

Robot adoption and FDI driven transformation in the automotive industry

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Abstract

This paper explores the relationship between inward Foreign Direct Investments and the adoption of industrial robots, across different segments of the automotive value chain. Using the International Federation of Robotics and fDiMarket datasets at a fine level of disaggregation of the automotive sector, we investigate the extent to which FDI is related to the operational stock of industrial robots in 34 countries over the period 2005-2014. We find distinct patterns linking FDI and robot adoption for different groups of countries *and* for different segments of the automotive value chain, that is, assembling and components production. With some relevant exceptions, FDI is found to be highly correlated with robot adoption in the assembling segment across major leading countries. However, this correlation becomes weak for components production. To explain this differential role of FDI in robot adoption, we formulate hypotheses around the country-specific drivers of robotisation for the components segment by pointing to the role of domestic ecosystems of suppliers and industrial policy as drivers of technology absorption and diffusion.

Keywords: automotive, industrial policy, fourth industrial revolution, industrial robots, global value chains, foreign direct investments

1. Introduction

During the last decade, the interest towards the alleged “fourth industrial revolution” has increased dramatically. A set of digital technologies are expected to have a profound impact on the international organisation of work and production, ultimately reshaping global value chains (OECD, 2017; UNIDO, 2017 and 2020). With a focus on robots in the automotive industry – i.e. a highly dynamic and transformative digital production technology with a relatively long history of application to the specific industry under observation – this paper investigates some of the potential drivers and mechanisms underlying the adoption of such production technology across different countries. Specifically, we focus on the actual and potential role of Foreign Direct Investments (FDI) in technology adoption, and provide new evidence of the relationship linking number of FDI received in a specific country and the operational stock of robots within the automotive sector.

In developing our analysis, we refer to the broader literature regarding the relationship between FDI and technological upgrading of recipient countries. Are FDI a key driver of technology transfer and adoption? Under which circumstances do FDI have a positive effect on the technology absorption and diffusion in the domestic ecosystem of companies? Are FDI enough to trigger the introduction of advanced technologies such as industrial robots? What is the role played by host country specific factors in the adoption and diffusion of industrial robots? What are the specific features of the automotive sector affecting these mechanisms?

Against this research agenda the paper will focus on the existence (or lack thereof) of a nexus between FDI and the adoption of industrial robots in the automotive sector. We proceed in this direction by innovatively combining two datasets, the International Federation of Robotics (IFR) dataset, and fDi Markets dataset, supplied by fDi Intelligence, a specialised division of FT Ltd. We focus on the middle part of the automotive value chain, concerning manufacturing production processes. By combining descriptive statistics at different levels of analysis, we explore the extent to which FDI are possibly driving the adoption of industrial robots and we formulate hypotheses on other complementary drivers and mechanisms. Specifically, taking advantage of the high level of data disaggregation and focusing on different segments of the automotive value chain – i.e. assembling and components production - we analyse the relationship between FDI and patterns of robot adoption across 34 countries for two periods:

- i) a ten-year period (2005-2014) with a data disaggregation distinguishing two segments of the industry – i.e. Automotive OEM¹ and Automotive Components;
- ii) a five-year period (2010-2014) considering four segments of the automotive value chain – i.e. ISIC Rev.4 Classes 2910 (motor vehicle assembling), 2931 (metal parts and plastics), 2933 (electric and electronic parts), 2939 (other parts which include seats, airbags, safety belts). This further level of disaggregation is only possible from 2010 due to data constraints.

Considering the cross-country heterogeneity in the patterns of robot adoption and the importance of domestic/regional value chains for technology diffusion, we formulate and explore a number of conjectures around the role of FDI and additional country-specific factors that could act as drivers

¹ Original Equipment Manufacturer. The term generally refers to the original producer of components. In the automotive sector it is used as a synonym of car producing companies, i.e., the final assemblers.

for robotisation. Special attention will be given to the potential role played in different countries by their domestic industrial ecosystem of suppliers and industrial policy incentives, that is, the extent to which a more or less developed domestic supply-chain and incentive packages can drive robots adoption and diffusion in the sector. We do so in the attempt to answer the main research question of the paper regarding the existence (or lack thereof) of correlation between FDIs and the increasing adoption of industrial robots at different segments of the automotive industry.

The paper is structured as follows. Section 2 presents a selective review of the literature on the relationship between FDIs and technical change, which we use to inform our research questions. We will consider both standard literature and more recent contributions which take into account global value chain mechanisms and local industrial policies, which are notably a crucial aspect of automotive sector dynamics. Section 3 considers the main features and trends that shaped the automotive sector in the last decades. Sections 4 and 5 present our sources of data and engage in a series of descriptive statistics to show different types of correlation (or absence thereof) between FDIs and robot adoption. Section 6 discusses our data and put forward some possible explanations based on alternative views on technological upgrading and industrialisation.

2. Foreign Direct Investments and Technical Change

A wide range of academic researchers have devoted their attention to the role of FDIs in stimulating growth and development. More specifically, the focus on technology spillovers and the associated learning opportunities have been increasingly covering an important part of the research on FDIs. Being the linchpin of this study on a specific production technology, e.g. industrial robots, and being the literature explicitly linking industrial robots and FDIs quite scant, we firstly engage in reviewing contributions on FDIs and technical change at a more general level. Since the 1980s, the role of FDIs and Multinational Corporations (MNCs) in promoting growth, employment, and economic diversification in emerging and developing countries has been widely debated. The literature and policy debates have recognised that FDIs can trigger productive transformation, however only to some extent and under specific conditions. Throughout the 1970s and 1980s, several concerns about the limited – and in some cases damaging – impact of MNCs and their FDIs in developing countries were raised, in particular with respect to their contribution to high quality industrialisation and technology transfer (Lall, 1978, 1979; Safarian, 1999).

Over the 1980s and 1990s, the structural transformation experience of some of the late industrialisers softened these critical perspectives. First, positive experiences of productive, technological and organisational capabilities development started to emerge across a number of late industrialisers, especially in South and East Asia, in particular among those countries who developed a *strategic engagement* with MNCs (Wade, 1990; Amsden, 1989; for more recent contributions see Andreoni and Chang, 2019; Chang and Andreoni, 2020). This strategic engagement resulted in the establishment of joint ventures and increasing technology transfer, the absorption of global production technologies and standards, which led to the development of domestic supply chains through localisation policies alongside global value chain integration (Lall, 2000; Mpanju, 2012). Second, the accelerating pace of technological change (UNCTAD, 2018), together with the rising cost of innovation, contributed in viewing MNCs as a strategic asset, and often the only way to link up to new global waves of innovation and technologies.

Despite the rising role of MNCs and FDI in emerging economies, the evidence of their impact on economic and technological upgrading of Least Developed Countries (LDCs) remains mixed, both in terms of technology absorption (through direct and indirect effects) and of technology diffusion. The next two sections review and unpack how technology absorption and diffusion have been analysed and supporting empirical evidence.

2.1 *Direct and Indirect Effects*

A standard distinction in the literature is between *direct* and *indirect* effects of FDI on host economies (Zanfei, 2012; Castellani et al., 2015).

