuEmp	0.881***	(0.0265)	0.491***	(0.0260)	0.495***	(0.0261)
ΔRetailEmp	1.470***	(0.0484)	0.567***	(0.0522)	0.560***	(0.0523)
ΔServiceEmp	1.263***	(0.0270)	0.832***	(0.0272)	0.833***	(0.0274)
ΔCommEmp	1.105***	(0.0349)	0.708***	(0.0320)	0.703***	(0.0321)
ΔAccAbsolute	—	—	0.00096***	(0.00023)	0.0013***	(0.00031)
ΔAccRelative	—	—	0.269***	(0.0106)	0.271***	(0.0107)
DistHSrail	—	—	—	—	0.00563	(0.00360)
DistAirport	—	—	—	—	0.00217	(0.00178)
R-squared	0.934		0.958		0.959	
Observations	1096		1096		1096	

Notes: * denotes significance at the 10 per cent level; ** denotes significance at the 5 per cent level; *** denotes significance at the 1 per cent level.

Compared with Model 1-3, Model 4-6 shows the expected signs of coefficients of variables, with statistical significance, although their magnitudes differ from those in the previous models. Most estimates for variables incorporated in the models are by and large consistent with those for the identified employment centres, except for variables for distance to the city centre and for distance to transport facilities.

In Model 3, the coefficient of distance to the city centre is found statistically significant and negative, but it is found statistically insignificant in Model 6, which indicates that being close to the city centre is not relevant to a change in the number of jobs in the region. Despite of the insignificant coefficient, I presume that to some extent the city centre still plays a key role in promoting the economy in the region. This role is not well revealed in the estimation for the job growth of the region. I suspect that the major reason for this is that the variable for proximity to the city centre is correlated with other variables, such as distance to a high-speed rail station. These estimated results, in part, are in line with findings in previous studies reporting an insignificant relationship between distance to the traditional centre and urban economic growth (Agarwal, 2015; Giuliano et al., 2012).

Estimates for distance to transport facilities in Model 6 are also different from those in Model 3. The coefficients of distance to both an international airport and a high-speed railway station are found statistically insignificant in Model 6. This may be due to a long distance from locations in the region to an international airport. The same logic can be applied to the case for a high-speed rail station; the mean distance from locations in the region to the closest high-speed rail station is around 12 km. Another reason might

be concerned with the fact that the spatial economic impacts of these transport facilities have not yet been fully realised in industries and an area near the stations and airport may not yet be mature enough for firms to be located.

Similar to Model 1-3, the coefficients of both absolute and relative labour accessibilities are found statistically significant and positive. The coefficients of these accessibilities are at 0.0013 and 0.271, respectively, which indicates that the number of jobs in the region would grow by 0.0013 units for one unit change in the level of absolute labour accessibility whereas it would grow by 0.271 units for one unit change in the level of relative labour accessibility. Both absolute and relative labour accessibilities are determinants of job growth in the Seoul region.

The magnitudes of the coefficients of these accessibilities are yet slightly different from those in the previous models. The coefficient of absolute labour accessibilities is lower than that in Model 3 whereas the coefficient of relative labour accessibility is similar to that in Model 3. The differences in the magnitudes might be due to the nature of the Seoul region in which its average employment density is lower than employment centers. Because the average number of jobs in the region is smaller than that in an employment centre, demand for labour force is naturally small in the region. On average, a smaller number of labour force is likely to be employed in the region than in employment centres. Thus, the extent to which access to total labour force influences job growth is less significant than the case for employment centres. This explains the smaller coefficient of absolute labour accessibility in Model 6.

A key finding obtained from the estimated results in Model 4-6 is both absolute and relative labour accessibility are positively related to a change in employment in the region. The degree to which these labour accessibilities influence job growth in the region differ with those in Model 1-3. In the entire Seoul region, access to the total labour force has smaller impacts on job growth than in employment centres.

5.6. Policy Implication

The results of the regression analysis for the growth of employment centres have several important and interesting policy implications. First, the findings obtained from the regression model suggest that different types of accessibility indicators are effective for capturing advantages or disadvantages resulting from access to different types of

facilities or resources. These accessibility indicators may be used by policy makers or researchers who intend to examine their relations with job growth in an employment centre. Using these accessibility indicators, they may seek to disentangle a complex process of employment centre growth in which different types of accessibility play a role. The indicators for distance to transport facilities may be useful to evaluating the proximity effects of these facilities, whereas the absolute and relative labour accessibility indicators may be more useful in cases in which the benefits arising from access to the labour force is required to be captured.

Second, the results obtained from the regression model include interesting policy implications for the link between employment centre growth and transport facilities. The results show that the variation of distance to a high-speed railway station is statistically significant with a change in jobs in employment centres in the Seoul region. This suggests that a high-speed railway station may be the driver of facilitating employment centre growth, but because of the long and complex process in which the completion of high-speed railway promotes economic development, its impacts on employment centre growth could be delayed or hidden. Policy makers may consider a long-term plan for employment centre growth in regard to the arrival of high-speed railways. For an international airport, I found that the variation of distance to an international airport is statistically significant with job growth of employment centres. This suggests that an international airport may be the driver for employment centre growth, but it depends on various factors, such as a firm's location choice and the rise and fall of industries near an airport. Policy makers may be interested in an international airport, but it may be an undesirable policy option to have an airport as the only source for job growth unless they consider that the link between an airport and an employment centre is not always linear.

Third, the results obtained from the regression model include an important policy finding. The results show that access to the total labour force has positive impacts on job growth in an employment centre as well as in the entire region, although its magnitude is slightly low. Labour force is ubiquitous in an urbanized area and is easily available to firms in an employment centre. That is access to total labour force may be insignificant to employment centre growth. However, it is found that absolute labour accessibility is a significant factor for job growth in an employment centre. An important point is not whether the amount of labour force is available around firms but whether employment centres actually have sufficient access to the labour force. The finding shows that the more an employment centre has access to the total labour force, the higher its

performance. It is suggested that increasing the level of absolute labour accessibility is still a practical option for policy makers to target employment centre growth even in an urbanized area where the population density is high.

Finally, the results obtained from the regression model provide some interesting policy findings that policy makers might consider in promoting job growth in an employment centre. The results show that a change in the level of relative labour accessibility is positively related to job growth in both an employment centre and the entire region. Access to the net labour force is important to a change in the number of jobs in employment centres as well as in the region. This finding highlights that competition for workers among employment centres is an important factor to be considered in determining the size of the labour force reached by firms in an employment centre and the region. The link between access to the net labour force and job growth is, to some extent, subject to the level of competition for workers with skills. An important policy objective, in this regard, is to apply relative labour accessibility, which considers both the 'demand' and 'supply' sides of accessibility, to policy for job growth in the region and employment centres.

5.7. Conclusion

This chapter aimed to understand the relationship between transport-induced labour accessibility and job growth in an employment centre. A distinctive feature compared to previous studies is that I improved the quality of the accessibility indicators to capture disaggregated interactions between the labour force and employment centres. I focused on a change in the number of jobs in an employment centre in relation to the level of transport-induced labour accessibility, controlling for variables relating to the growth of employment centres.

Based on the results obtained from the regression model, I showed that different types of accessibility indicators are useful in evaluating employment centre growth in relation to access to facilities, resources and the labour force. With improved ways of measuring such accessibilities, these indicators are effective in capturing changes in the level of absolute and relative labour accessibilities and access to transport facilities. These accessibility indicators may be useful for policy makers to determine how employment centres grow with changes in the level of such accessibilities and to evaluate which

accessibility indicator is a key determinant of centre growth.

Based on the results obtained from the regression model, I showed that distance to a high-speed railway station is significantly related to the growth of employment centres in the Seoul region. Whether an employment centre is close to a high-speed railway station is negatively relevant to the job growth of an employment centre. This may be attributed to the fact that the spatial economic impacts of the KTX had not yet been fully realised in the area around the stations by the time this study was conducted. The finding could also be the result of the complex and difficult nature of the transformation process driven by high-speed railways. The results suggest that a high-speed railway station may be the driver for facilitating employment centre growth, but because of the long and complex process in which high-speed railway promotes economic development, its impacts on employment centre growth could be delayed or hidden.

The results obtained from the regression model show that distance to an international airport is negatively related to the growth of employment centres. This could be the result of the growth trajectory of the industry sector near an airport or firms' location choices in the Seoul region. This is partly in line with the finding in a previous study that employment centre growth depends on the rise and fall of industries near an airport. The results suggest that an international airport may be a factor affecting employment centre growth, but its association with job growth could depend on various factors, such as a firm's location choice and the rise and fall of industries near an airport. This highlights that it may be an undesirable policy option for policy makers who want employment centres to grow to have an airport as the only source for job growth, unless they take into account that the link between an airport and employment centre is not always linear.

Based on the results obtained from the kernel estimation, I showed that employment centres in the Seoul region are not very different from each other in terms of the level of absolute access to the labour force. This indicates that, to a certain degree, they are connected to a potential labour force pool via the transport infrastructure, mainly because the labour force is ubiquitous in an urbanised area. I also showed that employment centres in the Seoul region are different from each other in terms of the level of relative access to the potential labour force. They differ in the degree to which each employment centre reaches the net labour force because they compete for the potential labour force in the region. These results suggest that a key feature distinguishing employment centres in the Seoul region is not the level of absolute labour accessibility, but the level of relative labour accessibility.

Based on the results obtained from the regression model, I showed that absolute labour accessibility has a positive relationship with job growth in an employment centre. The influence of access to the total labour force on the growth of employment centres is statistically significant, although its magnitude is relatively low. A key finding in this result is that despite of the fact that labour force is distributed everywhere in an urbanized area, access to the total labour force has significant impacts on employment centre growth. An important point is not whether the amount of labour force is available but whether employment centres actually have sufficient access to the labour force. This finding highlights that increasing the level of access to the total labour force will be still effective in increasing the performance of employment centres, although its magnitude is more or less not significant. Having more access to the total labour force is still a practical option for job growth in an urbanized area where the population density is high.

I found evidence that the relative access to the labour force is positively related to job growth in both an employment centre and the region. The higher the level of access to the net labour force, the more the number of jobs in employment centres grows. This confirms the hypothesis that access to the net labour force is one of key determinants of employment centre growth. The results suggest that the degree to which the labour force is available to an employment centre via transport networks is subject to the level of competition for workers in the Seoul region, as relative labour accessibility considers both the 'demand' and 'supply' sides of accessibility. A key finding is that increasing the level of access to the net labour force is an effective option for policy makers to increase job growth in both an employment centre and the region.

The results obtained from the regression model also showed that the growth of employment centres is determined by changes in the number of jobs in four major industries: manufacturing, service, retail and communication. A change in employment in these industries are positively associated with job changes in employment centres. Of these four industries, the service and communication industries have the largest impacts on employment centre growth. The results also show that job growth in employment centres is related to variables such as employment density and population density in employment centres.

6. The Effect of Rail Transit Investment on Residential and Commercial Land Values in Seoul

6.1. Introduction

In recent years, urban rail transit has regained traction as a planning tool for tackling a variety of issues in urban and regional areas in Asian and western countries. Investment in rail transport infrastructure requires a great amount of public spending and subsidies for its construction and maintenance. It also demands political agreement on the delivery of rail transit for all citizens who pay taxes. Moreover, it is increasingly recognised that the time-saving benefits of rail transit become relatively less significant in dense urban areas, mainly due to its inflexibility in terms of routes and stops compared with automobiles and buses (Banister & Berechman, 2000).

Despite these downsides, it is well known that rail transit plays a key role in supporting spatial development and promoting the urban and regional economy. There are two major reasons why rail transit investment remains a popular planning tool among policy makers. First, the provision of a new rail transit system can reduce the traffic congestion created by jobs concentrated in large cities like Seoul. Seoul's population has gradually decentralised towards the suburbs over the last several decades. This decentralisation is in part attributable to the high cost of living in Seoul. For example, rent for an average apartment has continuously risen since the financial crisis in 2008; and in the period between mid-2012 and early 2016, rent increased for 46 consecutive months. In addition, the commuting distance across the Seoul region has risen as population decentralisation has continued, although commuting times have generally been reduced over the same period due to commuters' increasing concerns about time management (Ma & Banister, 2006).

The other source of the growing interest in rail transit investment is that it encourages the creation of new spaces and activities or changes to existing ones through interaction with land use. Local and central governments are interested in applying the effects of rail transit investment to regenerate or revitalise areas whose physical and

socio-economic vitality has declined. The provision of rail transit impacts both the types and patterns of activities taking place in a given area and can even make lands more viable for residential and commercial development. The planning policy based on rail transit investment in Seoul has tended to target areas in which houses were hastily constructed during Seoul's rapid development period between the 1960s and 1980s. In addition, many sites in Seoul once used for government offices and public research institutes have become available or are scheduled to become vacant as they begin to relocate their operations outside of the city. This includes defence sites used by the military.

Although rail transit projects appear to be gaining popularity among policy makers in cities and regions in Asian countries, a key question regarding their execution and delivery is how and to what extent these projects will generate accessibility benefits. Evaluating the benefits of rail transit investment is of major interest to policy makers in local and central governments. The value of property or land is widely used as a means to assess the effects of rail transit investment. Also, land values are viewed as a useful indicator of the expected behaviours of stakeholders and the resulting changes in land-use patterns. For this reason, I explore variations in land values to assess the effect of the completion of rail transit on residential and commercial land values.

An extensive amount of scholarly research has been conducted to give governments guidance regarding the effects of rail transit projects (Debrezion et al., 2007; Hess & Almeida, 2007). Most of these studies have explored the relationship between proximity to rail stations and the value of nearby properties, testing the hypothesis that being close to a rail station increases the value of properties. The focus of these studies was on ascertaining how property values change as the distance to rail stations increases. This price gradient is useful for understanding overall changes in property values based on the distance to rail stations. For example, a negative price gradient means that rail transit has positive impacts on property values, and therefore high value-added land use is likely to occur near a rail station.

However, a simple price gradient does not provide a complete picture of the effect of rail transit investment. The provision of rail transit basically reduces travel costs and, interacting with land use, makes changes to the location choice decisions of households and firms. Through this interaction, the effects of rail transit projects may reach the immediate area of rail stations, changing the level of proximity to rail stations, and their secondary or indirect effects may extend further. Land-use changes are likely to take place according to the spatial scope of the rail transit effect. This wider scope

of the rail transit effect is not appropriately accounted for by a simple relation between property values and distances to rail stations.

In this regard, I hold the view that investment in rail transit has wider effects on land plots in the immediate area of rail stations as well as on neighbourhoods within walking distance of rail stations. These wider effects are not appropriately captured by a simple price gradient alone. While it may explain the proximity effects of rail transit, it does not represent a complete picture of the accessibility effects resulting from investment in rail transit. I argue that both the proximity and neighbourhood effects of rail transit investment are evaluated to fully account for the accessibility effects of rail transit investment.

I also argue that an exploration of the impact of rail transit investment on the value of disaggregated land uses is required to identify its relationship to land-use features. In the literature, previous studies on the impact of rail transit on property values have provided limited information on retail and mixed land uses. Accordingly, there is growing demand for more detailed evidence on the effect of rail transit projects in both urban and transport planning. This is because modern society's production and consumption activities have become increasingly diverse and various, which in turn demands flexible and mixed urban spaces that can accommodate such activities.

The objective of this study is to provide empirical evidence on the impact of rail transit in order to improve decision making about rail transit investment, addressing the research question: 'How and to what extent does rail transit investment affect residential and commercial land values?'. I focus on the proximity and neighbourhood effects of rail transit investment according to different types of residential and commercial land. The remainder of this chapter is organised as follows: The next section provides an introduction to a case area as well as a series of procedures for case setup. This is followed by a discussion of the research strategy, including the specification of econometric models and a definition of the measures used to capture the proximity and accessibility effects of rail transit investment. An overview of the data used in this study is reported in Section 6.4. In the exploratory results section, changes in proximity to rail stations before and after the completion of the Seoul Metro Line 9 are described. The main results section provides estimates obtained from three regression models: a multilevel hedonic model, a difference-in-difference model and a quantile regression model. Policy implications drawn from the results are presented in the following section. Finally, I conclude with a summary of the findings and recommendations for future research.

6.2. Case Study Setup

6.2.1. The Case of Seoul Metro Line 9

I use the construction of Seoul Metro Line 9 (SML9) as a case study to explore how and to what extent investment in rail transit impacts residential and commercial land values. Recently, SML9 opened its door to provide additional transport capacity to Seoul's metro network. SML9 was constructed as part of the third Seoul Underground Railway Plan, which was aimed at encouraging balanced urban development across Seoul by providing rail transport infrastructure to areas where public transport accessibility had lagged behind in comparison with other areas in Seoul (Lee, 2003).

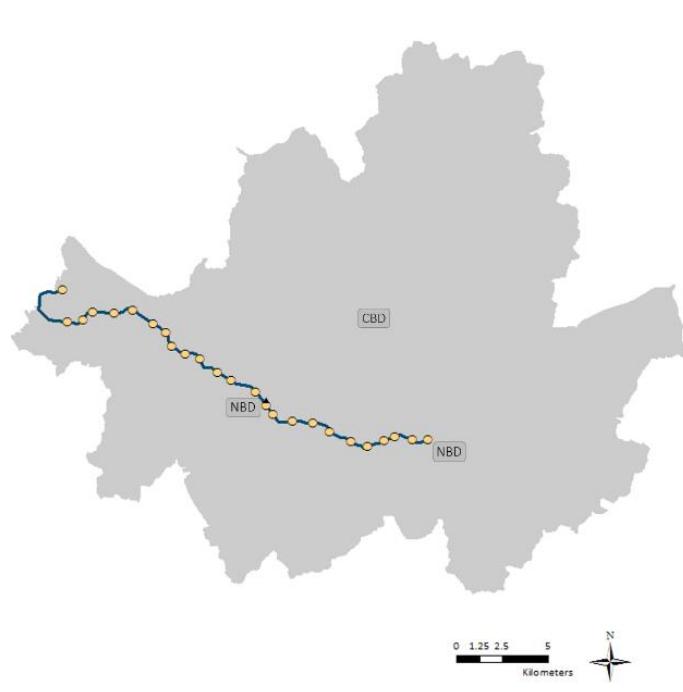
The purpose of SML9 is to construct a rail transit line that directly connects southwestern Seoul to south-eastern Seoul, which has been relatively less connected than other parts of the city. Specifically, the line is intended to provide rail transit to several areas in southwestern Seoul for which rail transit investment was lacking in the first and second underground expansion plans and to link this area to several areas in south-eastern Seoul. SML9 is also intended to tackle overcrowding issues on the existing metro lines caused by increasing travel demands on the part of commuters who reside outside Seoul but work in the city. To do so, SML9 will absorb some of the travel demand originating in satellite cities.

The SML9 project began in July 2009, with 27.0 km of new track and 25 stations. Among these 25 stations, 19 were newly constructed, while the other six were expanded (Metro9, 2015). SML9 is distinctive in that it directly connects two major financial and economic centres in the south of Seoul, Yeouido and Gangnam, calling at domestic and international transport nodes, such as Gimpo International Airport and the National Express bus terminal. Since the opening of SML9, travel times between the two employment centres have been considerably reduced, offering travel cost savings for commuters as well as convenience for businesses. Also, SML9 is the first metro line in Seoul's metro network to adopt standard and express services (see Figure 6-1).

Since the planned route of SML9 crosses Seoul from southwest to southeast, it has received much attention from planners, developers and even researchers regarding how it will impact the economy and the property market in Seoul. The common expectation about its effects is positive overall in terms of its role in contributing to

improved public metro transit as well as reduced travel times and costs. Together with this transit benefit, the impacts of SML9 on property values have been of interest.

Figure 6-1. Seoul Metro Line 9 and its Stations.



6.2.2. Case Study Setup

I set a land plot, i.e., the smallest area of land to which a value can be attached, as the spatial unit of analysis in this chapter. Land divisions in Seoul largely consist of two types of land plots: baseline and individual. While the values of baseline land plots are assigned by the government for taxation purposes on an annual basis, the value of individual land plots are assessed by surveyors with public certificates. I use land plots located within a 2-kilometer distance of SML9 stations, collected from the land registry.

