ADVANCING EARTH AND SPACE SCIENCE

Earth's Future

RESEARCH ARTICLE

10.1029/2022EF002695

Special Section:

The Future of Critical Zone Science: Towards Shared Goals, Tools, Approaches and Philosophy

Key Points:

- Produced capital is the largest contributor to inclusive wealth per capita growth in most cities
- The inequality of human capital between urban-rural and male-female groups is revealed
- Variation of innovation potential by city, which can be reflected by advanced produced capital and intangible capital

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

Y. Li,
liyuancolour@gmail.com

Citation:

Xue, Q., Cheng, D., Li, Y., Guan, D., & Zhao, W. (2022). Sustainable development pathways for Chinese cities: An assessment of the advanced inclusive wealth index. *Earth's Future*, *10*, e2022EF002695. https://doi.org/10.1029/2022EF002695

Received 29 JAN 2022
Accepted 15 AUG 2022

Author Contributions:

Data curation: Qianyu Xue, Danyang Cheng
Formal analysis: Qianyu Xue, Danyang Cheng

Sustainable Development Pathways for Chinese Cities: An Assessment of the Advanced Inclusive Wealth Index

Qianyu Xue[1], Danyang Cheng[2], Yuan Li[1], Dabo Guan[2,3], and Weichen Zhao[3]

[1]Institute of Blue and Green Development, Weihai Institute of Interdisciplinary Research, Shandong University, Weihai, China, [2]Department of Earth System Science, Ministry of Education Key Laboratory for Earth System Modeling, Institute for Global Change Studies, Tsinghua University, Beijing, China, [3]The Bartlett School of Sustainable Construction, University College London, London, UK

Abstract The inclusive wealth index (IWI) is a stock metric proposed internationally in recent years to measure a region's sustainable development potential. To explore sustainability more comprehensively in this context, this paper improves the inclusive wealth (IW) system proposed by the United Nations Environment Programme by extending the definition of intangible capital and refining the classification of different types of capital. We then used the advanced IWI to investigate the changes in per capita IW and its capital composition in China's 10 National Sustainable Development Agenda Innovation Demonstration Zones from 2010 to 2019, and proposed sustainable development pathways for Chinese cities. Our results underline the fact that IW and capital structure across different types of cities is highly variable. The growth of IW per capita in Shenzhen, an international metropolis, mainly depends on advanced produced capital and intangible capital. For Ordos, however—a resource-rich "energy city"—the per capita IW is driven by ordinary produced capital and restricted by non-renewable natural capital, thus showing a low level of sustainability. Through its consideration of four kinds of capital, this study also points out the inequality of human capital between urban-rural and male-female groups, and demonstrates how increasing educational attainment helps to promote the transfer of human capital between regions and sectors. In general, a strong potential for sustainable development is linked to the promotion of highly educated human capital, advanced produced capital and intangible capital, while the ecosystem service value of natural capital is also key.

Plain Language Summary As an indicator of sustainable development, the inclusive wealth index (IWI) can reflect the level, content and quality of wealth in a region. This paper improves on the IWI system issued by the United Nations Environment Programme, and introduces the elements of innovation such as intellectual capital in software and R&D investments in patents by bringing in a subject neglected by previous research: intangible capital. To implement the United Nations' 2030 Agenda for Sustainable Development, China has set up 10 National Sustainable Development Agenda Innovation Demonstration Zones (NIDZs) during its 13th Five-Year Plan period. NIDZs are prefecture-level cities with different geographical locations, resource endowments and development levels. This study looked at the variation of inclusive wealth per capita, and at four types of capital, in each NIDZ from 2010 to 2019 to reveal their sustainable development potential and provide a basis for designing future development paths. Across the NIDZs, there are differences in the distribution of human capital in urban and rural areas, sectors and genders, implying some degree of inequality. We divided the produced capital into advanced (such as produced capital accumulated in information and financial sectors) and ordinary (produced capital accumulated in agricultural and mining sectors, for instance) capital. Advanced produced capital and intangible capital (including computerized information capital, innovation capital, and economic competencies capital) jointly help in promoting industrial innovation, and reflect the potential for regional innovation. Natural capital meanwhile signifies a zone's endowment with and utilization of natural resources.

1. Introduction

Since the concept of sustainable development was formally put forward by the United Nations Conference on Environment and Development (the "Earth Summit") in 1992, most countries have gradually adopted it as an important guiding strategy for policy formulation. Traditional national accounting methods such as the gross national product (GDP) only focus on economic performance, ignoring non-material output and resource costs. GDP is thus not sufficient as a tool for measuring sustainability-related well-being (Mumford, 2016;

Funding acquisition: Yuan Li, Dabo Guan
Investigation: Qianyu Xue, Danyang Cheng
Methodology: Qianyu Xue, Danyang Cheng
Project Administration: Yuan Li, Dabo Guan
Resources: Qianyu Xue, Danyang Cheng
Software: Qianyu Xue, Danyang Cheng
Validation: Qianyu Xue, Danyang Cheng
Visualization: Qianyu Xue, Danyang Cheng
Writing – original draft: Qianyu Xue, Danyang Cheng
Writing – review & editing: Qianyu Xue, Danyang Cheng

Santos Gaspar et al., 2017; Stiglitz et al., 2009). Many studies have proposed other indicators to track regional sustainable development. They include the Human Development Index (HDI), which includes life expectancy, education attainment level and per capita GDP (Klugman et al., 2011); and the Ecological Footprint (EF), which measures the impact of human activities on the environment (Easterlin, 2003). However, even these indicators are incomplete, emphasizing only certain aspects of society, the economy and the environment, and are thus not enough to provide a comprehensive assessment of sustainable development (Polasky et al., 2015). Recently, several studies have emerged that propose a composite sustainable development index system (Sachs et al., 2019; Schmidt-Traub et al., 2015). However, the subjectivity in indicator selection has made agreement on a consistent indicator framework difficult among scholars. Moreover, results under the existing indicator system are more focused on comparing rankings between different regions and indicators. As a result, they cannot effectively guide a sustainable development pathway.

The United Nations University's International Human Dimensions Programme on Global Environmental Change (UNU-IHDP; the programme is now dissolved), with the United Nations Environment Programme (UNEP), published the first Inclusive Wealth Report (IWR) in 2012. This proposed an inclusive wealth index (IWI) as an indicator to measure an economy's progress toward sustainable development. Inclusive wealth (IW) encompasses a holistic assessment of produced capital as well as human and natural capital within a region. It is a multipurpose indicator, capable of measuring not only traditional stocks of wealth but also those less tangible—such as educational attainment, skills sets and health care, as well as environmental assets and the functioning of the key ecosystem services that form the backbone of human well-being. The increase in IW over time indicates that the development of a region is sustainable, while a decrease in IW indicates unsustainable development (Dasgupta & Mäler, 2000; K. Arrow et al., 2004; K. J. Arrow et al., 2012; P. Dasgupta et al., 2015). Since the IWR was published in 2012, studies have emerged that propose innovations to the indicator framework and the adoption of the IWI to assess sustainable development on national or subnational scales (Cheng et al., 2022; Endo & Ikeda, 2022; Fan et al., 2022; Ikeda et al., 2017; Islam & Managi, 2022; J. Fang et al., 2019; Jingyu et al., 2020; Jumbri & Managi, 2020; Zhang & Sun, 2018). However, research on improving the IWI system mostly focuses on human capital, natural capital and the inclusion of carbon emissions in additional adjustments, and rarely focuses on estimating intangible capital. UNU-IHDP & UNEP (2014) used the term "social capital" to describe any intangible capital that is not explicitly included in estimating IW. Corrado et al. (2005) clearly defined the concept of intangible capital, and proposed a classification framework for accounting it. With the increasing importance of innovation in economic development, many scholars have researched the contribution of intangible capital to economic growth (Belhocine, 2009; Clayton et al., 2009; Roth & Thum, 2013). These studies found that investment in intangible capital can help to significantly improve labor productivity and promote economic transformation. Intangible capital—including information capital, brand capital and other forms—is the decisive factor in innovation, and has become the main driving force for the sustainable economic development of developed countries (Corrado et al., 2009; Goodridge et al., 2013). To have a clearer understanding of a region's innovation potential, we have incorporated accounting of intangible capital into the IWI system.

As the largest developing country, China is keenly committed to the implementation of the United Nations' 2030 Agenda for Sustainable Development. China's many cities are diverse in terms of resource conditions and levels of economic development. Currently, studies assessing sustainable city-level development in China are on the rise. Most of them focus on constructing a framework to evaluate the sustainability of cities in terms of three dimensions: society, economy and environment (Chen & Zhang, 2020; Han et al., 2021; W. Li & Yi, 2020; Song et al., 2016; Sun et al., 2017). Others assess the sustainable development capability of a certain aspect, such as innovation (C. Fang et al., 2014; X. Yin et al., 2019), green construction (Tan et al., 2017; K. Yin et al., 2014; Y. Zhang et al., 2021) and urban resilience (Tang et al., 2021; T. Wang et al., 2019), among others, or quantify the impact of single issues such as inequality (B. Zhang et al., 2021) on a city's sustainable development. What these studies lack is a quantitative analysis of overall sustainable development across different kinds of cities, as well as discussion and guidance on sustainable development paths. This study therefore aims to provide the needed analysis and policy guidelines for such paths. Specifically, it examines the 10 National Sustainable Development Agenda Innovation Demonstration Zones (NIDZs) as representative of the range of Chinese cities. China positioned 10 prefecture cities as NIDZs during its 13th Five-Year Plan period (State Council, 2016). They differ in terms of population size, geographic location, resource endowment and level of economic development (see Table S1 in Supporting Information S1). At the same time, they have been supported by national fiscal policies in recent years (People's Government of Hunan Province, 2019; People's Government of Ordos, 2022;

People's Government of Shenzhen, 2021), and are developing in different ways, for example, Shenzhen focusing on improving innovation capacity and Guilin promoting the sustainable use of landscape resources.

