Chin. Geogra. Sci. 2020 Vol. 30 No. 5 pp. 791–809
https://doi.org/10.1007/s11769-020-1149-5

Springer Science Press
www.springerlink.com/content/1002-0063

Effects of the Northeast China Revitalization Strategy on Regional Economic Growth and Social Development

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Abstract: Measuring the economic and social effects of the Northeast China Revitalization Strategy is critical to addressing regional sustainable development in China. To shed light on this issue, an integrated perspective was adopted that is combined with the difference-in-differences method to measure the effects of the strategy on economic growth and social development in Northeast China. The findings suggest that the strategy has significantly improved regional economic growth and per-capita income by increasing its gross domestic product (GDP) and GDP per capita by 25.70% and 46.00%, respectively. However, the strategy has significantly worsened the regional employment in the secondary industry of the region. In addition, the strategy has not significantly improved regional infrastructural road, education investment or social security, and has had no significant effect on mitigating regional disparity. In addition, the policy effects are highly heterogeneous across cities based on city size and characteristics. Therefore, there is no simple answer regarding whether the Northeast China Revitalization Strategy has reached its original goals from an integrated perspective. The next phase of the strategy should emphasize improving research and development (R&D) and human capital investments based on urban heterogeneity to prevent conservative path-dependency and the lock-in of outdated technologies.

Keywords: policy evaluation; difference-in-differences (DID) method; regional disparity; urban heterogeneity; regional revitalization; old industrial base; Northeast China

Citation: REN Wanxia, XUE Bing, YANG Jun, LU Chengpeng, 2020. Effects of the Northeast China Revitalization Strategy on Regional Economic Growth and Social Development. *Chinese Geographical Science*, 30(5): 791–809. https://doi.org/10.1007/s11769-020-1149-5

1 Introduction

Regional disparity is an imbalance between regions or between different locations within the same region, which is a persistent problem for both developed and developing nations (Chen and Zheng, 2008; Candelaria et al., 2009). This phenomenon conflicts with the neoclassical growth model, which ultimately predicts worldwide economic convergence (Yang, 2002). Emerging evidence shows that regional disparity reflects a decline of internal factor mobility (Ganong and Shoag, 2017) and may contribute to weaker long-term growth if left unaddressed (Winkler, 2018). Therefore, regional policies play a significant role in reducing the regional

Received date: 2020-01-06; accepted date: 2020-04-25

Foundation item: Under the auspices of Young- and Middle- aged Science and Technology Talent Support Program of Shenyang City (No. RC180221), Strategic Priority Research Program of the Chinese Academy of Sciences (No. XDA23070501), Open Research Project of Shouguang Facilities Agriculture Center in Institute of Applied Ecology (No. 2018SG-B-01), National Natural Science Foundation of China (No. 41971166, 41701142)

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disparities and promoting a coordinated and harmonious regional development (Gbohoui et al., 2019). Many countries and regions have developed a series of important regional policies, such as, the European Union's Structural and Cohesion Funds, the United States' Tennessee Valley Authority (TVA) Policy, the United Kingdom's Regional Selective Assistance Policy, Germany's Innovative Regional Growth Cores Program, and China's Northeast China Revitalization Strategy.

Given the increasing importance of regional policies to reducing the disparities in development among regions and helping lagging regions, a large and growing body of literature has investigated regional policies' contribution to economic growth and convergence. The Structural and Cohesion Funds are two of the most important regional policies in the European Union (EU) that aim to facilitate a convergence of poor regions (in terms of per-capita income) to the EU average (Becker et al., 2018). Becker et al. (2010) explored the effect of the Structural Funds on regional performance and found positive per-capita gross domestic product (GDP) growth effects, but no employment growth effects. The counter factual simulations suggested that the EU place-based policy led to a positive welfare effect of 2.08% compared to a scenario without transfers (Blouri and Ehrlich, 2020). A follow-up study by Becker et al. (2013) emphasized that the effect was highly heterogeneous across regions and depended strongly on the region's absorptive capacity, and that the funds tended to display immediate effects but did not show much longevity beyond a programming period (Becker et al., 2018).

In addition, Kline and Moretti (2013) studied the long-run effects of one of the most ambitious regional development programs in US history: the TVA. They found that the TVA led to large gains in agricultural employment that were eventually reversed when the program's subsidies ended, and that gains in manufacturing employment, by contrast, continued to intensify well after federal transfers had lapsed. Criscuolo et al. (2019) found that the Regional Selective Assistance in the United Kingdom has led to an increase in regional employment and had positive effects on net firm entry and firm investment but no effects on total factor productivity. Falck et al. (2019) evaluated one of the largest place-based innovation policies in Germany, the Innovative Regional Growth Cores Program, and they did not find a research and development (R&D) spending multiplier greater than one nor quantifiable local spillover effects on nonsubsidized innovative firms.

Compared to the EU, China is weak in the area of regional policy implementation, evaluation and monitoring (European Commission, 2015). Nevertheless, many scholars have carried out related research based on qualitative and quantitative methods. Jia et al. (2020) evaluated the effects of the Great Western Development Strategy in China with a spatially discontinuous design and found that the strategy had raised the annual GDP growth rate by 1.60 percentage points in Northwest China, but no such effects were observed on nonfarm employment or wages. At the same time, the strategy improved the overall regional green economic efficiency, although this effect depended on time and regions (Zhou and Deng, 2020). Kong et al. (2018) used the difference-in-differences (DID) method and the panel data of 27 provinces and cities to estimate the net effect of the Great Western Development Strategy on economic growth by 4.66 percentage points. However, the policy effect was short-term and was mainly achieved from fixed asset investment, not from industrial structural adjustment and human capital improvement (He and Liu, 2016).

The Chinese government believes that with the interventions of the Northeast China Revitalization Strategy, Northeast China has achieved remarkable outcomes, such as improving the aggregate economy, promoting structural adjustment, and improving the competitiveness of state-owned enterprises (the State Council of the People's Republic of China, 2016). Meanwhile, experts from different fields have long disputed whether the strategy has succeeded or failed to fulfill its original goals. Most of these scholars have argued that the strategy had a significant short-term stimulus effect, which significantly increased the economic aggregate in the region (Jin and Chen, 2010; Zhang and Ding, 2013; Kang, 2015; Su et al., 2017; Zhao et al., 2017; Wei, 2018; Xiao and Zhang, 2019; Zheng and Wang, 2019). However, many scholars agreed that the strategy did not promote the optimization of the industrial structure and industrial agglomeration and believed that the policy had significantly upset the balance of the industrial structure and had a negative effect on its long-term economic growth (Su et al., 2017; Zhao et al., 2017; Zheng and Wang, 2019). Therefore, so far, no consensus has been reached about the policy effects from a statistical and integrated perspective, and the strategy's impacts on reducing regional disparities and the urban heterogeneity's impacts on policy effects are far from clear. The aim of this paper is therefore to assess the causal effects of the entire portfolio of the Northeast China Revitalization Strategy, one of the most important regional policies in China's development history, on economic growth and social development in Northeast China based on an integrated perspective using a reliable and comparable dataset and method. At the same time, we assess whether convergence or regional disparities and policy heterogeneity have been taking place in China. Our contribution is threefold. First, compared to the comprehensive regional policy evaluation system and extensive quantitative econometric techniques seen at the international level, China's regional policy evaluation is limited to qualitative descriptions or comparative analyses. In this study, we use a reliable and comparable dataset with an integrated perspective of economic growth and social development to accurately assess the policy effects of the strategy to fill the gap in current research. Second, we assess whether convergence among regions have been taking place in Northeast China through the implementation of the Northeast China Revitalization Strategy, which has not previously been a focus of study but is indeed one of the strategy's initial purposes. Finally, regional policy effects are highly heterogeneous and depends strongly on regional characteristics, but current research is very weak on this topic. We try to clarify the impact of urban heterogeneity on regional policy effects, and provide new ideas and directions for the next stage of the Northeast China Revitalization Strategy to further all-round revitalization of Northeast China.