First, a substantial body of literature found a positive *direct* effect of inward FDI on the host economies mainly in terms of: (i) changes in the composition of industry, as FDI brings in bundles of competencies and knowledge assets that increase the overall productivity level of the recipient economy (Dunning, 1993; Barba Navaretti and Venables, 2004; Criscuolo and Martin, 2009; Castellani et al., 2015; Denisia, 2010); (ii) employment creation, especially when MNCs contribute to import substitution and to the expansion of a country's export capacity (Ncunu, 2011; Chaudhuri and Banerjee, 2010 for FDI in agriculture).

With specific reference to low- and middle-income countries as recipient economies, Vacaflores (2011) studied the relationship between FDIs and employment in 12 Latin American countries and found a positive and significant effect. Latin American countries were among the highest recipients of FDIs starting from the 1980s but, once compared to other regions like South East Asia or Eastern Europe, the impact of FDI was much weaker in terms of employment growth and other parameters of industrial upgrading and competitiveness (Zhang, 2001). In contrast to these fast industrialisers, countries like Mexico did not engage strategically with MNCs, on the contrary their approach was one of “passive open-door policy with limited policy interventions and no industrial policy” (Lall, 1995). As a result, if we look at Mexico as an example, while the development of the auto cluster was impressive – export grew 18% a year over 1994-2002 – the country grew at a modest 3% and the expected automotive multiplier did not materialise (Mortimore and Vargara, 2004).

Second, for what concerns *indirect effects* on host economies, these occur through changes in the capabilities, strategies and performance of local firms, especially their value addition. The standard assumption is that FDIs will determine some kind of technological externalities, contributing to shifts in the local firms’ production function, or pecuniary externalities, determining shifts in the local firms’ profit function (Blalock and Gertler, 2008; Newman et al., 2014; Santos and Khan, 2018). Empirical evidence on these impacts is more controversial. Some studies found evidence of technological upgrading at a general level, where local firms learnt from MNCs by observing technologies employed by international actors and attracting employees trained by the same actors (Borensztein et al., 1998; Blomström and Sjöholm, 1999 for a study on Indonesia; Meyer, 2004). While the results based on cross-sector analysis revealed a positive impact of FDIs (see for example Makki and Somwaru, 2004; Aykut and Sayek, 2007), due to the fact that international activities take place in better performing countries, the availability of longitudinal firm level data has led to explore spillovers effects of multinational presence across and within industries, leading to less clear-cut results. In fact, a number of studies have found null or even negative impact of FDIs on the performance of host economies (Gorg and Greenaway 2004).

Moreover, it is important to stress the difference in FDI effects occurring across countries at different stages of development. Although empirical research shows a positive correlation between FDIs and productivity in developed countries (Caves, 1974 on Australia; Globerman, 1979 on

Canada; Pain and Hubert, 2000 on the United Kingdom), the picture becomes less clear when studies focus on developing countries that do not have sufficiently advanced and well-structured industrial ecosystems (see Andreoni, 2018 for a theoretical discussion and empirical analysis of industrial ecosystems). Xu (2000) carried out a study about more than 40 countries and found positive technology transfer in developed countries but not in developing countries. Similarly, positive effects are found on FDIs in manufacturing firms in the United States but not in Mexico and Venezuela (Atiken et al., 1996). Mixed results are found in a study on Uruguay where there are positive effects of FDIs but only in firms with small technological gaps (Blomstrom and Sjöholm, 1999). Referring to emerging economies, Hanson (2001) claimed that positive effects are very few and Gorg and Greenaway (2004) that most effects would be negative. A broader set of contributions adopting more granular mixed-methods has found that FDIs are not beneficial *per se* and that capabilities improvements and learning depend on local firms' absorptive capacity (Kokko 1994), on technological gaps separating foreign and local firms as a source of technological opportunities (Findlay 1978, Blomstrom and Wolff 1997, Castellani and Zanfei 2003), on catching up potential (Meyer and Sinani, 2009), and on the nature of activities involved (Castellani et al. 2015;).

2.2 Insights from global value chains and local production systems literatures

In the last two decades, the impact of FDIs on hosting countries has been increasingly studied through the analytical lenses of global value chains (GVCs). The GVCs literature points at the existence of two critical factors mediating the relationship between FDIs and technology diffusion, i.e., governance and upgrading within and along value chains (Gereffi 1994, 1999 and 2018; Gereffi and Lee, 2016; Ponte et al., 2019; Sturgeon, 2009). First, different types of GVC governance systems determine the ways in which MNCs manage, organize and orchestrate their suppliers on a 'glo-cal' scale and potentially result in 'endogenous asymmetries' (Milberg and Winkler, 2013). Second, upgrading – understood as a positive shift in the competitive position of a firm within and along value chains – depends on several institutional and economic actors in the process of local productive capabilities and linkages development (Gereffi and Lee, 2016; Andreoni, 2019; Dallas et al., 2019).

Despite the importance that this approach gives to understanding the interrelations at a global level, the sectoral characteristics are still important for many reasons. The ability of countries to link up through backward linkages, and then either add value forward or remain upstream, is strongly related to the specific sectors and types of FDI a country is able to attract and the types of linkages that develop from and around the FDI (Andreoni, 2019). Value creation and spaces for learning and development are distributed unevenly across value chains in different sectors (Andreoni and Chang, 2017), most often involving a fine-slicing of production and R&D activities also within sectors (Mudambi 2009, Papanastassiou et al. 2019).

The Local Production System (LPS) framework (Andreoni, 2019) points to the importance of looking at different *types of linkages* in a developing country's production system, how they develop both vertically along the FDI-driven global value chain and horizontally in the local economy at the intersection of several sectoral value chains and other actors (including public ones such as industrial research intermediate institutions and services providers). The local production system is made of multiple types of production, technological, consumption and fiscal linkages which are based on the existence of specific set of capabilities. This framework points to the importance of focusing on the productive, technological and organisational capabilities of local firms, linkages development across industries, institutions and political economy factors (Hirschman, 1958; Amsden, 1989; Chang, 1994; Lall, 2000; Andreoni, 2019; Andreoni and Chang, 2019) as well as the nature of investment projects and the technological level of investors (Castellani and Zanfei 2003, 2006).

Considering the multiple factors suggested within the GVCs and LPS, we can conclude that technology spillovers may not accrue when host economies have a weak industrial base – therefore, FDI might trigger low or no technological upgrading effects (in our specific case, robotisation) when occurring in local environments that are not responsive to the stimuli of foreign capital injections. In this sense, capability creation, absorptive capacity and production linkages are a key concern when considering spillovers to the rest of the economy (Jindra et al., 2009; Zanfei and Saliola, 2009; Meyer and Sinani, 2009) and different types of value chain integration (Ponte and Gereffi, 2019; Andreoni, 2019).

3. Industry context: how fragmentation of production and concentration of power shaped the automotive sector

When studying the relationship between FDIs and robotisation, a focus on the automotive sector is particularly relevant due to three specific structural characteristics of this industry. That is, its GVC structure and concentration, its early adoption of robots and the geographical distribution of its activities.