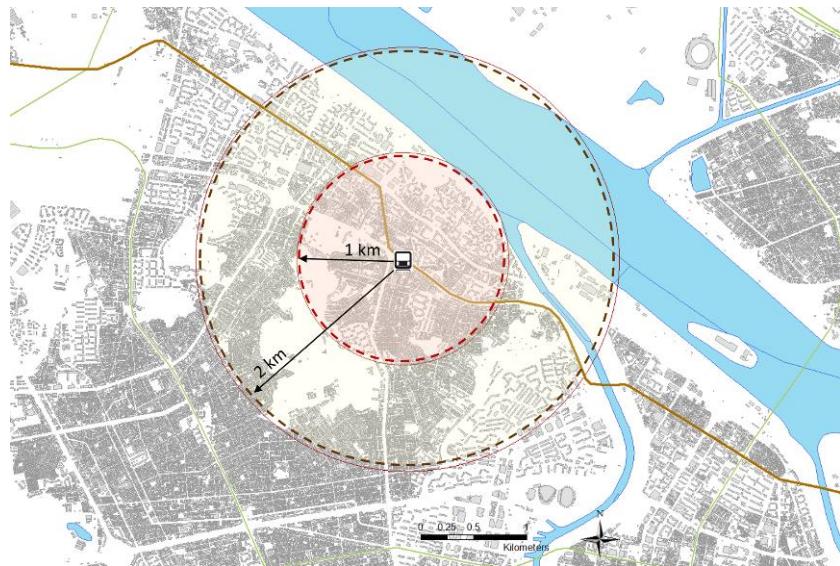
While the definition of the catchment area in which properties are affected by rail transit investment differs according to the study area's geographical characteristics, a radius between 0.5 and 2 kilometres from the railway station has been widely accepted as distinguishing between those properties within the influence of railways and those outside (Billings, 2011). I define the area within a 1-kilometer radius of SML9 stations as being under the influence of rail transit investment, which is also referred to as the treatment group in this study. This determination is based on the idea that properties

within a certain walking distance of rail stations are affected by rail transit investment, whereas properties beyond this range are unlikely to be associated with this investment. A UK-based study on the capitalisation of rail innovation used a concept similar to that used in this study; in that study, the effect of rail innovation was considered to extend to a 20–30-minute walking distance from rail stations (Gibbons & Machin, 2005). Given the higher population density and dense urban fabric in Seoul, I use a 15–20-minute walking distance from stations, which can be translated to a 1-kilometer distance on the assumption that the average walking speed of an ordinary person is 4 kilometres per hour.

I further classify residential and commercial land plots within the 1-kilometer buffer zone into three treatment groups to compare the accessibility benefits of SML9 by both the distance to stations and the neighbourhoods corresponding to the treatment groups. Land plots located within 200 meters of rail stations are defined as the 200-meter treatment group, while those within 500 meters are defined as the 500-meter treatment group. A 1000-meter treatment group consists of residential and commercial lands within a 1000-meter radius of the stations.

Alongside the treatment groups defined above, I also establish a control group to account for changes in unobserved and omitted variables related to neighbourhood features that could potentially influence the effects of SML9 on land values over the period of its construction. A basic rule for choosing the control group is that its properties should have neighbourhood and demographic characteristics similar to those of the treatment groups and yet be unaffected by rail transit investment (McDonald & Osuji, 1995). I define residential and commercial land plots within 1 to 2 kilometres of SML9 stations as controls, since they are comparable to those within the 1-kilometer buffer zone and yet are not affected by SML9. Figure 6-2 shows the control and treatment groups defined in this chapter.

Figure 6-2. The Definition of the Control and Treatment Groups



The temporal frame for the analysis in this study is designated as the two time periods before and after the operation of SML9. Focusing on changes in accessibility resulting from the completion of rail transit projects, I look at the short-term effect of new rail transit investment on land values, rather than its long-term effect. Some previous studies reported that, to a certain extent, the benefits or losses expected from rail transit investment tend to be capitalised some time before rail transit becomes effective with respect to commuters' travel behaviours or travel costs (Yiu & Wong, 2005). However, studies on the long-term effects of rail transit investment may provide little indication of how land values changed before and after the completion of new rail transit infrastructure, because it can be difficult to distinguish the effect of an actual change in accessibility from the effect of an anticipated change.

6.3. Research Strategy

In this section, I develop two accessibility indicators to capture the impact of rail transit investment. Together with the conventional proximity indicator that capture the travel cost saving, these indicators are expected to capture wider benefits arising from the development of rail transit. Three regression models are developed to explore various aspects of the impact of rail transit investment on land values. Multilevel hedonic model

focuses on ascertaining how the hierarchical structure of data accounts for the variation of land values in estimating the effect of rail transit development on land values. Difference-in-difference model pays attention to treatment effect of rail transit investment on residential and commercial land value before and after the development, controlling for changes in variables. It also addresses how different land uses respond to a change in accessibility resulting from rail transit investment. Quantile regression model focuses on lands at different price levels and explores how accessibility benefits of rail transit investment vary across lands with different values.

6.3.1. Accessibility Indicators

It is essential to define an indicator of the accessibility benefit of rail transit. As discussed, rail transit brings travel cost savings to land plots or neighbourhoods near to stations. To capture such benefits, I use the distance from a land plot to the nearest station. Investment in rail transit brings about further benefits to land plots near stations, as a reduction in travel costs theoretically stimulates interaction between economic actors and their wider environment. This is likely to open lands near stations to development by connecting them to places offering economic opportunities. Such benefits are not fully captured by the distance measure (Ahlfeldt, 2013). Thus, to capture changes in the locational centrality of land plots in the urban system, I use two accessibility measures based on a gravity-type form proposed by Hansen (1959) that has been widely used in various strands of literature relating to geography, transport and planning. These accessibility measures are advantageous in that they can evaluate the combined effects of land-use and transport elements and can also incorporate travellers' perceptions of travel costs (Geurs, 2006).

The first indicator, called the absolute employment accessibility indicator, captures a given area's total employment potential in Seoul, which is calculated as the weighted sum of employment discounted by travel cost. The specification for this measure is given in Eq. 6-1. The absolute employment accessibility in this equation refers to the potential for spatially distributed employment opportunities that may be reached from a given location via a means of transportation.

Equation 6-1. Absolute Accessibility Measure for Land Plots in Seoul

$$ACC_i = \sum_j E_j e^{-\alpha T_{ij}}$$

where E_j is employment opportunities (the number of jobs) at *dong* j . T_{ij} is the transport cost between land i and the centroid of *dong* j , and α is the spatial-decay parameter, which represents the extent to which workers value their commuting time. This employment distribution is used to represent production and consumption opportunities at all locations in Seoul. I use the value of -0.0267, estimated in the previous chapter, as the spatial-decay parameter for Seoul.

I also construct a relative employment accessibility indicator that captures a given area's relative employment potential in Seoul, which is equivalent to the ratio of the total number of employment opportunities to the total number of workers (employment opportunity seekers). The relative accessibility indicator takes into consideration the 'supply side of accessibility measurement as well as its 'demand side' — the competition for available employment opportunities.

In the urban system, workers who are suitable for available jobs are not spatially uniformly distributed, and each job is not for only one worker at any moment in time. Workers (the demand side) compete for job opportunities (the supply side). Various levels of demand potential exist around locations of employment opportunities, and thus this demand potential influences levels of employment opportunities. Access to employment opportunities is partly determined by the demand potential for the particular location of the opportunities. In this regard, the demand potential is incorporated in the accessibility indicator, together with employment opportunities. Based on the accessibility indicator presented by Shen (1998), I articulate this concept in the form of equation. A specification for this indicator is shown in Eq. 6-2.

Equation 6-2. Relative Accessibility Measure for Land Plots in Seoul

$$RACC_i = \sum_j (E_j \cdot e^{-\alpha \cdot T_{ij}} / \sum_m D_m \cdot e^{-\alpha \cdot T_{jm}})$$

where E_j refers to employment opportunity in *dong* j. T_{ij} refers to the travel time between *dong* i and j, while T_{jm} represents the travel time between *dong* j and m. D_m is the numerical value of the workforce²⁷ in *dong* m. On the right side of the equation, the numerator refers to the potential supply of employment, whereas the denominator indicates the potential demand for employment in Seoul (Shen, 1998).

6.3.2. Multilevel Hedonic Model

I use multilevel hedonic model to assess the accessibility impact of SML9 on residential and commercial land values. I also intend to ascertain how the hierarchical data structure accounts for the variation of land values in estimating the price effects of SML9. Multilevel hedonic model is used because of the hierarchical data structure in which land plots are nested in ward (*dong* in the context of Seoul). A number of land plots are normally located in *dong*, which means they share neighbourhood characteristics such as development density and economic activity (Jones & Bullen, 1993). Since they have the same neighbourhood attributes, land plots are likely to be correlated with each other. I estimate the multilevel hedonic model in log-log form as it provides better statistical fits than linear formulation. All continuous independent variables and the dependent variable are transformed to natural log form. Multilevel hedonic model used in this analysis is specified in Eq. 6-3.²⁸

Equation 6-3. Multilevel Hedonic Model

$$LV_{ij} = \alpha + \beta A_{ij} + \gamma S_{ij} + \delta N_{ij} + \lambda L_{ij} + \mu_{0j} + \varepsilon_{ij}$$

where LV_{it} denotes log of the CPI-adjusted land value per square meter of a land plot i in *dong* j. α is the overall mean across *dongs*. μ_{0j} is the effect of *dong* j on land values, which is also referred to as neighbourhood-level residual. ε_{ij} is a land plot-

²⁷ Labour force, in this study, is defined as the population whose age falls between 15 and 64.

²⁸ Although one may argue that accessibility attributes can be included among the contextual attributes, I distinguish between accessibility and contextual attributes because accessibility attributes are the main variables of interest in this study.

level residual, which measures the difference between the constant and the intercept for observations within a given *dong*.

Following empirical studies in the literature, I consider four categories of vector variables to account for their influences on the variation in land values: accessibility attribute, physical attribute, neighbourhood attribute and land-use attribute (Cheshire & Sheppard, 1995; Kestens, Theriault & Rosiers, 2004). As mentioned in previous section, the effect of rail transit investment is measured by three indicators: proximity to the nearest rail station, absolute employment accessibility and relative employment accessibility. A_{ij} refers to a vector variable that captures proximity to rail stations from land plot i as well as the level of absolute and relative employment accessibilities in land plot i in *dong* j . S_{ij} stands for a set of variables for the physical characteristics of a land plot i in *dong* j . N_{it} denotes a vector variable that captures neighbourhood characteristics of the area where a land plot i lies. L_{it} stands for a set of variables for land-use attributes of a land plot i .

β , γ , δ and λ are coefficients to be estimated. β is a coefficient of interest which reveals both the effect of proximity to rail stations on land values and the price effects of the absolute and relative employment accessibilities. One percent change in either the proximity or those accessibilities would change 0.01 percent in land values if β will be found 0.01. γ , δ and λ reveal the influence of each independent variable on land values.

6.3.3. Difference-in-Difference Model

I also employ a simple difference-in-difference (DID) model to determine both the proximity effect of SML9 and its neighbourhood effect on the variation in residential and commercial land values. A DID model is a quasi-experimental research approach used to infer the causal relationship between policy changes and subsequent outcomes. When changes in the level of local amenities take place over time due to urban and regional policy, the ways in which property prices respond to these changes are evaluated by an assessment with a DID model. In practice, DID models have been applied to evaluate the effects of policies such as changes in health care procedures, the opening of new schools and the opening of rail stations (Dubé et al., 2013; Gibbons & Machin, 2008).

In this application, the DID model compares the level of land values before and after

the opening of SML9 between the control group and the treatment group with and without exposure. In other words, the DID model compares land values between pre- and post-SML9's construction for lands with exposure to SML9, adjusting the difference among lands without exposure to SML9.

In the DID design, observations $i = (1, 2, \dots, n)$ are observed in two time periods before and after the completion of SML9, $T \in \{0, 1\}$, and are basically grouped as $G \in \{0, 1\}$ such that $G = 1$ indicates the treatment group. I decompose the treatment group into three treatment groups (200-metre, 500-metre and 1000-metre buffer zones) to assess variations in land values by distance among land plots with exposure to SML9 and to determine whether such variations are related to treatment groups by distance to rail stations compared with those land plots without exposure to SML9.

Eq. 6-4 indicates how group variable, G_{ij} , and time variable, T_t , are established in DID model used in this chapter. G_{ij} is basically a variable that equals 1 if a land plot falls into the pre-defined treatment groups j , and 0 otherwise. G_{ij} also stands for both proximity to the nearest rail station and employment accessibility (absolute and relative employment accessibilities) in the treatment groups.

I estimate the DID model in log-log form as it provides better statistical fits than linear formulation. All independent variables and the dependent variable are transformed to natural log form. The specification of a DID model is shown in Eq. 6-5.

Equation 6-4. Difference-in-Difference Variable Setting

$$G_{ij} = \begin{cases} 1 & \text{if land is located in the } j \text{ buffer zone} \\ 0 & \text{otherwise} \end{cases}$$

$$T_t = \begin{cases} 1 & \text{if after the development of SML9} \\ 0 & \text{otherwise} \end{cases}$$

Equation 6-5. Difference-in-Difference Model

$$LV_{it} = \beta_0 + \beta_1 T_t + \sum_{j=1}^3 \delta_j G_{ij} + \sum_{j=1}^3 \theta_j T_t G_{ij} + \gamma X_{it} + \varepsilon_{it}$$

where subscripts i and t denote an individual land plot and a point in time, respectively. LV_{it} is log of the CPI-adjusted land value per square meter of land plot i at time t . X_{it} is a vector of land and neighbourhood characteristics, such as the area of land, land use type, access to the road network, the level of development permit and floor area ratio. One would expect the land-use characteristics of a land plot to determine its value. The maximum floor area ratio allowed by zoning regulations is an example of such characteristic. I expect that the higher the maximum FAR of a land plot, the greater the demand for residential and commercial properties, leading to an increase in the value of these land plots.

β_1 , δ_j , θ_j and γ are coefficients to be estimated. δ_j reveals any change in land values between land plots with and without exposure to the rail transit investment at pre-completion of SML9. θ_j is the coefficient of interest which reveals any change in land values from the pre-development of SML9 to the post-development of SML9 that occurs in the exposed groups and not in the unexposed group. γ reveals the influence of independent variable on land values. ε_{it} is the error term.

The estimated coefficients can be interpreted as follows. δ_j indicates a percent change in land values between lands with and without exposure to SML9 before its completion. θ_j is the difference-in-difference estimates, that is, the percent change in the extent of values between lands with and without exposure to SML9, after controlling for differences between the two groups at pre-development of SML9.

6.3.4. Quantile Regression Model

While the average marginal effect obtained from the linear regression model is useful for understanding how the development of SML9 impacts land values overall, it does not present a complete picture of how SML9 impacts land plots with various features. The relationship between proximity to a rail station, level of employment accessibility and land values may not be constant across lands at different price levels. I hypothesise that changes in accessibility resulting from the completion of SML9 may work differently with different price segments, and thus its benefits might vary across lands at different price levels.

I apply a quantile regression model to test this hypothesis, and the estimates obtained from the model are expected to provide a more complete picture of the effects of SML9 on residential and commercial land values. The quantile regression model is first proposed by Koenker and Bassett (1982) as both an alternative and complement to standard regression models. I define 10 quantiles of the conditional distribution of land values by dividing it into equal intervals, ranging from 10% to 90%, following statistical practices in Wang, Potoglou, Orford, and Gong (2015). This choice corresponds to the standard used to divide income groups in South Korea, i.e., total households are divided into 10 groups based on income (The Statistics of Korea, 2016).

I estimate the quantile regression model in log-log form as it provides better statistical fits than linear formulation. All continuous independent variables and the dependent variable are transformed to natural log form. The specification of a quantile regression model is shown in Eq. 6-6.

Equation 6-6. Quantile Regression Model

$$LV_i = \alpha(\tau) + \beta_0(\tau)S_i + \beta_1(\tau)N_i + \beta_2(\tau)L_i + \gamma(\tau)A_i + \varepsilon_i$$

where i denotes an individual land plot, τ refers to the corresponding quantile of land value; $\alpha(\tau), \beta_0(\tau), \beta_1(\tau), \beta_2(\tau)$, and $\gamma(\tau)$ are the τ th quantile coefficients to be estimated. S_i is a vector of the physical characteristics of land plot i . N_i denotes a vector of the neighbourhood characteristics of the area where a land plot i is located. L_i stands for a vector of variables for land-use attributes of a land plot i . A_i represents a vector of variables that captures the distance to the nearest rail station, the absolute employment accessibility and the relative employment accessibility. The specification presented in Eq. 6-6 is estimated for both residential and commercial lands within a 1-kilometer radius of the station. Also, I estimate this specification for the pre- and post-completion of SML9 to compare potential differences in the association between land values and the variation in levels of accessibility effects of rail stations across different price groups of lands.

6.4. Data

The main data used in this chapter are the values of residential and commercial land

plots collected from the Korean Land Registry as maintained by the Ministry of Land, Transport, and Maritime Affairs in South Korea. The land value recorded in the land registry is the assessed value annually surveyed by the central and local governments for taxation purposes. The baseline land plots are surveyed first by the central government at the end of a given year; based on the assessed value of baseline land plots, individual land plots are then surveyed by publicly certified surveyors or the local government, taking into account various locational and socioeconomic attributes (MLTM, 2014).

As SML9 runs across five boroughs and 21 *dongs* in Seoul, I first collected data for land plots within these administrative districts. Of these land plots, observations located within the spatial scope of this chapter are ultimately selected as samples. Land plots falling within the calculated 1-kilometer radius were collected for the two time periods of 2008 and 2010. Increasing the radius to 2 kilometres, land plots falling between the 1-kilometer and 2-kilometer radius were collected and defined as the control group. This procedure is repeated for SML9's 25 stations. In total, 70,800 land plots are selected for the two time periods, 37,186 of which are located within a 1-kilometer radius of SML9 stations, with the remainder located between 1 and 2 kilometres of SML9 stations.

The land registry includes a range of information on the characteristics of a land plot, such as its slope, shape, size, road accessibility and land use. The level of each variable is obtained from a score given by the surveyor. For example, for the variable describing the shape of a land plot, scores ranging from 1 to 10 are given; when its shape is square, which is the most desirable condition for a land plot, a score of 1 is assigned. In a similar fashion, for the variable describing the slope of a land plot, a score of 2 is given when the slope of a land plot is flat. More detailed descriptions of how scores are given by the surveyor in relation to the physical characteristics of land plots are presented in Appendix D. I collected this information to account for its potential effect on land values.

As land values are determined by physical, neighbourhood and land-use features, I also collected relevant information that explained these characteristics from various sources, such as the Korean Census, the Land Registry and the statistics for land and transport. Using the information collected, I created a series of control variables to incorporate them into regression models. For example, a variable describing green amenities was created by calculating the distance from a land plot to the nearest park or green space, using the transport network data for Seoul.

Table 6-1 presents descriptive statistics of the variables included in the dataset. The mean and standard deviation statistics are summarised for residential and commercial lands for the pre- and post-completion stages of SML9. In the interest of space, the shortened variable names are used in the left-hand column. The number of observations is 35,400 for each period, 20,874 of which represent residential land plots. In the pre- and post-opening of SML9, I observe variations in land values when they are adjusted by the consumer price index (CPI). Residential land values per square meter rose by 6.2% before and after the operation of SML9, while commercial land values increased by 4.3% over the same period.

In terms of land use, about 58% of residential land plots are used for housing, whereas 7% are used for apartments, the favourite residential type in Seoul. The average of the maximum FAR allowed by the zoning system for residential lands in the study area in Seoul is 200%, which means that two times the floor area can be built on the corresponding land plot. For commercial lands, the sample collected is dominated by retail. More than 60% of commercial land plots are being used for retail, while mixed-use land plots comprise 12% of the sample.