Based on the IWI accounting method published in the newly released IWR 2018 (Cheng et al., 2022; Managi & Kumar, 2018), this paper adjusts and improves indicators of IWI to fit the sustainable development assessment system for Chinese cities. The adjusted indicator system was then applied to the 10 NIDZs. We calculated the IW of each NIDZ over the period from 2010 to 2019, and explored the differences in and trends of their capital structures. To further understand the specific distribution of various kinds of capital in the NIDZs, we compared differences in human capital (urban and rural, and male and female); and we divided produced capital into ordinary and advanced, and natural capital into renewable and non-renewable. Intangible capital, reflecting the region's innovation, was also added to the IWI index system. The findings fully analyzed the problems and potential challenges in the development process and explored the sustainable development potential of a range of cities. They provide an empirical basis for promoting efficient utilization of resources and formulating guiding strategies for sustainable development according to local conditions. By subdividing the four types of capital, we also discovered the inequality distribution of human capital on spatial and gender scales, as well as the connection between intangible capital per capita, advanced production capital and IW. Additionally, the improved IWI index system in this paper can also be applied to the study of sustainability at the regional, national and global levels, while usefully clarifying the links between key factors affecting sustainable development.

2. Materials and Methods

The inclusive wealth index (IWI) system provides a measure of sustainability—including human, produced, natural and intangible forms of capital—which can measure a region's level of well-being with more accuracy than GDP. Based on the methodology presented in the study by Cheng et al. (2022) and Managi & Kumar. (2018), the accounting method and index in this paper are described in detail as follows. The research results of this article are unified to the price level in 2000 with the currency of yuan (￥).

2.1. Inclusive Wealth Index

The accounting method of inclusive well-being is based on the concept of a shadow price—that is, the marginal contribution to the intertemporal well-being of a unit of capital, which reflects the capacity of resources to generate future revenue streams. The resulting total IW can be expressed as:

$$\begin{aligned} IW_t &= HCW_t + PCW_t + NCW_t + ICW_t \\ &= P_{HC} \cdot H_t + P_{PC} \cdot P_t + P_{NC} \cdot N_t + P_{IC} \cdot I_t \end{aligned} \tag{1}$$

In Equation 1, HCW_t, PCW_t, NCW_t, and ICW_t represent the wealth of human capital, produced capital, natural capital and intangible capital, respectively; P_{HC}, P_{PC}, P_{NC}, and P_{IC} correspond to the shadow prices of the four kinds of capital. The stock of human capital, produced capital and natural capital is represented as H_t, P_t, N_t, and I_t. When the shadow price is fixed, the IW in the t period does not decrease, indicating that development at this moment is sustainable (K. Arrow et al., 2004; K. J. Arrow et al., 2012; Dasgupta, 2003; Hamilton & Clemens, 1999). As Yamaguchi (2014) noted, resources have a finite carrying capacity, and the expansion of population can have a wealth-diluting impact because of declining resources per capita. Therefore, in this paper we determine whether a region is sustainable based on the increase or decrease in IW per capita (IW_{pct}) while ensuring that the shadow price is constant. IW per capita (IW_{pct}) can better represent the sustainable development capacity of a region, as shown in Equation 2. $P_{residents}$ is the number of people resident in the NIDZs.

$$IW_{pct} = \frac{IW_t}{P_{residents}} \tag{2}$$

2.2. Human Capital

Human capital wealth (HCW) is calculated via the stock of human capital (HC) and the shadow price per unit of human capital (P_{HC}). We divide human capital into urban and rural, and male and female. According to the method proposed by IWR 2018, the gains of education will eventually return to human capital. This method of calculating human capital wealth is shown in Equation 3.

$$HCW = e^{(Edu \cdot \rho)} \cdot P \cdot P_{HC} \tag{3}$$

In Equation 3: $e^{(Edu \cdot \rho)}$depends on the educational level of a region, where *Edu* represents the average length of education of the urban, rural, male and female resident population. ρ is the rate of return on education, which is 0.079 for urban and 0.061 for rural populations, and 0.085 is for male and 0.0729 for female populations, respectively. *P* measures the population structure of a city and represents the number of people in the labor force who are older than "school-age + average years of education." In this paper, the distribution of human capital in urban and rural areas is represented as the number of urban and rural residents aged 15–64. When studying the distribution of male and female human capital in various sectors, we found that the data on the employed population and the population aged 15–64 in each NIDZ differ to some extent. Considering that the employed population by sector can better reflect the regional employment structure of the male and female labor force, it is more reasonable to use data on the employed population to calculate male and female human capital. P_{HC} is the shadow price of a unit of human capital, which is calculated according to the present value of income, as shown in Equation 4:

$$P_{HC} = \int_0^T \bar{r}_t \cdot e^{-\delta \cdot t} dt \tag{4}$$

where $\bar{r}$, δ and T refer to the average labor remuneration, the discount rate and the expected duration of working life, respectively. $\bar{r}_t$ is calculated using the average value of the average wage of employees on the duty of each sector from 2000 to t (year), and the GDP deflator is used to further maintain the average wage at the price level based on 2000. The expected years of work (T) are calculated as follows:

$$T = (1 - mor) \cdot \sum_g disra_g \cdot proa_g \tag{5}$$

where mor is the mortality rate of the population; $proa_j$ is the proportion of the population of different age groups g in the labor force population aged 15–64 in each city; $disra_g$ is the absolute value of the difference between the median of each age group and the retirement age. This paper divides the labor force from 15 to 64 years old into 15–19, 20–24, 25–29…56-60 and 60–64 age groups at four-year intervals; and the average retirement age of the labor force is 57.5 years. For example, for the 15–19 years age group, the median is 17, so the number of years to average retirement age is 40.5.

2.3. Produced Capital

The produced capital wealth is calculated using the perpetual inventory method (PIM) (King & Levine, 1994). To study the distribution of produced capital in different sectors, this paper divides produced capital into advanced and ordinary. Manufacturing and services can also be subdivided in this way (National Bureau of Statistics, 2013, 2017; Shao & Wu, 2020); thus, advanced produced capital encompasses the advanced manufacturing and advanced service industries—the latter including the information, leasing, SECH (general name of scientific research, education, culture and health sectors), financial and real estate sectors. Ordinary produced capital includes other services (such as transport and wholesale sectors) as well as the agriculture, mining, ordinary manufacturing, electricity and construction sectors. The specific industrial sectors, and the depreciation rates of each sector, are shown Tables S2 and S3 in Supporting Information S1. Most of the existing literature sets the estimated year of the capital stock in the base period as 1952 or 1978 (Zhang et al., 2004). Considering the availability of city statistical data in those early years, this paper chose 1978 as the base period. The specific calculation equation is as follows:

$$K_{st} = K_{s0}(1 - \delta)^t + \sum_{j=1}^t I_{sj}(1 - \delta)^{t-j} \tag{6}$$

$$K_{s0} = \frac{I_{s0}}{\delta + \gamma_s} \tag{7}$$

In Equations 6 and 7, four variables are involved: K_{st} represents the produced capital stock of the sector s in year t, and K_{s0} represents the produced capital stock of the sector in the base year; δ is the depreciation rate; γ_s is the steady growth rate. According to the property classification of sector s, γ_s is calculated as the geometric annual growth rate of GDP of the primary, secondary and tertiary industries from 1978 to 2019. I_{sj} is the investment of the sector *s* in the current year *j*, and the gross fixed capital formation is usually used as a reasonable index of *I* (Zhang et al., 2004). Due to the lack of data on total fixed capital formation at the city level, the investment *I* of sector s is estimated by the product of fixed-asset investment (*FAI*) of the sector and the correction coefficient (*CF*) (Ke & Xiang, 2012), as shown in Equation 8:

$$I_s = FAI_s \cdot CF \tag{8}$$

The fixed-asset investment price index (*IPI*) of the province where each demonstration zone is located can be used to maintain I_{sj} the price level of 2000. For the missing *IPI* data before 1990, according to the method proposed by Zhang et al. (2004), the investment implied deflator (*IID*) is used instead. The gross fixed capital formation (*GFCF*) and its index (*GFCI*) of province *b*, in which city *u* is located, can be used to calculate the *IID*. The *IID* calculation formula is as follows:

$$IID_{ut} = \frac{GFCF_{bt}}{GFCI_{bt} \cdot GFCF_{b\cdot(t-1)}} \tag{9}$$

2.4. Natural Capital

We divide natural capital into renewable and non-renewable. Natural capital-non-renewable (NC-nonre) only includes mineral capital wealth, the increase or decrease of which measures the intensity of mineral resource utilization. And natural capital-renewable (NC-renew) includes agricultural capital, forestry capital and water capital.

2.4.1. Mineral Capital

Considering the availability of data and the proportion of mineral resources reserves, three fossil fuels (coal, natural gas and petroleum) and nine metallic and nonmetallic minerals (vanadium, copper, iron, lead, manganese, phosphorus, zinc, bauxite and magnesite) are selected. The calculation equation of mineral welfare (*MW*) is as follows:

$$MW_{mu} = Stock_{mu} \cdot PM_m \cdot RC_m \tag{10}$$

where $Stock_{mu}$, PM_m and RC_m respectively refer to the basic reserves, the shadow price and the rental rate of mineral resource *m*. The shadow prices for coal, iron ore, manganese, vanadium, bauxite, magnesite and phosphate are calculated by dividing the annual industrial output of each mineral from 2000 to 2019 by annual ore production. Oil, natural gas, copper, lead and zinc are all priced in the international market. All mineral prices are converted to 2000 prices using the GDP deflator in China or the United States. And the rental rates of coal, oil, natural gas, vanadium, copper, iron, lead, manganese, phosphorus, zinc, bauxite and magnesite are 0.28, 0.32, 0.13, 0.08, 0.04, 0.10, 0.14, 0.08, 0.14, 0.08, and 0.08, respectively.

2.4.2. Agricultural Capital

In this paper, the area of agricultural land is divided into arable land and pasture land, and the methods used for calculating resource wealth and shadow price of both are the same. Taking arable land as an example, the arable land wealth (*ALW*) is defined as the annual arable land area *A* multiplied by its shadow price *PA*; and the shadow price is calculated by the net present value method. The equation is as follow:

$$ALW = PA \cdot A \tag{11}$$

$$PA = \sum_{t=1}^{\infty} \frac{\overline{WA} \cdot RC}{(1+r)^t} = \overline{WA} \cdot RC \left(1 + \frac{1}{r}\right) \tag{12}$$

Where $\overline{WA}$ is the wealth value of arable land per hectare, which is calculated from the average ratio of planting output value to arable land area in each city from 2000 to 2019, and converted to the price level in 2000 by using the GDP deflator. *RC* is the rent rate of agricultural land, assumed to be constant at 0.28; and *r* represents the discount rate and takes a value of 0.08.