First, the fragmentation of production and the huge amount of FDIs resulting from both outsourcing and concentration trends, deeply reshaped the industry and contributed to the ‘producer-driven’ definition of the automotive GVC (Gereffi, 1994). The automotive GVC is characterised by a small set of final assemblers with relatively high market power, an increasingly exclusive club of Tier 1 suppliers, which are also becoming closer to the final OEMs (Wong, 2017), and a series of Tier 2 and Tier 3 suppliers which are more dispersed despite being increasingly controlled by OEMs. The last decades have witnessed a consolidation in the automaker markets around sixteen major players. In 2015, ten OEMs accounted for three quarters of global production with the top five accounting for 50% of total production (International Organization of Motor Vehicle Manufacturers, 2015)². Global firm leaders focus on the design part of vehicles that is where an important share of the value added lies (Sjoestedt, 1987). Pre-production and engineers activities, “where conceptual designs are translated into the parts and sub-systems that can be assembled into a drivable vehicle, remain centralized in or near the design clusters that have arisen near the headquarters of lead firms” (Sturgeon et al., 2008: 8).

This concentration phenomenon has been accompanied by the rise of first tier mega suppliers. Over the past four decades component manufacturers dropped from 40.000 in 1970 to less than 3000 in 2015 (Wong, 2017). Hence, fewer larger first-tier suppliers have survived and consolidated while, at the same time, they have developed close relationship with big OEMs. In this emerging configuration of the automotive value chain, OEMs still control and manage the entire supply chain. However, since OEMs are the mere final assembler of the product *à la Foxconn* (McGee, 2016), they put pressure on their suppliers, especially Tier 1, and have forced them to take

² The forecast of production engineered by the leading OEM (less than 10) is 83% of global output in light vehicles (IHS Markit, 2018)

increasing responsibilities in investments and supply chain management. Indeed, given the small number of global automotive firms and their strong purchasing power, suppliers can be forced towards the adoption of specific standards, information systems and even production technologies. As pointed out by Sturgeon et al. (2009), “with consolidation, we must question the staying power of smaller, lower tier, local suppliers” and, thus, the increasing “endogenous asymmetries” along the value chain in different countries (Milberg and Winkler, 2013). Indeed, the relationship between OEMs and suppliers appear to follow similar global benchmarks, but can also develop differently in different country contexts.

Second, the automotive sector absorbs almost 37% of the total number of industrial robots worldwide (IFR, 2015), a share which makes it the top sector for adoption of robots. Automotive has benefitted from a continuous technology push, stemming from investment in automated production technologies from major car producers since the 1970s. The automotive sector has always been the bedrock of manufacturing automation advances due to its high-volume production, standardisation and production and product modularisation. This characterisation stems from the degree of transnational dispersion of production in automotive industry (Birkinshaw J. et al., 2016; Winroth and Bennett, 2017; Serfati and Sauviat, 2019). Moreover, the automotive sector provides an effective illustration of the possibility that companies can create and well manage long-distance business relationships (Sturgeon and Lee, 2005).

Third, the automotive sector is characterised by sectoral and market dynamics resulting in a specific spatial organisation and distribution of production. The fragmentation of automotive production is based on networks that tend to organise regionally, much more than globally (Jetin, 2018). Regionalisation was favoured by the widespread adoption of modularisation in the 1990s (Sako, 2003) and by the importance to be ‘next-door’ to car assemblers, especially for Tier 1 suppliers that are located close to (when not fully integrated with) assembly plants, in order to better synchronise just-in-time-delivery of complex modular units (Frigant and Lung, 2002).

MNEs are key actors affecting the characteristics of automotive industry which we have highlighted; they contribute to industrial concentration, as well as to technology diffusion and to the geographic dispersion of production. The role played by FDIs in robot adoption in particular

makes a special case that needs to be explored from this perspective . Sections 4 and 5 will provide some evidence in this sense.

4. Data

This study builds on the use of two innovative sources of data that have not been matched before, to the best of our knowledge. The paper undertakes a quantitative approach, based on the analysis of secondary data that have been collected by international organisations, namely the fDi Intelligence of the Financial Times for the fDi market dataset and the International Federation of Robotics for data on industrial robots. FDI data and industrial robot data are combined through some descriptive statistics so to explore correlations between industrial robot adoption and FDI. We added a further element to this, as we unpack the automotive sector into two main sub segments of its value chain, e.g. automotive assembly and automotive components, and we observe the relationship between FDI and industrial robots along these two segments for 2005-2014.

International Federation of Robotics dataset collects data on the diffusion of industrial robots, produced by nearly all industrial robots suppliers world-wide (IFR, 2015). According to International Organisation for Standardization, an industrial robot is defined as: “an automatically controlled, reprogrammable, multi-purpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications” (IFR, 2015)³. Based on this definition, the IFR dataset provides data on the number of robots by industry following ISIC rev. 4 classification, by country and per year. Moreover, for the automotive sector IFR dataset provides also a sub-classification of different segments of the value chain. Data on stock of robots are expressed in number of units adopted.

fDi Markets database is an online dataset that compiles data on cross-border investment projects with details on the sectors and sub sectors, whose classification corresponds to NACE Rev.2 or NAICS 07, on industry activities (i.e. the business functions involved in the FDI project, including inter alia: Manufacturing, R&D, Design Development and Testing, HeadQuarter services, Sales and Logistics) and on locations of investments with different degrees of geographical aggregation. Out of more than 142,000 observations of investments to which we have access over the 2003-

³ <https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en>

2014 period, we use investments in the automotive industry, considering the two *industry sectors* Automotive OEM and Automotive Components. Among the numerous valuable pieces of information that fDi Markets provides, we use *destination_country*, *year*, *industry_activity* and *sub_sector*. Out of all industry activities detected for automotive industry and for its sub-sectors we considered just *Manufacturing activities* (hence excluding sales, R&D and headquarter services, etc.), in order to provide full consistency with the other data coming from IFR which are just related to manufacturing applications of industrial robots. In addition, to match our two sources of data we use a conversion table supplied by the US Bureau of Census⁴.

We refer to 34 countries, which constitute almost 97% the robots' adoptions and 99% of the inward FDIs in the automotive sector. Tables 1 and 2 use data from our main sources to highlight the geographic concentration of industrial robot adoption and of FDIs in the automotive industry: the top 5 countries account for almost 60% of inward FDIs in this sector, while the top 5 adopting countries account for about 80% of all robots in the world.

[Tables 1 and 2]

The automotive segments we consider for our analysis are: ISIC *2910* motor vehicle manufacturing (OEM assembly), *2931* metal and plastic parts, *2933* electric/electronic parts and *2939* other parts, which includes car seats, airbags and safety belts. As aforementioned, we analyse the relationship between FDIs and industrial robots across 34 countries for two periods: i) a ten-year period (2005-2014) with a data disaggregation distinguishing two segments of the industry – i.e. Automotive OEM and Automotive Components; ii) five-year period (2010-2014) considering four segments of the automotive value chain – i.e. 2910 (motor vehicle assembling), 2931 (metal parts and plastics), 2933 (electric and electronic parts), 2939 (other parts which include seats, airbags, safety belts). Section 5 will present our two parts of the analysis.

Although the two datasets present extremely rich and detailed information, they do have some limitations. First, within the automotive classification there are two unspecified classes, which are Unspecified AutoParts (class 2999) and Automotive Unspecified (class 299). We inserted sub-

⁴ <http://www.census.gov/eos/www/naics/concordances/concordances.html>) from NAICS to ISIC rev. 4.

class 2999 within the auto component sub-class and redistributed 299 proportionally between Auto Assembly and Auto Parts. Instead, for the bubble graphs at four sectors disaggregation below we could not insert any of these classes⁵. The second limitation is due to the fact that up until 2010 IFR data referring to the United States, Mexico and Canada were aggregated. Figures for Canada and Mexico started “from zero” in 2010 when they were disaggregated.