Table 6-1. Summary Statistics of Variables in the Regression Models

Name of variables	Description	Residential land plots		Commercial land plots	
		Mean	S.D.	Mean	S.D.
Land value for the pre-completion phase of SML9	CPI-adjusted value of land plot per square meter before the completion of SML9	2,474,995	1,183,519	4,892,249	3,330,834
Land value for the post-completion phase of SML9	CPI-adjusted value of land plot per square meter after the completion of SML9	2,561,088	1,220,472	5,026,098	3,417,160
Proximity to rail stations for the pre-completion phase of SML9	The distance between land plots and the nearest station before the completion of SML9	840.90	611.92	677.40	608.13
Proximity to rail stations for the post-completion phase of SML9	The distance between land plots and the nearest station after the completion of SML9	505.20	249.80	401.63	229.03
Physical features					
Area	The area of a land parcel (m ²)	498.46	3,536.13	399.52	3,065.70
Shape	The shape of a land parcel, ranging from 1 to 5	3.58	2.23	3.28	1.71
Slope	The slope of a land parcel, ranging from 1 to 5	2.37	0.61	2.05	0.23
Road access	The way to access the main road network with a range between 1 and 11	8.12	1.54	5.69	2.70
Neighbourhood features					
Dist_CBD	Distance to CBD (meters)	9,537	2,753.40	9,085	2,331.86
Dist_Gangnam	Distance to subcentre, Gangnam (meters)	11,296	6,201.52	10,585	5,758.15
Dist_YDP	Distance to subcentre, Yeongdeungpo (meters)	149,449	2,870.27	149,159	2,766.80
Park amenity	Distance to park (meters)	205.71	115.31	242.19	131.65
School amenity	Distance to school (meters)	300.97	175.42	362.11	193.68
Retail amenity	The retail area per person (m ² per person)	1.14	1.09	1.42	1.14
Portion of residential development permitted	The ratio of the area permitted for residential development to the total area permitted by the authority	0.26	0.17	—	—
Portion of commercial development permitted	The ratio of the area for commercial development to the total area permitted by the authority	—	—	0.53	0.14
Portion of developable land	The ratio of developable lands to total lands	0.37	0.10	0.36	0.09
Land-use features					

House	Dummy variable: 1 if land is used for house, 0 otherwise	0.58	0.49	–	–
Low-rise multi-family housing ²⁹	Dummy variable: 1 if land is used for low-rise multi-family housing, 0 otherwise	0.22	0.41	–	–
Apartment	Dummy variable: 1 if land is used for apartment, 0 otherwise	0.07	0.26	–	–
Raw residential land	Dummy variable: 1 if land is residential but not in use, 0 otherwise	0.05	0.21	–	–
Retail	Dummy variable: 1 if land is used for retail, 0 otherwise	–	–	0.43	0.50
Office	Dummy variable: 1 if land is used for office, 0 otherwise	–	–	0.07	0.26
Mixed	Dummy variable: 1 if land is used for mixed-use, 0 otherwise	–	–	0.28	0.45
Retail raw land	Dummy variable: 1 if land is retail-use but not in use, 0 otherwise	–	–	0.02	0.14
Mixed raw land	Dummy variable: 1 if land is mixed-use but not in use, 0 otherwise	–	–	0.01	0.10
Floor Area Ratio	The maximum floor area ratio allowed by the zoning system	209.96	65.52	320.96	190.54
ln (Floor Area Ratio)	Log of the maximum floor area ratio allowed by the zoning system	5.31	0.28	5.65	0.45

6.5. Exploratory Results

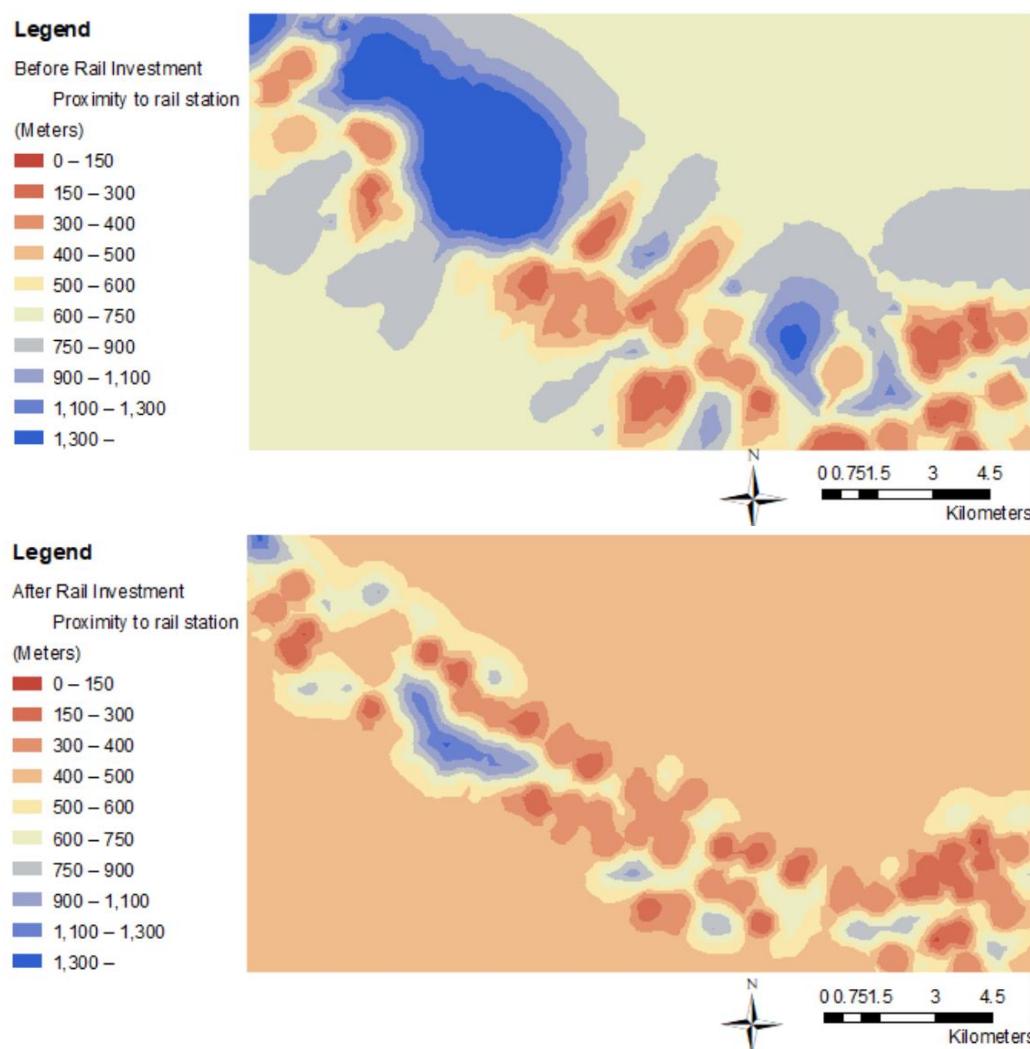
Here I report the results on the changes in proximity to rail stations before and after the completion of SML9. Figure 6-3 shows spatially interpolated levels of proximity to rail stations for the pre- and post-completion phases of SML9. Changes in proximity to rail stations are captured by the distance from land plots to the nearest station before and after the completion of SML9. All the measurements and calculations are carried out using ArcGIS software. The level of proximity to rail stations before the opening of SML9 is mapped on the left-hand diagram, coded in predefined domains. The corresponding level after the completion of SML9 is mapped on the right-hand diagram.

Looking at the left-hand side of the diagram, the level of proximity to rail stations is significantly low in the northwest of the study area and is also relatively low in the southeast of the study area. Since the opening of SML9, the level of proximity to rail

²⁹ Low-rise multi-family housing, hereafter abbreviated as “low-rise MFH” differs from apartment in physical attributes and public awareness in the Korean context. Apartment is usually designed with better layout and is constructed with additional facilities and services such as garden, security system, and public playground. In addition, apartment is the most popular residence type in Korea.

stations has improved overall in the study area, although the spatial extent and degree of proximity to rail stations vary. As expected, land plots in the northwest of the study area have acquired the best benefits in terms of proximity to rail stations, as they have become connected to the rail network through the completion of SML9. To a lesser extent, land plots in the southeast of the study area have also experienced an increase in proximity to rail stations after the opening of SML9.

Figure 6-3. A Change in Proximity to Rail Station Before and After Seoul Metro Line 9



The diagrams also show that the completion of SML9 brings proximity effects to areas that are already served by the existing metro lines. For example, the level of proximity to rail stations improved in Yeouido and Young-deungpo, where the existing metro lines offer rail services. In terms of the spatial extent of SML9's accessibility effect, the

highest intensity is exhibited in the immediate vicinity of SML9 stations and gradually decreases as the distance to the stations increases. This confirms that the control and treatment groups are appropriately defined in terms of the radial distance from subway stations. A similar pattern holds for both absolute employment accessibility and relative employment accessibility.

In sum, the distance from land plots to the nearest station in the study area decreased mainly because SML9 gave the plots enhanced access to the transport network. As seen in Table 6-1, residential and commercial land values in the study area increased over the study period. In combination with the change in proximity to rail stations observed in Figure 6-3, a possible inference may be that a relationship exists between variations in residential and commercial land values and the distance to rail stations. However, the association between changes in the distance to rail stations driven by rail transport innovation and variations in land values has not yet been positively proven, because other factors may be correlated with land values. More sophisticated analysis is required to reveal whether changes in proximity to rail stations lead to variations in land values. The effects of changes in proximity to rail stations on land values are tested by the regression models specified in the next section.

6.6. Regression Results

6.6.1. Multilevel Model Results

The results obtained from the multilevel hedonic models are presented in Table 6-2 and 6-3. Since the accessibility impact of SML9 may vary due to diverse land types, I estimate multilevel hedonic models separately for residential lands in Table 6-2 and for commercial lands in Table 6-3. To determine the accessibility impact of SML9, I also estimate residential and commercial multilevel hedonic models for pre-completion of SML9 and post-completion of SML9. The estimates for pre-completion of SML9 are presented under columns (1) – (3) in each table whereas those for post-completion of SML9 are presented under columns (4) – (6). The focuses of these models are on assessing the accessibility impact of SML9 on land values before and after the completion of SML9 and on ascertaining how the hierarchical data structure accounts for the variation in land values in estimating the price effects of SML9.

The estimates for between-dong variance and between-land plot variance provide

subtle but interesting results regarding the variation in land values. For parameters for variance in Model 1 Model 1 in Table 6-2, the between-dong (level 2) variance in land value is estimated as 0.0371, and the within-dong between-land plot (level 1) variance is estimated as 0.0215. Thus, the total variance is 0.0586, which is relatively low. This might suggest that hierarchical structure of the data has little association with the variation in land values.

With those coefficients, the variance partition coefficient can be calculated, which shows how the variation in land values is explained by the difference between dong. The variance partition coefficient is 0.633, which means 63.3% of the variance in land values can be attributed to the difference between dong. This suggests that the variation in land values is largely related to difference between neighbourhood features at the dong level. Comparing between Model 1 and Model 4, the variance partition coefficient has slightly increased from 63.3% to 66.4%, which indicates that the degree to which the difference between dong influences the variation in land values has raised. This may be due to the opening of SML9.

The accessibility effects resulting from the completion of SML9 are described by three variables, one of which captures distance to the nearest station, while the other two capture absolute and relative employment accessibilities, respectively. The latter two accessibility variables are calculated using the specifications defined in Eq. 6-1 and 6-2. As the three accessibility variables may be strongly inter-correlated, a model that includes these variables together would have caused a high level of multicollinearity. To obtain stable estimates, I estimate the models with each of these three variables, generating three separate estimates for both residential and commercial lands.

In Column (1), the coefficient of distance to the nearest rail station is found negative and statistically significant at the 1-percent level, indicating that close proximity to rail stations is related to a change in residential land values. The closer residential lands are to a rail station, the higher their values. Yet, its magnitude is somewhat small at -0.0077, which may be because this area did not receive enough of rail transit service before the development of SML9.

The estimated results for absolute and relative employment accessibilities are reported in Column (2) and (3), which are similar to that for distance to rail stations. The coefficients of absolute and relative employment accessibilities are found positive and statistically significant at the 1-percent level. The more opportunities for employment from a land plot are provided by SML9, the higher the value of the corresponding

residential land. Yet, similar to results for distance to rail stations, the magnitudes of the coefficients of absolute and relative employment accessibility are small at around 0.0349 and 0.0284, respectively. This indicates employment opportunities in this area are relatively low before the completion of rail transit.

Comparing the estimates for pre-completion of SML9 with those for post-completion of SML9, the coefficients of the three accessibility variables have considerably increased. For distance to the nearest rail station, the coefficient has increased around seven times, from -0.0077 to -0.0529. The distance to the nearest station has become significantly close to residential land plots, and this has raised residential land values. The result suggests that a 1% decrease in the distance to the nearest rail station would lead to a marginal increase in residential land values by 0.052% on average. This finding is consistent with previous studies.

The coefficients for absolute and relative employment accessibilities have significantly increased after the completion of SML9. More employment opportunities have been brought about by the development of SML9. The price effect of absolute employment accessibility after the opening of SML9 is 0.313, which is around nine times higher than that before the development of SML9. This suggests that the value of residential lands would increase by 0.313% for additional 1% increase in the level of absolute employment accessibility. Similar findings hold for relative employment accessibility.

The magnitudes of the coefficients of absolute and relative employment accessibilities are larger than that of distance to the nearest rail station. This may suggest that variations in land values are better explained by the two accessibility indicators than by the indicator of distance to the nearest rail station. This difference may be derived from the following two types of benefits provided by rail transit investment.

While rail transit investment offers a reduction in the distance to a rail station by providing additional nodes connecting to the rail network, it also connects lands to places with wider employment opportunities, stimulating interaction with people and ideas. The latter benefit is likely to have larger impacts on lands than the former, such as making such lands viable and providing the public or private sectors with development opportunities. While the indicator of distance to a rail station can capture the benefit of proximity to a rail station, it cannot capture the benefits arising from increased interaction and development opportunities. This indicates that the absolute and relative accessibility indicators may be more effective and useful for investigating those benefits. Overall, the estimated results show that both absolute and relative

accessibility indicators can be used as effective means of evaluating the benefits of rail transit investment.

The results obtained from the multilevel hedonic model also show that the coefficients of both the area of land and FAR are positive and statistically significant. The physical features of land plots are found to affect residential land values significantly. The coefficient of land slope indicates that flat land plots receive higher price premiums than land plots with steep slopes. Similarly, land plots with regular shapes are more favoured on the market than land plots with odd shapes. With regard to the type of residential lands, apartment is the most favourable residential type in the area.

All other variables show the expected signs of coefficients with statistical significance and are consistent with the findings in the literature. For example, residential land plots with immediate access to road network have higher values than those having less access. Similarly, residential land plots close to a school show higher values compared with those far away. Interestingly, the coefficients for both retail amenity and residential development permission are statistically insignificant before the completion of SML9. Yet, these coefficients become statistically significant after the completion of SML9

Table 6-2. Results of Multilevel Hedonic Model for Residential Land

Variable	Pre-completion of SML9						Post-completion of SML9					
	(1)		(2)		(3)		(4)		(5)		(6)	
	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.
Proximity to stations	-0.00775**	0.0033	-	-	-	-	-0.0529***	0.0026	-	-	-	-
Absolute accessibility	-	-	0.0349**	0.0109	-	-	-	-	0.313***	0.0152	-	-
Relative accessibility					0.0284**	0.0112					0.317***	0.0154
Distance to CBD	-0.875***	0.0327	-0.880***	0.0327	-0.879***	0.0329	-0.810***	0.0311	-0.651***	0.0335	-0.663***	0.0332
Distance to sub-centers	0.182***	0.0077	0.185***	0.0077	0.185***	0.0077	0.160***	0.0073	0.168***	0.0073	0.166***	0.0073
Greenspace amenity	0.0124***	0.0020	0.0132***	0.0021	0.0130***	0.0021	0.0084***	0.0019	0.0087***	0.0019	0.0085***	0.0019
School amenity	-0.0134***	0.0023	-0.0136***	0.0023	-0.0134***	0.0023	-0.0171***	0.0022	-0.0189***	0.0022	-0.0188***	0.0022
The area of land	0.0220***	0.0012	0.0221***	0.0012	0.0221***	0.0012	0.0180***	0.0012	0.0181***	0.0012	0.0181***	0.0012
Floor space by zoning	0.258***	0.0061	0.259***	0.0061	0.259***	0.0061	0.236***	(0.0059	0.242***	0.0058	0.242***	0.0058
House	-0.0262***	0.0042	-0.0265***	0.0042	-0.0264***	0.0042	-0.0277***	0.0040	-0.0292***	0.0040	-0.0289***	0.0040
Flat	-0.0368***	0.0046	-0.0369***	0.0046	-0.0369***	0.0046	-0.0348***	0.0043	-0.0358***	0.0043	-0.0356***	0.0043
Apartment	0.164***	0.0062	0.163***	0.0062	0.163***	0.0062	0.179***	0.0059	0.180***	0.0059	0.181***	0.0059
Shape	-0.0104***	0.0005	-0.0104***	0.0005	-0.0104***	0.0005	-0.0111***	0.0005	-0.0109***	0.0005	-0.0109***	0.0005
Slope	-0.0773***	0.0026	-0.0775***	0.0026	-0.0774***	0.0026	-0.0720***	0.0025	-0.0730***	0.0025	-0.0729***	0.0025
Land plot's access to road network	-0.0370***	0.0009	-0.0370***	0.0009	-0.0370***	0.0009	-0.0382***	0.0008	-0.0387***	0.0008	-0.0386***	0.0008
Retail amenity	0.0307	0.0841	0.0346	0.0845	0.0333	0.0844	0.191***	0.0506	0.179***	0.0513	0.179***	0.0509
Portion of residential development permission	-0.236	0.146	-0.224	0.147	-0.228	0.147	0.171**	0.0561	0.173**	0.0568	0.172**	0.0564
Constant	19.86***	0.396	19.36***	0.398	19.84***	0.393	20.66***	0.311	14.46***	0.453	19.01***	0.329
$\zeta_{\mu 0}^2$	0.03716		0.03747		0.03736		0.03820		0.03924		0.03869	

ς_e^2	0.02153	0.02152	0.02153	0.01933	0.01931	0.01931
Adjust R-square	0.5766	0.5745	0.5752	0.5635	0.5557	0.5598
Observations	20874	20874	20874	20874	20874	20874

Note: * denotes significance at the 10 percent level; ** denotes significance at the 5 percent level; *** denotes significance at the 1 percent level

Table 6-3 presents the estimated results for commercial lands. As carried out for residential lands, separate estimation for the three accessibility indicators are carried out to obtain stable results. The estimates for pre-completion of SML9 are presented under columns (1) – (3) whereas those for post-completion of SML9 are presented under columns (4) – (6).

For parameters for variance in Model 1 in Table 6-3, the between-dong (level 2) variance in land value is estimated as 0.0981, and the within-dong between-land plot (level 1) variance is estimated as 0.0499. Thus, the total variance is 0.0148, which is higher than residential lands but still relatively low in general. The hierarchical data structure explains the share of variance slightly better in commercial lands than in residential lands, but the variation in commercial land values is little relevant to the grouping structure of data.

The variance partition coefficient is 0.662, which means 66.2% of the variance in land values can be attributed to the difference between dong. The variance in commercial land values is explained larger by the difference between dong than by the difference between land plots. Comparing between the period before and after the completion of SML9, the variance partition coefficient has decreased from 66.2% to 58.7%, which indicates that the degree to which the variance in land values is affected by the difference between dong has decreased.

The estimated results for distance to the nearest stations in Column (1) show that its coefficient is found negative and statistically significant at the 1-percent level, similar to those for residential lands. As found in previous studies, close proximity to rail station is related to a change in commercial land values in Seoul. Yet, unlike residential lands, the magnitude of the coefficient of distance to rail stations is not small at -0.0516, which might indicate that to some extent commercial lands were being more benefit from connection to rail stations than residential lands before the development of SML9.

Similar results hold for absolute and relative employment accessibilities. Their coefficients are found positive and statistically significant at the 1-percent level. The more opportunities for employment are provided by SML9, the higher the value of the corresponding commercial lands. The magnitudes of the coefficients of absolute and relative employment accessibilities are larger in comparison to that of distance to rail stations. Compared with the corresponding coefficient for residential lands, the magnitudes of those accessibilities are larger, indicating that commercial properties are more sensitive to the degree of employment accessibility than residential properties.

Comparing between the estimates for pre-completion of SML9 and those for post-completion of SML9, the coefficients of the three accessibility variables have increased. Yet, the variations in these coefficients are not as large as those in residential lands, which shows that residential

lands have received more accessibility benefits from the development of SML9. The smallest coefficient variation has been observed with distance to the nearest rail station, increased by 62%, from -0.0516 to -0.0835.

Compared to the coefficient of distance to rail stations, those of absolute and relative employment accessibilities have increased larger after the completion of SML9, from 0.0690 to 0.514 for the case of relative employment accessibility. The development of SML9 has increased more the level of absolute and relative employment accessibilities than distance to rail stations with regard to the variation in commercial land values. For example, for additional 1% increase in the level of absolute employment accessibility, the value of commercial lands would increase by 0.496%.

For other independent variables, similar results to residential lands are found. The coefficients of both the area of land and FAR are positive and statistically significant. The coefficient of land slope indicates that flat land plots receive higher price premiums than land plots with steep slopes. With regard to the type of commercial lands, retail is the most favourable commercial type in the area. Office is the second favourable commercial land type.