10.1029/2022EF002695

2.4.3. Forest Capital

For the accounting of forest resources wealth, this paper mainly relies on the methods in IWR 2014, which introduces the wealth accounting of forest timber resources and forest non-timber resources. Regarding the wealth of forest timber resources, the timber quantity was expressed as the volume of living wood. As shown in Equation 13:

$$FTW = Lt \cdot Ca \cdot PT_n \cdot RC \tag{13}$$

where *FTW* represents the wealth of forest timber, *Lt* represents the stock of living wood, and *Ca* represents the percentage of commercially available wood, with a value of 0.38. PT_n represents the shadow price of timber, which is calculated as the average price of timber in each province from 2000 to 2019, and converted to the price level in 2000 by using the GDP deflator; *RC* represents the forest rent rate, with a value of 0.76. For forest non-timber resources, it can be converted into the marginal contribution of ecosystem services to economic development. The calculation of non-timber forest ecosystem service wealth (FESW) can be expressed as Equation 14:

$$FESW = \int_0^{\infty} Q \cdot F \cdot bp \cdot e^{-\delta \cdot t} dt \tag{14}$$

where *F*, *Q*, and *bp* represent the forest area and the marginal contribution of forest ecosystem services to well-being respectively, which is ￥21061/ha/year, and the proportion of forests that can provide benefits for human beings is 0.1.

2.4.4. Water Capital

Considering the importance of water as a natural resource, this study established a water resources evaluation system for cities based on the method of Ouyang et al. (2004). According to Costanza et al. (1997), water ecosystem services can be divided into four types of services: supply, regulation, support and cultural (recreation and cultural education). And they can be divided into seven forms of sub-water capital: water resource supply, hydropower generation, water purification, carbon sequestration and oxygen release, biodiversity maintenance, leisure and entertainment, and culture and education. The value of each sub-water capital (SWV_d) refers to the annual economic benefits. Water capital wealth (*WW*) is calculated using the net present value method (NPV), as shown in Equation 15.

$$WW = \sum_{t=1}^{\infty} \frac{\sum_{d=1}^{7} SWV_d}{(1+r)^t} = \left(\sum_{d=1}^{7} SWV_d\right) \cdot \left(1 + \frac{1}{r}\right) \tag{15}$$

2.5. Intangible Capital

According to Corrado et al. (2005), Zheng and Yang (2020), Tian et al. (2016), and Yang et al. (2015), intangible capital is an important factor in regional innovation capacity. Among forms of such capital, computerized information capital reflects the knowledge embedded in computer software and databases, which we measure using intangible capital investments in the software industry. Innovative capital includes both scientific R&D and non-scientific R&D capital. Scientific R&D refers primarily to creative activities in manufacturing and telecom to create new applications, reflecting scientific knowledge in patents and licenses; while non-scientific R&D primarily refers mainly to R&D outside the above areas including mineral exploration, new construction and engineering design, and new product design in the financial sector. Economic competencies capital includes brand capital, which covers advertising and market research expenditures and facilitates the formation of brands and trademarks, and firm-specific competencies capital, which reflects the knowledge embedded in the specific human and organizational resources of the enterprise and contributes to the quality of management and the skills of the staff hired to promotes the operational efficiency of the enterprise. The accounting method of intangible capital also adopts the perpetual inventory method, as shown in Equations 16 and 17:

$$Z_{ft} = Z_{f0}(1-\delta)^t + \sum\nolimits_{j=1}^{t} I_{fj}(1-\delta)^{t-j} \tag{16}$$

$$Z_{f0} = \frac{I_{f0}}{\delta_f + \gamma_f} \tag{17}$$

where Z_{ft} represents the stock of intangible capital of type *f* in year t, and Z_{f0} represents the stock of intangible capital of type *f* in the base year; δ_f is the depreciation rate; γ_f is the steady growth rate, calculated as the geometric average growth rate of intangible capital investment of type *f*; and I_{fj} is the investment in the current year *j*. The corresponding price indices are adopted to maintain I_{fj} the price level of 2000. And the specific indicators are shown Tables S4, S5, and S6 in Supporting Information S1.

3. Data Sources

In the indicators data of human capital, education level and age structure data from different regions and genders are obtained from the 2010 and 2020 population censuses of each province, and the Sample Survey of 1% of the Population of each province. This study adopts the rate of return on education for urban men, urban women, rural men and rural women from 2000 to 2019, published in the China Human Capital Report 2020 (Central University of Finance and Economics, 2020). According to the 1-year benchmark lending rate provided by the Almanac of China's Finance and Banking, this paper assumes that the discount rate of human capital is always 0.08. The average labor remuneration data from 2000 to 2019 are from the China City Statistical Yearbook. And the population mortality data are from the statistical yearbooks of the NIDZs.

For indicators in produced capital, the fixed-asset investment data of different sectors and the GDP of the primary, secondary and tertiary industries are from the statistical yearbook of each NIDZ, and the fixed-asset investment price index is from the China Statistical Yearbook. Data of Gross Domestic Product of China (1952–1995) provides data on gross fixed capital formation and its index for each NIDZ's province from 1978 to 1995. As for the depreciation rate of investment in various sectors, the data obtained by Tian (2016) is adopted; we assume that the depreciation rate of anyone industry is consistent among different cities. In the data of intangible capital investment and price index, the investment data of computer software come from China's Electronic Information Industry Statistical Yearbook; the scientific R&D investment data come from the statistical yearbook of each NIDZ and its province; the non-scientific R&D investment data come from China Land and Resources Almanac, the China Statistical Yearbook and China's Input-output Table; the brand investment data are from the China Statistical Yearbook on Culture and Related Industries and the China Statistical Yearbook of the Tertiary Industry; and the firm-specific competencies investment data are from the statistical yearbook of each zone. The price index data used are all from the statistical yearbook of the province where the NIDZ is located, and the depreciation rate data of all kinds of intangible capital investment are from Zheng and Yang (2020) and Yang et al. (2015).

Natural capital covers most indicators, among which the basic mineral reserves data can be obtained from each NIDZ's mineral resources master plan, and other official documents. For city with missing mineral base reserve data, we use its province's basic mineral reserves multiplied by the city's share of the province's total mining output value to estimate. The annual industrial output and ore production data of minerals required to calculate the shadow price are from China Land and Resources Almanac; the international price data of minerals come from the World Bank, Macrotrends, Metalary, Thomson Reuters Datastream and The Wall Street Journal. The rental rate of each mineral is derived from the net profits of listed companies in the corresponding industry. For agricultural capital, the planting output value and arable land area data from 2000 to 2019 are from the statistical yearbook of each NIDZ from 2001 to 2020, while the pasture land area data are mostly from the Geographical Information Monitoring Cloud Platform (GIM Cloud, http://www.dsac.cn/). The rent rate of agricultural land can be found in the study of Li and Liu (2014). For forestry capital, data on forest area and living wood stock come from the Statistical Yearbook 2020 of each NIDZ or China's 13th Five-Year Plan for National Economic and Social Development. The timber price data are from China Forestry Statistical Yearbook 2001–2017 and the China Forestry and Grassland Statistical Yearbook 2018–2019; the data for the rent rate of forest resources and the proportion of forests providing benefits for people are obtained from IWR 2014; and the data of the marginal contribution of forest ecosystem services to well-being is from the study of de Groot et al. (2012). For water capital, data of all indicators are from the China Statistical Yearbook 2017, Water Resources Bulletin 2016 by city, and the official government website for each NIDZ.

4. Results

4.1. Produced Capital: The Largest Contributor to IW Per Capita Growth in Most Cities

Patterns in IW per capita growth over 2010–2019 differ significantly across the cities studied. Lincang has the highest IW per capita growth rate, with 61.3%; Ordos meanwhile witnessed a decline in such growth, with a rate