5. Stylised facts on the relationships between FDI and robotisation

The analytical investigation of the relationship between FDI and robotisation is structured in two main steps – comparative and dynamic – and, for each of them, we identify patterns at different levels of disaggregation of the automotive industry. By doing so we aim at capturing first the heterogeneous rate of robotisation across different countries and segments of the automotive value chain; and second how they have followed different patterns over the last two decades.

5.1 Comparative analysis

We conducted our first comparative analysis at two levels of disaggregation and used descriptive statistics to show the relationship between FDI inflow and industrial robots adoption within the two segments 2910 (Automotive OEMs) and 2930 (Automotive Components). Figure 1 and 2 present the distribution between industrial robots in these two segments and inward FDI. Our aim is to show how different countries are placed differently according to the automotive segments each graph refers to. While it is not surprising to find the biggest automotive players in the top right quadrant, with these graphs we aim to emphasise the different position of developed, emerging and developing countries between the Assembly and the Components segments.

Figure 1 illustrates the distribution of FDI at the OEMs level; we use the sum of inward FDI between 2005 and 2014 and the stock of industrial robots in the same time frame. Although the lack of strong correlation is an interesting finding *per se*, as it points to high heterogeneity even for the assembly segment of the automotive sector, interesting patterns emerge once these scatterplots are divided into quadrants.

⁵ We contacted the administrators of IFR dataset in Germany and after a careful analysis we claimed that these data could not be inserted in any other classes.

[Figure 1]

At the top of Figure 1, there are either industrialised countries or fast industrialisers: the upper left quadrant includes developed economies, which have a strong presence of industrial robots in their automotive industry but do not attract a high number of FDI's (e.g., Japan, South Korea, Germany, Italy). Interestingly these are all countries that undertook important transformation plans to shift their entire economy towards automated production. If we look just at the automotive sector, this occurred despite a relative lower number of FDI's if compared to developed countries on the top right quadrant. Instead, in the upper right quadrant one finds countries where the increasing number of FDI's seems to be correlated more with the increase in robots adoption. These are countries that either have a long tradition in the sector and still play a pivotal role attracting FDI's (e.g. United Kingdom and Spain) or they are big attractors of FDI's and rapidly industrialising countries (e.g. China, Mexico within North America, and to some extent Brazil). In the bottom part of the graph there are both developed countries with a modest automotive sector and emerging economies, such as the Eastern European countries, linked up to the German automotive value chain. Dynamic economies such as Thailand, Turkey, Russia and India are also present in the right part of the graph, thus showing both a relatively high degree of attractiveness for FDI's and a general upgrade of the OEMs-related production processes (especially Turkey); these are countries growing a lot as a result of policies that encourage the development of the automotive sector as well as opening doors to FDI's (Barnes and Black, 2017).

Automotive components graph distribution across countries is presented in Figure 2. Within the top quadrants (i.e., with a large number of robots), as expected, we find industrialised countries with a highly developed automotive sector. Among emerging economies in the upper quadrants, the only case (apart from China) is Thailand, which is catching up quickly, also as a result of a new and dynamic automotive sector (Deloitte, 2019). This example could indicate that Thailand was not only able to attract an important number of FDI's, but it has also been able to channel them in the direction of technological diffusion and upgrade via development of supply chains of components producers (Sadoi, 2012). Other countries, such as India, Brazil and Russia received more FDI's than Thailand, but their respective auto components segments use fewer industrial robots (IFR, 2015). A final consideration on these first graphs is that the better position that Thai

components' segment has *vis a vis* its OEMs one (previous graph) is an element that suggests the presence of an important system of local suppliers. Differently, taking as an example the sluggish position of South Africa's auto components, it confirms the low number of suppliers' activities both in terms of international activities (FDIs) and in terms of local technological pull (Black A. et al., 2017).

[Figure 2]

5.2 Dynamic analysis

The second part of our analysis presents a series of bubble graphs that intend to show the trend of FDIs and industrial robot adoption across different segments of the automotive value chain at a finer level of disaggregation and over time. We use this tool as it allows us to plot on the same graph our two variables of FDIs and industrial robots against a time dimension on the horizontal axis. The analysis takes advantage of the high disaggregation of our data that is possible for the 2010-14 period, thereby allowing us to consider the following four industry segments: 2910 (motor vehicle assembling), 2931 (metal parts and plastics), 2933 (electric and electronic parts), 2939 (other parts which include seats, airbags, safety belts). When we indicate 2930 we refer to the sum of all components parts (2931, 2933, 2939). In order to build these graphs, we considered the 20 countries (from Table 2) that received the largest amounts of FDIs in the automotive sector in the period 2010-2014. The bubble graphs presented in Figure 3 and 4 correlate three variables, using the value of FDIs inflow (vertical axis), the number of robots (the size of the bubble), and how this relation changes over a four-years' time horizon (horizontal axis). Figure 3 depicts an interesting dynamic relation between FDIs and industrial robots across time and across different segments of the value chain.

First, vehicle assembly segment (2910) is characterised by a stable and massive use of robots (the size of the bubble) and a decreasing level of FDIs (except in the final year), the latter presumably as a consequence of the global financial crisis and the impact on global demand of automotive and of cars in particular (Van Biesebroeck and Sturgeon, 2010). However, the global crisis affected countries differently. While hitting severely American and, to a less extent, European companies supported by intense cross border activities, the crisis gave at the same time the opportunity to

Indian and Chinese auto manufacturers to expand their markets and to become world players (UNIDO, 2009; Bai, 2012). In this sense, FDIs dynamics are also very much related to global and especially developed world's demand cycles. The increase of FDIs in 2014 went in parallel with the first increase in car registration in the European market after six years of recession (Rosemain, 2014).

Second, auto components sectors (2931, 2933 and 2939) appear to follow a different pattern, which is less related to major shocks at the global level; in fact, in 2012, one of the most problematic years for motor assemblers, sees a peak in both FDIs and in industrial robots' adoption for component manufacturers. This could suggest that FDIs in assembling (OEMs) and in components segments of the value chain operate differently. While FDIs in all automotive segments fluctuate significantly, and particularly so in the assembly stage, the adoption of industrial robots is slow but pretty stable, showing that this production technology is steadily becoming more diffused in the industry, with a remarkable increase in the case of components. Therefore, the adoption of robots and the presence of inward FDIs are not clearly correlated over time, although some evidence exists that the relation is negative in the case of assembly and slightly positive in the case of components at least in the first part of the examined period. We replicated the same exercise in Figure 4 with a two level disaggregation so to better highlight how assembly and components segments behave differently.

[Figure 3]

[Figure 4]

Figure 5 zooms into Figure 3 with a focus only on the auto components segment. A closer look at different sub-segments of auto components reveals further heterogeneity within this segment, and this may have to do with the specific characteristics of production processes and technologies required for different auto components. Examining in detail the reasons underlying these differences is beyond the scope of this paper⁶. Suffice here to observe diverging patterns of FDI

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Although there are a number of reasons underlying this heterogeneity in robots adoption across different components, one of the main ones is related to the degrees of freedom that companies have in automating (or not) their production processes for specific components. For instance, an important number of metal parts' operations have to be produced automatically due to quality and safety reasons, no matter where they are produced. Some specific spot welding and laser welding operations are characterised by

and robot adoption: Metal parts (2931, the green bubbles in Figure 5) show a peak of FDIs in 2012 and a steady substantial increase in industrial robots; airbag, safety belts and seats (2939, yellow bubbles) present a pretty stable, slightly decreasing, level of FDIs investments with a stable increase in the use of industrial robots. Electrical and electronic parts (2933, the blue bubbles) are attracting an important number of FDIs but they still present a small, although increasing, number of industrial robots.