Several variables that are significant determinants of residential land values turn out insignificant in the commercial lands model. For example, distance to school variable is not a significant coefficient in the commercial model. Intuitively, this may be because being close to a school has little association with variations in commercial land values.

All other variables show the expected signs of coefficients with statistical significance and are consistent with the findings in the literature. For example, commercial land plots with immediate access to parks have higher values than those far away from parks and green areas. Also, commercial land plots with immediate access to road network have higher values than those having less access. Interestingly, the coefficients for both retail amenity and commercial development permission are statistically insignificant before the completion of SML9. Yet, these coefficients become statistically significant after the completion of SML9.

Table 6-3. Results of Multilevel Hedonic Model for Commercial Land

Variable	Pre-completion of SML9						Post-completion of SML9					
	(1)		(2)		(3)		(4)		(5)		(6)	
	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.
Proximity to stations	-0.0516***	0.0038	-	-	-	-	-0.0835***	0.0032	-	-	-	-
Absolute accessibility	-	-	0.0634***	0.0161	-	-	-	-	0.496***	0.0235		
Relative accessibility	-	-			0.0690***	0.0164	-	-			0.514***	0.0238
Distance to CBD	0.194***	0.0522	0.236***	(0.0529	0.228***	0.0532	0.270***	0.0491	0.495***	0.0517	0.484***	0.0514
Distance to sub-centers	0.00974	0.0109	0.0172	0.0110	0.0172	0.0110	-0.00597	0.0103	0.00649	0.0104	0.00423	0.0104
Greenspace amenity	0.0526***	0.0035	0.0557***	0.0035	0.0557***	0.0035	0.0467***	0.0033	0.0529***	0.0034	0.0523***	0.0034
School amenity	-0.00108	0.0042	0.00223	0.0042	0.00214	0.0042	-0.000605	0.0040	-0.000507	0.0040	-0.000806	0.0040
The area of land	0.00362*	0.0017	0.00351*	0.0017	0.00350*	0.0017	0.00145	0.0016	0.000982	0.0016	0.00107	0.0016
Floor space by zoning	0.303***	0.0056	0.312***	0.0056	0.312***	0.0056	0.293***	0.0053	0.299***	0.0054	0.299***	0.0054
Slope	-0.0597***	0.0088	-0.0610***	0.0088	-0.0610***	0.0088	-0.0512***	0.0083	-0.0554***	0.0084	-0.0550***	0.0084
Road	-0.0603***	0.0008	-0.0603***	0.0008	-0.0603***	0.0008	-0.0609***	0.0007	-0.0613***	0.0007	-0.0613***	0.0007
Shape	0.00191	0.0011	0.00210	0.0011	0.00209	0.0011	0.00210*	0.0010	0.00208*	0.0010	0.00206	0.0010
Office	0.191***	0.0087	0.194***	0.0088	0.193***	0.0088	0.187***	0.0083	0.188***	0.0083	0.187***	0.0083
Retail	0.213***	0.0053	0.214***	0.0053	0.214***	0.0053	0.202***	0.0050	0.203***	0.0051	0.203***	0.0051
Mixed	-0.00733	0.0055	-0.0106	0.0056	-0.0105	0.0056	-0.0126*	0.0052	-0.0131*	0.0053	-0.0131*	0.0053
Retail amenity	0.266	0.1940	0.238	0.198)	0.242	0.198	-0.369***	0.0871	-0.410***	0.0858	-0.405***	0.0847
Portion of commercial development permission	-0.528	(0.525)	-0.452	0.536)	-0.465	0.534	3.045***	0.629	3.188***	0.620	3.158***	0.612
Constant	11.60***	0.576	9.934***	0.602	10.90***	0.581	13.38***	0.551	3.851***	0.718	10.98***	0.560
$\zeta_{\mu 0}^2$	0.09817		0.10217		0.10136		0.06412		0.06220		0.06069	

ς_e^2	0.04992	0.05047	0.05047	0.04498	0.04559	0.04553
R-squared	0.6083	0.6039	0.6040	0.6386	0.6337	0.6342
Observations	14489	14489	14489	14489	14489	14489

Note: * denotes significance at the 10 percent level; ** denotes significance at the 5 percent level; *** denotes significance at the 1 percent level

6.6.2. Difference-in-Difference Model Results

In this section, a DID model is used to reveal how and to what extent the completion of rail transit leads to changes in the overall neighbourhood in the surrounding area of rail stations and to changes in the relationship between variations in land values and the three accessibility indicators: distance to rail station, absolute employment accessibility and relative employment accessibility. I explore changes in residential and commercial land values before and after the completion of SML9 with regard to changes in proximity to rail station as well as in employment accessibilities.

6.6.2.1. Estimated Results for Residential Land

Table 6-4 presents the results of a DID model for residential lands. Since estimates are likely to vary by the diverse types of residential lands, I separate the sample into three types of residential lands: house, low-rise multi-family housing (MFH) and apartment. I look into SML9's effect for the three predefined treatment groups to assess how the effect varies across the different neighbourhoods corresponding to the groups. The focus of analysis is on real changes in both the distance to a rail station and employment accessibilities resulting from rail transit investment and their associations with land values. The results are organised for the three types of residential lands, alongside the results for all residential land plots.

Any changes in the values of land plots in the treatment groups are controlled for by land plots located outside the influence of the SML9's construction. The neighbourhood effect of SML9 is captured by the coefficient of SML9 opening \times treatment, which calculates the interaction between the time periods before and after the SML9's construction and the spatial locations of lands, depending on whether they fall into the control group or the treatment group.

The coefficient for all residential lands is found positive and statistically significant for all circular treatment groups, indicating that the completion of SML9 has led to an overall change to the neighbourhoods within 1000 meters in terms of the level of land values. This neighbourhood effect rises as the radial size of the treatment group shrinks to 500 meters and 200 meters.

The estimated results for all residential lands also show that the completion of SML9 has brought proximity benefits to all residential lands within 1000 meters on average. The proximity effect of SML9 is captured by the interaction coefficients of time \times

distance to the nearest rail station, which calculates the interaction between the time period before and after the opening of SML9 and the network distance to the nearest rail station. This interaction coefficient is found negative and statistically significant for all treatment groups, from the 1000-metre treatment group to the 200-metre treatment group. While the effect of proximity to a station on residential values is negative for residential lands, its magnitude is relatively weak in comparison with previous studies, which reported an average effect of 4.6% for residential properties within 1/4 mile of the station (Debrezion et al., 2007). This may be the case where a large portion of the proximity benefits of SML9 goes to riders who use SML9 and enjoy travel cost savings. The modest price effect of improved proximity may also be explained by Seoul's developed metro network, which provides easier access to rail services than in cities lacking such infrastructure.

Regarding land plots for the house category, the estimated results reveal that both the house neighbourhood and its proximity to rail station has been influenced by the completion of SML9. The coefficient of the neighbourhood effect is positive and statistically significant, which indicates that residential land values in the house neighbourhood has increased overall after the completion of SML9. The neighbourhood effect is larger with smaller treatment groups; the effect increases as the radius of the treatment group decreases. The coefficient of the proximity effect is negative and statistically significant across all treatment groups.

The proximity effect for house lands is larger than the neighbourhood effect in terms of the magnitude, although the overall trends with the treatment groups are similar with each other. The lower coefficient of the neighbourhood effect may in part be attributed to the fact that some neighbourhood effects were capitalised long before they become effective. The values of houses lands may also be inflated by expectations for redevelopment. In fact, the opening of rail transit may contribute to an increase in development opportunities for less attractive types of dwellings than for apartments, such as houses in the context of South Korea (Gelézeau, 2001).

The estimated results for low-rise MFH and apartment lands show a slightly different pattern from that for house lands, with insignificant coefficients for neighbourhood effects across all treatment groups, although this coefficient for low-rise MFH is found statistically significant only with a 500-meter radius of SML9 stations. These insignificant coefficients indicate that both low-rise MFH and apartment neighbourhoods have experienced little change in terms of land values before and after the opening of SML9. This result may be attributed to the fact that this study focuses

on a real change in residential land values rather than on a long-term relation between land values and the completion of rail transit projects. Some empirical studies have found that the expected benefits of rail transport investment are capitalised into property values before the rail is actually completed (McMillen & McDonald, 2004; Yiu & Wong, 2005). This may be the case for apartments in Seoul because most individual apartments or apartment blocks tend to be planned some time ahead of the opening of nearby rail stations. Also, since the construction of apartments tends to be completed ahead of the start of rail transit, a real change in accessibility resulting from its completion is likely to be minimal, as found in the estimates.

For absolute and relative employment accessibility, the coefficients of these indicators are found statistically significant and positive for all residential land types, with relative employment accessibility having slightly larger price effects than absolute employment accessibility. The magnitudes of the coefficients of these accessibilities has increased during the construction period of SML9 in all residential land types, confirming that rail transit investment has led to an increase in access to job opportunities.

Looking into the estimated results by the treatment group, the accessibility effects of both absolute and relative employment accessibilities are positive across all circular treatment groups. For house and low-rise MFH lands, the accessibility effects rise as the radial size of the treatment group decreases from 1000 meters to 500 meters; the largest effect is observed at the 500-meter treatment group, and the effects reduce slightly within a 200-meter radius of SML9 stations due to noise and congestion. For apartment lands, the largest effect is observed within a 1000-meter distance of stations; the effects then reduce as the radius of the treatment group decreases.

Compared the estimated results by residential land types, apartment lands receive the largest accessibility benefits from the completion of SML9 among the three land use types. Low-rise MFH land plots are the second largest recipient from the completion of SML9. For example, the coefficient of relative employment accessibility for apartment lands within a 1000-meter radius of rail stations is 0.707 whereas that for low-rise MFH is 0.373. This indicates that for one percent increase in the level of relative employment accessibility, the value of apartment lands would increase by 0.707%.

Table 6-4. Results of Difference-in-Difference Model for Residential Land

Variable	All		House		low-rise MFH		Apartment	
	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.
Within a 1000-meter radius								
SML9 opening × Treatment (Neighbourhood effect)	0.0156 ***	0.0042	0.0148**	0.0052	0.0100	0.008	0.0100	0.0151
SML9 opening × Distance to station (Proximity effect)	-0.0235***	0.0042	-0.0239***	0.0051	-0.0177**	0.0084	-0.0518***	0.0152
SML9 opening × Absolute accessibility (Absolute accessibility effect)	0.2576***	0.0125	0.2033***	0.0155	0.3503***	0.0254	0.6782***	0.0457
SML9 opening × Relative accessibility (Relative accessibility effect)	0.2892***	0.0127	0.2282***	0.0158	0.3734***	0.0255	0.7078***	0.0463
Within a 500-meter radius								
SML9 opening × Treatment (Neighbourhood effect)	0.0201***	0.0052	0.0234***	0.0063	0.0209*	0.0112	-0.0077	0.0170
SML9 opening × Distance to station (Proximity effect)	-0.0282***	0.0050	-0.0399***	0.0061	-0.0273**	0.0101	-0.0303*	0.018
SML9 opening × Absolute accessibility (Absolute accessibility effect)	0.3088***	0.0153	0.2923***	0.0190	0.3800***	0.0306	0.6401***	0.0550
SML9 opening × Relative accessibility (Relative accessibility effect)	0.3423***	0.0156	0.3197***	0.0193	0.4053***	0.03068	0.6658***	0.0557
Within a 200-meter radius								
SML9 opening × Treatment (Neighbourhood effect)	0.0306**	0.0114	0.0366**	0.0144	0.0445	0.0286	-0.0004	0.0274
SML9 opening × Distance to station (Proximity effect)	-0.0540***	0.0060	-0.0536**	0.0075	-0.0502***	0.0122	-0.0087***	0.0229

SML9 opening × Absolute accessibility (Absolute accessibility effect)	0.3083***	0.0188	0.2830***	0.0243	0.3465***	0.0361	0.6064***	0.0698
SML9 opening × Relative accessibility (Relative accessibility effect)	0.3383***	0.0189	0.3169***	0.0245	0.3677***	0.0359	0.6306***	0.0705
Structural controls	YES		YES		YES		YES	
Neighbourhood controls	YES		YES		YES		YES	
Year effect	YES		YES		YES		YES	
Adjust R-square ³⁰	0.6771		0.5614		0.6825		0.8506	
Observations	41748		24228		9190		2976	

Note: * denotes significance at the 10 percent level; ** denotes significance at the 5 percent level; *** denotes significance at the 1 percent level

³⁰ Since a series of DID estimations are carried out in this table, only adj R-squared for the estimation of 1000-m radius is presented.

6.6.2.2. Estimated Results for Commercial Land

Table 6-5 presents estimates for commercial lands. Since variations in land values may be affected by unique features of different types of commercial lands, I separate commercial land plots into three types: retail, office and mixed commercial lands. Results for the three types of commercial lands are organised under the corresponding headings, alongside the results for all commercial lands.

The coefficients of the neighbourhood effects for all commercial lands are statistically significant and positive within circular groups of less than 500 meters by radius. These effects grow larger with smaller treatment groups. In comparison with residential lands, the magnitudes of the neighbourhood effects for commercial lands are more or less similar to those for residential lands with circular groups less than 500 meter, indicating that residential and commercial lands have received similar neighbourhood benefits from the construction of rail transit.

For the proximity effect for all commercial lands, the coefficients of proximity to rail station are found negative and statistically significant across all treatment groups, as found in residential lands. Yet, the pattern is different from each other; the proximity effects for commercial lands reduce as the radial size of treatment group decreases whereas those for residential lands increase as the size of treatment group reduces. With the 200-meter treatment group, the estimated proximity effect for all commercial lands is -0.0232. Its magnitude reaches at -0.0378 for the 1000-meter-radius treatment group, which indicates that commercial land values would increase by 0.0378% for one percent change in distance to rail station.

The estimated results for the three different types of commercial lands provide further findings on how the completion of SML9 impacts commercial land values in relation to changes in the overall neighbourhood and proximity to stations. For retail lands, the coefficient of the neighbourhood effect is positive and statistically significant only for the 500-meter treatment group by radius. This finding may be explained by an expected increase in pedestrian footfall in areas near new SML9 stations, providing improved opportunities for retail businesses. Retail lands command the highest neighbourhood effect among the three types of commercial lands, at the 500-meter treatment group by radius. The overall benefit for retail lands may be due to the capability of the retail industry to attract customers to areas near stations.

Yet, the coefficients of the neighbourhood effect for retail lands are not statistically

significant within the 1000-meter and 200-meter treatment groups. I suspect that this may be due to the competition between retail stores. According to previous studies, large retail stores tend to take locations near rail or metro stations as they can afford to pay the rent for these locations (Lee, 2013). Where they set up their business may change the retail environment of the area, creating new tensions with existing retail stores, especially small retail stores. This increased competition may weaken the accessibility benefits for businesses in proximity to stations.

Similar results are found for mixed land plots, where the coefficients of proximity to rail station are negative and statistically significant with all treatment groups, indicating that the completion of SML9 has brought proximity benefit to mixed lands on average. The magnitude of the proximity coefficient is about 0.032% of the corresponding land value for a 200-meter radius of SML9 stations. Unlike the estimates for retail lands, this figure grows larger as the radius of the treatment group decreases. The proximity benefits of the opening of SML9 for the 200-meter treatment group is nearly twice that for the 1000-meter group. Compared with retail lands, the proximity benefit for mixed lands is nearly similar to that for retail lands with treatment groups smaller than 200 meters whereas the former is one-third of the latter with the 1000-meter treatment group.

Similar to retail lands, the neighbourhood effect for mixed lands is found modestly positive and statistically significant for the 500-meter group by radius. This may be due to the nature of mixed lands, where residential uses are incorporated together with retail and office uses. As seen in Table 6-4, residential lands receive neighbourhood benefits from the completion of SML9, since commuters who reside in these areas enjoy reductions in travel costs when the new metro transit opened. In this regard, neighbourhood for mixed use has some characteristics of residential lands with respect to neighbourhood change. The positive neighbourhood effect for mixed use is likely due to this residential characteristic incorporated within mixed lands.

As for land plots for offices, neither neighbourhood effects nor proximity effects are found statistically significant within circular treatment groups smaller than 500 meters by radius. The insignificant neighbourhood effect suggests that the completion of SML9 has led to little changes to office neighbourhood in the short term. This may be explained by either early appreciation of the expected effect of SML9 prior to its opening or to a delay in the overall effect of SML9 on the value of office lands until the system is fully operational. There is also a possibility that rail transit investment in the land values of office neighbourhood may not be as significant as other factors, such as employment density, energy savings and clustering with offices (Fuerst & McAllister,

2011).

Only the coefficient of proximity to rail station is found negative and statistically significant for office lands with the 1000-meter treatment group. This indicates that proximity to the metro network is an important determinant of office land values, which is consistent with findings in the property literature on the determinants of office rents. Interestingly, this effect exists only with office lands located within a 1000-meter distance of SML9 stations; except for the 1000-meter threshold, the proximity effect is no longer statistically significant. Proximity to rail station appears to be less important for treatment groups smaller than 1000 meters by radius, which likely indicates the presence of more important factors related to variations in office land values than close proximity to rail transit.

For absolute and relative employment accessibility, the coefficients of these indicators are found statistically significant and positive in all commercial lands. The magnitude of the coefficient of relative employment accessibility is found slightly higher than that of absolute employment accessibility. These findings show that the completion of SML9 has led to an increase in access to job opportunities.

As for the estimated results by the treatment groups, the coefficients of both absolute and relative employment accessibilities are positive across all circular groups by radius. For all commercial lands, the accessibility effect grows larger as the radial size of the treatment group decreases. Similar pattern is observed for retail and mixed lands; the smallest accessibility effects are observed at the 1000-meter treatment group, and the effects then increase with circular groups smaller than 1000 meters by radius. By contrast, the coefficient of absolute and relative employment accessibilities for office lands decreases as the size of treatment group reduces; the largest accessibility effect is observed at the 500-meter treatment group.

Compared the estimated results by the type of commercial lands, office lands receive the largest accessibility benefits from the completion of SML9 among the three land use types. With the 1000-meter treatment group, the coefficient of relative employment accessibility is 1.0842. Its magnitude reaches to 1.1787 with the 500-meter-radius treatment group, which indicates that office land values would increase by 1.178% for one percent change in the level of relative employment accessibility. Retail lands receive the second largest accessibility benefits from the completion of SML9.

Table 6-5. Results of Difference-in-Difference Model for Commercial Land

Variable	All		Retail		Office		Mixed	
	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.
Within a 1000-meter radius								
SML9 opening × Treatment (Neighbourhood effect)	0.0119	0.0073	0.01161	0.0125	-0.0168	0.0281	0.0127	0.0088
SML9 opening × Distance to station (Proximity effect)	-0.0378***	0.0054	-0.0488***	0.0088	-0.0612**	0.0225	-0.0163**	0.0073
SML9 opening × Absolute accessibility (Absolute accessibility effect)	0.2598***	0.0192	0.3692***	0.0323	0.9858***	0.0922	0.1206***	0.0231
SML9 opening × Relative accessibility (Relative accessibility effect)	0.3032***	0.0195	0.4181***	0.0329	1.0842***	0.0913	0.1323***	0.0234
Within a 500-meter radius								
SML9 opening × Treatment (Neighbourhood effect)	0.0232**	0.0085	0.0292**	0.0144	-0.0167	0.0316	0.0214**	0.0101
SML9 opening × Distance to station (Proximity effect)	-0.0306***	0.0058	-0.0430***	0.0092	-0.0370	0.0252	-0.0247**	0.0078
SML9 opening × Absolute accessibility (Absolute accessibility effect)	0.2949***	0.0213	0.3706***	0.0352	1.0743***	0.1080	0.1944***	0.0260
SML9 opening × Relative accessibility (Relative accessibility effect)	0.3312***	0.0217	0.4107***	0.0361	1.1787***	0.1070	0.2026***	0.0264
Within a 200-meter radius								
SML9 opening × Treatment (Neighbourhood effect)	0.0303 **	0.0136	0.0250	0.0205	0.0068	0.0535	0.0226	0.0181
SML9 opening × Distance to station (Proximity effect)	-0.0232***	0.0065	-0.0345***	0.0102	0.0287	0.0271	-0.0320***	0.0082

SML9 opening × Absolute accessibility (Absolute accessibility effect)	0.3551***	0.0245	0.4496***	0.0406	0.8908***	0.1301	0.2788***	0.0280
SML9 opening × Relative accessibility (Relative accessibility effect)	0.3833***	0.0249	0.4903***	0.0415	0.9664***	0.1288	0.2824***	0.0284
Structural controls	YES		YES		YES		YES	
Neighbourhood controls	YES		YES		YES		YES	
Year effect	YES		YES		YES		YES	
Adjust R-square ³¹	0.6423		0.4836		0.7241		0.5276	
Observations	29052		12588		2034		8036	

Note: * denotes significance at the 10 percent level; ** denotes significance at the 5 percent level; *** denotes significance at the 1 percent level

³¹ Since a series of DID estimations are carried out in this table, only adj R-squared for the estimation of 1000-m radius is presented

6.6.3. Quantile Regression Model Results

Aside from the findings in previous sections, I also perform a quantile regression analysis to provide further implications on the impact of the completion of SML9 on residential and commercial land values in terms of how the impact varies across different price groups of lands. The graphical results based on the estimates obtained from the quantile regression model are presented in Figures 6-4 and 6-5. The estimated results for residential land plots are reported in Figure 6-4 whereas those for commercial land plots are described in Figure 6-5.