2 Materials and Methods

2.1 Study area

Northeast China (NEC) consists of Liaoning Province, Jilin Province, Heilongjiang Province and the eastern part of the Inner Mongolia Autonomous Region (including Hulun Buir City, Hinggan League, Tongliao City, Chifeng City) (Fig. 1), with an area of 1.26 × 10^6 km^2 and a population of 120 million (Ren and Ma, 2018). NEC is the largest old industrial base in China that was persistently influenced by the past planned economy (Xu, 2017). It has been locked into concentrated heavy industry made up of state-owned enterprises, and the critical industry of manufacturing has failed to innovate and transform since the beginning of the 1990s. In 2003, the ratio of heavy industry in NEC to all its state-owned and nonstate-owned industries was 79.60%, which is nearly 20.00% higher than the national average (Sun and Liu, 2004). More importantly, in 2002, Liaoning Province had 765 000 laid-off workers, 830 000 people were registered as unemployed in cities and towns, and 1.60 million people had employment needs, which resulted in fierce social tension

Fig. 1 Distributions of the research area as treatment group and China's other regions with cities as control group

(Sun, 2004). The so-called ‘Northeast Phenomenon’ emerged (Li and Li, 1996; Li, 2000), that is, declining industrial output and profits that bankrupted a vast number of state-owned enterprises, exacerbated unemployment, and entrenched social problems. The region has lost its leading position and begun to lag behind the coastal areas (Zhang, 2008).

How to reduce the growing absolute regional disparities is a major long-term issue (Minarčíková, 2016) and a top policy priority (Wei, 2002; Fan, 2006; Kamiński, 2009), especially for the old industrial regions with a prolonged decline of traditional sectors and a lack of capital, technological and labor assets (Birch et al., 2010). To control rising regional disparities and improve regional development, the Chinese government enacted the Northeast China Revitalization Strategy in 2003, which aimed to stop NEC’s rapid economic downturn to improve its employment and maintain social stability (the State Council of the People’s Republic of China, 2003).

Due to the extreme lack of data on the eastern part of Inner Mongolia, to avoid analysis error, this study removes the region, and only Heilongjiang, Jilin and Liaoning provinces are chosen as the research area. Specifically, the 34 prefectural-level cities located in Liaoning, Jilin and Heilongjiang provinces are included as the treatment group, and 205 other prefectural-level cities in the other six geographical regions (North China (NC), East China (EC), South China (SC), Central China (CC), Southwest China (SWC) and Northwest China (NWC), Fig. 1)), are selected as the control group to assess policy effects, regional disparity and policy’s heterogeneity. In this study, NC includes Hebei and Shanxi provinces with 20 prefectural-level cities; EC includes Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi and Shandong provinces with 71 prefectural-level cities; CC includes Henan, Hubei and Hunan provinces with 42 prefectural-level cities; SC includes Guangdong, Hainan provinces and Guangxi Zhuang Autonomous Region with 32 prefectural-level cities; SWC includes Sichuan, Guizhou and Yunnan provinces with 20 prefectural-level cities; and NWC includes Shaanxi, Gansu, Qinghai provinces, Ningxia and Xinjiang autonomous regions with 20 prefectural-level cities. Moreover, this study does not include Beijing, Shanghai, Tianjin, Chongqing, Hong Kong, Macau, Tibet, and Taiwan.

2.2 Revitalization policies

The regional policies are here considered important policies implemented or approved at the national level, and their periods range from 2003 to 2015. After sorting, there are 51 major regional policies, including 20 industrial development and enterprise reform policies; 13 fiscal and financial policies; six resource-based city transition policies; four social security policies; and eight science, technology, education, talent and open policies. This study only introduces more details regarding the first four policies, which is relatively important. This study does not measure the effects of a single or a specific policy and instead measures the effects of the Northeast China Revitalization Strategy, which is the foundation and general term for the revitalization policies.

Industrial development and enterprise reform policies are the subjects and the key concerns of the strategy to revitalize economic growth. These policies mainly included: 1) the directive and comprehensive policies, such as the Northeast China Revitalization Plan, which is very comprehensive and focuses on not only its clear development direction and goals but also key tasks and management mechanisms; 2) policies to upgrade and transform traditional heavy industries and develop their continuation industries; 3) polices to the support for agriculture; and 4) policies related to reforming state-owned enterprises.

The fiscal and financial policies focus on: 1) exempting historical tax arrears; 2) exempting agricultural taxes and the resource taxes of some mines and oilfields; 3) discounting some taxes and fees, such as corporate income tax concessions and free trade zone policies; 4) deducting value-added tax; and 5) increasing investments inthe controlling and reconstruction of coal mining subsidence and old industrial areas.

The resource-based city transition policies are mainly dedicated to establishing and improving a long-term mechanism for sustainable development and nurturing and expanding alternative industries by focusing on solving social problems such as employment and strengthening ecological restoration.

The social security policies focus on: 1) urban social security, involving social insurance systems such as basic old-age care, basic medical care and unemployment for urban employees and a minimum living security system for urban residents; 2) investments in depressed coal mining areas to facilitate resettlement of local residents; and 3) the renovation of shanty towns.

2.3 Models and methods

2.3.1 Evaluation description

This paper is interested in the effects of the strategy intervention, the 'treatment' (the Northeast China Revitalization Strategy (2003–2015)), on the outcome (socioeconomic development in the treatment group) in a 'post' period (after the strategy intervention) compared to the (potential) outcome if the treatment group is not subject to the strategy.