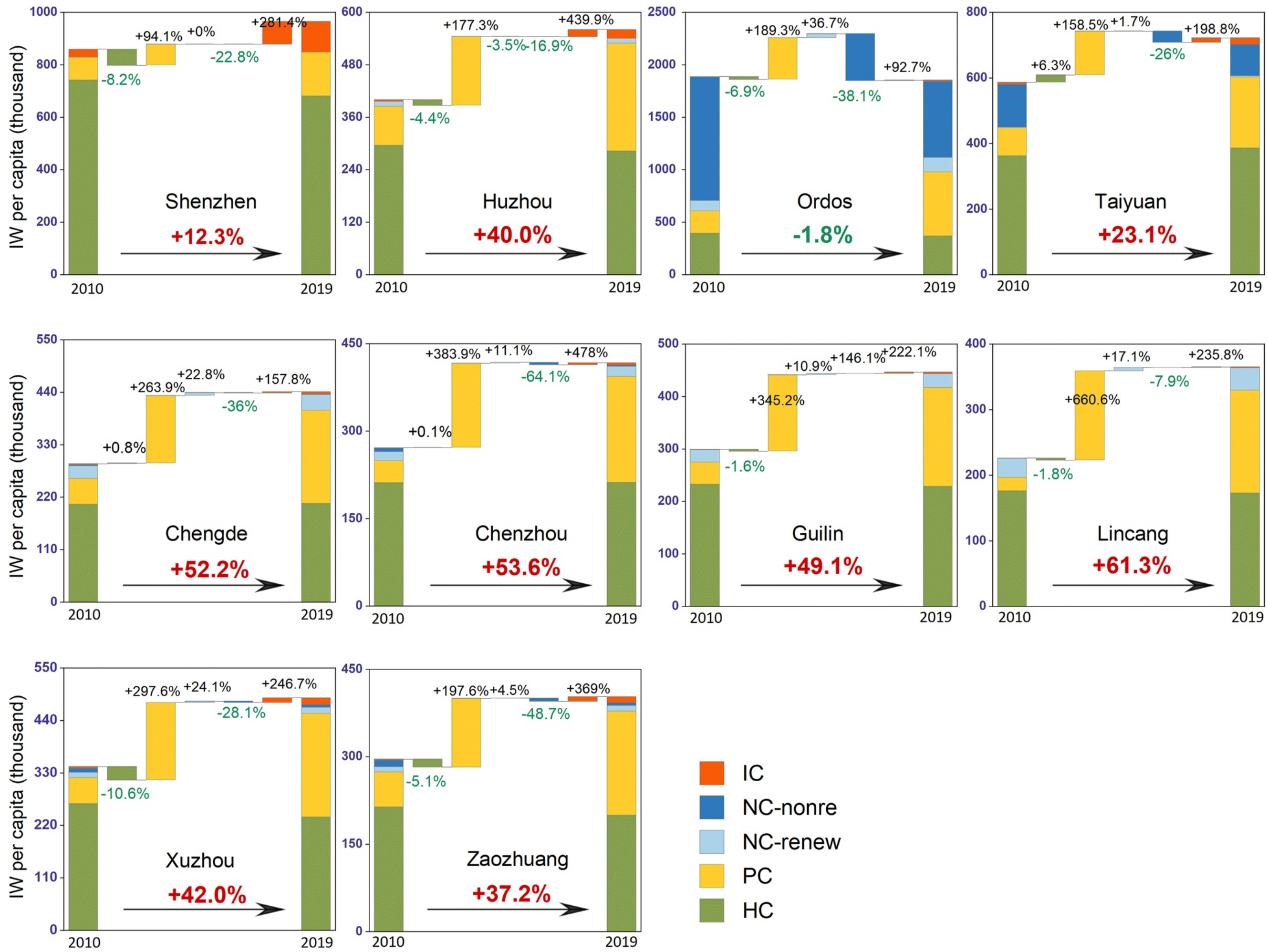

Figure 1. Contribution of the different types of capital to changes in the National Sustainable Development Agenda Innovation Demonstration Zones inclusive wealth per capita (units: thousand yuan) growth from 2010 to 2019. The length of the two bars at the left and right of each panel in the figure represents the inclusive wealth (IW) per capita in 2010 and 2019 respectively, and the length of various colors ranged along the bars represent the wealth value per capita of human capital, produced capital, natural capital-renewable (NC-renew), natural capital-non-renewable (NC-nonre) and intangible capital respectively. The corresponding percentage on each color bar represents the growth of each kind of capital from 2010 to 2019, and the percentage on the arrow represents the growth of IW per capita from 2010 to 2019.

of −1.8%. Produced capital is a key factor in determining IW per capita growth. It grew rapidly and contributed the most in the IW increment over 2010–2019 in most of the NIDZs (Figure 1). In cities including Chengde, Chenzhou, Guilin and Lincang, produced capital dominated IW per capita growth, while the other types of capital contributed just −1%–4%. Specifically, per capita produced capital in Lincang grew from 20.6 thousand yuan in 2010 to 156.8 thousand yuan in 2019, accounting for 9.1%–42.9% of IW, respectively. This trend can be attributed to significant investment in infrastructure construction in recent years, in the context of rapid development in the secondary and tertiary industries.

Other forms of capital also play vital roles in determining the change in IW per capita growth. In some high-tech cities such as Shenzhen, intangible capital is a key factor in promoting such growth. Specifically, intangible capital per capita in Shenzhen saw an increase from 30.5 thousand yuan to 116.5 thousand yuan over 2010–2019, with a growth rate of 281.4%, which contributed 81.5% of total IW per capita growth. Technological progress thus becomes the major driving force in Shenzhen's sustainable development. This is unsurprising: Shenzhen, as a modern, international, innovative city China is striving to build, is gradually becoming a national base for the development of high-tech industries. In 2019, Shenzhen ranked first in the country in terms of the number of patent applications and grants (Shenzhen Market Supervision Administration, 2020).

For some resource-dependent cities such as Ordos and Taiyuan, non-renewable natural capital affects the IWI per capita growth significantly. For instance, due to the large-scale exploitation of mineral resources, non-renewable natural capital in Ordos dropped by 38.1% over 2010–2019, corresponding to the loss of IW per capita of 447.6 thousand yuan. For cities heavily reliant on non-renewable natural capital, where fossil fuels are rapidly depleting, there is a growing need to enhance other forms of capital to transform the development pathway from unsustainable to sustainable. For instance, in Taiyuan, human, produced and intangible capital grew dramatically by 6.3%, 158.5%, 198.8% over 2010–2019, respectively, resulting in an increase of 169.3% in IW per capita growth.

Some cities in China, such as Xuzhou and Zaozhuang, are facing a decline in human capital per capita, which has a significant negative impact on the growth of IW per capita. The economy of Zaozhuang, for instance, once depended on resource-based industries, and a large proportion of the labor force is engaged in mining. With these resources now depleted, many resource-based enterprises, especially those involved in coal mining, have closed down, causing a decrease in jobs and income and a loss of labor. The human capital per capita of Zaozhuang, for example, decreased by 5.1% in 2019 compared with 2010, contributing −10.0% to IW per capita, with the share of the labor force here in the resident population decreasing from 74.2% to 64.0%.

4.2. Inequality in Distribution of Human Capital Along Regional and Gender Dimensions

This study further looks into the inner structure of each form of capital, and investigates the distribution of human capital between male and female, urban and rural, and by sector. Figure 2 shows significant differences in the distribution of human capital by region, gender and sector, reflecting the inequality between urban and rural development and in the employment status of men and women. Generally, the wealth of human capital per capita in urban areas is higher than that in rural areas. That can be attributed to the relatively poor state of education services, and the lower share of the labor force in the resident population, in rural areas. Specifically, in 2010, people in urban areas had spent, on average, two years longer in education than those in rural areas; and in 2019 this gap tended to widen in most cities, including Guilin, Lincang and Chenzhou. Furthermore, rural areas saw a higher decline in the rate of human capital per capita, compared to urban areas, from 2010 to 2019. This phenomenon can be attributed to rural labourers relocating to cities: according to the data (National Bureau of Statistics, 2020), rural regions in China have seen a loss of 160 million people in the past decade. The rural labourers who remain tend to be older and less advanced in terms of educational attainment, and engaged in labor-intensive industries with low added value, resulting in a dramatic decline in human capital. For example, the average duration of education among Guilin's rural labor force declined from 2010 levels, as did the proportion of the rural labor force here in the total labor force, which dropped by around 10%, resulting in a significant 22.7% drop in human capital per capita. The migration of the rural labor force to urban areas also creates challenges for cities to some extent. It is difficult, for instance, for such migrant populations to enjoy a level of social welfare identical to the urban population's, including housing, medical treatment and educational opportunities; and this can lead to or exacerbate social conflict.

Moreover, there is significant inequality between males and females in the NIDZs (Figure 2b). For all the zones, human capital per capita among males is higher than that for females, and the ratio of male to female human capital per capita is between 1.12 and 1.80. The distribution of human capital in different sectors by gender shows more detailed explanations of the disparity. The proportion of male human capital involved in secondary industries (including mining, electricity, construction and manufacturing) was always higher than that in female human capital. For example, in Ordos the difference between the two is as high as 24.7%. Female human capital is more likely to be associated with the agriculture and service sectors. However, the proportion of female human capital in the advanced service sector such as financial and SECH was higher than that of male human capital. In some high-tech or provincial capital cities such as Shenzhen and Taiyuan, 25.5% and 37.2% of female human capital, respectively, were distributed in advanced service sectors, compared to 20.7% and 18.9% for male human capital. As advanced service sectors usually provide high salaries and have a high demand for highly skilled labor, the development of this industry contributes to the promotion of gender equality in human capital.

The educational level of the labor force is likely to become an important factor driving the accumulation and transfer of human capital between regions and sectors in the future. So many labor-intensive enterprises have moved out of Shenzhen that the city's ability to absorb more migrant labor has slowed. However, the improvement in the educational level of the labor force of Shenzhen was not enough to offset the decline in the proportion of labor force in the resident population, with human capital per capita falling 8.2% from 2010 to 2019. The

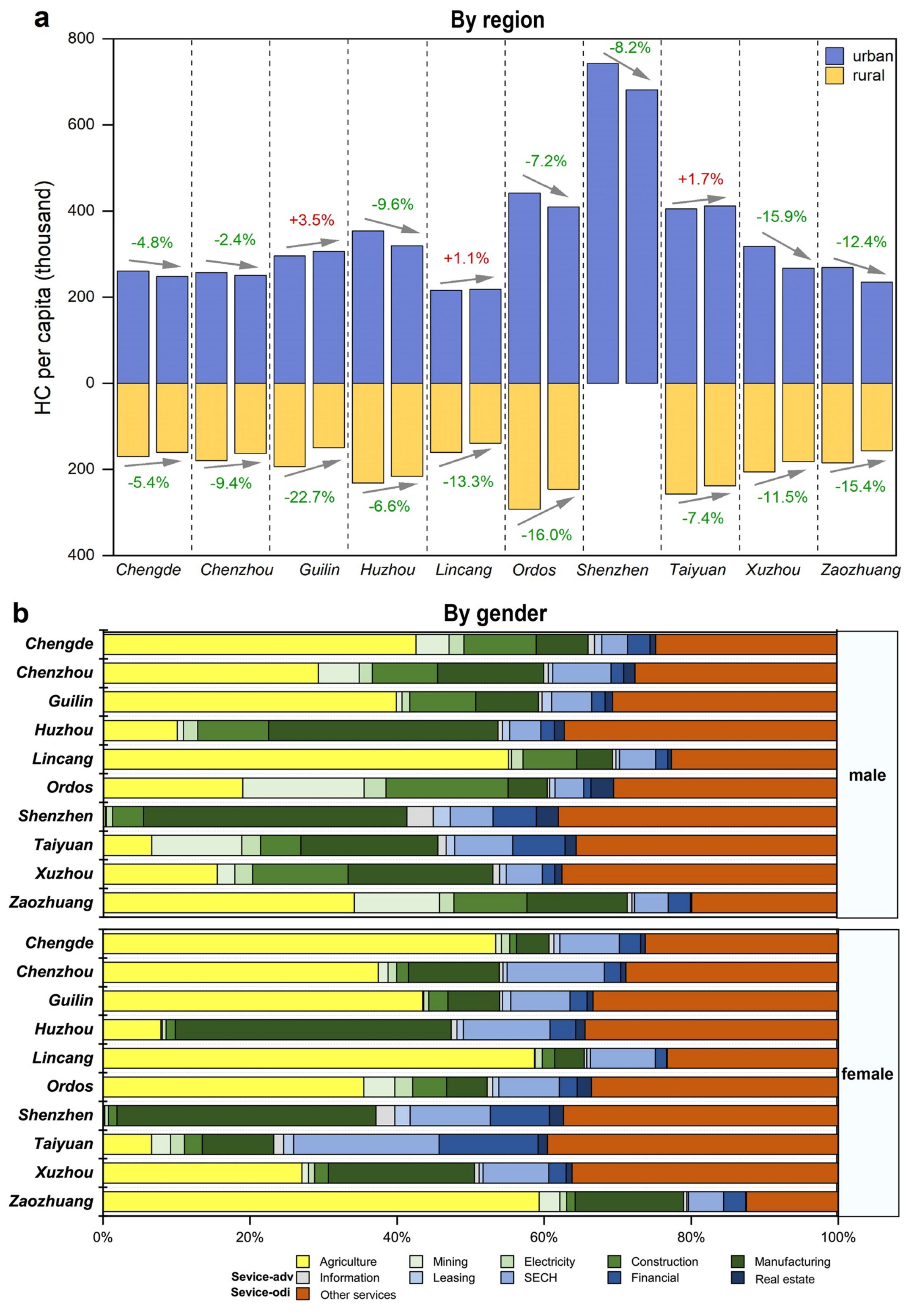

Figure 2. The specific distribution of human capital by region and gender in the 10 National Sustainable Development Agenda Innovation Demonstration Zones. Figure 2a shows the urban and rural human capital per capita wealth (unit: thousand yuan) and its growth rate in each demonstration zone from 2010 to 2019. Figure 2b shows the percentage of male and female human capital in 11 sectors in 2019. The information, leasing, SECH, financial and real estate sectors are divided into advanced services (Service-adv), while services outside the above sectors are classified as other services, that is, ordinary services (Service-odi).