The diagrams in the figures shows graphical estimates of how the impact of rail transit investment varies across different quantiles of land values. The impact is captured by both proximity to rail station and absolute and relative employment accessibility. The estimated results for the pre-completion of SML9 are presented on the left side, whereas the estimated results for the post-completion of SML9 are presented on the right side. The graphical estimates, therefore, can be interpreted as the treatment effects of SML9 at each quantile before and after the completion of SML9.

In the diagrams, the estimated results of proximity to the nearest station is plotted as a solid curved line in the first row of the diagrams whereas those of both absolute and relative job accessibilities are plotted in the second and third rows. The dashed line in each diagram indicates the average effect of the corresponding variable when it is estimated with the OLS estimator. The grey area represents a 90% confidence interval for the quantile regression estimates. Each diagram has horizontal quantiles ranging from 10% to 90% of the land values, while the vertical line indicates the effect of the corresponding covariate.

Estimated Results for Residential Lands

The diagrams on the left side in Figure 6-4 clearly reveal that the relationship between both proximity to rail station and job accessibility and residential land values varies across different segments of residential land values. In the first row of the diagram, it can be observed that the relationship between distance to the nearest station and residential land values is weak at the lower quantile of the distribution, whereas it is stronger with higher quantiles of the distribution before the development of SML9.

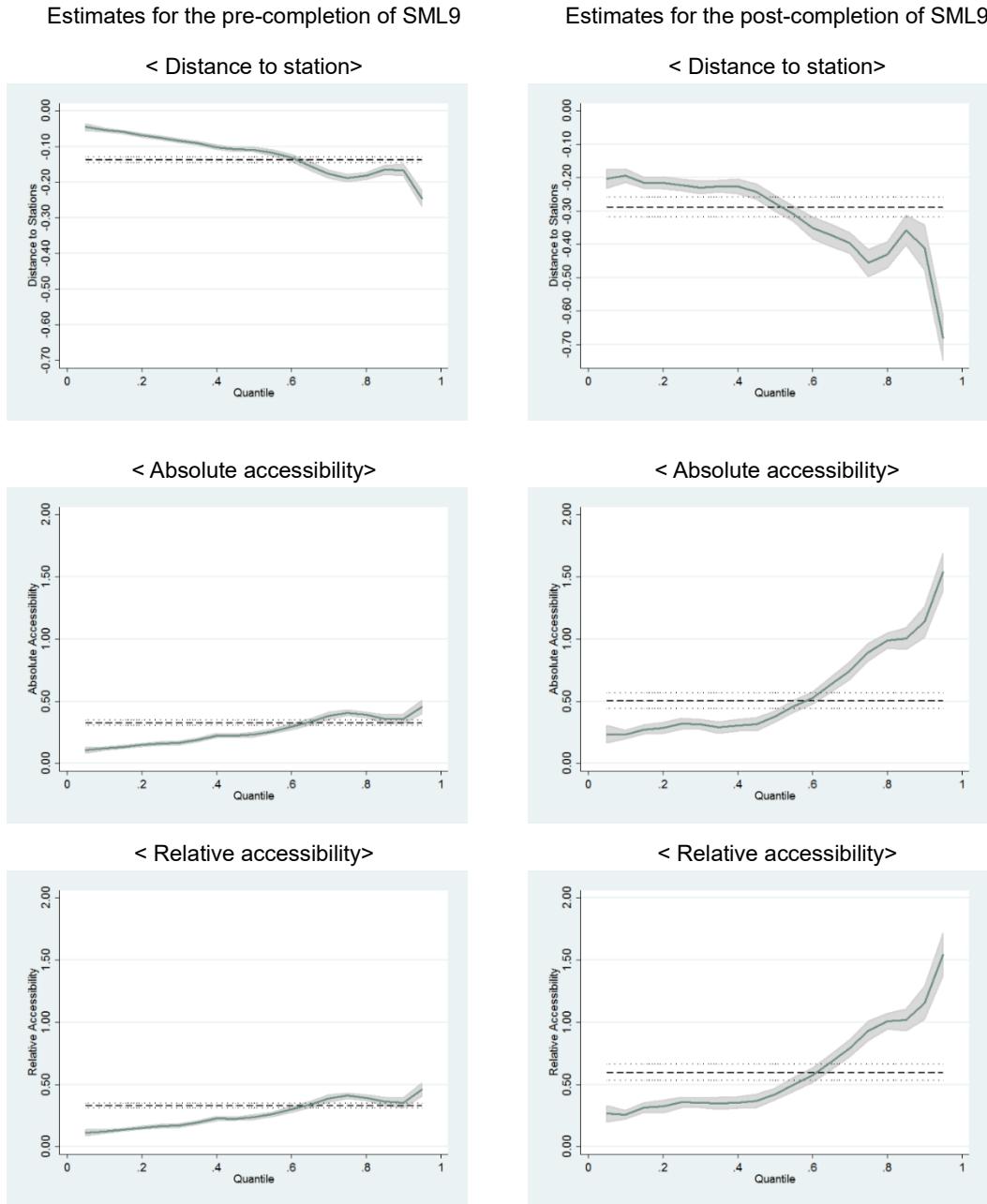
The effect of proximity to rail station on residential land values is not distributed constantly across residential lands with different values. The distance to the nearest rail station has a smaller impact on residential land values at the lower quantiles of the distribution. The monetary benefits of distance to rail station gradually increase to the 60% quantile, where it equals its mean effect; beyond the 60% quantile, it becomes larger than the mean effect. The strongest proximity effect on residential land values is observed at the 90% quantile of the distribution. These results suggest that residential lands at the lower quantiles of the distribution receive less monetary benefits from being close to stations than those at the upper quantiles.

The second row in the left side diagram in Figure 6-4 reveals that the relationship between absolute employment accessibility and residential land values varies across quantiles of the distribution of residential land values. The association is overall weak at the lower quantile, whereas it is strong at the upper quantile. The effect of absolute employment accessibility on residential land values is smallest at the 10% quantile of residential land values. The magnitude of this effect is around 0.2 at the 10% quantile, whereas it is around 0.5 at the 70% quantile of the distribution.

The effect of absolute employment accessibility on residential land values increases gradually with quantiles of the distribution. The price effect of absolute accessibility continues to increase until the 70% quantile, and slightly decrease, but becomes highest at the 90% quantile. The estimated results show that the price effects of absolute employment accessibility are not distributed constantly across residential lands with different values. The higher residential land values are, the more the effects of absolute accessibility on residential land values.

In the third row in the left side diagram in Figure 6-4, the graphical estimate for relative employment accessibility is reported, which is similar to those for absolute employment accessibility. It is revealed that the relationship between relative employment accessibility and residential land values is not distributed constantly across quantiles of the distribution of residential land values. On average, the higher the quantile of the distribution is, the more the effect of relative employment accessibility on residential land values. The smallest effect of relative employment accessibility on residential land values is found at the 10% quantile of the distribution of residential land values.

Figure 6-4. Graphical Results of the Quantile Regression Model for Residential Land



SML9's Proximity and Accessibility Effects on Residential Land Values

I make a comparison between the graphical estimates before and after the completion of SML9 to assess the treatment effects of SML9 at each quantile of the distribution of

residential land values. I focus on a change in the relationship between distance to the closest rail station and residential land values as well as on a change in the relationship between both absolute and relative employment accessibilities and residential land values. The estimated results for the pre-completion of SML9 are presented on the left side, whereas the estimated results for the post-completion of SML9 are presented on the right side.

Clearly, as shown in the dashed lines between the diagrams of the first row in Figure 6-4, the average effect of distance to the nearest rail station on residential land values has increased in terms of its magnitude during the study period.³² This suggests that the opening of SML9 has brought positive proximity benefits to residential land plots on average, which confirms the robustness of DID estimates for the causal effects of the opening of SML9 on residential land values.

Looking at the lower quantiles of the distribution on the first row of the right-side diagram, the effect of distance to the nearest rail station on residential land values has increased as much as the average effect does during the study period. Yet, the slope at the lower quantiles after the opening of SML9 is roughly similar to that before the completion of SML9, although a slight variation in the slope is observed. This indicates that the magnitude of the proximity effect has increased while the relationship between distance to rail station and residential land values has remained more or less the same before and after the opening of SML9 at the lower quantiles of the distribution.

Beyond 50% quantile of the distribution of residential land values, the magnitude of the price effect of distance to the nearest rail station has increased considerably. The slope at these quantiles is much steeper, although the pattern is similar to that before the completion of SML9. This implies that residential lands at these quantiles have received a large portion of the proximity benefit from the completion of SML9, relative to the lower quantiles. The proximity effect continues to rise until the 80% quantile where it becomes slightly weak. The largest improvement in the proximity effect is observed at 90% quantile of the distribution.

Overall, the arrival of SML9 has brought disproportionate proximity benefits to

³² The effect of distance to a rail station is represented as negative figures because proximity benefits become larger as proximity to a rail station increases.

residential land plots near rail stations. The magnitude of the proximity effect is larger at the upper quantiles than at the lower quantiles. These results suggest that residential lands at the lower quantiles of the distribution has received less proximity benefit from rail transit investment than those at the upper quantiles.

As for absolute employment accessibility, the graphical estimates are presented in the second row of the diagrams in Figure 6-4. Comparing between the diagram on the left side and that on the right side, the average effect of absolute employment accessibility on residential land values has increased as shown in the dashed lines, from around 0.3 to 0.5. This suggests that the opening of SML9 has led to an increase in absolute access to jobs. More job opportunities have become available to population residing in the area due to SML9.

The effects of absolute access to jobs on residential land values are not constantly distributed across quantiles of the distribution of residential land values. At the lower quantiles, the price effect of absolute accessibility is slightly less than the average treatment effect. The slope at the lower quantiles is more or less similar before and after the opening of SML9, although the magnitude of the accessibility effect is higher after the development of SML9.

The accessibility benefit on residential land values changes completely beyond the 50% quantile of the distribution. The magnitude of the accessibility benefit is a way larger than the average treatment effect. The slope at these quantiles is much steeper, implying a large portion of the accessibility benefit is largely concentrated at these quantiles. As the quantile increases, the accessibility benefit continues to rise. The largest accessibility effect is observed at 90% quantile of the distribution.

Similar to the proximity effect, the opening of SML9 has brought about disproportionate accessibility benefits to residential land plots. The magnitude of the accessibility benefit has increased much larger at the upper quantiles than at the lower quantiles after the completion of SML9. This result suggests that residential lands at the lower quantiles of the distribution has received less accessibility benefits from rail transit investment than those at the upper quantiles.

As for relative employment accessibility, its effect on residential land values is similar to that of absolute employment accessibility, although its average magnitude is higher than absolute employment accessibility. The graphical estimates are presented in the

third row in Figure 6-4. Comparing between the diagram on the left side and that on the right side, the effect of relative employment accessibility on residential land values has increased on average, from around 0.35 to 0.65. This indicates that relative access to jobs has increased due to the opening of SML9. More net job opportunities have become available to population residing in the area.

The benefit of relative access to jobs resulting from the development of SML9 is not distributed constantly across different segments of commercial land values. It has increased smaller at the lower quantiles of the distribution whereas it has risen considerable at the upper quantiles. Overall, the development of SML9 has led to disproportionate accessibility benefits to residential land plots near rail stations. A higher magnitude of the accessibility benefit has been generated at the upper quantiles of the distribution due to the completion of SML9. Residential lands at the lower quantiles has received smaller accessibility benefit from rail transit investment than those at the upper quantiles.

Estimated Results for Commercial Lands

The diagrams on the left side in Figure 6-5 reveal that the relationship between both proximity to rail station and employment accessibility and commercial land values varies across different quantiles of commercial land values. In the first row of the diagram, it can be observed that the relationship between distance to the nearest station and residential land values is nearly flat across all the quantiles of the distribution, except for quantiles beyond 80%. The weakest relationship can be observed at residential lands with the 10% quantile.

The distance to the nearest rail station has a smaller impact on commercial land values at the lower quantiles of the distribution. The price effect of distance to a rail station gradually increase, although the slope is gentle. It becomes equivalent to the average effect at around 80% quantile. Beyond this point, the slope becomes steeper, indicating the accessibility effect becomes larger. The strongest relation between distance to the nearest station and commercial land values is observed at the 90% quantile of the distribution.

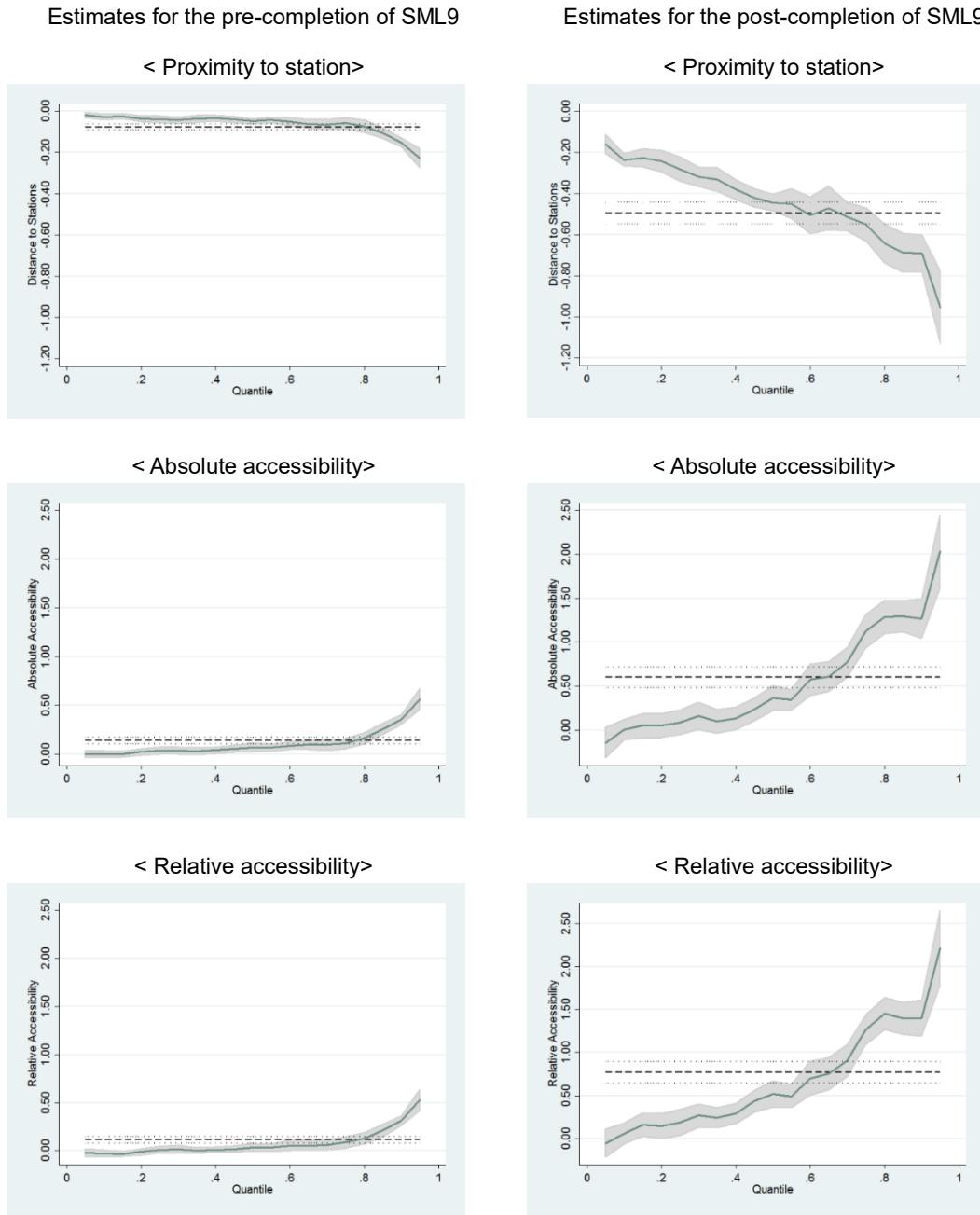
In the second row of the left side diagram in Figure 6-5, it is revealed that the relationship between absolute employment accessibility and commercial land values is

not constant across quantiles of the distribution of commercial land values. The association is overall weak at the lower quantile, whereas it is strong at the upper quantile. Yet, the difference in the relationship is not large since the slope is gentle.

The effect of absolute employment accessibility on commercial land values increases gradually with quantiles of the distribution until the 80% quantile of the distribution. Beyond this point, the price effect of absolute accessibility surges. The price effect is smallest at the 10% quantile of residential land values whereas it is the largest at the 90% quantile. The magnitude of this effect is around 0.05 at the 10% quantile, whereas it is around 0.5 at the 90% quantile of the distribution. The estimated results show that the effect of absolute employment accessibility is not distributed constantly across commercial lands with different values. The higher commercial land values are, the more the absolute accessibility effect on commercial land values.

The third row in the left side diagram reveals that the graphical estimates for relative employment accessibility are similar to those for absolute employment accessibility. It is observed that the relationship between relative employment accessibility and commercial land values is not distributed constantly across different segments of commercial land values. Yet, the degree to which relative employment accessibility influence commercial land values does not differ across the quantile, except for quantiles beyond 80%. On average, smaller accessibility effects are found at the lower quantiles of commercial lands. The higher the quantile of the distribution is, the more the effect of relative employment accessibility on commercial land values.

Figure 6-5. Graphical Results of the Quantile Regression Model for Commercial Land



SML9's Proximity and Accessibility Effects on Commercial Land Values

A comparison between the graphical estimates before and after the completion of SML9 is carried out to explore how the treatment effects of SML9 vary across different

quantiles of the distribution of commercial lands. The estimated results for the pre-completion of SML9 are presented on the left side, whereas the estimated results for the post-completion of SML9 are presented on the right side.

In the first row of the diagram in Figure 6-5, the graphical estimates for the price effect of distance to the nearest station are presented. Comparing the diagrams on the left and that on the right side, the average effect of distance to the closest rail station on commercial land values has increased, from around 0.08 to 0.48, which indicates that the opening of SML9 has brought about positive proximity benefits to commercial land plots near rail stations. Compared to residential lands, the magnitude of the proximity effect is larger, suggesting that commercial land plots have received higher proximity benefits from the development of SML9.

As for a change in the slope of the proximity effect, it has become much steeper after the opening of SML9. The relationship between distance to the closest rail station and commercial land values has changed completely due to the opening of SML9, from flat one to inclined one. The price effect of distance to the nearest rail station has increased considerably throughout the quantiles of the distribution. It increases gradually from the low quantile to the high quantile

The estimated results show that the proximity effect resulting from the development of SML9 is disproportionate across the quantiles of the distribution of commercial lands. The magnitude of the proximity effect is larger at the upper quantiles than at the lower quantiles. Commercial lands at the lower quantiles of the distribution have received less proximity benefit from rail transit investment than those at the upper quantiles.

As for absolute employment accessibility, the average effect of absolute employment accessibility on commercial land values has increased before and after the development of SML9, from around 0.2 to 0.65. More opportunities for employment have become available to economic activities in commercial lands in the area due to SML9. Compared to residential lands, the magnitude of the average treatment effect on commercial lands is larger.

Interestingly, the pattern of the price effect of absolute employment accessibility has changed during the study period. Before the development of SML9, the accessibility effect on commercial land values is nearly flat across all the quantiles of the distribution, except for the quantiles beyond 80%. But this pattern has dramatically changed after

the development of SML9. The price effect of absolute accessibility has become different across the quantiles. It increases gradually from the low quantile to the high quantile.