[Figure 5]

Interestingly, the more we focus on countries at the technological frontier the more robots tend to be used across more segments of the automotive value chain, including some of those which are traditionally more labour-intensive. For instance, looking at NAFTA and Germany (Figure 6), even production of electric/electronic parts (grey bubble) and leather/synthetic seats and airbags (yellow bubble) appear to be associated with the adoption of an important number of robots. For illustrative purposes we focus on a selection of countries which have different degrees of involvement in the global automotive value chain⁷, and we observed that there is no strong correlation between the number of robots adopted and the inflow of FDIs. This is visualized in Figure 6 as there is presence of big sized bubbles even in relation to a relatively small amount of inward FDIs (e.g., see Germany).

[Figure 6]

6. Discussion

The automotive sector is characterised by specific dynamics that influence the distribution of its international activities. More than truly global, over the last decades the sector has increasingly clustered in specific regional areas, the most important of which are NAFTA, Germany and Eastern Europe, East Asia, Argentina/Brazil to a certain extent and, more recently, China.

operational tasks that, for the quality and ergonomics of the process, can be only automated. Differently, the production of seats or airbags are mainly constituted by operations that could be automated (and they are likely to be increasingly automated) but can still be performed manually.

⁷ For all of these countries unclassified robots represent less than 5% of all adopted robots over the period we considered.

Historically, the automotive sector has been a major driver of industrialisation in several successful country experiences. The length and complexity of its value chain, alongside the development of production and technological complementarities, allowed countries involved in the automotive sector to achieve several goals.

The automotive sector has also been a fertile field for many improvements in production technologies, being the sector characterised by intensive economies of scale and by the use of automated machines since the 1970s (Sjoestedt, 1978). Industrial robots were not an exception in this respect, and the first introduction of spot welding and arc welding robots took place in the automotive sector (APO, 1987). The use of industrial robots, despite not being recent, experienced a growth due to improvements in technologies, the consequent increase in productivity and, to a certain extent, flexibility.

Our descriptive statistics suggest that it is difficult to claim strong correlation between inward FDI and industrial robots' adoption in the automotive sector, especially when we look for patterns across different segments of the value chain – assembling and components production – and for different types of components. However, there exist some interesting FDI related patterns that characterise the adoption of new technologies. That is, the heterogeneity of FDI-led robotisation especially when comparing the Automotive OEM with Automotive Components. Building on the literature, existing evidence and our new descriptive analyses, we formulate the following three sets of considerations and hypotheses for further research.

First, Automotive OEMs clearly are the main drivers of robotization; if we look at the number of robots (e.g. the size of the bubbles), OEMs encompass the majority of industrial robots (IFR, 2015). This is largely expected because OEMs are large in size, have a high market power and have the capacity to invest in new technologies and because of the operations they perform. The assembly of a motor vehicle requires an increasing number of robots in the pressing shop, the body shop and the paint shop. Thus, we glimpse two main dynamics that develop as effect of FDI from big OEMs. On the one hand, they are the first adopters of industrial robots in their new facilities, and this is increasingly the case with the increase in quality standards and safety issues that led to the introduction of, for instance, electrostatic coating in the paint shop and different types of new

laser and spot welding robotic cells in the press shop and body shop. On the other hand, they could also activate foreign capital inflows involving components suppliers, especially big international Tier 1 suppliers which are closely linked to OEM operations. In this sense, since OEMs are the leading actor for organisational and technological innovation, they also have the power and ability to manage the modular production and the mastering of new technologies both at the plant level and along the supply chain (Jacobides et al., 2015).

Second, FDIs-induced robotisation driven by OEMs is however not sufficient to fully explain our data when we look at robotisation in the components' segments of the automotive value chain. It appears that FDIs *per se* are not a crucial driver for this segment of the value chain. First, as shown in our bubble graphs, there is no correspondence between the amount of FDIs and the increase in robots' adoption (the size of our bubbles, see Figure 5) over time. Instead, it seems that the diffusion of industrial robots is a steady, although slow, trend that continued to increase despite the decrease both in inward auto components FDIs and the use of industrial robots at the OEMs level. While significant differences emerge across segments of the automotive industry, these unclear correlations between FDIs and robotisation over time might reflect a remarkable heterogeneity of FDI induced adoption patterns also across countries.

Third, the most successful countries in terms of industrial robot adoption in the components segment, such as Thailand, Czech Republic and Turkey, have adopted consistent policy packages at the national level in order to attract FDIs while boosting complementary aspects (e.g. education, infrastructure, R&D incentives) for technology upgrade (see Barnes et al., 2017 for Thailand; Taymaz and Yilmaz, 2017 for Turkey (although they state that the success is mitigated by the lack of organizational capabilities); Hill, 2007 for Czech Republic). In other words, these countries made a general effort to improve their position in global value chains including both FDI attraction and a conscious effort to upgrade their local production system towards the development of an ecosystem of domestic suppliers. An industrial ecosystem is based on the development of a series of complementarities based on the existence of linkages between close but dissimilar types of firms. Firms and organisation that are linked to each other along sectoral value chains (vertical linkages), and across different sectors (horizontal linkages) trigger the development of complementary capabilities (Andreoni, 2019). Thailand is one example in this sense. It is the

developing country (China excluded) with the highest number of industrial robots, and one of the highest in the automotive sector (IFR, 2015). The ‘robotisation’ of the country is based on a series of policies that aim at building up the local ecosystem. Demand and supply policies have been combined in a way where technological skills push met demand pull in a country where firms have been ‘accompanied’ by fiscal incentives to adopt industrial robots. Lastly, a wide range of enabling institutions and infrastructures permitted the Thai government to provide the right set up for firms both local and international (Barnes et al., 2016). Because components production suppliers are more fragmented than big OEM assemblers, they rely on a series of close complementarities that can be fully developed and explored in geographical proximity with OEMs and with the right incentives provided from government, MNCs and other local intermediate actors. This third set of consideration restates the importance of strategic engagements with FDIs in the host economy, including restricting the scope and modalities of operation of MNCs, especially with respect to their engagement with domestic suppliers. High technologies require time to be absorbed and mastered and they build up on production systems that are complex and need to be adapted to local conditions. And this is why to strengthen the relationship between FDI and robotisation, FDIs should be strategically managed through appropriate industrial policy.

7. Conclusion

This paper examines the relationship between inward FDIs and industrial robots’ adoption, disaggregating the automotive sector and looking at how FDIs and industrial robots are distributed across different segments of the value chain. The granularity of our data permits to innovatively combine two crucial information for the automotive sector: inward FDIs and process technology upgrade. This is a first, largely descriptive attempt to explore the relation between FDIs and robots’ adoption, as a manifestation of how FDIs could act as a trigger for a technological upgrade. We found that different segments of the value chain as well as different groups of countries are characterised by distinct patterns of FDIs and robot adoption. While FDIs play a role for the adoption of robots in the OEMs segment (particularly of emerging countries), it seems less the case for the components segment. We put forward some potential explanations for this, specifically focussing on the role that structural characteristics of the industry and policy play in shaping the trajectory of industrial robots’ adoption.