combined share of human capital in agriculture, mining, electricity, construction and ordinary services exceeded 80%, implying that Lincang, Chengde, Ordos, Guilin and Zaozhuang have a generally undereducated workforce. Accordingly, the employment structure dominated by labor-intensive industries further affects the cultivation of high levels of education and skills among the labor force. The decline of urban human capital in Xuzhou and Huzhou (15.9% and 9.6%, respectively) was even larger than that in rural areas (11.5% and 6.6%, respectively). On the one hand, the average length of education for the urban population in the two zones increased slowly. This also hinders the transfer of labor to advanced services, leaving human capital concentrated in ordinary services and manufacturing sectors. On the other hand, the decline of expected working years and the proportion of labor force in the resident population also severely limited the growth of human capital per capita, indicating the aging of the population as the local young people tend to work in more developed urban areas. In the future, there will be a need to further improve the quality of the workforce and the industrial structure, thereby promoting more equitable development of human capital.

4.3. Variation of Innovation Potential by City, Which Can Be Reflected by Advanced Produced Capital and Intangible Capital

Figures 3a and 3b reflect the stock and composition of per capita produced capital and per capita intangible capital in 2019. The three cities with the highest share of advanced produced capital in total produced capital, Shenzhen (71.3%), Taiyuan (48.6%) and Huzhou (47.6%), also correspond to the highest intangible capital per capita (116.5, 20.1, and 20.2 thousand yuan respectively), reflecting a high capacity for innovation. It should be noted that Taiyuan's secondary industry is still dominated by ordinary manufacturing; its advanced manufacturing sector accounts for just 3.9% of the total produced capital in 2019. Therefore, the city needs to promote the development of high value-added industries in the future to further increase the innovation-driven power of advanced produced capital to the economy. In terms of intangible capital, Huzhou's innovative capital accounted for 72.7%, which reflects the city's many patents resulting from its significant levels of scientific R&D. From 2015 to 2019, the average annual number of patent applications in Huzhou was approximately 28,000 (People's Government of Huzhou, 2021), with an upward trend. Similarly, Taiyuan also has an absolute share of innovative capital in the intangible capital, with 67.8% of non-scientific R&D capital alone, corresponding to high investment in financial products and construction engineering design. Huzhou is located in an economically strong province with a skilled, highly mobile workforce, while Taiyuan is a provincial capital with regional and policy advantages, such as the talent introduction policy. Thus, a supportive environment for innovation can drive intangible capital growth.

Seven other cities, and in particular Chengde, Chenzhou, Guilin and Lincang, have low shares of advanced produced capital (16.6%, 20.0%, 28.6% and 21.7%, respectively) and low levels of intangible capital per capita (4.6, 4.2, 3.1, and 1.4 thousand yuan respectively), indicating a relatively weak capacity for innovation. Among these, the three cities with the highest proportion of produced capital in mining and power sectors are Ordos (17.5%, 9.3%), Chengde (14.8%, 7.9%) and Chenzhou (10.8%, 6.2%). Moreover, their manufacturing industries mainly produce raw materials and resource-intensive primary products with low technological levels and economic efficiency. Together with the data in Figure 1, this shows that the growth of IW per capita in these cities is driven by ordinary produced capital, and reveals weak potential for sustainable development over time. Looking further at the composition of intangible capital, non-scientific R&D capital makes up 85.5% of Ordos's intangible capital, with mineral exploration capital making a significant contribution. As the number of depleted mines grows, Ordos' investment in mineral exploration will decrease, which may lead to the slow growth of intangible capital per capita. As for Xuzhou and Zaozhuang, they also lack the accumulation of advanced produced capital and intangible capital. Together with the data in Figure 2, this shows a rapid loss of urban and rural human capital—a weak environment for innovation that in turn spells weak potential for sustainable development.

Innovative capacity has become an important driver of sustainable development in cities such as Shenzhen, with a high per capita IW and high potential for innovation. However, there is a large gap between the wealth of the sub-capitals that constitute the city's intangible capital, with the wealth of computerized information capital being much higher than that of other sub-capitals. Shenzhen should increase its investment in economic competencies capital, which accounts for only 3.6% of intangible capital. In particular, the city needs to enhance firm-specific competencies capital, promote firms' spending on employee technical training and organizational management, and attract skilled workers more effectively and quickly. In addition, Shenzhen should promote

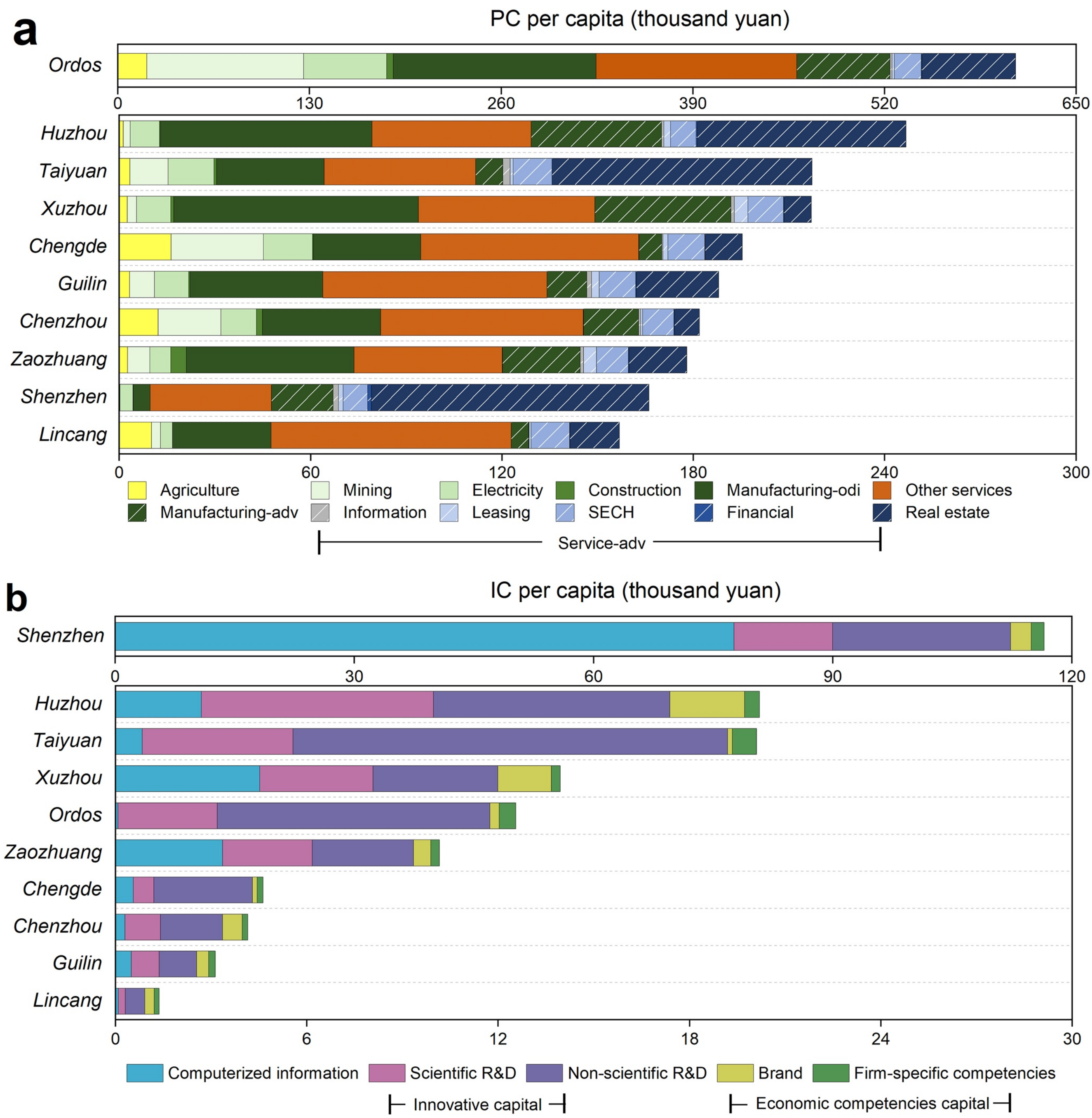

Figure 3. The wealth of produced capital per capita and intangible capital per capita (unit: thousand yuan) and their composition in the 10 National Sustainable Development Agenda Innovation Demonstration Zones (NIDZs) in 2019. Figure 3a shows the specific distribution of produced capital per capita across the 12 sectors. The manufacturing sector is divided into advanced manufacturing (manufacturing-adv) and ordinary manufacturing (manufacturing-adv); and the division of the service industry is the same as Figure 2. Figure 3b shows the wealth of intangible capital per capita (unit: thousand yuan) and its composition in the 10 NIDZs in 2019. The scientific R&D capital and non-scientific R&D capital together make up innovative capital; and brand capital and firm-specific competencies capital together make up economic competencies capital.

regional cooperation to drive other cities to improve their level of innovation, and ultimately narrow the intangible capital gap between regions.