The magnitude of the accessibility benefit is lower than the average treatment effect before the 65% quantile whereas it becomes larger after that quantile. From the 70% quantile of the distribution, the slope becomes slightly steeper, indicating the association between absolute accessibility and commercial land values changes slightly. The magnitude of the accessibility effect of SML9 continues to rise as the quantiles increase, yet it is stagnant at around 90% quantile. The largest accessibility effect of SML9 is observed at the 95% quantile.

Similar to the proximity effect, the benefits of absolute access to job opportunities are disproportionate across the quantiles of the distribution of commercial lands. The magnitude of the accessibility benefit has increased much larger at the upper quantiles than at the lower quantiles after the completion of SML9. These results suggest that commercial lands at the lower quantiles of the distribution has received less accessibility benefits from rail transit investment than those at the upper quantiles.

The estimated results similar to absolute accessibility are observed for relative employment accessibility, which are presented in the third row of the diagram. The average treatment effect of relative access to jobs has increased during the study period, as shown in the dashed lines, from around 0.2 to 0.75. The development of SML9 has brought about accessibility benefits to economic activities in commercial lands. Compared to absolute employment accessibility, the magnitude of relative employment accessibility is larger.

The pattern of the price effect of relative access to jobs is roughly the same as that of absolute accessibility. Before the development of SML9, the price effect of relative employment accessibility is nearly flat across all the quantiles of the distribution, except for the quantiles beyond 80%. After the development of SML9, the accessibility effect has become different across the quantiles of the distribution. It increases gradually from the low quantiles of the distribution to the high quantiles.

With regard to the price effect of relative employment accessibility, the development of SML9 has brought about disproportionate accessibility benefits to commercial lands in the area. Commercial lands at the lower quantiles has received smaller accessibility

benefit from rail transit investment than those at the upper quantiles. The magnitude of the accessibility benefit has increased much larger at the upper quantiles than at the lower quantiles after the completion of SML9.

6.7. Policy Implication

The results of the three regression analyses on the case of SML9 have some important policy implications. First, the findings obtained from the multilevel hedonic model suggest that both absolute and relative accessibility indicators are effective indicators for capturing the accessibility effects of the development of rail transit. Together with the existing measure based on distance to the nearest rail station, these accessibility indicators may be effectively used by policy makers or researchers to evaluate changes in both proximity and accessibility effects resulting from rail transit investment. Having multiple means of measurement may enable them to make an accurate decision on rail infrastructure projects. The proximity indicator may be appropriate in cases in which a simple evaluation of the direct benefits of rail transit is required, whereas the absolute and relative accessibility indicators may be more useful in cases in which either wider benefits of rail transit investment need to be evaluated or the quality of access to jobs or workers is required to be captured in relation to the labour market.

Second, the results obtained from the DID model include interesting policy findings. The results show that the opening of SML9 has brought about positive yet modest proximity benefits to residential and commercial lands near stations, as well as to lands in the surrounding neighbourhood of rail stations. This modest benefit indicates that to some extent, riders who commute by SML9 benefit from the completion of this line. The findings suggest that policy makers could target the delivery of new rail transport infrastructure in such a way that the benefits of rail transit are not only distributed to the immediate area of a rail station or to riders who will use new rail services, but are also extended to the wider population and various businesses. These policy objectives appear to have paid off to some extent in the development of SML9, although not all were planned or intended.

Third, the results obtained from the DID regression analysis provide interesting policy findings that policy makers could consider when developing rail transit. The results

show that the magnitude and pattern of both the proximity and neighbourhood benefits of developing rail transit differ across different types of residential and commercial lands, and that these benefits vary with the distance to a rail station. This finding highlights the importance of interactions between different types of land uses and rail transit in determining land values. The outcome of rail transit investment may be to some extent dependent upon the ways in which lands with different uses are arranged in relation to the provision of rail transport infrastructure. An important policy objective, in this regard, is to implement an integrated approach to addressing the way different types of lands interact with rail transit investment to promote diverse activities and services.

Finally, policy makers may be interested in the uneven distribution of rail transit benefits across lands at different price levels. They may target how the cost of rail transit investment should be distributed as well as how the benefit of rail transit development should be spread among the stakeholders. These implications follow from the results obtained from the quantile regression model. The results show that both proximity to a rail station and the level of employment accessibility are differently associated with variations in residential and commercial land values at different price levels. The most important finding obtained from the quantile regression model is that the benefits of the completion of SML9 vary across different price groups of residential and commercial lands. The findings are particularly important because many issues involved in the debate on rail transit investment are centred on the question of who pays for its cost and who benefits from its development.

6.8. Conclusion

This chapter has explored the impact of the development of Seoul Metro Line 9, a new metro transit system running from west to east in Seoul, on residential and commercial land values. A distinct feature added to previous studies in the literature is that I examined how and to what extent the development of rail transit results in a change in the distance to a rail station and the overall neighbourhoods of residential and commercial lands near new stations. Another novel feature is that I explored how the proximity and neighbourhood effects of the completion of rail transit vary by diverse types of land use. Additionally, I tested the applicability of the absolute and relative accessibility measures in capturing the accessibility benefits of rail transit investment. I

focused on real changes in the distance to rail stations resulting from rail transit investment and its associations with land values, rather than on the anticipated accessibility effects of rail transit before it has even been constructed.

Based on the results obtained from the multilevel hedonic model, I showed that the absolute and relative accessibility indicators are effective in terms of capturing changes in access to jobs in relation to the development of rail transport projects. Alongside a measure for distance to a rail station, these accessibility measures may be useful for policy makers in evaluating how the development of rail transit will change the level of accessibility to jobs or workers.

Based on the results obtained from the DID model, I showed that the development of SML9 has positive yet modest proximity effects on residential and commercial lands close to rail stations as well as on lands in the surrounding neighbourhood of rail stations. Both proximity and neighbourhood benefits were generated by the opening of SML9. SML9 also to some extent provides proximity benefits to commuters. These findings emphasise that with appropriate policy guidelines, the development of rail transit may be regarded as an urban and regional strategy for the immediate area of a rail station, as well as for its wider neighbourhood.

I found strong evidence that the proximity and neighbourhood effects of the development of SML9 are heterogeneous according to the type of residential and commercial lands. The results suggest that interactions between land uses and rail transit plays a key role in determining residential and commercial land values. These findings highlight that rail transit investment will be less effective in terms of spreading benefits across society unless appropriate policies are implemented that consider the ways in which lands with different uses are arranged in relation to the provision of rail transit.

Based on the results obtained from the quantile regression model, I showed that the link between proximity to SML9's rail stations and land values varies across lands at different price levels. It was found that residential and commercial lands at different price levels received uneven benefits from the completion of SML9. These findings suggest that rail transit investment will be undervalued in terms of its benefits to society unless appropriate policies that address such disproportionate benefits are implemented in relation to the development of rail transit. This does not necessarily imply the immediate adoption of radical land taxation schemes, since a progressive

local tax system is already in place. Rather, a balanced combination between planning tools and taxation schemes may be a more practical option for policy makers and planners.

7. Conclusion

This chapter provides a summary of the study that was conducted to answer the research questions in this thesis. It summarizes the findings obtained from the three analyses. Based on these findings, it also provides policy implications for professionals and policy makers. Lastly, it also discusses limitations of the research and provides suggestions for future research.

7.1. Summary of Findings

The goal of the current study was to provide reliable empirical evidence for the extent to which transport infrastructure impacts on economic performance by investigating three different aspects of economic performance: productivity, employment centre growth, and land values. The study has focused on both user benefits (land values) and wider economic benefits (productivity and employment) of transport infrastructure improvement to explore its economic effects. As for the spatial extent of study, the current study has focused on micro level economic effects in the Asian context. Another objective of the current research was to develop more advanced accessibility indicators to better capture the economic effects of transport infrastructure improvement. The thesis posed three research questions that were explored in the three respective analysis chapters. To answer these questions, respective empirical strategies were developed, and various accessibility measures and spatial variables were created.

The thesis has developed three empirical strategies for the three respective analysis chapters. Each methodology was designed to be the most suitable technique for investigating the assigned research question. Various models were applied with sophisticated techniques, including the multilevel hedonic model, the dynamic panel model, the IV model, the difference-in-difference model, and the quantile model. The estimations using econometric models were challenging due to various issues that are common in this type of analytical approach. Advanced econometric techniques were developed to overcome these issues, including the use of a two-stage approach to obtain the average elasticities of a firm's output with respect to the input factors, the use of a first-difference model to correct the bias arising from unobserved

characteristics of variables, the creation of instrument variables to correct the endogeneity of workforce accessibility benefits, and the use of a dynamic panel model to address the potential bias arising from the simultaneity of the input factors. Various independent variables were created to account for the dynamics of the variable of interest and capture their interrelationships. The variables considered in this research included variables for firm characteristics, industrial location policies, variables for employment centre characteristics, variables for land characteristics, built environment variables, amenity variables, and variables for socio-economic characteristics.

Following the development of the methodology, various indicators of accessibility were created for the Seoul region, including absolute and relative workforce accessibility, proximity to the nearest subway station, proximity to the closest high-speed rail station, absolute and relative job accessibility, and proximity to an international airport. The indicator of accessibility was the key factor on which this research relied to explore the research questions. As such, a new dataset and more sophisticated spatial techniques were applied to enhance the quality of the accessibility indicators compared to those used in previous studies. Travel costs between the origins and destinations were calculated using GIS techniques based on the actual transport network. For absolute and relative workforce accessibility indicators, commuters' preferences for travel modes were considered in the measurement of travel costs. The spatial-decay parameter, which explains the degree to which commuters respond to changes in distance, was estimated and incorporated into the calculation of the measure.

The first analysis in this research was conducted to explore the link between transport-induced economic effects and a manufacturing firm's productivity. The discussion on the productive effect of transport infrastructure has received the attention of scholars, as it is concerned with the indirect benefits of transport infrastructure. I contributed to this discussion by developing more sophisticated accessibility indicators and providing empirical evidence on transport-induced productive effects at the firm level. The analysis first showed that firm output is determined by three input factors – capital, labour, and intermediate inputs – which is in line with many previous studies. The amount of intermediate inputs is the most influential factor of firm output, and the amount of labour is the second-most influential factor, proving its continuing importance in production.

The analysis demonstrated that transport-induced workforce accessibility improvement

leads to an increase in firm productivity, with an average elasticity of 0.0600. Transport infrastructure improvement strengthens the level of agglomeration economies and the spatial interaction between firms and workers, changing the way in which firms and workers access economic activities. The estimated results are largely within the range of elasticities of transport-induced economic effects reported in previous studies.

The analysis showed that transport-induced workforce accessibility is positively related to firm productivity in disaggregated manufacturing sub-sectors. It is also shown that the level of transport-induced economic effects differs across different manufacturing sub-sectors. The productive benefits induced by workforce accessibility are not the same for all manufacturing sub-sectors. Diverse features in manufacturing production affect the degree to which manufacturing sub-sectors benefit from transport-induced workforce accessibility. The magnitude of transport-induced economic effects is concerned with the way final products are produced. It was found that Computer & ICT sector has higher elasticity in its workforce accessibility than the industry average. This sector requires workers who can manage advanced technology and work with complicated assemblies. Transport infrastructure connects firms in this sector to workers who have specific qualifications for such production work, reducing search friction and improving the spatial interactions between firms and workers.

The analysis also demonstrated that firm productivity is determined by its industrial location policy and firm characteristics such as its age, ownership, and financial management capability. Regarding a manufacturing firm's age, the older the manufacturing firm, the higher its production efficiency. Regarding firms' ownership, firms owned by individual investors are less efficient than firms owned by commercial corporations. Regarding the industrial location policy, firms located outside the growth management area are more efficient than those located within the area. A government's spatial policy that regulates economic activities affects the demand for and supply of firms' business activities.

The second analysis in this research was conducted to examine whether transport-induced labour accessibility could lead to employment centre growth. The discussion on employment centre growth is important in that employment growth is concerned with the spatial structure of urban areas, the density of economic activities, and real estate development. I contribute to this discussion by proposing more sophisticated indicators of accessibility. The analysis first identified that employment centres in the Seoul region

are not very different from each other in terms of absolute labour accessibility, indicating that to some degree, they are connected to the labour force pool. Yet, employment centres have different levels of relative labour accessibility, indicating that the number of net workers who can be accessed by employment centres differs.

The analysis has also demonstrated that absolute and relative accesses to the labour force are key determinants of employment centre growth, although their magnitude are different from each other. Despite of the fact that labour force is distributed everywhere in an urbanized area, access to the total labour force has significant impacts on employment centre growth. A key concern regarding employment growth is not whether the amount of labour force is available but whether employment centres actually have sufficient access to the labour force. Having more access to the total labour force is still a practical option for job growth in an urbanized area where the population density is high. The results also showed that access to the net labour force is a key determinant of employment centre growth, highlighting that the net labour force is not ubiquitous in some sense, even in an urbanized area, because firms compete for workers with skills/ Given that relative labour accessibility considers both the 'demand' and 'supply' sides of accessibility, increasing the level of relative access to the labour force may be an effective tool for policy makers to consider for the growth of employment centres.

The analysis has also showed that both a high-speed rail station and an international airport may have the potential for promoting the growth of employment centres. Their successes regarding employment centres are however subject to a few conditions. For a high-speed railway station, the realization of its effect could take a long time due to the long and complex process in which the completion of a high-speed railway facilitates economic development. An international airport's success, on the other hand, depends on the rise and fall of industrial sectors in the vicinity of the airport.

The third analysis was carried out to explore the impact of rail transit investment on residential and commercial land values. This discussion is centred on the debate regarding who benefits from rail transit investment and who pays for it. I contribute by looking into various aspects of the impacts of rail transit investment. The key contribution of the study is that it provides insights into the discussion on the diverse and disproportionate distribution of impacts of rail transit projects. The analysis demonstrated that the completion of SML9 brought about positive yet modest proximity and accessibility effects on residential and commercial lands in the vicinity of rail

stations as well as on lands in the overall neighbourhood of rail stations. Riders who commuted by SML9 experienced proximity benefits due to its opening. The findings suggest that the development of rail transit is an effective urban policy for areas close to rail stations as well as for the neighbourhoods surrounding rail stations.

The analysis has also showed that the outcome of rail transit investment is, to some degree, dependent upon the way in which different types of residential and commercial lands are arranged in relation to the provision of rail transit infrastructure. The magnitude and pattern of proximity, accessibility and neighbourhood benefits of the completion of SML9 differ across various types of residential and commercial lands. These findings suggest that investment in rail transit will be less effective in terms of spreading its benefits to society unless appropriate policies are implemented to address the interactions between lands with different uses and the provision of rail transit.

The analysis has also demonstrated that residential and commercial lands at different price levels receive different levels of proximity and accessibility benefits from the completion of rail transit. This finding suggests that the effects of rail transit investment may not be fully realized unless such disproportionate effects are addressed by appropriate planning policies in relation to the development of rail transit.

The overall conclusion is that understanding the economic effects of transport infrastructure and the three analyses of its different aspects makes it clear that transport infrastructure is important in promoting productivity, employment centre growth, and land value. Transport infrastructure could lead to an increase in economic performance and economic development. The economic effects of transport infrastructure are more than just time-saving. Not only is a reduction in travel costs the source of its economic effects, but an increase in productive benefits arising from spatial agglomeration induced by transport infrastructure is also the source of transport infrastructure's economic effects. In terms of the spatial extent of the economic effects of transport infrastructure, this research shows that the economic effects of transport infrastructure are not confined to an area near the transport network. The extent of the economic effects can reach beyond the vicinity of the transport network into the network's surrounding neighbourhood.

7.2. Policy Implications

Several interesting and important policy implications can be drawn from the research findings, which may add to the list of policy makers' considerations in formulating transport and planning policies.

The first analysis provides several important and interesting policy implications that policy makers may consider in relation to the development of transport infrastructure. First, the results show that both the size of the population in origins and the number of jobs at destinations are determinants of the number of commuting trips. This finding suggests that jobs are not uniformly distributed across the region, which might be one of the reasons for diverse journey-to-work patterns in the region that result in commuters' sensitivity to changes in the commuting distance. An important policy objective is to consider journey-to-work patterns in the evaluation of transport infrastructure projects. Policy makers may target the formulation of transport-planning policies based on the idea that jobs are unevenly distributed in urbanized areas. They may also be interested in tackling the various problems that arise from a long distance between home and work.

Second, the estimated results show that transport-induced workforce accessibility improvement leads to an increase in firm productivity in the manufacturing industry. This finding suggests that transport infrastructure improvement can provide indirect, productive benefits as well as direct time-saving benefits. The provision of transport infrastructure fosters the spatial agglomeration in which firms and workers benefit economically, changing the way they access economic activities and resources. Policy makers may be interested in such productive benefits of transport infrastructure that include time-saving benefits. They may target a transport-planning policy that can foster agglomeration economies and facilitate the spatial interactions between firms and workers. An important policy objective may be to build practical guidance for transport infrastructure projects as to how they should be applied in practice.

Third, the results show that transport-induced workforce accessibility is positively and statistically related to firm productivity, even in disaggregated manufacturing sub-sectors, suggesting that the positive link between transport-induced economic effects and firm productivity holds even at the disaggregated industry level. The results also

show that the level of transport-induced economic effects differs across the different manufacturing sub-sectors. This finding suggests that the degree to which manufacturing sub-sectors benefit from transport-induced workforce accessibility depends on the different features in production. In other words, the magnitude of transport-induced workforce accessibility is closely related to the way that final products are produced. Policy makers may be interested in the features in production in formulating transport planning policies. They may begin considering different features of manufacturing sub-sectors in production, together with the potential effects of transport infrastructure at the disaggregated level.

Fourth, the results suggest that transport infrastructure can lead to an increase in firm productivity in addition to time-saving benefits. This does not, yet, necessarily mean that any transport infrastructure development automatically brings about such productive benefits for stakeholders. Two conditions are required for transport infrastructure projects to result in an increase in firm productivity. One is that the delivery of transport infrastructure projects should ensure enough of an increase in workforce accessibility to change the way in which firms and workers access economic activities and the spatial interactions between them. The other condition is that diverse features in production should be considered with the level of workforce accessibility in terms of how these characteristics interact with a change in workforce accessibility.

The second analysis has several important and interesting policy implications that policy makers may consider in relation to the development and management of employment centres. First, the findings obtained from the regression models suggest that different types of accessibility measures are effective in capturing any changes to the level of access to transport facilities as well as the level of absolute and relative labour accessibility. These accessibility indicators may be useful for policy makers or researchers to determine how employment centres grow with changes to the levels of such accessibilities and to evaluate which accessibility indicators are key determinants of a centre's growth. Using these accessibility indicators, researchers may attempt to disentangle complex processes of employment centre growth in which different types of accessibility play a role.

Second, the results show that variations in the distance to a high-speed railway station are significantly related to change in the number of jobs in employment centres in the Seoul region. The findings suggest that a high-speed railway station may have the potential for employment centre growth. However, because the process in which the completion of a high-speed railway promotes economic development is long and complex, its impacts on employment centre growth could be delayed. Policy makers may target long-term plans for employment centre growth regarding the development of high-speed railways to materialize the growth's benefits on the development of employment centres. Regarding international airports, the results show that variations in the distance to international airports is statistically related to the job growth of employment centres. This suggests that an international airport may have potential for employment centre growth depending on various factors, such as a firm's location choice or the rise and fall of industries near the airport. Policy makers may be interested in an international airport. It however may be an undesirable policy option to have an airport as an only source for job growth unless the policy makers consider that the link between an airport and employment centre is not always linear.

Third, the results have showed that access to the total labour force is positively related to a change in the number of jobs both in an employment centre and in the entire region, although its magnitude is slightly low. Despite the fact that labour force is ubiquitous in an urbanized area, it was found that absolute labour accessibility is a significant factor in job growth of an employment centre. A key concern regarding employment growth is not whether the amount of labour force is available to centres but whether employment centres actually have sufficient access to the labour force. The finding suggests that policy makers may target a planning policy for employment centres in such a way that the employment centres have a sufficient level of absolute labour accessibility.

Fourth, the results show that relative access to the labour force via the transport network is a key determinant of job growth in employment centres. Access to the net labour force is important to a change in the number of jobs in employment centres as well as in the region. Access to the net labour force is not ubiquitous, even in urbanized areas, because firms compete for skilled workers. This finding suggests that competition between employment centres for the labour force is important to determining the amount of the labour force that is accessed by firms in an employment

centre. Policy makers or planners may be interested in access to the net labour force that considers competition for workers in determining how job growth in employment centres can be achieved. Policy makers may target a planning policy in such a way that the level of relative labour accessibility increases to ensure the growth of employment centres.