In this paper, in accordance with the reference (Abadie, 2005), we denote the potential outcomes under treatment (policy intervention treatment, E) for NEC at time T (pre vs. post) as Y_T^E, with $T = 0$, 1, and $E = 0$, 1. Specifically, Y_0^0 and Y_0^1 are applied for no treatment outcome and with treatment outcome at time $T = 0$ ('pre': policy time before 2003 (including 2003), which is considered the time at which the strategy has not been implemented), respectively, and generally one would assume that $Y_0^0 = Y_0^1$, which means that the region's pre-treatment outcome is not affected by its subsequent treatment assignment. This is called the 'common trend assumption'. Therefore, Y_1^0 represents the outcome that would be observed for the region at time 1 ('post', $T =$ 1: policy time 2004−2015 (including 2004) is considered as the time that the strategy is implemented) if the region does not receive the policy intervention (no treatment, $E = 0$). Y_1^1 denotes the outcome at time 1 if the region does receive the policy intervention (with treatment, $E = 1$). Causal inference is interested in comparing outcomes under the treatment and control conditions, for example, $Y_1^1 - Y_1^0$. Therefore, the average treatment effects evaluated in the paper are assumed as $\Delta = E\left(Y_1^1 - Y_1^0\right)$. Actually, we observe only one of the two potential outcomes for the region; that is, for the treatment group with $E = 1$, we observe its potential outcomes under treatment, and for the control group with $E = 0$, we observe its potential outcomes under control. The DID (difference-in-differences) method is used to solve the problem and evaluate the policy effects.

2.3.2 DID and propensity scores matching method

The DID method is usually used to evaluate policy effects and is one of the most crucial identification strategies in applied economics (Bertrand et al., 2004; Athey and Imbens, 2006). DID models compare changes over time in a group unaffected by a policy to changes over time in a group affected by the policy, and attributes the DID to the effect of the policy. According to the reference (Stuart et al., 2014), the DID design can be illustrated in the simplest form of a 2 × 2 table with the observed data in Table 1.

To obtain standard errors and significance levels for the DID estimate, a parametric model is usually fit using a long dataset with each observation reflecting a city at a particular time point, with the model of the general form in the Equation (1):

$$Y_{it} = \alpha + \beta E_{it} + \gamma T_{it} + \delta E_{it} T_{it} + \rho Z_{it} + \varepsilon_{it} \quad (1)$$

where Y_{it} is the value of the outcome observed for i-th prefectural-level city at t-th year; E_{it} is an indicator of city i year t being in the exposed group (treatment group vs. control group); T is the policy time (post (1) vs. pre (0)); Z represents the control variables; α, β, γ, δ and ρ are the regression coefficients; and ε is the random disturbances.

Table 1 Illustrative DID (difference in differences) design

Policy time	Treatment group	Control group	Difference
Pre	Y_0^1	Y_0^0	$Y_0^1 - Y_0^0$
Post	Y_1^1	Y_1^0	$Y_1^1 - Y_1^0$
Change	$Y_1^1 - Y_0^1$	$Y_1^0 - Y_0^0$	$\Delta = \left(Y_1^1 - Y_0^1\right) - \left(Y_1^0 - Y_0^0\right) = \left(Y_0^1 - Y_0^0\right) - \left(Y_1^1 - Y_1^0\right)$

Notes: Y_0^0 and Y_0^1 are applied for no treatment outcome and with treatment outcome at time $T = 0$; Y_1^0 represents the outcome that would be observed for the region at time 1; Y_1^1 denotes the outcome at time 1 if the region does receive the policy intervention; pre: policy time before 2003 (including 2003); post, policy time 2004−2015 (including 2004)

From the Equation (1), it is found that for the cities that implement the strategy (E = 1), the regional development before (T = 0) and after (T = 1) revitalization are $\alpha + \beta$ and $\alpha + \beta + \gamma + \delta$, respectively. The difference in the socioeconomic development in NEC before and after the implementation of the revitalization strategy is $\Delta Y_t = \gamma + \delta$ which includes the role of the strategy and other policies. For the cities not affected by the revitalization policy (E = 0), the socioeconomic development before (T = 0) and after (T = 1) revitalization are α and $\alpha+\gamma$, respectively, and their difference is $\Delta Y_0 = \gamma$, which does not include the impact of the strategy on regional development. Therefore, the difference for the treatment group before and after the revitalization ΔY_t minus the difference for the control group before and after the revitalization ΔY_0 are the impacts of the revitalization strategy on the socioeconomic development of the region $\Delta\Delta Y = \delta$. Therefore, the point estimate of δ from this model is equivalent to a nonparametric approach that takes the difference in the changes over time between the groups (Δ in Table 1).

For both groups, two potential outcomes at each time point are defined (Y^0, Y^1), but only one outcome is observed, whereas the other outcome remains an unobserved counterfactual. According to the DID approach, the effect of the strategy is identified by comparing the changes in economic growth and social development $E\left(Y_{t+1}^1 - Y_t^0 \middle| E=1\right)$ of the treatment group between period t and t+1 to the counterfactual trend in economic growth and social development, $E\left(Y_{t+1}^0 - Y_t^0 \middle| E=1\right)$, that they would have experienced in the absence of the treatment. The counterfactual trend is approximated by the actual change in economic and social development, $E\left(Y_{t+1}^0 - Y_t^0 \middle| E=0\right)$ of the control group according to the crucial 'common trend assumption'. That is, the DID methods provide unbiased effect estimates if the trend over time would have been the same between the treatment (with policy intervention) and control groups (without policy intervention) in the Equation (2) (Stuart et al., 2014):

$$E\left(Y_{t+1}^0 - Y_t^0 \middle| E=1\right) = E\left(Y_{t+1}^0 - Y_t^0 \middle| E=0\right) \tag{2}$$

In fact, however, the assumption of time-invariant selection bias is implausible for many targeted policies (Khandker et al., 2010). In addition, a key issue in policy evaluation is that treatment and outcomes might be correlated because of the presence of unobservable characteristics (Gobillon and Magnac, 2016). Propensity scores matching (PSM) methods are another non experimental study design that is often used to handle this type of confounding. To make the common trend assumption more plausible, the respective control groups are based on the similarity in propensity scores in the integrated PSM and DID models (Stuart et al., 2014).

The specific steps are as follows: 1) use PSM to identify the control group whose characteristics are closest to the treatment group and 2) use the matched treatment group and control group to implement DID regression to estimate the average treatment effect on the matched treatments ($ATT^{DID-PSM}$) in the Equation (3):

$$ATT^{DID-PSM} = \frac{1}{N_1} \sum_{i \in E=1 \cap S} \left[Y_{i,t+1}^1 - Y_{i,t}^0 - \sum_{i \in E=0 \cap S} W_{ij} \left(Y_{j,t+1}^0 \right) - Y_{j,t}^0 \right] \tag{3}$$

where N_1 is the number of samples in the treatment group matched with ones in the control group; j represents the j-th prefectural-level city in the control group; S is the matched sample set in the full group; and W_{ij} represents the kernel matching weights, which are obtained from the reference (Leuven and Sianesi, 2012).

2.3.3 Regional disparity evaluation

Government policies, openness, market integration, public infrastructure, education attainment, geographical factors and migration are all factors that result in regional disparities in China (Zhang and Zou, 2012). The most popular measures of regional disparity include dispersion indices, Lorenz Curve indices, and entropy or information-theoretic indices (Fan and Sun, 2008). The coefficient of variation (CV) is a popular dispersion index that is easily computed but is sensitive to outliers. The Gini coefficient is widely used based on the Lorenz Curve but is easily affected by high values. The Theil index, as an entropy index, can be decomposed into additive terms that depict the disparity among and within groups of elements in a system (Theil and Scholes, 1967) but is sensitive to income transfers from the poor to the rich (Conceição and Ferreira, 2000). In this study, we use the CV, the Gini coefficient and the Theil index with STATA 16.1 statistical software to evaluate the regional disparity changes in China's seven geographical regions and then determine whether the strategy has resulted in regional convergence between NEC and the developed regions in China, such as EC and CC.