Our study has important limitations. First, we cannot claim any causality. This is an exploratory study that only aims to shed some lights on heterogenous dynamics of robotisation. We pointed to correlations that exist in some cases and do not show up in others, and puts forth some conjectures on the possible determinants of such correlations (and absence thereof). Second, the existence of unspecified classes is particularly limiting in the disaggregation at four segments. Nonetheless, our results open for a new stream of research that goes beyond the existent empirical literature on the new technologies, which remains at the macro level and mainly focusses on the impact of robotics on labour. We have highlighted the importance of studies at a fine-grained sectoral level, which might help disclose hidden dynamics and yield interesting insights that are difficult to grasp at an aggregated level.

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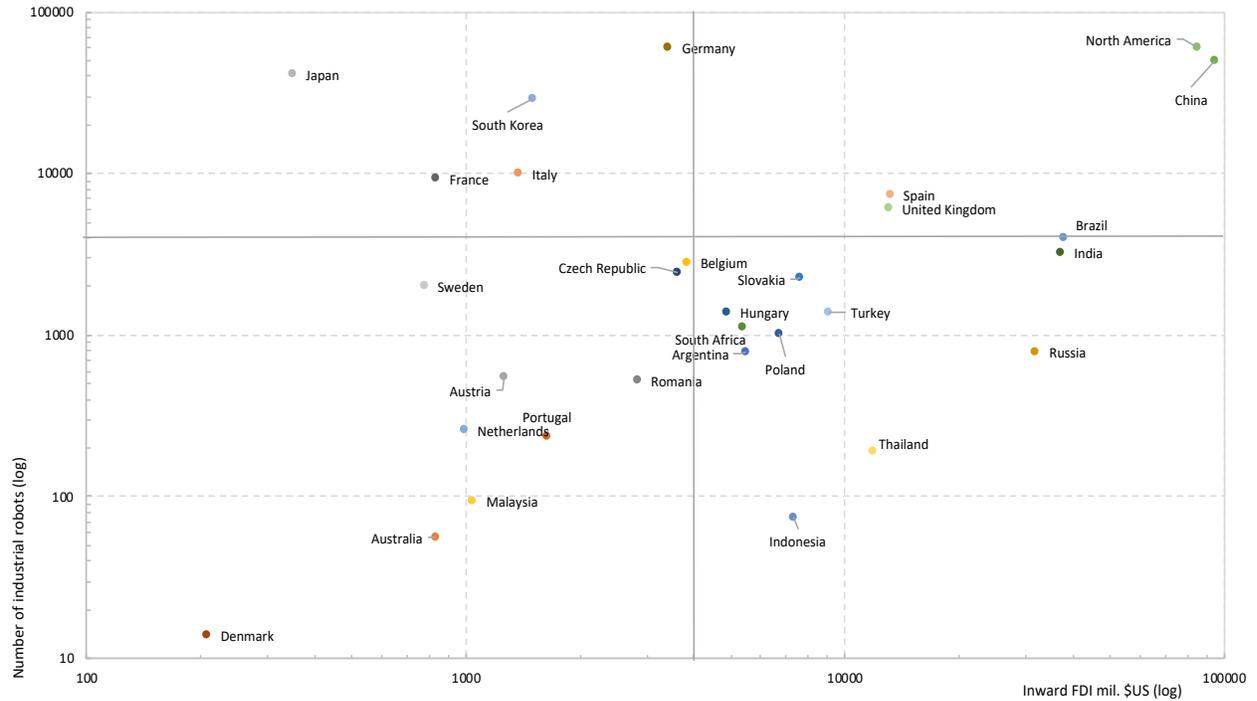
Tables and Figures

Table 1 and 2: Authors' elaborations on IFR and fDiMarkets data (2005-2014)

Country	Number of Robots in Automotive	% tot
Japan	113526	21%
US*	98569	18%
Germany	93082	17%
China	67570	12%
South Korea	58024	11%
Italy	16940	3%
France	15272	3%
Spain	14179	3%
United Kingdom	9989	2%
Thailand	6652	1%
Mexico*	6604	1%
Brazil	5518	1%
India	5180	1%
Czech Republic	5111	1%
Canada*	4627	1%
Belgium	3871	1%
Sweden	3505	1%
Slovakia	3092	1%
Turkey	2578	less than 1%
Poland	2495	less than 1%
Austria	2041	less than 1%
Hungary	1818	less than 1%
South Africa	1411	less than 1%
Portugal	1172	less than 1%
Russia	1129	less than 1%
Netherlands	1064	less than 1%
Argentina	999	less than 1%
Romania	736	less than 1%
Finland	459	less than 1%
Indonesia	393	less than 1%
Malaysia	256	less than 1%
Australia	228	less than 1%
Denmark	181	less than 1%
Vietnam	10	less than 1%
Total 2014	548281	around 97%

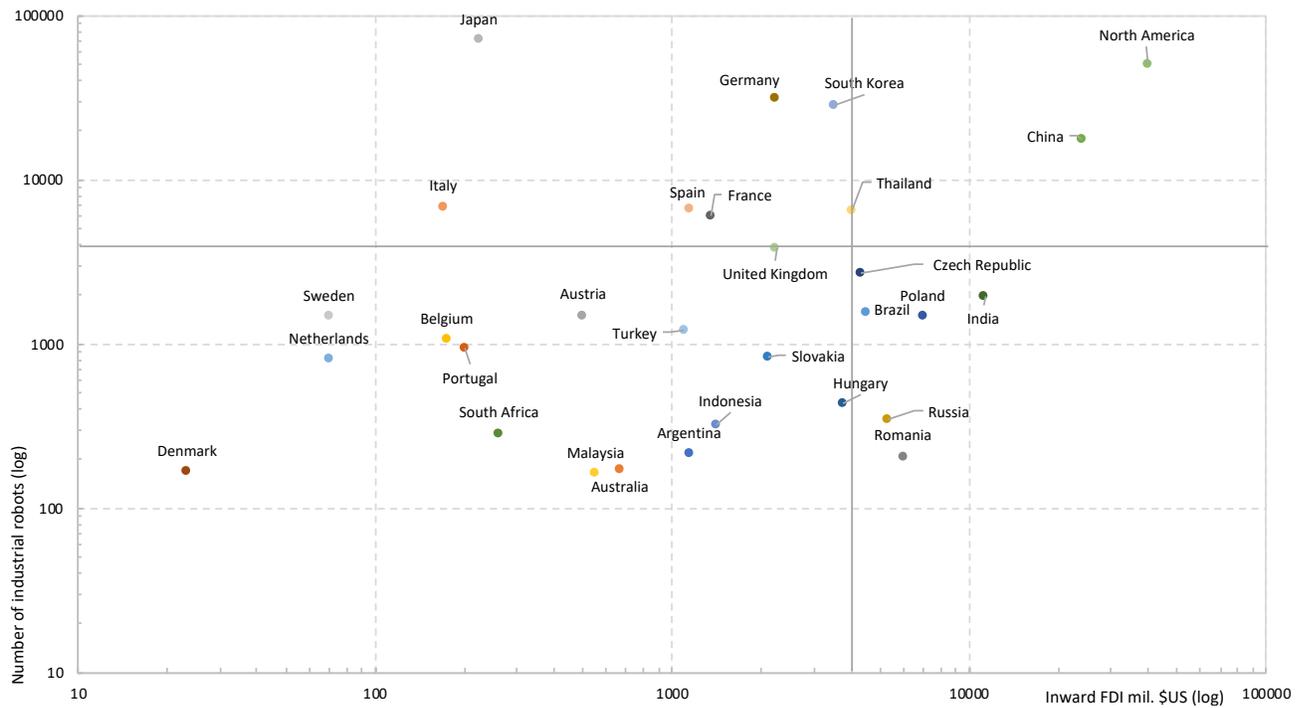
Country	Investment in auto FDI_milUS\$	% tot
China	151774.28	24%
Mexico	63355	10%
US	55030	9%
India	51921.74	8%
Brazil	45657.46	7%
Russia	41887.96	7%
Canada	24824	4%
Spain	21855.52	3%
Thailand	19336.18	3%
UK	17634.03	3%
Poland	16639.42	3%
Slovakia	12839.45	2%
Turkey	11924.78	2%
Hungary	10863.1	2%
Czech Republic	10451.64	2%
Romania	9776.9	2%
Indonesia	9705.49	2%
South Korea	7352.61	1%
Germany	7135.77	1%
Argentina	6983.47	1%
South Africa	6145.99	1%
Belgium	5997.97	1%
Australia	4288.39	1%
Austria	3748.33	1%
Portugal	3576.99	1%
Vietnam	3305.62	1%
France	3029.3	less than 1%
Malaysia	1826.01	less than 1%
Sweden	1759.2	less than 1%
Italy	1705.87	less than 1%
Netherlands	1151.74	less than 1%
Japan	602.43	less than 1%
Denmark	254.3	less than 1%
Finland	97.6	less than 1%
Total 2014	634438.54	around 99%