The third analysis of SML9 development has several important policy implications that policy makers could consider in the development of rail transit. First, the results show that the absolute and relative employment accessibility i are effective indicators for capturing any changes in job accessibility that results from rail transit investment. These findings suggest that, together with existing proximity indicators, accessibility indicators may be useful for policy makers or researchers in evaluating changes in both proximity and accessibility benefits resulting from rail transit investment. Policy makers may be interested in having multiple indicators to make better decisions regarding the development of rail transit. The proximity indicator may be suitable for cases in which direct effects of rail transit need to be evaluated, whereas absolute and relative accessibility indicators may be useful for cases in which either wider benefits of rail transit investment need to be evaluated or the quality of access to jobs or workers needs to be captured in relation to the labour market.

Second, the results show that the completion of SML9 results in positive yet modest proximity and accessibility benefits for residential and commercial lands near stations and in the surrounding neighbourhoods of rail stations. It also offers certain benefits to riders who commute by SML9. The findings suggest that the development of rail transit is an effective urban policy for an area in the vicinity of a rail station as well as for the overall neighbourhood surrounding the rail station. Policy makers may target the delivery of new rail transport infrastructure in such a way that the benefits of rail transit are spread throughout the immediate area of a rail station and among the riders who will use new rail services, also extending to the surrounding neighbourhoods and a range of businesses.

Third, the results show that the magnitudes and patterns of proximity and neighbourhood benefits that result from the completion of SML9 differ across different types of residential and commercial lands. The outcome of rail transit investment may be dependent upon the way that lands with different uses interact with the provision of

rail transport infrastructure. The findings suggest that rail transit investment will be less effective at spreading its benefits to society unless appropriate policies for the interaction between lands with different uses and the provision of rail transit are implemented. Policy makers could target an integrated approach for the benefits of rail transit investment to be fully taken by stakeholders, focusing on the interactions between land use and rail transit investment that facilitate diverse activities and services for commuters.

Fourth, the results show that residential and commercial lands at different price levels receive different levels of proximity and accessibility benefits from the completion of rail transit. This suggests that rail transit investment will be undervalued in terms of its benefits to society unless appropriate policies that can address such disproportionate benefits are implemented in relation to the development of rail transit. Policy makers may be interested in the uneven distribution of rail transit benefits across lands at different price levels. They might target policies regarding how the benefits of rail transit investment should be spread among stakeholders. This does not necessarily imply the immediate adoption of radical land taxation schemes, mainly because a progressive local tax system is already in place. A balanced combination between planning tools and taxation schemes may be a more practical option for policy makers and planners. Policy makers may also target policies on how the cost of rail transit investment should be distributed, as many issues involved in the debate on rail transit investment are centred on the question of who pays for the rail transit and who benefits from its development.

7.3. Originality of Study

The originality of the current study is underpinned by the following four points. First, to the best of my knowledge, the current study is the first research exploring the micro-level economic effects of transport infrastructure improvement at the metropolitan level in Asian countries. The study firstly has investigated both user benefits and wider economic benefits of transport infrastructure investment in the Asian context.

Second, data was collected from primary source although some data collected from secondary sources was also used in the analysis. For example, I collected locations of both tram and train stations in the Seoul region from various sources for the periods of

1897, 1930, and 1960. I geocoded their locations on the map and calculated the number of those stations to obtain their densities at the municipality level.

Third, more advanced accessibility indicators have been developed to better capture the economic effects of transport infrastructure improvement, which has improved their quality and accuracy in four aspects. For example, I have improved the way to measuring travel costs from using assumed straight lines to calculating travel costs base on the actual transport network. I have also considered commuters' choice of travel modes in the calculation of travel costs to reflect the way in which commuters respond to a change in the distance commuting distance in the Seoul region.

Fourth, I have developed existing statistical models further to investigate the impact of transport infrastructure. For example, I added two interaction terms to a difference-in-difference model to reveal proximity, accessibility, and neighbourhood effects of the completion of SML9. The proximity effect of SML9 was captured by an interaction between time period before and after the completion of SML9 and network distance to rail station. Its neighbourhood effect was captured by an interaction between time period before and after the completion of SML9 and the spatial location of land, depending on whether they fall in the control group or treatment group.

7.4. Limitations and Future Studies

The current study has contributed to our understanding of changes in accessibility induced by transport infrastructure and how and the extent to which these transport-induced accessibility changes impact firm productivity, employment centre growth, and land value. However, this thesis has several limitations.

The first analysis has three limitations. First, the accessibility indicators do not fully account for workers' individual characteristics that may be linked to the level of workforce accessibility, based on the assumption that specified workers have the same characteristics in terms of production. For example, workers with children may have different productivity levels than those with less responsibilities. Similarly, the analysis did not consider characteristics of the labour market, such as the unemployment rate, mainly due to the lack of data at the micro level. As mentioned in the previous section, the vitality and quality of the labour market are likely to be associated with the magnitude of productive benefits that arise from the transport-induced economy.

Second, only a few instrument variables derived from the spatial patterns of historical rail stations were used to correct the endogeneity issue. More instrument variables from various sources might be more useful in reducing the amount of endogeneity in workforce accessibility.

Third, due to the data availability, the estimated results of the IV model for the manufacturing industry did not compare with those for other industries such as business services, construction, and retail. Future studies could use the same analyses for different industries and compare them to provide useful implications for transport-planning policies. It may also be more beneficial to conduct international works to provide more reliable and general evidence on the economic effects of transport infrastructure improvement.

The second analysis has four research limitations. First, the study period of one decade was relatively short for investigating employment centre growth, although it was similar to study periods used in previous studies. The trajectory of employment centre growth is likely to change within ten years. Growth in the region may increase or decrease. Longer study periods would decrease deviation that may be created by the growth trajectory. The reason for the research's short study period was the lack of both employment data and transport network data at a sufficiently spatial level.

Second, a relatively simple regression model was applied to investigate the link between transport-induced labour accessibility and the growth of employment centres, although the model has been widely used to investigate the relationship between variables of interest and dependent variables. Using more advanced regression models would uncover more dynamic aspects of employment centre growth and its relationship with transport-induced labour accessibility.

Third, the method used to delineate the employment centres was not statistically robust or scientific, although it is widely used in the literature. The cut-off method is based on the idea that the number of employment centres to be identified depends on how the researchers decide on the cut-off standard while considering the spatial context in a given area. All the outcomes, thus, are completely dependent on the researchers' local knowledge of the relevant area. A more generous cut-off standard would identify more employment centres. The main barrier to using more scientific identification methods in this study was the absence of a generalized approach that can be applied scientifically to any city. Future studies could focus on the development of more reliable identification

methods for employment centres, which may be very useful in various types of studies.

The third analysis has two research limitations. First, the study period between 2008 and 2010 was relatively short, although it focused on analysing the immediate changes in the level of accessibility before and after the completion of SML9. Future studies could focus on the long-term effects of the opening of SML9, as these effects may indicate different or interesting patterns regarding price effects that derive from changes to accessibility.

Second, due to the time at which this study was conducted, it did not cover all the stages of SML9. It only looked at the completion of Stage 1. As of 2016, Stage 2 of SML9 was completed, and the final stage is scheduled to be completed in 2019. Future studies could use the same analysis as that used to complete all the stages of SML9 to compare the estimated results with those obtained from the third analysis.

8. Appendix

Appendix A. Definition of Industrial Sector in South Korea

The classification of industries in Korea is defined by the KSIC (Korean Standard Industrial Classification). The manufacturing industry is divided into 2-digit KSICs ranging from food production (code 10) to other manufacturing (code 33).

Table 8-1. Korean Standard Industrial Classification for Manufacturing Industry

Sector	Definition	KSIC (2-digit)
1	Manufacture of food products	10
2	Manufacture of beverages	11
3	Manufacture of tobacco products	12
4	Manufacture of textiles (except apparel)	13
5	Manufacture of apparel (clothing, accessories and fur articles)	14
6	Tanning and dressing of leather, manufacture of luggage and footwear	15
7	Manufacture of wood products of wood and cork (except furniture)	16
8	Manufacture of pulp, paper and paperboard	17
9	Printing and reproduction of recorded media	18
10	Manufacture of coke, hard-coal and lignite fuel briquettes and refined petroleum products	19
11	Manufacture of chemicals and chemical products (except pharmaceuticals, medicinal chemicals)	20
12	Manufacture of pharmaceuticals, medicinal chemicals and botanical products	21
13	Manufacture of rubber and plastic products	22
14	Manufacture of other non-metallic mineral products	23
15	Manufacture of basic metal products	24
16	Manufacture of fabricated metal products (except machinery and furniture)	25
17	Manufacture of electronic components, computer, radio, television and communication equipment and apparatus	26
18	Manufacture of medical, precision and optical instruments, watches and clocks	27
19	Manufacture of electrical equipment	28
20	Manufacture of other machinery and equipment	29
21	Manufacture of motor vehicles, trailers and semitrailers	30
22	Manufacture of other transport equipment	31

23	Manufacture of furniture	32
24	Other manufacturing	33

Appendix B. Conceptual Model of a Firm's Production

I construct a simple relationship between a firm's output and input factors. Following the tradition set out in the existing literature, I make use of the Cobb-Douglas production function³³ as a basic conceptual framework for the relationship between a firm's production and input factors. The Cobb-Douglas production function is widely used as a standard function representing such a conceptual relationship (Ackerberg et al., 2007). The specification of a firm's production can be expressed as follows:

Equation 8-1. Conceptual Production Function

$$Y = f(K, L, M)$$

where Y represent the economic output of a firm and K, L, and M refer to the input factors (the capital stock, labour, and intermediate inputs, respectively). While a large part of a firm's output is explained by the number of input factors used in production, a firm's output is also affected by how efficiently and intensively such inputs are utilised in production (Solow, 1957). In other words, the level of a firm's output varies by the efficient with which the input factors are used in the production process (Comin, 2010). The portion of output not explained by the number of input factors used in production is Total Factor Productivity (TFP).

The efficient level of a firm's production is largely determined by both firm-specific characteristics and the spatial environment where a firm is situated (Ackerberg et al., 2007; Combes & Gobillon, 2015). Firm-specific characteristics refer to a firm's individual characteristics and its business strategy. A firm's ownership structure is a typical

³³ The Cobb-Douglas production function is based on the assumption that the economic output of firms is proportionate to the increase in the amount of the three input factors: the capital stock, labour and intermediate inputs (Douglas, 1976).

example of such firm-specific characteristics. A firm's ownership structure is concerned with corporate governance³⁴ which determines a firm's investment in R&D capability directly relating to its long-term business performance.

The transport infrastructure network is related to a firm's spatial environment in terms of the level of workforce accessibility. Changes in the level of workforce accessibility are likely to bring about changes in the efficiency level at which economic actors operate in relation to production. As discussed in Chapter two, firms benefit from being located close to the labour market because both workforce and jobs are likely to be better matched (Combes et al., 2012; Puga, 2010a). Better matching between workforce and jobs increases the productivity of economic actors.

Productive benefits that result from transport infrastructure are not proportionately related to a firm's output, and instead take a different channel to one taken by the input factors in production (Henderson, 2003). While the level of workforce accessibility is concerned with the spatial environment where firms are located, input factors are concerned with the production process itself. A variable that reflects workforce accessibility is therefore supposed to be treated differently from the input factors in the production function. The way in which the level of workforce accessibility impacts on firms' productivity and the level at which it operates regarding firm's productivity are different from the input factors.

I incorporate a term that represents the efficiency level of production into the conceptual model, following the practice in the existing literature (Ding, Guariglia & Harris, 2015; Graham, 2007b). The use of the term in production function is a common practice to discern the efficient level of production from the input factors (Acemoglu, 2008; Ciccone, 2002). A firm's output can be defined as a function of the input factors and a variable for the efficiency level of production, as shown in Eq. 8-2.

Equation 8-2. Conceptual Production Function with the Efficiency Level of Production

$$Y = A \cdot f(K, L, M)$$

³⁴ Corporate governance is the system by which companies are directed and controlled. "The purpose of corporate governance is to facilitate effective, entrepreneurial and prudent management that can deliver the long-term success of the company"(Council, 2014)

where Y is the economic output of a firm and A denotes a vector of variables that influence on the efficiency level of production, including the level of workforce accessibility³⁵. K , L and M represent the amount of capital stock, labour and intermediate inputs that feed into the production process. For example, a firm's age is closely related to its productivity because younger firms are likely to be more innovative in terms of the level of technologies and capital. Younger firms tend to be more productive than older firms.

I formulate a conceptual model that describes the relationship between firm's output, the input factors and the level of workforce accessibility. The core point of this conceptual model is that the level of workforce accessibility is a factor that changes the spatial environment where firms are located, and that therefore affects the efficiency level of production and firm productivity.

Appendix C. Additional Regression Results for Chapter Five

This section provides the estimated results of the models that includes the size of employment as an independent variable. The estimated results show that the size of an employment centre at the initial period is found to be statistically significant and positive, which indicates that the formation and growth of employment centres are related to productive advantages arising from the concentration of economic activities. This is consistent with the findings in a number of previous studies, which reported that the positive advantages of employment agglomeration operate at the sub-city-region level (Fujita et al., 2001; Giuliano & Small, 1999). The positive coefficient of employment centre size suggests that the productive benefits of employment clusters outweigh the disadvantages of employment agglomeration, such as congestion. This means that the number of jobs in employment centres is likely to continue to grow to the point at which the positive advantages are cancelled out by the disadvantages.

³⁵ A change in production function is considered to be Hicks-neutral unless the change does affect the balance of the input factors (labour, capital, and the intermediate) on the production process of firms or industries (Wood & Woods, 1989). In this analysis, the level of workforce accessibility resulting from transport infrastructure is a driver for the change in productivity, since it encourages firms to be more efficient and productive.

Table 8-2. The Estimated Results with the Size of Employment

Model for Employment Centers			Model for the Seoul region	
	Coefficient	Std. Error	Coefficient	Std. Error
Constant	10895.9**	(3674.8)	2330.6***	(411.3)
Emp2000	0.137**	(0.0611)	0.235***	(0.0219)
Den2000	-0.204**	(0.0986)	-0.119***	(0.0321)
Popden2000	-0.0935	(0.117)	-0.0522***	(0.0116)
DistCBD	-0.144	(0.0953)	-0.0132	(0.00902)
R-squared	0.038		0.168	
Observations	136		1096	

Notes: * denotes significance at the 10 per cent level; ** denotes significance at the 5 per cent level; *** denotes significance at the 1 per cent level.

Appendix D. Description of Physical Characteristics of Land Plots

Table 8-3. Description of the Slopes of Land Plots

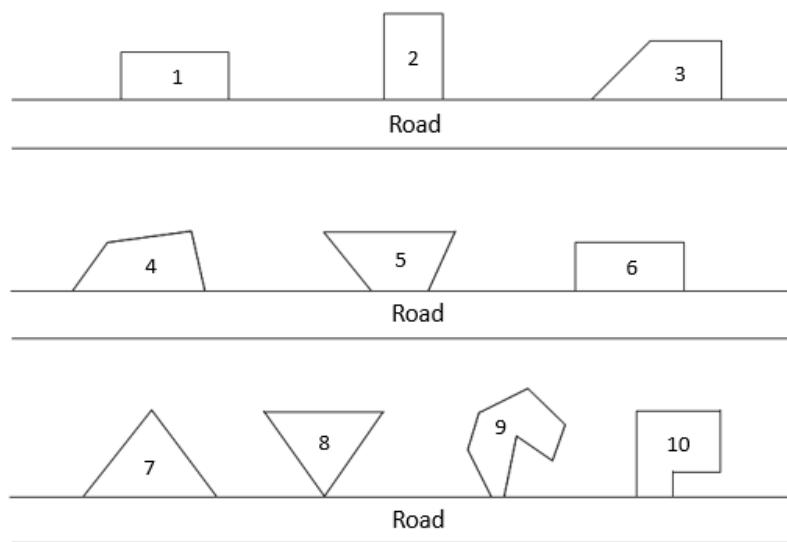
Type	Value	Description
A	1	Land plot much lower than the surrounding area
B	2	Flat land plot
C	3	Land plot somewhat higher than the surrounding area, with the slope of less than 15°
D	4	Land plot somewhat higher than the surrounding area, with the slope of more than 15°
E	5	Land plot much higher than the surrounding landscape

Table 8-4. Description of Road Accessibility of Land Plots

Type	Value	Description
A	1	Land plot linked to roads larger than 25m wide
B	2	Land plot linked to 8-12 meters wide road and roads larger than 25m wide
C	3	Land plot linked to a road less than 8-meter wide and roads larger than 25m wide
D	4	Land plot linked to 12-25m wide roads
E	5	Land plot linked to 12-25m wide roads and other roads

F	6	Land plot linked to a road larger than 8m wide but less than 12m wide
G	7	Land plot linked to 12-25m wide roads and other roads
H	8	Land plot linked to a road less than 8m wide
I	9	Land plot linked to a road for automobiles
J	10	Land plot linked to a road for motorcycles
K	11	Land plot connected to at least two roads for walkers only
L	12	Land plot not connected to any roads

Figure 8-1. Description of the Shapes of Land Plots



Appendix E. Planning Tool for Land Value Capture

It is important to know whether land value taxation has negative impacts on the economy by disrupting the productive nature of land. To gain understanding of the interaction between taxation and the productive nature of land from an economic perspective, we review two relevant theories for land taxation: theory of economic rent and tax capitalization.

In micro-economic theory, the concept of 'economic rent' refers to the amount that a factor of production earns over and above 'transfer earnings' (payment that is necessary to keep it in production) (Foldvary, 1999). The amount earned over and

above transfer earnings is subject to demand for, and supply of, a factor for production (land, in this case). The surplus earnings may occur when demand for land increases because land cannot be reproduced in greater quantities and is geographically fixed. The increased demand cannot be met by more provision of land, and hence this mismatch of demand and supply produces the surplus earnings, or economic rent. For example, the provision of a light railway transport system would lead to an increase in transport accessibility in an area, and subsequently demand for the area would go up due to a growing number of people who prefer to live near transport hubs. Yet, since land supply of this area is limited, surplus earnings occur and the landowners will benefit from increased land price. Given that this surplus is the result of the scarcity of land in production, taxation of this surplus does not interfere the nature of productive land and thus will not cause distortion in the economy.

King (1990) supported the view that a tax on land value does not result in economic distortion. Whitehead (2014) also showed that basing tax on the economic rent will not cause any change in demand or supply, stating that “landowners earning economic rents cannot alter their position, which is already the most profitable one, and the tax will simply cream off their profits.”(Whitehead, 2014, p. 413)

Land value may be defined as the total monetary value of usage for the land, the bundle of rights that are attached to it, and the set of neighbourhood characteristics that are concerned with the land. Examples of the bundle of rights attached to the land include the rights to sell and lease the land, the right to subdivide, the right to air and water quality protection, transport accessibility, access to amenities, environmental quality, and crime levels. These are typical examples of neighbourhood attributes affecting the value of land. These techniques for land value capture can fall broadly into two groups: one is fees and taxes, which can be subdivided into one-time assessments and annual property taxes, and the other is nontax value capture tools.

Table 8-5. Techniques for Land Value Capture

What is Taxable?	What is the Basis for Determining the Tax or Fee?	When is the Tax or Fee Collected?
Development Fees	Market value of new private investment in development	Cost of overseeing new development or mitigating impact of development on

		public infrastructure	granted
Estate tax	Generally, all land and property included in estates above a defined threshold of total value	Value of land and property transferred as part of an inheritance	Once, following death of estate owner
Capital gain tax	Sale of real property	Value of real property sold minus original purchase price and any subsequent improvement costs	Once, as part of income tax system
Transfer tax and stamp tax	Transfer of registered land title or other land rights to another party	Market value of real property transferred	Once, when registered land title or rights are formally transferred
Betterment tax	Increment in real property value due to public investment or approved change in land use	Land and improvement value after change minus land and improvement value before change	Once, at time of investment or when permission to change land use is granted
Land rent or lease	Right to occupy and use publicly owned land	Varies widely	Annually, but can be more frequent
Annual property tax	Privately owned or controlled land and immovable improvements	(1) Market value of land and property, or (2) physical characteristics of land and property	Due annually, payable either annually, monthly, or quarterly

Appendix F. The Case Area: the Seoul Region

8.F.1. Rationale for the Selection of the Case Area

The Seoul region is the case area for this research. The region includes Seoul, the capital city of South Korea, and two other major areas, the city of Incheon and Gyeonggi province. The choice of the Seoul region as a case area is based on three reasons. First, the transport infrastructure network in the Seoul region has improved considerably over the last decade. The population and number of jobs in the region has increased over many decades because of its economic development and this has created a strong demand for people's mobility. In response to this demand, a great deal of transport infrastructure development has been carried out and the existing transport infrastructure in the region has been expanded.