2.3.4 Impact evaluation of urban heterogeneity on policy effects

We examine the impacts of urban heterogeneity on the strategy effects, which includes city size and city characteristics. Referring to the definition of city size mentioned in the document of the '*Notice of the State Council on Adjusting the Standards for Dividing City Size*' (the State Council of the People's Republic of China, 2014), we classify the 239 cities into five types of city size and then use the DID model mentioned above with STATA 16.1 statistical software to evaluate the impacts of city size on the policy effects.

In addition, we use the proportion of the secondary industry (*sec_indus*) as a variable for the urban industrialization level, which is one of the urban characteristics. We divide the indicator of *sec_indus* into three equal parts: the first-class grouping is for the low-industrial cities, and the second and third groupings are for the high-industrial cities. We do the same with the indicators of *gov* as government scale and *sci_car_exp* and *educ* representing R&D investment and human capital, respectively. We also use the DID model with STATA 16.1 statistical software to evaluate the impacts of urban characteristics on the policy effects.

2.4 Data and variables

This study uses panel data from 239 prefectural-level cities in 25 provinces and autonomous regions in China's seven geographical regions from 1994 to 2015 to assess policy effects, regional disparity and policy's heterogeneity. Most of the data in the following analysis are drawn from the China City Statistical Yearbooks from 1995 to 2016 (Urban Socioeconomic Investigation Department, National Bureau of Statistics of China, 1995–2016). Some of the data on some cities, such as the data on the urbanized population in Jinzhou City and Dandong City in Liaoning Province, are obtained from the Province Statistical Yearbooks and the City Statistical Communique of National Economic and Social Development in the specified years. Other missing data are supplemented by using the average growth rate method.

In addition, social security indicators are shown for the first time in the China City Statistical Yearbooks of 2012 (Urban Socioeconomic Investigation Department, National Bureau of Statistics of China, 1995–2016), which makes it impossible to analyze the social security development caused by the implementation of the strategy. Therefore, this study attempts to use the provincial-level data from the China Statistical Yearbooks from 2001–2016 to measure social effects (National Bureau of Statistics of China, 2001–2016); moreover, we do not include the eastern of Inner Mongolia Autonomous Region.

To measure the economic growth effects, this study takes the logarithm of the real GDP (*lngdp*) and real GDP per capita (*lnpergdp*) of each city as explanatory variables (Table 2). The base year is 1994, real GDP is calculated by using the real GDP growth rate according to comparable prices, and real GDP per capita is equal to the real GDP of each city divided by the registered household population at the end of the year.

Scholars believed that skill, investment, innovation, capital formation, human capital, a market-oriented reform, urbanization, infrastructure, final consumption, and government administrative costs are all drivers of economic growth (Treasury and Department of Trade and Industry and Office of the Deputy Prime Minister, 2003; Wang et al., 2009). Therefore, to control for the influence of other variables, this study also selects a series of control variables shown in Table 2.

Industrial structure is an essential reason for the difference in economic growth. The upgrading of industrial structure is crucial to promoting regional economic growth and is the key content of the economic restructuring and transformation of the old industrial bases in NEC. Therefore, this study uses the indicators of industrialization or the ratio of secondary industry (*sec_indus*), the proportion of tertiary industry (*thi_indus*), and the proportion of employees in secondary industry (*sec_indus_empl*) to characterize industrial structure adjustment.

Investment is an essential driving force of China's economic growth. The introduction of foreign investment plays an active role in promoting technological progress, employment and competition and in improving management. Some scholars believed that foreign direct investment (FDI) was one of the most important variables to explain the miracle of China's economic growth (Hu, 2004). Of course, some scholars argued that

Table 2 Definitions and calculation methods for the explanatory variable and control variables used in the policy evaluation models

Variable	Description	Calculation methods
lngdp	Economic growth	ln (real GDP)
lnpergdp	Per capita income	ln (real GDP per capita)
gov	Government scale	Local public budget expenditure/GDP × 100
fdi	Foreign direct investment	Amount of foreign capital utilized × exchange rate × 100/GDP
far	Fixed asset investment	Fixed assets investment in current year/GDP × 100
thi_indus	Service industry development	Tertiary industry as a percentage of GDP
sec_indus	Industrialization	Secondary industry as a percentage of GDP
sec_indus_empl	Industrial employment	Rate of employed persons in secondary industry
educ	Educational level/human capital	Enrollment of students in tertiary education/registered household population at year-end (pop)/100
sav	Total savings rate	Total savings of urban and rural residents/GDP × 100
per_rub_road_area	Social development	Urban road area per capita
sci_car_exp	R&D investment	Expenditure for science and technology/GDP × 100
urb	Urbanization	Non-agricultural population/pop × 100
edu_exp	Education investment/social progress	Education expenditure/GDP × 100
insur_pop	Insured population/social security	In-service employee pension insurance/resident population × 100 at provincial level
lngdp_pro	Economic development	ln (real GDP at provincial level)
elderly_sup_ratio	Elderly population support	Elderly population support ratio at provincial level
birth_rate	Birth rate	Birth rate at provincial level
urb_reg_unemp_rate	Unemployment rate	Urban registration unemployment rate at provincial level
indus	Industry development	Industry added values to GDP × 100 at provincial level
budget_exp	Local fiscal expenditure	Local fiscal general budget expenditure as a percentage of GDP at provincial level

large amounts of foreign capital inflows have slowed domestic independent research and innovation, creating a severe technical dependence (Wang, 2004; Zhang, 2005). Therefore, we choose the two indicators of FDI level (*fdi*) and fixed asset investment level (*far*) to explore their roles in regional economic development. FDI is converted into the RMB exchange rate against the US dollar.

In the process of China's economic development, multilevel governments always play important roles. This study uses local public budget expenditures as a percentage of GDP (*gov*) to measure the role of government in promoting regional economic growth. In addition, the high capital formation rate is one of the most important factors supporting China's economic growth. Rapid capital formation is mainly due to high savings with high investment. China also maintains a large amount of investment with high savings. Therefore, the savings rate of urban and rural residents (*sav*) is also a controlling factor that affects regional economic development.

Old industrial areas face the challenge of recovering and repositioning their economies by promoting a transition toward more knowledge-intensive forms of development. A well-developed regional innovation system is a critical factor in the renewal of old industrial areas (Todtling and Trippl, 2004). Technological innovation and human capital have played increasingly important roles in China's economic development. This study uses the proportion of science expenditures to GDP (*sci_car_exp*) and the number of tertiary education students to population (*educ*) to measure regional R&D investment and human capital levels. An essential aspect of the investment environment that affects economic growth has been proven to be the quality of the infrastructure, particularly roads and telecommunications (Geng and Weiss, 2007). Due to restrictions on telecommunications data, this study selects urban road area per capita (*per_urb_road_area*) to characterize infrastructure construction.