Figure 1: Automotive assembly FDI and industrial robots



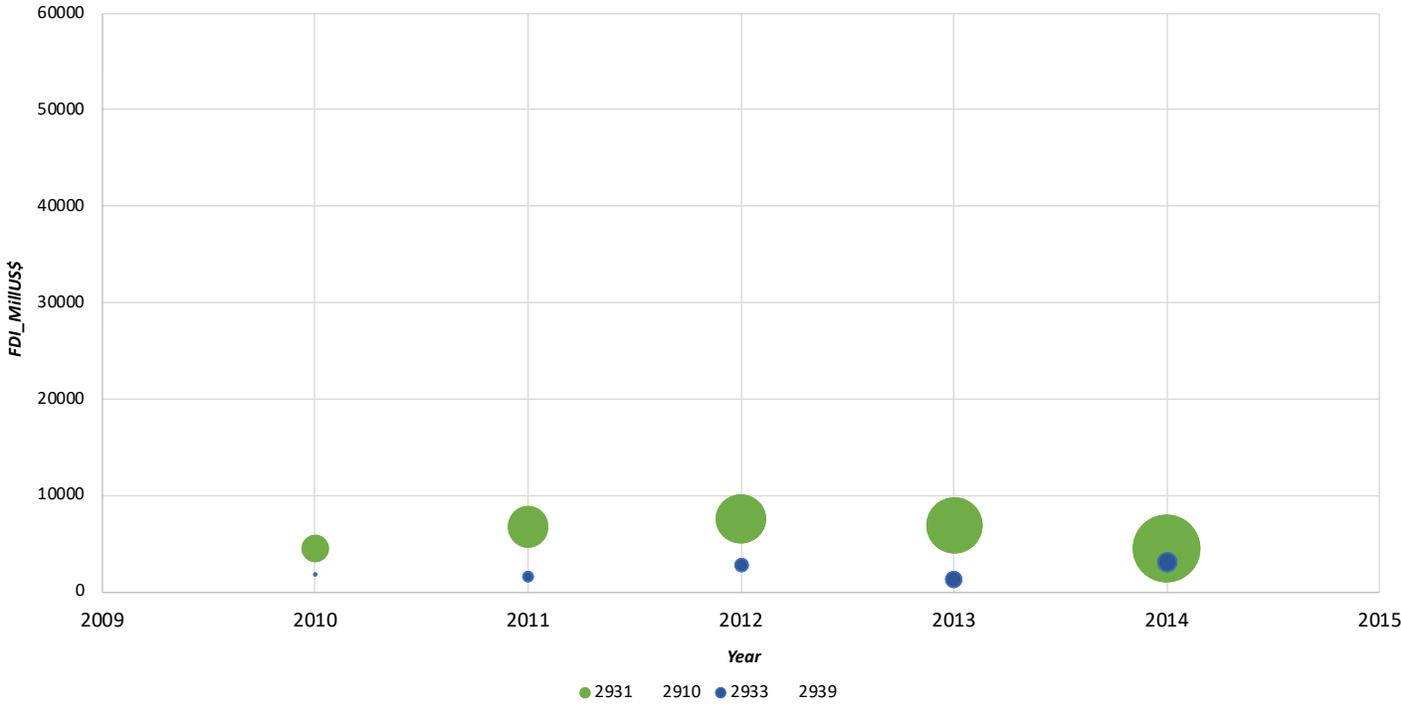
Source: Authors based on IFR and fDi Markets data, 2005-2014 data.

Figure 2: Auto components FDI and industrial robots



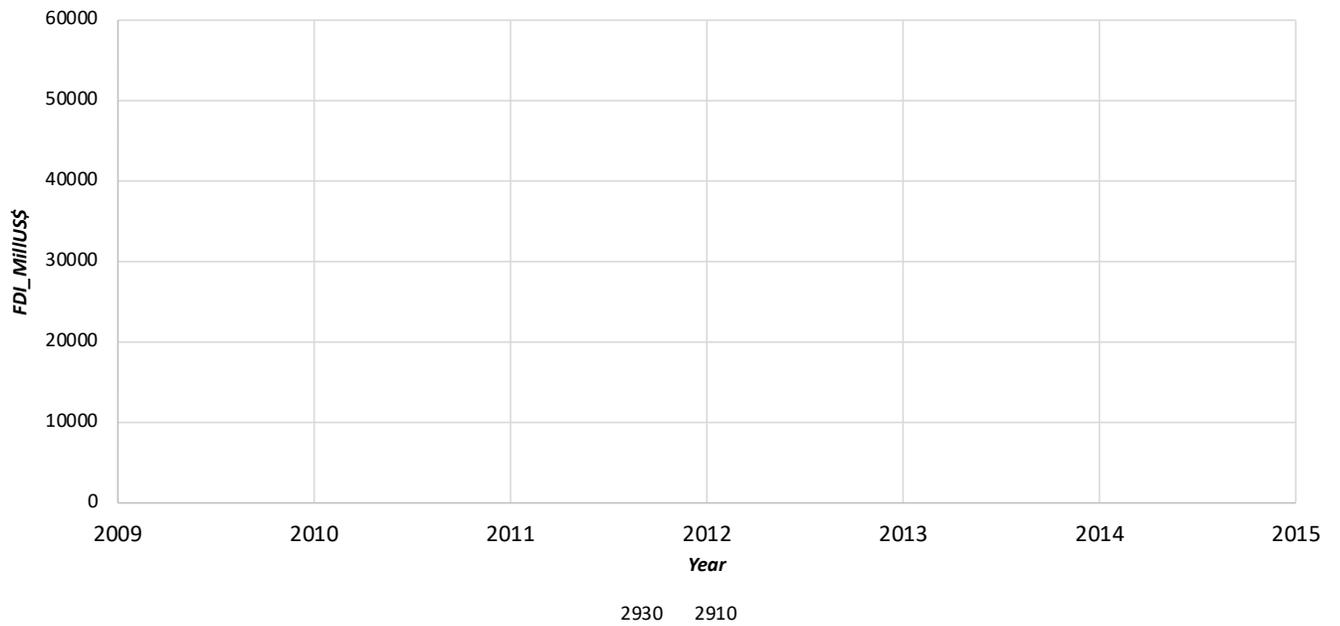
Source: Authors based on IFR and fDi Markets data, 2005-2014 data.