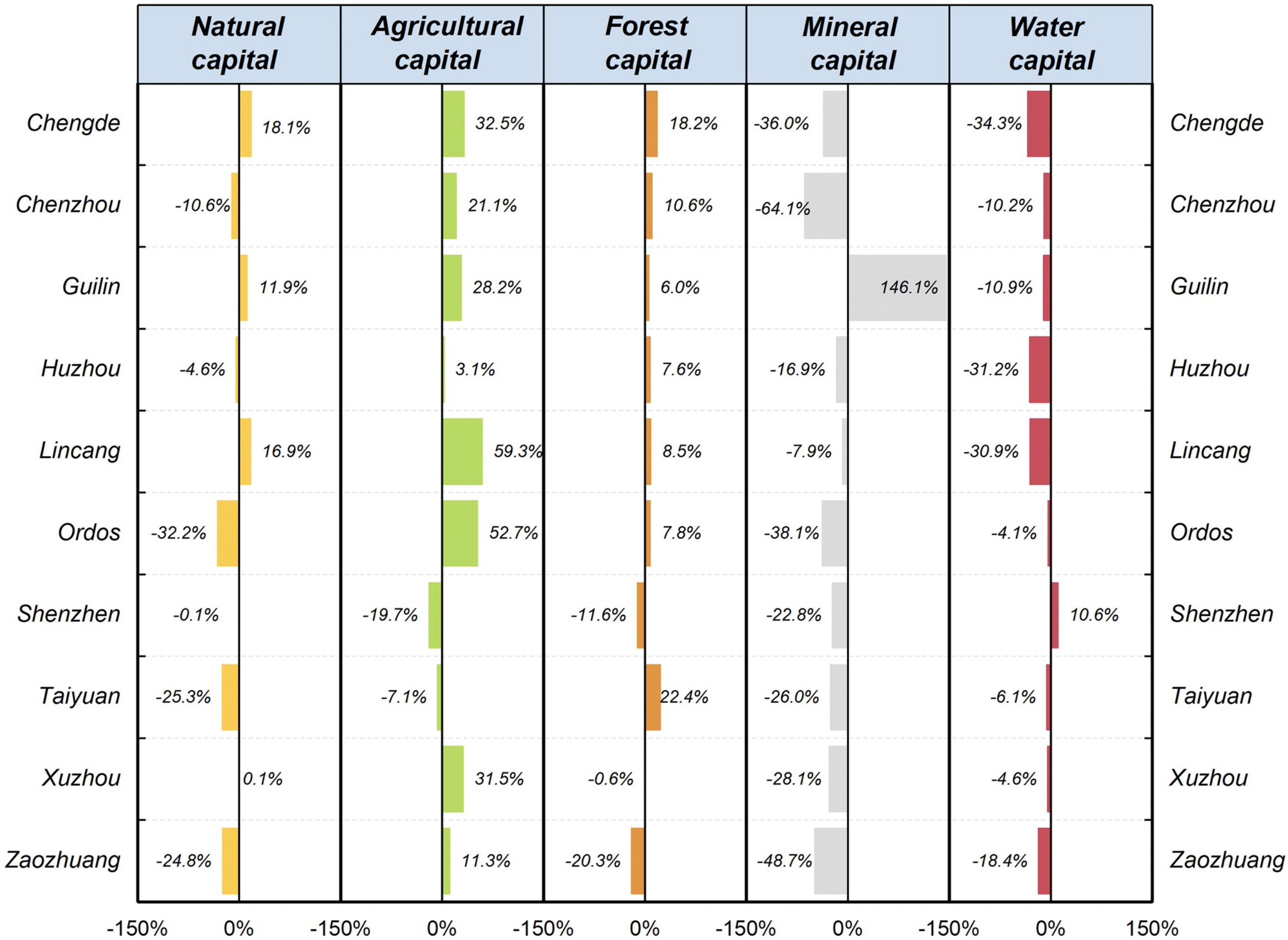

Figure 4. The growth rate of natural capital (NC) per capita and its composition between 2010 and 2019. The composition of NC per capital wealth is shown for each National Sustainable Development Agenda Innovation Demonstration Zones, from 2010 to 2019. The percentage next to each colored bar represents the growth rate of NC per capita and its composition.

4.4. The Rapid Decline in Natural Capital Is Mainly Due To the Consumption of the Mineral

To further study the utilization of natural resources in each NIDZ, we analyzed changes in four different types of capital—mineral, forestry, agricultural and water—over 2010–2019. Overall, there is usually growth in renewable natural capital (barring water) per capita over time, whereas nonrenewable natural capital per capita generally shows a downward trend (shown in Figure 4). The NIDZs with rising natural capital stock per capita (Chengde, Guilin, Lincang and Xuzhou) mainly rely on the growth of agricultural and forestry capital stock. For instance, Guilin's renewable natural capital wealth per capita increased by 10.9% between 2010 and 2019. The city's abundant agricultural and forestry resources have made the ecological industry, with tourism as the core, one of its economic pillars. The composition of Lincang's natural capital is similar to that of Guilin's, and is rich, for instance, in resources such as tea trees and medicinal plants. However, external conditions such as technical levels and infrastructure have meant that the comprehensive benefits of ecological industries in these four NIDZs are scant.

For the NIDZs that face dramatically declining natural capital per capita (Chenzhou, Ordos, Taiyuan and Zaozhuang), the decline of minerals is the prime factor. For instance, Ordos has significant stock advantages in both renewable and non-renewable capital, especially in mineral capital per capita: this was 727.1 thousand yuan in 2019, down 38.1% compared with 2010. However, due to weak capacity in innovation, the utilization efficiency of mineral resources in Ordos is insufficient. Meanwhile, the extensive development of coal resources has caused ecological damage and water pollution in some river basins. It is also worth noting that the form of

10.1029/2022EF002695

renewable capital in Zaozhuang is not promising. Due to a decrease in forest area, the forest capital per capita has dropped by 20.3% compared to 2010. The reason for this is that the forest resource management force in the rural areas of Zaozhuang is insufficient. The exploitation of mineral resources has left Zaozhuang facing yet more serious environmental problems.

Additionally, there are some NIDZs (Shenzhen and Huzhou) facing declining natural capital per capita where the cause is a loss of renewable natural resources including water, forestry and agricultural capital. With the expansion of urban construction, protecting cultivated land has become ever more urgent an issue. In 2019, agricultural capital in Shenzhen decreased by 19.7% compared with 2010. Meanwhile, Shenzhen's forestry capital per capita fell by 11.6%, which was attributed to the rapid population growth resulting in a decrease in forest area per capita and the stock of living wood per capita. It is key for economically developed cities to factor in the conservation and cultivation of renewable resources to avoid a decline in natural capital, which will hinder sustainable development.

5. Conclusions

This paper analyzes the trend in the development of IW per capita, and its composition in 10 National Sustainable Development Agenda Innovation Demonstration Zones (NIDZs) in China over the period 2010–2019. The results show that the future trajectory of IW per capita in each NIDZ will vary under different capital-driven effects. The future growth of IW per capita in Shenzhen and Huzhou, for instance, cannot only be driven by produced capital and intangible capital, but is also restricted by aspects of human capital such as education level of the labor force. Shenzhen, in particular, needs to accelerate the construction of high-level universities to train higher education talents; and invest more in firm-specific competencies capital to attract more well-educated workers (Zheng & Yang, 2020). The non-renewable natural capital dominating in Ordos and Taiyuan severely restricts the growth of IW per capita. It is worth noting that IW per capita in Ordos has shown a downward trend, and that its sustainable development capacity is weak. Ordos will therefore need to accelerate the transformation of its traditional resource-based industries and the development of high-tech industries. Due to the accelerating accumulation of produced capital, the IW per capita of Chengde, Chenzhou, Guilin and Lincang will still be in a phase of rapid growth in the future. However, their stock of advanced produced capital and intangible capital is not enough to provide innovation power for development, leading to weak sustainable development potential in the long run. For Xuzhou and Zaozhuang, the loss of their urban and rural labor force is serious, and there is an urgent need for a transformation and upgrading of resource-based industries to provide employment opportunities for the surplus labor force.

We further analyzed the sustainable development potential of each demonstration area by subdividing the four types of capital. There are significant differences in the distribution of human capital by region, gender and sector. The transfer of rural human capital to urban areas has led to a general lack of young laborers in rural areas and an aging population, which hinders sustainable rural economic development (Camarero & Oliva, 2019; Tao et al., 2020). Therefore, the government should expand investment in rural education, especially in Lincang, Chengde and Zaozhuang, where the agricultural sector has a high proportion of human capital, there is an urgent need to train groups of professional farmers to improve agricultural production efficiency; and it should promote rural infrastructure construction and increase jobs for the remaining labor force. The labor migration also brings traffic congestion, environmental degradation, and housing constraints to urban areas, which negatively affects the fertility preferences of the urban population and, in turn, the growth of human capital per capita (Chen et al., 2020; J. Liu et al., 2020). Under such circumstances, the government needs to accelerate the optimization of maternity policies and the implementation of maternity benefits for female workers (Huang et al., 2019). From the perspective of gender, the proportion of female human capital in the advanced service sector is higher than that of the male equivalent, especially in Shenzhen—a special economic zone and international metropolis—and Taiyuan, the economic centre and provincial capital of Shanxi Province. In these NIDZs, regional economic status and advantages, along with policy support, have encouraged the growth of gender equality in the employment environment. For the NIDZs where female human capital is widely distributed in ordinary sectors (e.g., agriculture and ordinary services), such as Lincang, Zaozhuang, Chengde and Guilin, improving the average length of time people spend in education is needed, along with accelerating the transfer of human capital to advanced sectors (e.g., advanced services and manufacturing) and urban areas.

When looking at the distribution of produced capital and intangible capital in each NIDZ, we conclude that there is a positive correlation between the stock of advanced produced capital and intangible capital that reflects the potential for innovation. Although Shenzhen, Huzhou and Taiyuan have a high proportion of advanced produced capital, the real estate sector accounts for a large proportion of that. Local governments should pay attention to the fact that inflated real estate investment may hinder the ability of cities to innovate (Lu et al., 2018; L. Yu & Cai, 2021; Yu & Zhang, 2017). This implies that a large amount of non-creative labor is shifted to real estate development, which is not conducive to long-term sustainable economic growth. Investment in the information, SECH and advanced manufacturing sectors should thus be expanded to promote technological progress and sustainable economic growth. Similarly, the composition of intangible capital in each NIDZ is unbalanced, lacking firm-specific competencies capital such as the firm's employee technical training and organizational management expenses. By 2025, Shenzhen plans to build into an international innovative city (Shenzhen Science and Technology Innovation Committee, 2022); thus, it is crucial to enhance firm-specific competencies capital in order to accelerate the attraction of highly skilled talents from global enterprises. Mineral exploration accounts for the highest proportion of non-scientific R&D capital in Ordos, for instance, and as mineral stocks are exhausted, the growth of intangible capital will slow. There are also huge differences in the spatial distribution of intangible capital stock. Lincang, Chenzhou and Guilin have the least intangible capital per capita among the NIDZs, and low advanced produced capital, resulting in weak production efficiency and sustainable development potential. These cities need to strengthen investment in intangible and human capital to improve the innovation environment and thus gradually generate agglomeration effect of innovation factors (Lao et al., 2021; J. Wang & Deng, 2022).