The key issue for China's regional development is to ensure the access to public services, especially social security and education (European Commission, 2014). Most of China's public expenditures account for a large proportion of administrative expenditures, primarily for local governments. Only a relatively small portion is used to meet basic welfare and social development needs, such as education, health care and social security. To analyze the social effects of the implementation of the strategy, this study uses the ratio of education expenditure to GDP (*edu_exp*) to measure public services, that is, the social effects. Achieving educational equity is a type of government action. Government educational expenditures lead to differences in regional education quality. Differences in education quality affects human capital investment decisions, which, in turn, affects regional development quality and income imbalance. In addition, we choose *sec_indus_empl* as an employment indicator to evaluate social development.

Social security is related mainly to economic development, household savings, household consumption, education level, human capital and population aging (Bellettini and Ceroni, 2000; Aydede, 2006). The pension system is the most significant component of the entire social security system. Therefore, this study chooses the proportion of in-service employee pension insurance to the resident population at provincial-level (*insur_pop*) as the explanatory variable. Based on data validity, the logarithm of real GDP at the provincial level (*lngdp_pro*), elderly population support ratio at the provincial level (*elderly_sup_ratio*), birth rate at the provincial level (*birth_rate*), urban unemployment registration rate at the provincial level (*urb_reg_unemp_rate*), industry added values to GDP at the provincial level (*indus*) and local fiscal general budget expenditure as a percentage of GDP at the provincial level (*budget_exp*) are selected as the control variables. The descriptive statistics of each variable mentioned above are shown in Table 3.

Table 3 Descriptive statistics of each variable used in the study

Variable	Full group			Control group			Treatment group		
	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
sec_indus	5258	47.870	11.285	4850	48.012	11.115	408	46.188	13.031
thi_indus	5258	35.371	8.254	4850	35.294	8.304	408	36.286	7.586
far	5257	44.850	28.731	4849	43.682	28.878	408	58.729	22.739
fdi	5255	2.821	4.811	4847	2.878	4.957	408	2.144	2.398
gov	5255	9.816	7.335	4847	9.296	7.147	408	15.996	6.705
sav	5255	57.925	35.451	4847	56.415	34.427	408	75.859	41.986
educ	5258	1.102	1.822	4850	1.088	1.851	408	1.262	1.419
sec_indus_empl	5258	42.035	14.539	4850	42.133	14.711	408	40.882	12.257
per_urb_road_area	5249	8.354	8.449	4841	8.271	8.635	408	9.338	5.709
sci_car_exp	5019	0.122	0.223	4611	0.121	0.227	408	0.125	0.165
urb	3555	33.045	17.188	3385	32.198	16.872	170	49.913	14.567
lngdp	5258	14.885	1.319	4850	14.844	1.327	408	15.376	1.112
lnpergdp	5258	9.121	1.132	4850	9.061	1.133	408	9.828	0.839
edu_exp	5258	0.082	0.431	4850	0.082	0.446	408	0.080	0.161
birth_rate	480	11.557	2.910	432	12.079	2.573	48	6.859	0.735
elderly_sup_ratio	390	12.379	2.550	351	12.450	2.590	39	11.746	2.081
urb_reg_unem_rate	474	3.585	0.718	426	3.519	0.680	48	4.177	0.785
indus	480	38.089	9.724	432	37.595	9.990	48	42.530	5.111
budget_exp	480	21.545	16.995	432	22.000	17.819	48	17.450	3.555
insur_pop	480	13.615	11.378	432	13.281	11.847	48	16.626	4.698
lngdp_pro	480	8.511	1.159	432	8.478	1.199	48	8.810	0.640

Notes: Obs = observation; SD = standard deviation; the variables in the first column are the same as those in Table 2

3 Results

3.1 Economic effects

The DID regression results show that the strategy has significantly promoted the growth of GDP and GDP per capita in the region, which increased by 25.70% and 46.00%, respectively (Table 4). To overcome the systematic differences in the economic growth trends in NEC and other regions that is consistent with the assumptions and reduce the bias of the DID method, this study uses the PSM-DID model with kernel matching for a robustness test. The results show that the estimated coefficients of the average growth effects are 26.20% and 47.50% for GDP and GDP per capita, respectively. The strategy has significantly promoted economic growth and per-capita income in NEC and proven the robustness of the DID analysis.

3.2 Social effects

The regression results of the strategy's social effects are shown in Table 5. The results show that the strategy does not have significant impacts on infrastructural road construction (*per_urb_road_area*) or educational improvement (*edu_exp*) and has a significant negative impact on regional employment in secondary industry (*sec_indus_empl*) in NEC, which decreased by 769.30% and 759.10% based on the DID and PSM-DID models, respectively.

Table 4 Economic effects evaluation and robustness test of the Northeast China Revitalization Strategy in Northeast China with the DID and PSM-DID models

Variable	DID		PSM-DID	
	lngdp	*lnpergdp*	*lngdp*	*lnpergdp*
$T \times E$	0.257***	0.460***	0.262***	0.475***
	(0.0226)	(0.0288)	(0.0762)	(0.0592)
sec_indus	0.00950***	0.0329***	0.0106***	0.0331***
	(0.000989)	(0.00126)	(0.00191)	(0.00149)
thi_indus	0.00789***	0.0400***	0.0369***	0.0427***
	(0.00118)	(0.00150)	(0.00249)	(0.00193)
far	0.00546***	0.00365***	0.00298***	0.00124**
	(0.000243)	(0.000310)	(0.000757)	(0.000588)
fdi	−0.00932***	−0.00184	0.0330***	0.0396***
	(0.00126)	(0.00161)	(0.00386)	(0.00299)
gov	0.0179***	0.0129***	−0.0284***	−0.00817***
	(0.00103)	(0.00132)	(0.00307)	(0.00238)
sav	−0.00117***	0.000465**	−0.00558***	−0.00223***
	(0.000164)	(0.000210)	(0.000531)	(0.000412)
educ	0.0717***	0.113***	0.158***	0.108***
	(0.00426)	(0.00543)	(0.00941)	(0.00731)
sec_indus_empl	0.0123***	0.00586***	0.0166***	0.0162***
	(0.000511)	(0.000652)	(0.00125)	(0.000973)
per_urb_road_area	0.00642***	0.00481***	0.0438***	0.0424***
	(0.000568)	(0.000725)	(0.00257)	(0.00199)
sci_car_exp	0.380***	0.0402	0.952***	−0.813***
	(0.0243)	(0.0310)	(0.0747)	(0.0580)
Constant	12.87***	5.263***	11.800***	4.719***
	(0.0705)	(0.0900)	(0.132)	(0.102)
Observations	5007	5007	4964	4964
R-squared	0.862	0.742	0.509	0.612

Notes: Standard errors in parentheses; $^{***}P < 0.01$, $^{**}P < 0.05$, $^{*}P < 0.1$; the variables are the same as those in Table 2; DID, difference-in-differences; PSM, propensity scores matching