The second reason is the spatial change that has taken place in the region over the last several decades, which is closely connected to the development of transport infrastructure in that the latter follows the former and vice versa. Transport network improvement has been parallel to the urban spatial change in the Seoul region, as is the case in other large cities, such as London, Chicago, and Los Angeles. Transport infrastructure has played a key role in connecting people and places in the process of spatial decentralization in the region.

The last reason for the choice of the Seoul region comes from its key role in the national and global economy. As of 2015, the population in the Seoul region is around 25.6 million, which is over 45% of the total population in South Korea. Its population size makes it one of the largest metropolitan areas in the world. In addition, the Seoul region ranks high on the list of Global Cities of the Future 2015, alongside global mega-cities such as London, New York, Tokyo, and Shanghai. Table 8-6 gives an overview of how the Seoul region performs in the category of "connectivity" and "economic potential" across cities in the world.

Table 8-6. Rankings of Global Cities of the Future

Top 10 Connectivity				Top 10 Economic Potential			
Rank	City	Country	Region	Rank	City	Country	Region
1	London	UK	Europe	1	Beijing	China	Asia

2	Paris	France	Europe	2	London	UK	Europe	Pacific
3	Tokyo	Japan	Asia Pacific	3	Shanghai	China	Asia Pacific	
4	Seoul	Korea	Asia Pacific	4	New York	US	North America	
5	New York	US	North America	5	Tokyo	Japan	Asia Pacific	
6	Los Angelis	US	North America	6	Paris	France	Europe	
7	Istanbul	Turkey	Europe	7	Seoul	Korea	Asia Pacific	
8	Shanghai	China	Asia Pacific	8	Moscow	Russia	Europe	
9	Moscow	Russia	Europe	9	Wuhan	China	Asia Pacific	
10	Beijing	China	Asia Pacific	10	Chongqing	China	Asia Pacific	

Source: 2015 Global Cities of the Future, fDi Intelligence by Financial Times

According to the fDI intelligence, various factors are considered for the category of “connectivity” and “economic potential”. For example, credit rating, index of Economic Freedom, and labour productivity are considered in the category of “economic potential”. For the category of “connectivity”, distance to nearest international airport and number of international destinations served from airports are taken into account.

The Seoul region ranks fourth in the category of “connectivity”,³⁶ one step above New York, which indicates that it is very well connected by physical infrastructure with major economic zones or major cities. In the category of “economic potential”, the Seoul region ranks seventh, along with major Asian cities such as Beijing and Shanghai, suggesting that it is one of the core economic power stations in the world.

8.F.2. Population and Households in the Seoul Region

Population growth in the Seoul region has been phenomenal, with an average rate of

³⁶ The category of “connectivity” refers to both physical and internet connection to other parts of the world, according to the definition of Global Cities of the Future.

6.6% per year since 1970. The Seoul region's population more than doubled between 1970 and 2000, although the growth rate has slowed slightly in recent years. The Seoul region's population is expected to grow further in the future, according to the population projection conducted by the Statistics Office of Korea (The Statistics Office of Korea, 2016). Figure 8-2 shows the Seoul region's population growth in comparison with the growth trend for Seoul and for the other geographical areas in the region. The figure covers the time period between 1970 and 2010.

The population growth trend differs per area in the region. Most of the population growth took place in the area outside Seoul, which indicates that most of the migrated population settled outside Seoul and the population that used to live in Seoul tended to move out of Seoul for various reasons. In fact, Seoul's population continued to grow until about 1990, reaching 10.6 million, but since then, the total population in Seoul has declined slightly. This is mainly attributed to a range of population control policies that came into effect by around that time. In 2004, the Gyeonggi population reached around 10 million, similar to the Seoul population, and started to overtake the Seoul population in 2005, which led to the strong need for a change in the spatial strategy across the region.

Figure 8-3 shows the change in the number of households in the Seoul region, which increased by 9.4% per year between 1980 and 2010. The high growth rate of households is mainly due to a surge in single-person households, which increased more than 13 times between 1980 and 2010. In comparison to the growth rate of the total number of households, the number of single-person households rose by around 44% per year. A possible reason for such growth could be the fact that people and society in Seoul have changed in terms of economic, demographic, cultural, and social aspects (Chung et al., 2012). For example, growing financial independence is one of the key reasons for the rise of single-person households. An increase in both the average age of marriage and life expectancy is another reason for the considerable increase in single-person households.

Figure 8-2. The Growth Trend of Population in the Seoul Region³⁷

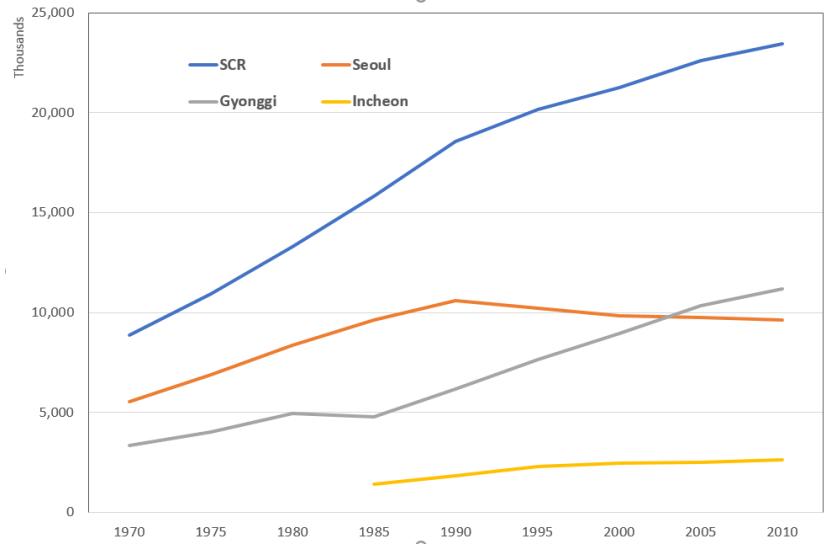
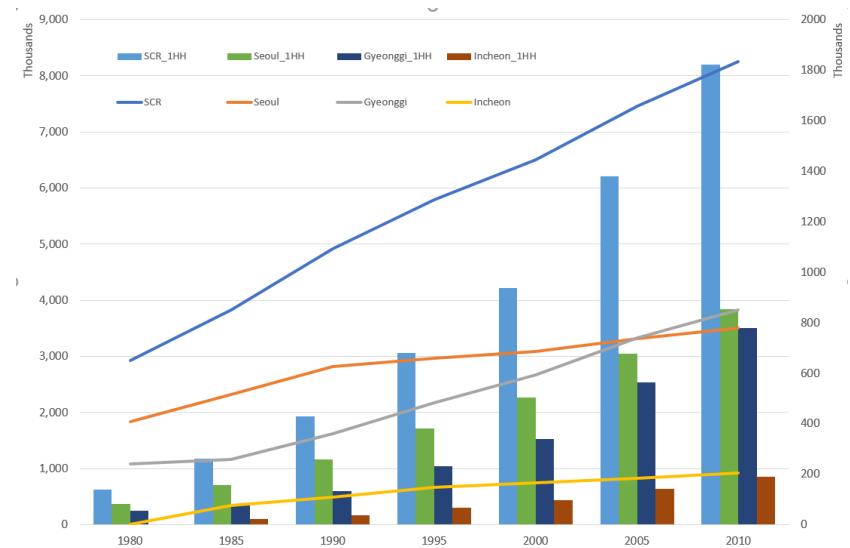


Figure 8-3. The Growth Trend of Households in the Seoul Region

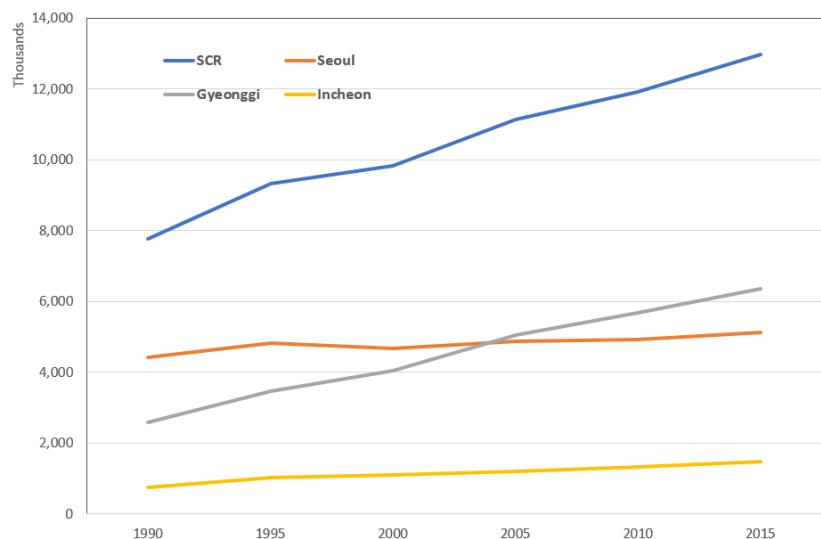


8.F.3. Employment in the Seoul Region

³⁷ Incheon city was designated as a metropolitan city in 1981, separated from Gyeonggi province. Incheon's population before 1981 was calculated together with the Gyeonggi population.

As with the population, the employment rate in the Seoul region has also increased considerably. Figure 8-4 shows the change in the number of jobs in the region since 1990. Jobs in the region increased by around 67% between 1990 and 2015 and, during the study period between 2000 and 2012, the number of jobs in the region rose by 21.4%, which, although significant, is moderate compared to the growth in the 1970s when the country experienced rapid industrialization. From a geographical perspective, most of the increase in jobs took place outside Seoul, partly because of a series of industrial policies to curb economic activities within the inner-city area. It can be observed that the number of jobs in Gyeonggi province began to be greater than that in Seoul in 2005.

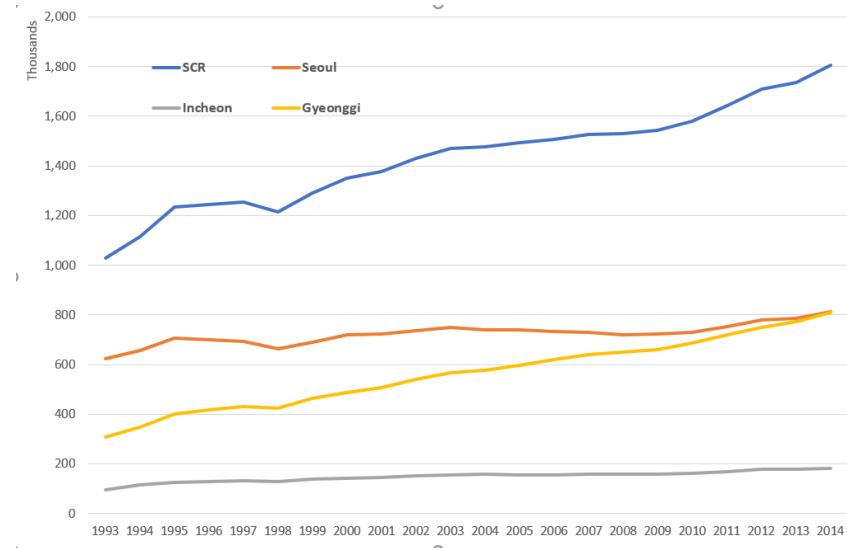
Figure 8-4. Changes in the Number of Jobs in the Seoul Region



Throughout the study period, the number of firms in the Seoul region also climbed by around 0.3 million, from 1.3 million in 2000 to 1.6 million in 2010. Figure 8-5 shows the change in the number of firms in the region. The number of firms in Seoul was nearly two times larger than those in Gyeonggi province in the early 1990s. Since then, the number of firms in Gyeonggi province has grown continuously whereas that in Seoul remained at the same level, demonstrating that a series of industrial policies to curb the number of firms within Seoul was effective. The difference in the number of firms between Seoul and Gyeonggi province gradually reduced since 1995 and in 2014, the

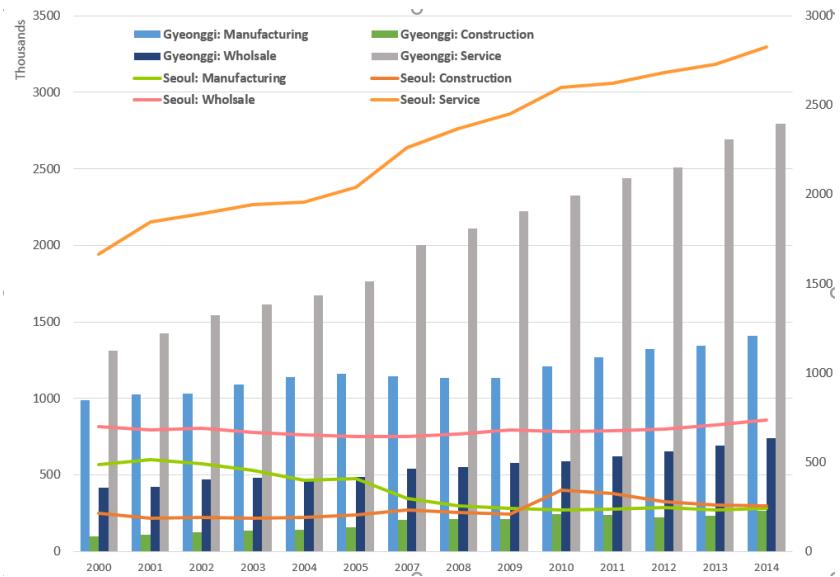
number of firms in both areas was nearly the same.

Figure 8-5. Changes in the Number of Firms in the Seoul Region



The Seoul region's largest industry is the service industry, with an over 60% share of industry overall in 2012. The manufacturing industry is the next largest. The service industry's proportion of total industry increased by around 10% between 2000 and 2010. This growth in the service industry was considerable in Seoul where cultural and creative firms were promoted rather than heavy manufacturing ones (see Figure 8-6). The proportion of the service industry of the total industry grew to nearly 68% over industry overall in Seoul between 2000 and 2012. In terms of location, many traditional manufacturing firms were relocated to outside Seoul. While the share of the manufacturing industry dropped in Seoul, it rose in Gyeonggi province, employing around 0.8 million workers in 2000 and 1.13 million in 2012. Although the manufacturing industry tends to decrease, it is still the second largest industry in the region and contributes most to the economy.

Figure 8-6. Employment by Industries in Seoul and Gyeonggi Province



To some extent, the distribution of employment is determined by the government's policies, but it is also affected by where firms locate their factories and facilities. As firms have grown due to the fast capitalisation process, their influence on the distribution of jobs has become significant. These large firms have constructed factories and facilities that have hired a large number of employees. Their location decisions for new factories have thus had significant impacts on the location of employment in the region. Two distinctive examples for this type of employment concentration are an LCD cluster in Paju and a semiconductor cluster in Pyeongtaek (See Figure 8-7).

Figure 8-7. Employment Clusters of Large Firms in the Seoul Region



8.F.4. The Development of Transport Infrastructure in the Seoul Region

Korea's public rail transportation officially started in 1899 when the first railway, Gyeongin Line, began operations, linking Seoul to Incheon, a city with an international port that had opened in 1883 (Korea Transport Institute [KOTI], 2006). Since then, a series of railway lines have been constructed to promote the exchange of goods and resources between locations and to stimulate the growth of local and regional economies. Gyeongui Line was built in 1905 to link Yongsan, the centre of distribution in the country at the time, with Pyongyang and Sinuiju. The Gyeongbu Line was built in 1906, forming the railway line crossing the Korean Peninsula from the south to the north (Cho, Kim, Sung & Lee, 2011).

Soon after the opening of railway services, an electric locomotive started operation as urban public rail transportation in 1899. The electric rail transit, called Seoul Electric Locomotives, ran from the centre of Seoul to major commercial areas within Seoul, making a total journey of over 60 kilometres.³⁸ Before this, a typical means of transportation was animal-powered transportation such as a horse-powered wagon and a rickshaw. The introduction of public rail transit to and within Seoul was an innovation

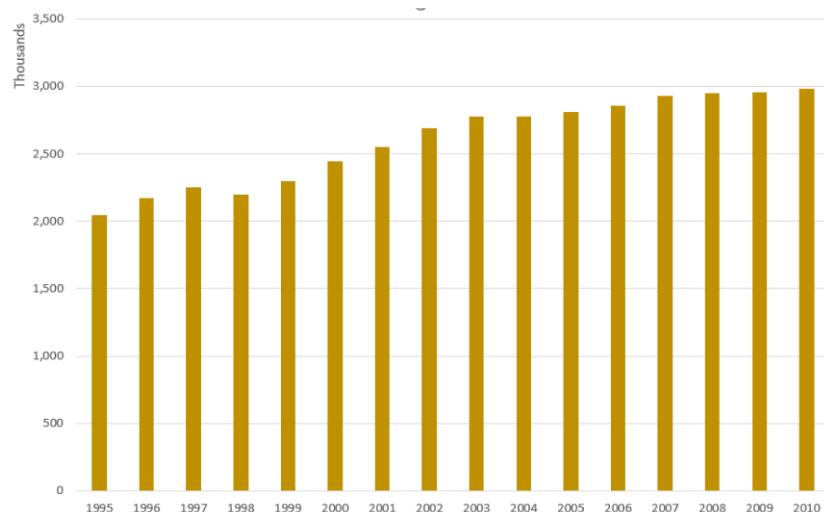
³⁸ Seoul electronic locomotives started its operation in 1899 and ended in 1968 as a plan for Seoul Metro line 1 was announced and its construction started.

in transport technology and contributed to improving the quality of public transportation in South Korea (Korea Transport Institute [KOTI], 2006).

In the early stage of economic development in South Korea, rail transport infrastructure was at the centre of passenger travel and logistics at the urban and regional levels. Until motorways gained currency, railways were the dominant means of transportation in both passenger travel and freight transport (Ko, 2015). The government prioritised railways as major transportation for economic development.

However, road transport was the main mode of transportation in South Korea until the recent resurgence of rail transit. The main reason for this was the decreasing cost of car ownership (see Figure 8-8). In addition, innovation in car manufacturing, called Fordism, brought about a reduction in car production costs, which caused a favourable environment for the rise of the automobile (Amin, 2011; Shiomi & Wada, 1995). Along with the growth of car ownership, the government built more road transport infrastructure to meet the rising demand.

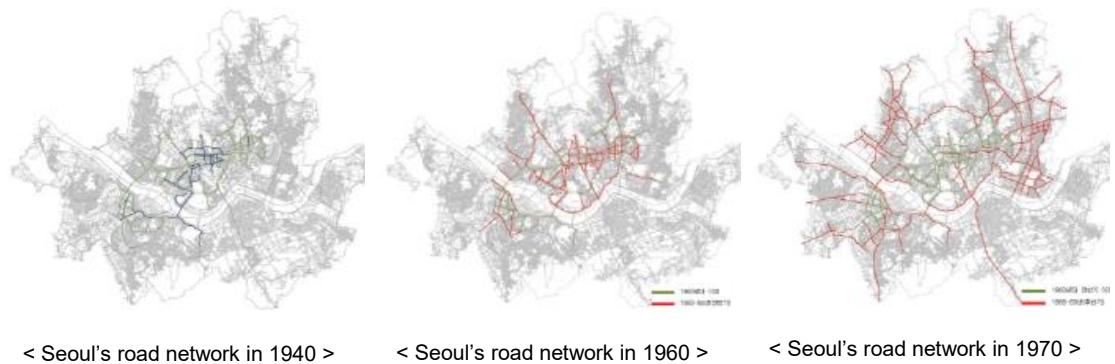
Figure 8-8. Car Ownership in Seoul



The spatial expansion of economic activities was another major reason for the construction of transport infrastructure in the Seoul region. Economic activities, population, and employment require a physical connection with other economic activities and thus a transport infrastructure network.

Taking closer look at a change in transport infrastructure, Figure 8-9 shows the development of the road transport infrastructure network in Seoul. In the 1950s, the majority of the road transport network was concentrated around the city centre, supporting economic activities taking place in the inner city. In the 1960s, the extent of road transport infrastructure began to expand towards the south-west of Seoul where many jobs were being created in the light manufacturing sector. The expansion of road transport infrastructure continued towards the industrial and residential districts that were significantly developed in the South of Seoul in the 1970s.

Figure 8-9. The Development of Road Transport Infrastructure in Seoul



< Seoul's road network in 1940 > < Seoul's road network in 1960 > < Seoul's road network in 1970 >

Source: the Seoul city government and the author

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