Natural capital is important as a base on which to build other capital, so conserving natural resources is crucial to improving sustainability. For Guilin, Lincang and Chengde, all rich in landscape as a natural and cultural legacy but weak in intangible capital, policy support is needed to introduce high-quality labor to boost the local eco-economy. Ordos and Taiyuan, both rich in mineral capital per capita, but need to move away from dependence on traditional energy sources. In addition, under the constraint of the national carbon neutrality target by 2060, energy-intensive less developed cities should gradually shift to the use of clean energy and technology, and strengthen ecological governance to reduce the environmental damage caused by mining (Bai et al., 2021; Mi et al., 2018). Currently, Zaozhuang, Xuzhou and Chenzhou, where resources are now becoming exhausted, should promote the transformation and upgrading of traditional industries, gradually promote advanced produced capital to drive the growth of IW per capita, and protect renewable resources through afforestation and other means. Shenzhen and Huzhou, both with low natural capital stock. However, the service value of their ecosystems should not be ignored. A shortage of water has become a common problem, making it crucial to protect lakes and waterways. And water stress affects urban and rural populations differently; for example, water stress from irrigated agriculture may not affect urban populations (X. Liu et al., 2019; Schlosser et al., 2014). In short, it is difficult to emphasize any one element to form a lasting, driving force to promote the overall development of this region. While formulating the personalized path of sustainable development, we need to take into account coordination between various factors.

Data Availability Statement

All datasets are available online (https://zenodo.org/record/5912688#.YxgFY6FBxPY), including: (a) Data tables required to calculate the inclusive wealth of these 10 cities in 2010 and 2019; (b) Matlab code. The Statistical Yearbooks Database is publicly available and can be downloaded in the (http://tongji.oversea.cnki.net/oversea/engnavi/navidefault.aspx).

Acknowledgments
We acknowledge supports from National Natural Science Foundation of China (71873059).

References

Arrow, K., Dasgupta, P., Goulder, L., Daily, G., Ehrlich, P., Heal, G., et al. (2004). Are we consuming too much? *The Journal of Economic Perspectives*, *18*(3), 147–172. https://doi.org/10.1257/0895330042162377

Arrow, K. J., Dasgupta, P., Goulder, L. H., Mumford, K. J., & Oleson, K. (2012). *Sustainability and the measurement of wealth*. Environment and Development Economics. https://doi.org/10.1017/S1355770X12000137

Bai, Y., Zheng, H., Shan, Y., Meng, J., & Li, Y. (2021). The consumption-based carbon emissions in the Jing-Jin-Ji urban agglomeration over China's economic transition. *Earth's Future*, *9*(9). https://doi.org/10.1029/2021EF002132

Belhocine, N. (2009). Treating intangible inputs as investment goods: The impacton Canadian GDP. *IMF Working Papers*, *09*(240), 1. https://doi.org/10.5089/9781451873870.001

Camarero, L., & Oliva, J. (2019). Thinking in rural gap: Mobility and social inequalities. *Palgrave Communications*, *5*(1), 95. https://doi.org/10.1057/s41599-019-0306-x

Central University of Finance and Economics. (2020). China human capital report 2020. Retrieved from http://cedcdata.cufe.edu.cn/cedc/metadata/toDataDetail.html?dataId=ff808081701641600l745468e3aa00d7

Chen, Y., Li, X., Huang, K., Luo, M., & Gao, M. (2020). High-resolution gridded population projections for China under the shared socioeconomic pathways. *Earth's Future*, *8*(6). https://doi.org/10.1029/2020EF001491

Chen, Y., & Zhang, D. (2020). Evaluation of city sustainability using multi-criteria decision-making considering interaction among criteria in Liaoning province China. *Sustainable Cities and Society*, *59*, 102211. https://doi.org/10.1016/j.scs.2020.102211

Cheng, D., Xue, Q., Hubacek, K., Fan, J., Shan, Y., Zhou, Y., et al. (2022). Inclusive wealth index measuring sustainable development potentials for Chinese cities. *Global Environmental Change*, *72*, 102417. https://doi.org/10.1016/j.gloenvcha.2021.102417

Clayton, T., Dal Borgo, M., & Haskel, J. (2009). *An innovation index based on knowledge capital investment: Definition and results for the UK market sector*. IZA Discussion Paper.

Corrado, C., Hulten, C., & Sichel, D. (2005). Measuring capital and technology: An expanded framework. In *Measuring capital in the new economy* (pp. 11–46). University of Chicago Press.

Corrado, C., Hulten, C., & Sichel, D. (2009). Intangible capital and US economic growth. *Review of Income and Wealth*, *55*(3), 661–685. https://doi.org/10.1111/j.1475-4991.2009.00343.x

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., et al. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387*(6630), 253–260. https://doi.org/10.1038/387253a0

Dasgupta, P. (2003). Human well-being and the natural environment. https://doi.org/10.1093/0199247889.001.0001

Dasgupta, P., Duraiappah, A., Managi, S., Barbier, E., Collins, R., Fraumeni, B., et al. (2015). How to measure sustainable progress. *Science*, *350*(6262), 748. https://doi.org/10.1126/science.350.6262.748

Dasgupta, P., & Mäler, K. G. (2000). Net national product, wealth, and social well-being. *Environment and Development Economics*, *5*(1), 69–93. https://doi.org/10.1017/S1355770X00000061

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., et al. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services*, *1*(1), 50–61. https://doi.org/10.1016/j.ecoser.2012.07.005

dos Santos Gaspar, J., Marques, A. C., & Fuinhas, J. A. (2017). The traditional energy-growth nexus: A comparison between sustainable development and economic growth approaches. *Ecological Indicators*, *75*, 286–296. https://doi.org/10.1016/j.ecolind.2016.12.048

Easterlin, R. A. (2003). Explaining happiness. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1633144100

Endo, K., & Ikeda, S. (2022). How can developing countries achieve sustainable development: Implications from the inclusive wealth index of ASEAN countries. *The International Journal of Sustainable Development and World Ecology*, *29*(1), 50–59. https://doi.org/10.1080/13504509.2021.1910591

Fan, J. L., Li, K., Zhang, X., Hu, J., Hubacek, K., Da, Y., et al. (2022). Measuring sustainability: Development and application of the inclusive wealth index in China. *Ecological Economics*, *195*, 107357. https://doi.org/10.1016/j.ecolecon.2022.107357

Fang, C., Ma, H., Wang, Z., & Li, G. (2014). The sustainable development of innovative cities in China: Comprehensive assessment and future configuration. *Journal of Geographical Sciences*, *24*(6), 1095–1114. https://doi.org/10.1007/s11442-014-1141-z

Fang, J., Lau, C. K. M., Lu, Z., Wu, W., & Zhu, L. (2019). Natural disasters, climate change, and their impact on inclusive wealth in G20 countries. *Environmental Science and Pollution Research*, *26*(2), 1455–1463. https://doi.org/10.1007/s11356-018-3634-2

Goodridge, P., Haskel, J., & Wallis, G. (2013). Can intangible investment explain the UK productivity puzzle? *National Institute Economic Review*, *224*, R48–R58. https://doi.org/10.1177/002795011322400104

Hamilton, K., & Clemens, M. (1999). Genuine savings rates in developing countries. *The World Bank Economic Review*, *13*(2), 333–356. https://doi.org/10.1093/wber/13.2.333

Han, Z., Jiao, S., Zhang, X., Xie, F., Ran, J., Jin, R., & Xu, S. (2021). Seeking sustainable development policies at the municipal level based on the triad of city, economy and environment: Evidence from Hunan province, China. *Journal of Environmental Management*, *290*, 112554. https://doi.org/10.1016/j.jenvman.2021.112554

Huang, J., Qin, D., Jiang, T., Wang, Y., Feng, Z., Zhai, J., et al. (2019). Effect of fertility policy changes on the population structure and economy of China: From the perspective of the shared socioeconomic pathways. *Earth's Future*, *7*(3), 250–265. https://doi.org/10.1029/2018EF000964

Ikeda, S., Tamaki, T., Nakamura, H., & Managi, S. (2017). Inclusive wealth of regions: The case of Japan. *Sustainability Science*, *12*(6), 991–1006. https://doi.org/10.1007/s11625-017-0450-4

Islam, M., & Managi, S. (2022). Valuation of nature's contribution in Ladakh, India: An inclusive wealth method. *Sustainability Science*, *17*(3), 905–918. https://doi.org/10.1007/s11625-021-01030-w

Jingyu, W., Yuping, B., Yihzong, W., Zhihui, L., Xiangzheng, D., Islam, M., & Managi, S. (2020). Measuring inclusive wealth of China: Advances in sustainable use of resources. *Journal of Environmental Management*, *264*, 110328. https://doi.org/10.1016/j.jenvman.2020.110328

Jumbri, I. A., & Managi, S. (2020). Inclusive wealth with total factor productivity: Global sustainability measurement. *Global Sustainability*, *3*, e5. https://doi.org/10.1017/sus.2020.1

Ke, S., & Xiang, J. (2012). *Estimation of the fixed capital stocks in Chinese cities for 1996—2009 (in Chinese)*. Statistical Research.

King, R. G., & Levine, R. (1994). Capital fundamentalism, economic development, and economic growth. *Carnegie-Rochester Conference Series On Public Policy*, *40*, 259–292. https://doi.org/10.1016/0167-2231(94)90011-6

Klugman, J., Rodríguez, F., & Choi, H. J. (2011). The HDI 2010: New controversies, old critiques. *The Journal of Economic Inequality*, *9*(2), 249–288. https://doi.org/10.1007/s10888-011-9178-z

Lao, X., Gu, H., Yu, H., & Xiao, F. (2021). Exploring the spatially-varying effects of human capital on urban innovation in China. *Applied Spatial Analysis and Policy*, *14*(4), 827–848. https://doi.org/10.1007/s12061-021-09380-9

Li, G., & Liu, J. (2014). *Estimation of China's provincial inclusive wealth index: 1990–2010*. China Industrial Economics.