Table 5 Social effects of the Northeast China Revitalization Strategy in Northeast China with the DID and PSM-DID models

Variable	DID			PSM-DID		
	per_urb_road_area	*sec_indus_empl*	*edu_exp*	*per_urb_road_area*	*sec_indus_empl*	*edu_exp*
T × *E*	−0.651	−7.693***	0.00386	−0.823	−7.591***	0.0107
	(0.805)	(0.758)	(0.00728)	(0.877)	(1.076)	(0.00876)
lngdp	2.948***	13.20***	0.0288***	0.455	3.014***	0.0277***
	(0.933)	(0.878)	(0.00540)	(0.581)	(0.753)	(0.00257)
lnpergdp	−0.00952	−1.558**	−0.0332***	0.939	−1.351*	−0.0428***
	(0.833)	(0.781)	(0.00440)	(0.631)	(0.815)	(0.00341)
sec_indus	−0.0218	0.396***	0.000445	0.0505***	0.733***	3.80e-05
	(0.0354)	(0.0391)	(0.000317)	(0.0167)	(0.0262)	(0.000171)
thi_indus		0.740***		0.312***		
		(0.0439)		(0.0375)		
sci_car_exp	2.555	−8.171***	0.0495***	6.392***	−0.894	0.0790***
	(1.716)	(1.598)	(0.0155)	(1.662)	(2.122)	(0.0170)
far	0.0129	−0.0174*		0.0151	−0.0159	
	(0.0109)	(0.0102)		(0.0106)	(0.0128)	
gov	−0.123**	−0.113***	0.00238***	−0.0989**	0.0124	0.00333***
	(0.0479)	(0.0422)	(0.000426)	(0.0454)	(0.0523)	(0.000448)
pop	0.00180	−0.00250		−0.000489	−0.00508**	
	(0.00300)	(0.00282)		(0.00171)	(0.00231)	
educ	0.190	−0.299*	0.0299***	−0.213	−1.078***	0.0433***
	(0.189)	(0.177)	(0.00171)	(0.177)	(0.223)	(0.00201)
urb	0.0612**	0.0154	0.000186	0.0340**	0.178***	0.000646***
	(0.0256)	(0.0245)	(0.000234)	(0.0159)	(0.0212)	(0.000156)
per_urb_road_area		−0.0361**			0.00348	
		(0.0169)			(0.0564)	
sav	0.0166**		6.65e-05	0.0114*		−3.14e-05
	(0.00666)		(6.02e-05)	(0.00656)		(6.62e-05)
fdi			0.00110***	0.323***		0.000404
			(0.000390)	(0.0583)		(0.000617)
Constant	−38.610***	−178.400***	−0.162**	−13.250***	−40.170***	−0.0636**
	(8.357)	(7.861)	(0.0695)	(3.393)	(4.276)	(0.0249)
Observations	3317	3317	3317	3123	2995	3029
R-squared	0.066	0.384	0.212	0.117	0.494	0.303

Notes: Standard errors in parentheses; *** $P < 0.01$, ** $P < 0.05$, * $P < 0.1$; the variables are the same as those in Table 2; DID, difference-in-differences; PSM, propensity scores matching

The regression results of the strategy's social security effect are shown in Table 6, which shows that the strategy has a positive but not significant effect on social security improvement.

Table 6 Social security effect of the Northeast China Revitalization Strategy in Northeast China with the DID and PSM-DID models

Variable	DID	PSM-DID
	insur_pop	*insur_pop*
$T \times E$	2.509	15.200*
	(1.895)	(8.213)
lngdp_pro	−11.170***	−5.155**
	(0.827)	(2.110)
birth_rate	1.083***	−2.261**
	(0.245)	(1.098)
elderly_support_ratio	1.749***	1.311**
	(0.160)	(0.551)
urban_reg_unemp_rate	−0.418	3.350
	(0.664)	(3.239)
indus	0.340***	0.0888
	(0.0557)	(0.298)
budget_exp	0.203***	−0.00852
	(0.0493)	(0.193)
Constant	62.250***	63.710**
	(8.331)	(30.540)
Observations	386	63
R-squared	0.665	0.505

Notes: Standard errors in parentheses; *** $P < 0.01$, $^{**}P < 0.05$, $^{*}P < 0.1$; the variables are the same as those in Table 2; DID, difference-in-differences; PSM, propensity scores matching

3.3 Regional disparity

The regional disparity changes of China's seven geographical regions in 1994–2003 and 2004–2015 are shown in Table 7. For the economic development disparity measured by the variable of *lngdp*, the change rates of the three indices are zero or negative, which shows that the economic disparity improved not only on the national level but also on the regional level. Meanwhile, the national economic disparity per capita, as measured by *lnpergdp*, significantly increased, which indicates that after more than twenty years of rapid development, China's income disparity is rapidly worsening, especially in the developed regions such as CC and EC (Table 7). Table 7 also shows that the social development disparities, such as disparities in urban road area and employment in secondary industry, have the worst performance in NEC among regions in China. In addition, education equality in China deteriorated after 2004, and there are significant differences in education equality among the seven regions. In general, the strategy has worsened intraregional disparities in per-capita income and infrastructural road construction and improved the intraregional disparities in economic growth, employment and education in NEC. However, interregional disparities in economic growth between NEC and other regions have particularly widened with the implementation of the strategy.

Table 7 Changes in regional disparities in China's seven geographical regions in 1994–2003 and 2004–2015

Varible	Disparity measures	N-Mean	NC	NEC	EC	CC	SC	SWC	NWC
lngdp	CV (%)	−1.270	−2.630	−1.370	−1.200	−1.410	−1.540	−1.430	−7.410
	Gini coefficient (%)	−2.220	−2.380	0.000	−2.130	−2.560	0.000	0.000	−6.520
	Theil index (%)	0.000	0.000	0.000	−25.000	0.000	0.000	0.000	0.000
lnpergdp	CV (%)	13.590	27.380	2.410	21.700	29.030	−2.040	0.000	−7.090
	Gini coefficient (%)	14.550	29.550	6.820	22.810	37.780	0.000	1.920	−5.710
	Theil index (%)	40.000	50.000	0.000	50.000	60.000	0.000	0.000	−12.500
per_urb_road_area	CV(%)	−64.640	−16.070	7.380	−31.250	−22.740	−66.330	−13.500	−24.320
	Gini coefficient (%)	−16.620	−9.470	12.550	−16.450	−19.460	−15.600	−14.870	−23.210
	Theil index (%)	−50.320	−21.050	15.000	−37.790	−37.410	−55.340	−27.890	−42.440
sec_indus_empl	CV (%)	−24.940	−18.020	−5.660	−25.970	−35.600	−20.180	−45.930	−29.710
	Gini coefficient (%)	−24.770	−19.140	−6.150	−25.370	−35.780	−21.050	−46.610	−30.950
	Theil index (%)	−42.670	−35.000	−3.920	−44.780	−56.760	−36.460	−69.660	−51.490
edu_exp	CV (%)	43.930	−30.330	−20.290	84.090	−10.500	36.010	−13.250	−22.450
	Gini coefficient (%)	−0.130	2.510	−5.990	4.630	−3.040	0.480	−6.390	−11.320
	Theil index (%)	8.520	−14.290	−20.180	30.970	−11.320	17.800	−15.420	−27.900

Notes: N-Mean = national mean values; CV = coefficient of variation; NC = North China, NEC = Northeast China, EC = East China, SC = South China, CC = Central China, SWC = Southwest China, NWC = Northwest China

Due to a lack of prefectural-level data on social security, this study does not evaluate the regional disparity changes of the social security indicator, and the same is true regarding evaluation of the urban heterogeneity impact in the following sections.