Figure 3: FDI and industrial robots' distribution across four segments in time



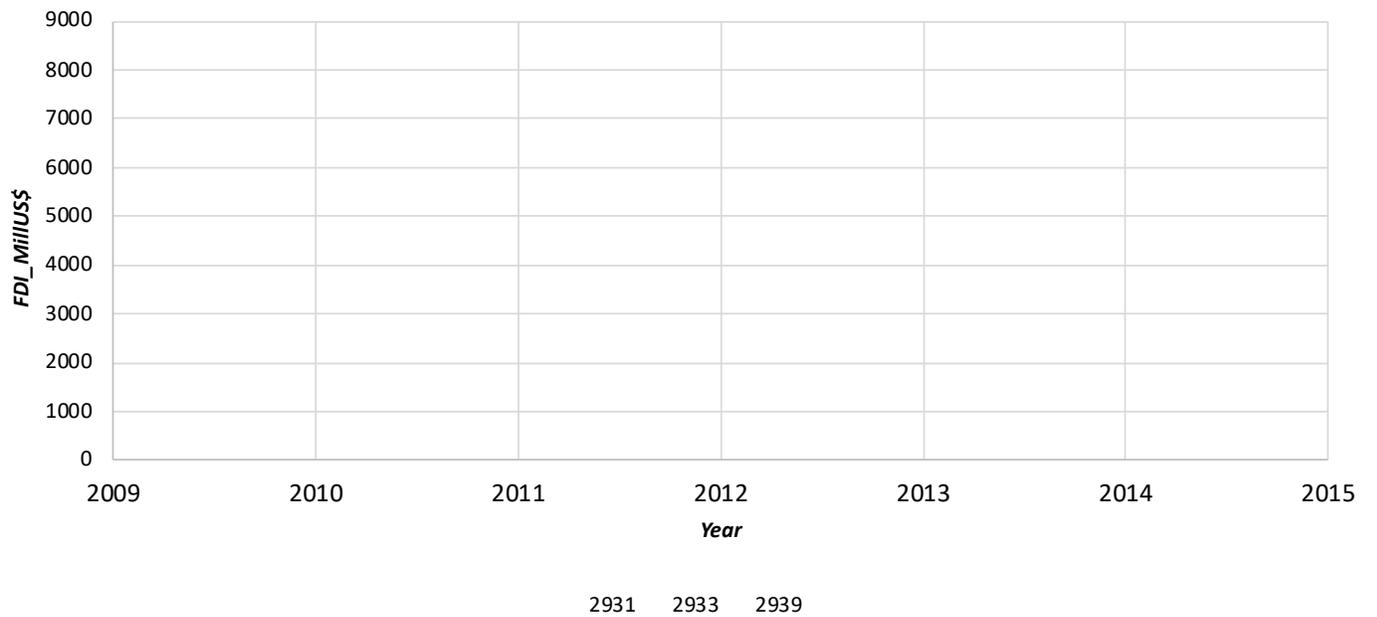
Source: Author based on IFR and fDi Markets data. *Vertical axis: FDI intensity; Horizontal axis: year; Size of the bubble: N. of robots (stock); Colour of the bubbles: different subsectors.*

Figure 4: FDI and industrial robots' distribution across two segments (assembly and parts)



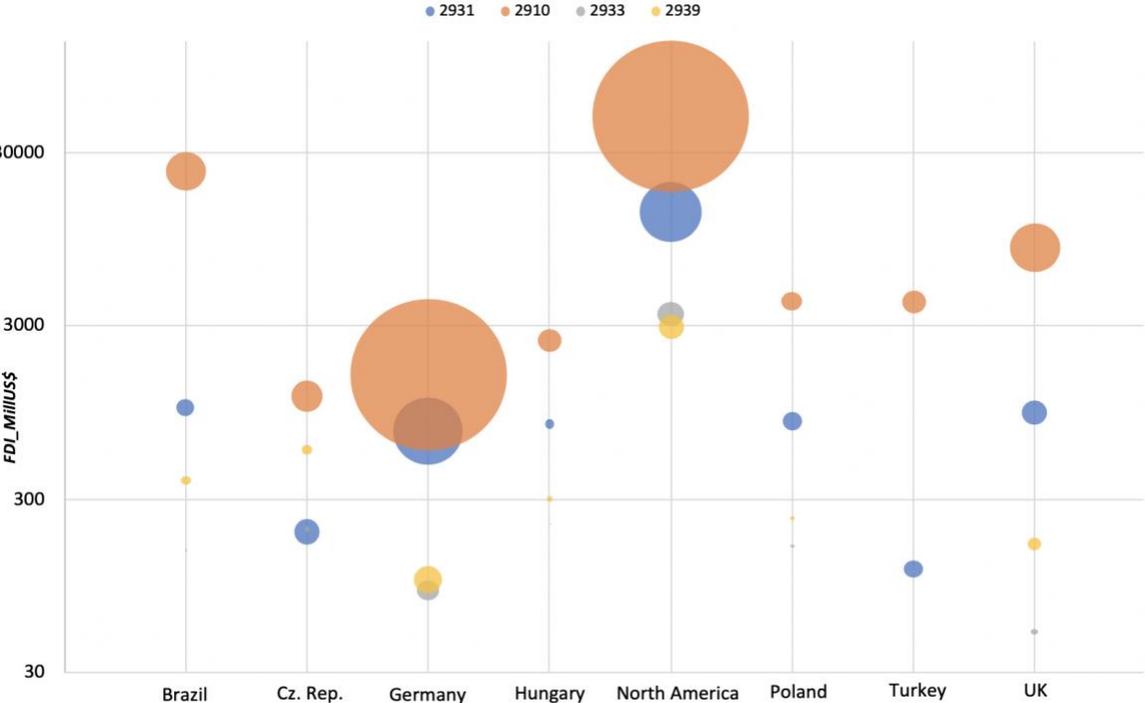
Source: Author based on IFR and fDi Markets data. *Vertical axis: FDI intensity; Horizontal axis: year; Size of the bubble: N. of robots (stock); Colour of the bubbles: different subsectors.*

Figure 5: FDI and industrial robots' distribution across three sub-segments of components parts



Source: Author based on IFR and fDi Markets data. *Vertical axis: FDI intensity; Horizontal axis: year; Size of the bubble: N. of robots (stock); Colour of the bubbles: different subsectors.*

Figure 6: Relation between FDIs and robot's adoption, four-subsectors (country focus)



Source: Author based on IFR and fDi Markets data. *Vertical axis: FDI intensity; Horizontal axis: selection of countries; Size of the bubble: N. of robots (stock in 2015); Colour of the bubbles: different subsectors.*