Li, W., & Yi, P. (2020). Assessment of city sustainability—Coupling coordinated development among economy, society and environment. *Journal of Cleaner Production*, *256*, 120453. https://doi.org/10.1016/j.jclepro.2020.120453

Liu, J., Xing, C., & Zhang, Q. (2020). House price, fertility rates and reproductive intentions. *China Economic Review*, *62*, 101496. https://doi.org/10.1016/j.chieco.2020.101496

Liu, X., Tang, Q., Liu, W., Veldkamp, T. I. E., Boulange, J., Liu, J., et al. (2019). A spatially explicit assessment of growing water stress in China from the past to the future. *Earth's Future*, *7*(9), 1027–1043. https://doi.org/10.1029/2019EF001181

Lu, Y., Zhang, K., & Ou, Y. (2018). Does land finance hinder regional innovation? Based on the data of 267 prefectural-level city in China. *Journal of Financial Research*. Retrieved from https://kns.cnki.net/kcms/detail/detail.aspx?FileName=JRYJ201805007%26DbName=CJFQ2018

Managi, S., & Kumar, P. (2018). *Inclusive wealth report 2018*. Taylor & Francis.

Mi, Z., Zheng, J., Meng, J., Shan, Y., Zheng, H., Ou, J., et al. (2018). China's energy consumption in the new normal. *Earth's Future*, *6*(7), 1007–1016. https://doi.org/10.1029/2018EF000840

Mumford, K. J. (2016). Prosperity, sustainability and the Measurement of wealth. *Asia and the Pacific Policy Studies*. https://doi.org/10.1002/app5.132

National Bureau of Statistics. (2013). Regulations on the division of the three industries. Retrieved from http://www.stats.gov.cn/tjsj/tjbz/201301/t20130114_8675.html

National Bureau of Statistics. (2017). High-tech industry (manufacturing) classification. Retrieved from http://www.stats.gov.cn/tjsj./tjbz/201812/t20181218_1640081.html

National Bureau of Statistics. (2020). The 7th National census Bulletin. Retrieved from http://www.stats.gov.cn/tjsj/tjgb/rkpcgb/qgrkpcgb/

Ouyang, Z., Zhao, T., Wang, X., & Miao, H. (2004). Ecosystem services analyses and valuation of China terrestrial surface water system. *Acta Ecologica Sinica*.

People's Government of Hunan Province. (2019). Several policy measures on supporting Chenzhou city to build a national sustainable development Agenda innovation demonstration zone (in Chinese). Retrieved from http://www.hunan.gov.cn/hnszf/szf/hnzb_18/2017_106457_18/2017nd1q11700090b/szfbgtwj_98720_88_1qqcu/201910/t20191014_10482882.html

People's Government of Huzhou. (2021). Huzhou intellectual property development "14th five-year plan. Retrieved from http://www.huzhou.gov.cn/art/2021/9/16/art_1229566545_3832353.html

People's Government of Ordos. (2022). Science and technology support program for creating national sustainable development agenda innovation demonstration zone in Ordos in 2022 (in Chinese). Retrieved from http://www.ordos.gov.cn/xw_127672/jreeds/202207/t20220707_3239483.html

People's Government of Shenzhen. (2021). Science and technology innovation action plan for the early demonstration area of socialism with Chinese characteristics. Retrieved from http://www.gov.cn/zhengce/zhengceku/2021-02/26/content_5588985.htm

Polasky, S., Bryant, B., Hawthorne, P., Johnson, J., Keeler, B., & Pennington, D. (2015). Inclusive wealth as a metric of sustainable development. *Annual Review of Environment and Resources*, *40*(1), 445–466. https://doi.org/10.1146/annurev-environ-101813-013253

Roth, F., & Thum, A. E. (2013). Intangible capital and labor productivity growth: Panel evidence for the EU from 1998–2005. *Review of Income and Wealth*. https://doi.org/10.1111/roiw.12009

Sachs, J., Schmidt-Traub, G., Kroll, C., Lafortune, G., & Fuller, G. (2019). SDG index and dashboards Report 2018. *Consumption and Violence*.

Schlosser, C. A., Strzepek, K., Gao, X., Fant, C., Blanc, É., Paltsev, S., et al. (2014). The future of global water stress: An integrated assessment. *Earth's Future*, *2*(8), 341–361. https://doi.org/10.1002/2014ef000238

Schmidt-Traub, G., Karoubi, E. D., & Jessica, E. (2015). *Indicators and a monitoring framework for the sustainable development goals: Launching a data revolution for the SDGs[M]*. Sustainable Development Solutions Network.

Shao, J., & Wu, C. (2020). Influencing factors and capability improvement of high-end service industry in China: Based on provincial panel data (in Chinese). *Journal of Commercial Economics*.

Shenzhen Market Supervision Administration. (2020). Shenzhen 2019 annual IPR statistical analysis report. Retrieved from http://amr.sz.gov.cn/xxgk/qt/ztlm/sjfb/tjfx/cqtj/

Shenzhen Science and Technology Innovation Committee. (2022). Shenzhen science and technology innovation "fourteen five" plan. Retrieved from http://www.sz.gov.cn/cn/xxgk/zfxxgj/zwdt/content/post_9517708.html

Song, T., Yang, Z., & Chahine, T. (2016). Efficiency evaluation of material and energy flows, a case study of Chinese cities. *Journal of Cleaner Production*, *112*, 3667–3675. https://doi.org/10.1016/j.jclepro.2015.08.080

State Council. (2016). China's construction plan of national sustainable development agenda innovation demonstration zones. Retrieved from http://www.gov.cn/zhengce/content/2016-12/13/content_5147412.htm

Stiglitz, J. E., Sen, A., & Fitoussi, J. P. (2009). Report by the commission on the measurement of economic performance and social progress.

Sun, X., Liu, X., Li, F., Tao, Y., & Song, Y. (2017). Comprehensive evaluation of different scale cities' sustainable development for economy, society, and ecological infrastructure in China. *Journal of Cleaner Production*, *163*, S329–S337. https://doi.org/10.1016/j.jclepro.2015.09.002

Tan, S., Yang, J., Yan, J., Lee, C., Hashim, H., & Chen, B. (2017). A holistic low carbon city indicator framework for sustainable development. *Applied Energy*, *185*, 1919–1930. https://doi.org/10.1016/j.apenergy.2016.03.041

Tang, M., Liu, P., Chao, X., & Han, Z. (2021). The performativity of city resilience for sustainable development of poor and disaster-prone regions: A case study from China. *Technological Forecasting and Social Change*, *173*, 121130. https://doi.org/10.1016/j.techfore.2021.121130

Tao, Z., Guanghui, J., Guangyong, L., Dingyang, Z., & Yanbo, Q. (2020). Neglected idle rural residential land (IRRL) in metropolitan suburbs: Spatial differentiation and influencing factors. *Journal of Rural Studies*, *78*, 163–175. https://doi.org/10.1016/j.jrurstud.2020.06.020

Tian, C. (2016). Estimation on capital stock of sectors in China: 1990–2014 (in Chinese). *The Journal of Quantitative & Technical Economics*.

Tian, K., Ni, H., & Li, L. (2016). National measures of intangible asset and its role in growth of China economy (in Chinese). *China Industrial Economics*.

United Nations University-International Human Dimensions Programme and United Nations Environment Programme (UNU-IHDP&UNEP). (2014). *Inclusive wealth report 2014: Measuring progress toward sustainability*. Cambridge University Press.

Wang, J., & Deng, K. (2022). Impact and mechanism analysis of smart city policy on urban innovation: Evidence from China. *Economic Analysis and Policy*. https://doi.org/10.1016/j.eap.2021.12.006

Wang, T., Guomai, S., Zhang, L., Li, G., Li, Y., & Chen, J. (2019). Earthquake emergency response framework on campus based on multi-source data monitoring. *Journal of Cleaner Production*, *238*, 117965. https://doi.org/10.1016/j.jclepro.2019.117965

Yamaguchi, R. (2014). Inclusive wealth with a changing but aging population. *Economics Letters*, *124*(1), 21–25. https://doi.org/10.1016/j.econlet.2014.04.011

Yang, L., Han, Z., & Wang, K. (2015). *Estimation of R&D expenses included in GDP and its impact under the SNA2008 (in Chinese)*. Statistical Research.

Yin, K., Wang, R., An, Q., Yao, L., & Liang, J. (2014). Using eco-efficiency as an indicator for sustainable urban development: A case study of Chinese provincial capital cities. *Ecological Indicators*, *36*, 665–671. https://doi.org/10.1016/j.ecolind.2013.09.003

Yin, X., Chen, J., & Li, J. (2019). Rural innovation system: Revitalize the countryside for a sustainable development. *Journal of Rural Studies*, *93*, 471–478. https://doi.org/10.1016/j.jrurstud.2019.10.014

Yu, L., & Cai, Y. (2021). Do rising housing prices restrict urban innovation vitality? Evidence from 288 cities in China. *Economic Analysis and Policy*, *72*, 276. https://doi.org/10.1016/j.eap.2021.08.012

Yu, Y., & Zhang, S. (2017). Urban housing prices, purchase restriction policy and technological innovation. *China Industrial Economics*. https://doi.org/10.19581/j.cnki.ciejournal.2017.06.020

Zhang, B., Nozawa, W., & Managi, S. (2021). Spatial inequality of inclusive wealth in China and Japan. *Economic Analysis and Policy*. https://doi.org/10.1016/j.eap.2021.04.014

Zhang, J., & Sun, W. (2018). Measurement of the ocean wealth of nations in China: An inclusive wealth approach. *Marine Policy*, *89*, 85–99. https://doi.org/10.1016/j.marpol.2017.12.012

Zhang, J., Wu, G., & Zhang, J. (2004). The estimation of China's provincial capital stock: 1952–2000 (in Chinese). *Economic Research Journal*.

Zhang, Y., Mao, Y., Jiao, L., Shuai, C., & Zhang, H. (2021). Eco-efficiency, eco-technology innovation and eco-well-being performance to improve global sustainable development. *Environmental Impact Assessment Review*, *89*, 106580. https://doi.org/10.1016/j.eiar.2021.106580

Zheng, S., & Yang, M. (2020). *Measuring China's provincial intangible capital stock:2000~2016 (in Chinese)*. Management World.