3.4 Impacts of urban heterogeneity

The impacts of the city size on the policy effects are shown in Table 8. We find that the strategy has significantly promoted the economic growth and per-capita income of cities of all sizes in NEC, especially of Type I and Type II cities, such as Anshan City, Jinzhou City, and Jilin City. In addition, the social effects have significant feedbacks to city size heterogeneity; for example, city size has significantly decreased and increased the education investment (*edu_exp*) in Type-I large cities and Type-II large cities, respectively. Hence, the policy effects are highly heterogeneous across cities and depend strongly on city size.

The impacts of the urban characteristics on the policy effects are shown in Table 9. We find that the heterogeneity of the urban characteristics has significant impacts on the policy effects of economic growth and social development in NEC; for example, the cities with a larger government scale and greater R&D investment have higher economic growth and per-capita income than the cities with low government expenditure and low R&D investment.

Table 8 Impacts of city size heterogeneity on the Northeast China Revitalization Strategy's policy effects in Northeast China

Variable	Medium-sized cities	Large cities	Type II large cities	Type I large cities	Extralarge and above cities
	$5\times10^5 \leq$ population < 10×10^5	Population $\geq$ 10×10^5	$10\times10^5 \leq$ population < 30×10^5	$30\times10^5 \leq$ population< 50×10^5	Population $\geq$ 50×10^5
lngdp	0.453***	0.502***	0.492***	0.503***	0.350***
	(0.114)	(0.0207)	(0.0270)	(0.0484)	(0.0379)
lnpergdp	0.437***	0.536***	0.517***	0.528***	0.351***
	(0.109)	(0.0205)	(0.0256)	(0.0472)	(0.0357)
per_urb_road_area	−1.389	−0.524	−0.399	0.0330	−0.974**
	(1.737)	(0.843)	(0.438)	(3.640)	(0.495)
sec_indus_empl	4.35	−9.144***	−10.11***	−9.675***	−6.998***
	(−3.834)	(−0.763)	(−1.172)	(−1.692)	(−1.499)
edu_exp	0.000917	0.00474	0.0203***	−0.0180**	−0.0215
	(0.00224)	(0.00736)	(0.00499)	(0.00884)	(0.0266)
Control variables	YES	YES	YES	YES	YES

Notes: Standard errors in parentheses; *** $P < 0.01$, ** $P < 0.05$, * $P < 0.1$; the variables are the same as those in Table 2

Table 9 Impacts of urban characteristics heterogeneity on the Northeast China Revitalization Strategy's policy effects in Northeast China

Variable	Low industrialization	High industrialization	Low government expenditure	High government expenditure	Low R&D	High R&D	Low human capital	High human capital
lngdp	0.471***	0.457***	0.389***	0.477***	0.184***	0.523***	0.538***	0.484***
	(0.0371)	(0.0324)	(0.106)	(0.0315)	(0.0693)	(0.0250)	(0.0380)	(0.0307)
lnpergdp	0.453***	0.530***	0.103	0.608***	−0.0340	0.602***	0.465***	0.607***
	(0.0458)	(0.0339)	(0.131)	(0.0348)	(0.0818)	(0.0285)	(0.0477)	(0.0357)
per_urb_road_area	−0.312	−1.210***	−0.113	−0.409	−0.585	−0.413	1.008	−0.974***
	(1.864)	(0.423)	(6.416)	(0.380)	(0.794)	(0.997)	(2.235)	(0.349)
sec_indus_empl	−6.879***	−7.261***	−1.770	−4.998***	−0.0576	−8.37***	−10.72***	−6.383***
	(1.068)	(1.136)	(4.610)	(0.741)	(2.322)	(0.794)	(1.600)	(0.798)
edu_exp	−0.00844	0.00729	0.0117	0.000148	0.0479***	−0.00522	0.0143*	−0.00197
	(0.00920)	(0.0116)	(0.00748)	(0.0121)	(0.00731)	(0.00887)	(0.00786)	(0.0123)
Control variables	YES	YES	YES	YES	YES	YES	YES	YES

Notes: Standard errors in parentheses; *** $P < 0.01$, ** $P < 0.05$, * $P < 0.1$; the variables in the first column are the same as those in Table 2

4 Discussion

4.1 Control variables in economic effect evaluation

FDI (*fdi*) has played an uncertain role in the economic growth and per-capita income improvement of the region during the implementation of the strategy, which is contrary to most past research results, for example, Geng and Weiss (2007) argued that the share of foreign-invested enterprises in economic activity appears to have a positive growth effect either directly through its impact on efficiency or indirectly through externalities. However, a classic reference suggests that FDI contributes to growth to a greater extent than domestic investment only when the host country has a minimum threshold stock of human capital (Borensztein et al., 1998). Meanwhile, human capital accumulation cannot assert its productive role in the process of growth until an economy crosses a threshold level of development (Ahsan and Haque, 2017) because empirical growth studies have often found an insignificant, and even negative, impact of human capital on economic growth for many undeveloped countries or regions (Schündeln and Playforth, 2014). Accordingly, the improving the regional educational level and human capital is vital to promoting regional economic sustainable development in NEC, one of the lagging regions in China, and vice versa.

4.2 Social development in Northeast China

The strategy does not have a significant impact on infrastructural road construction and educational investment in NEC, which will greatly affect the cultivation of talent and the input of human capital and ultimately affect the development and agglomeration of technology-based industries. In addition, the strategy has a significant negative impact on regional employment in secondary industry in NEC, which mostly results from the economic downturn, the employment spillovers caused by the development of the knowledge-intensive industry and huge labor outflow. Simultaneously, economic mobility is the main cause of interregional labor outflow, and high-tech and management talents tends to characterize the labor outflow in the region (Zhang, 2019).

The most notable result is that the economic growth variable *lngdp_pro* has a significant intentional inhibiting effect on the participation of employees in social security, which indicates that the economic development achievements in the region do not benefit locals' livelihood and basic social security but instead produce seriously limited regional social development. We also find that the flow of fiscal revenue and expenditure has undergone serious deviations, and more revenue has flowed to the industrial sector rather than to the social sector. As an old industrial base, NEC is experiencing serious population aging and a low birth rate and net immigration (Shao et al., 2019; Yi et al., 2019). With the increase in retirees, the pension fund gap is gradually increasing, and putting great pressure on the current social security system. The heavy social burden in the region has constrained the improvement of corporate competitiveness. Heilongjiang, Jilin and Liaoning provinces have successively become pilot provinces for social security reform, but funding is a difficult challenge that plagues social security reform (Zhao, 2020).

Furthermore, the strategy has indeed some social security and reduced taxes for bankrupt enterprises and laid-off workers and furnished significant funds and support for governance of coal mining subsidence areas. However, most of these policies have immediate effects rather than long-term effects (Becker et al., 2018; Kong et al., 2018). In addition, data on re-employment and resecurity of laid-off workers, coal mining subsidence areas, *etc*. are not available. Therefore, this paper focuses on stable and long-term social effect indicators, such as social security, education inequality and infrastructure road construction.

4.3 Regional disparity convergence

Fan and Sun (2008) revealed that since 2004, both interregional and intraregional disparity in China has declined. The interregional economic growth disparity in NEC has declined, but its performance is worse than other geographical regions, especially NWC. The Great Western Development Strategy may have performed much better in improving regional economic and per-capita income disparities in NWC. Empirical results show that key determinants of regional per-capita income disparity include labor mobility, economic development, regional population density, and the degree of fiscal decentralization (Gbohoui et al., 2019). Currently, the main direction of high-level talent flow is from the inland to the eastern seaboard, which has made EC a net-inflow region and NEC, CC and NWC net-outflow regions (Zhou et al., 2018). NEC appeared to be falling behind in human capital growth, and the contributions from urbanization, education and population aging are all less favorable than those in other regions. Human capital supply could largely accounts for China's regional disparities (Wang and Rickman, 2018), and the reduction of internal labor migration cost in China account for the majority of the drop in regional disparities (Hao et al., 2020). Hence, optimizing human capital migration costs and improving human capital equality are the key measures to narrow interregional and intraregional disparities in China.

4.4 Policy effect heterogeneity

R&D investment (*sci_car_exp*) has the most significant positive effect on the economic growth of the large cities with populations of three to five million, and the lowest positive effect for the megacities with populations of more than five million, such as Shenyang City, Dalian City, Changchun City and Harbin City, which are the most important cities in NEC. Although the four cities are the most important driving forces and agglomeration centers for the innovation in the region, their innovation-driven spillover capabilities need to be improved, which means that the four cities' abilities to drive innovation development inter regionally and intra rgionally are still poor. Therefore, promoting the clustering and spillover capabilities of the science and technology innovation in the four core cities is an important part of the all-around revitalization strategy in the next stage.

In this study, *sci_car_exp* is a part of *gov*, which indicates that most of the funds for science and technology flow to the secondary industry sector, which is dominated by state-owned enterprises, and fewer funds flow to tertiary education. Therefore, public expenditure should be optimized, and private investment should strive to promote high-tech-based industry development and human capital agglomeration in NEC, which are the underlying drivers of regional sustainable development (Florida et al., 2008).

In NEC, the government has played a key role in determining the flow of financial funds and most R&D investment to the secondary industry sector, which is dominated by state-owned enterprises. This phenomenon not only further aggravates the imbalance in the industrial structure but also causes difficulties in private sector financing, which leads to the development of a weak financial industry, a lack of internal driving forces and spillover effects for long-term sustainable development. This finding is also verified by the fact that the cities with high level of industrialization have shown lower economic growth effects. Therefore, NEC should develop much more powerful tools in the next phase of its revitalization strategy to avoid path-dependency and a lock-in of traditional and outdated technologies and to prevent the protection of nonviable state-owned firms.

Importantly and interestingly, the strategy has resulted in the effects of a higher economic growth and better social development in the cities with low human capital. This finding differs from the results of many recent studies (Diebolt and Hipp, 2019). Education is a critical determinant of regional development, and the level of education (the quality of human capital), not the total quantity of education (the number of people with some education), is basic and vital to regional development (Gennaioli et al., 2013). That is, the underlying driver of economic development is highly skilled and highly educated people, namely, human capital (Florida et al., 2008). The most commonly used human capital measures are education-based, such as average years of schooling, proportion of labor force with a certain level of education, and various enrollment rates (Mellander and Florida, 2006; Florida et al., 2008; Barro and Lee, 2013). However, education can only partially measure the human capital of an individual because it omits post school education, on-the-job learning, training, etc. (van Aswegen and Retief, 2020). In addition, education-based measures generally fail to reflect the quality of schooling (Manuelli and Seshadri, 2014). The Jorgenson-Fraumeni (J-F) lifetime income approach is widely used in estimating human capital stock (Lange et al., 2018). In our study, due to limitations in data validity, we applied the share of the population who are students enrolled in colleges and universities as an indicator. These students are not highly skilled and may not be working, and their productivity ability and economic value remain to be determined. This indicator cannot capture all aspects of an individual's human capital, and the data are generally less available. Therefore, our measurement method may, to some extent, reduce the effectiveness of targeted human capital for the strategy evaluation.

NEC is a region with rich higher education resources. By the end of the year 2018, there were 2663 colleges and universities in China, of which Liaoning Province had 115, Jilin Province 62, and Heilongjiang Province 81, accounting for 9.69%. Although universities are one of the three factors that affect the uneven distribution of human capital (Florida et al., 2008), the distribution of education and skills does not coincide with the distribution of universities. This phenomenon is closely related to the highly mobile nature of human capital because human capital is not only stock but also a flow. Therefore, although there are many students with higher education in NEC, when they graduate, many of them flow to other regions or other countries with good economic development prospects (Zhao and Liu, 2018), customer amenities and tolerance. The outflow of the regional population includes the dual outflow characteristics of quantity and quality (Jiang et al., 2016). The serious outflow of professional talent and highly skilled people in NEC has become a hot topic and a great threat to the sustainable development of the region (Fraumeni et al., 2019). In addition, the region's population has begun to shrink, and this trend should persist for a long time. Therefore, R&D investment and human capital improvement based on different urban realities, such as population, location, and public expenditure, are daunting challenges for the revitalization and reinvention of the region in the future and should also be considered for the next phase of the strategy.

5 Conclusions

Whether the Northeast China Revitalization Strategy is a success or a failure has been a topic of ongoing debate. To shed light on this issue, we adopted an integrated perspective and use the DID method to measure the effects of the strategy on the region's economic growth and social development. We have also investigated the changes in regional disparities that resulted from the strategy and the impacts of urban heterogeneity on the strategy's policy effects. Moreover, these results have passed the robustness test with the PSM-DID method.

The evidence suggests that the strategy has significantly improved NEC's economic growth and per-capita income by increasing its GDP and GDP per capita by 25.70% and 46.00%, respectively. The strategy has not significantly improved NEC's social development, such as infrastructural road construction, education improvement and social security. Importantly, the strategy has significantly worsened the employment in the secondary industry of NEC. Decreasing regional disparities was one of the original goals of the strategy, and we find that NEC's performance in reducing regional disparities in economic growth and social development is worse than that of NWC and better than that of EC. From another aspect, it is determined that the strategy has no significant effect on mitigating regional disparity. In addition, the policy effects are highly heterogeneous across cities and depend strongly on city size and characteristics. Therefore, there is no simple answer regarding whether the strategy is successful in fulfilling its original goals in terms of regional sustainable development from an integration and statistical perspective.

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