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## SPATIAL ECONOMETRIC MODEL OF CHINA'S REGIONAL LABOR PRODUCTIVITY: THE ROLE OF POPULATION AGING



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*The accelerated aging of China's population poses structural challenges to economic growth, compounded by significant regional imbalances in demographic structure and labor productivity dynamics. The aim of the study is to analyze the key drivers and constraints of regional labor productivity with an emphasis on quantifying the impact of population aging, spatial interaction effects, and other factors in the context of interregional differentiation. The novelty of the research lies in the synthesis of the theory of aging and spatial economics, the inclusion of aging as an independent factor in the model with spatial effects. For the analysis, the methods of calculating Moran indices were used to identify spatial clusters and build SAR models with fixed effects. The empirical database includes data from the National Bureau of Statistics of China for 2001–2022 for 31 provinces. The result of the study was a SAR model that confirmed the significant negative impact of the demographic burden coefficient of older people on the economy, in which every 1% increase reduces labor productivity by five points through a reduction in labor resources and “dilution of capital”. The paper reveals a strong positive spatial dependence, regional heterogeneity of effects and the key positive role of capital productivity, which requires the transformation of economic policy towards the creation of innovation corridors and investments in human capital.*

*Population aging, average labor productivity, economic growth, spatial effects.*

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## Introduction

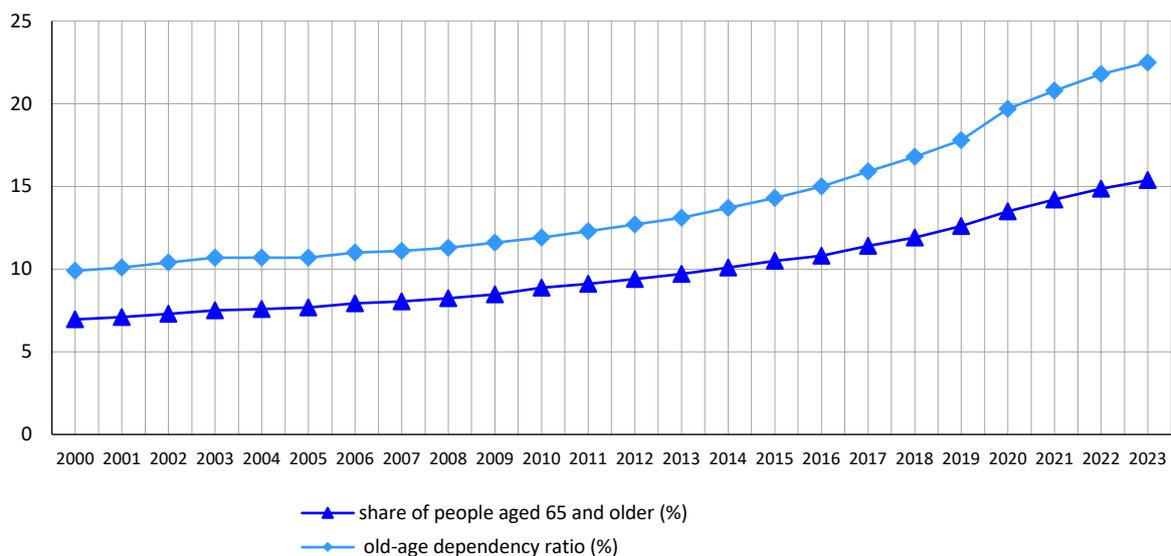
The shift in the age structure of the population is one of the most significant challenges of our time. Specifically, at the current stage of social development, there is a clear trend toward an increase in the proportion of elderly people.

It is important to note that this dynamic is progressing faster than changes in other age groups within the global population structure. According to forecast data from the United Nations, by the middle of the 21st century, the global share of people aged 65 and over will reach 16% of the total population. Such a demographic transformation will have a significant impact on the social structure and economy of all states.

The UN has developed clear criteria for assessing the degree of population aging in various countries and regions worldwide: a share of the population aged 65 years and older exceeding 7% characterizes a society as “aging”; a figure of 14% indicates “deep aging”, and exceeding 21% signifies “super-aging”. Since 2000, the People’s Republic of China has moved into the category of “aging” countries: the share

of the elderly population in the country exceeded 7%. By 2021, the situation had worsened: the proportion of citizens over 65 reached 14.19%. China took only 21 years to transition to the stage of deep aging, significantly less than France (126 years), the UK (46 years), and Germany (40 years). Furthermore, statistical data for 2023 indicates that the demographic situation in China continues to deteriorate<sup>1</sup>: the elderly population reached 216 million people, accounting for 15.37% of the country’s total residents. This means that for every fourth elderly person in the world, there is a citizen of China. According to demographers’ forecasts, the peak of aging in China will occur in 2057, when the number of people over 65 will reach 425 million and constitute between 32.9% and 37.6% of the total population.

Simultaneously, an increase in the old-age dependency ratio is observed. This ratio reflects the number of persons of retirement age (65 years and older) per 100 persons of working age (15 to 64 years). In 2000, this figure stood at nearly 10%; in subsequent years, its value continuously increased (Fig. 1). The working



**Figure 1. Population aging indicator in China, 2000–2023**

Source: stats.gov.cn

<sup>1</sup> Source: stats.gov.cn.

population bears a huge burden of caring for the elderly; social costs for this cohort are also rising, placing immense pressure on budget expenditures.

Population aging entails a whole range of economic and social consequences. On one hand, an increase in the number of retirement-age people leads to a significant rise in social security expenditures (pensions and healthcare), and the labor market may experience a supply shortage due to the shrinking working-age population. On the other hand, an increase in the number of elderly people with financial savings may lead to the emergence of a range of industries and services targeted at older adults (healthcare, pension funds, cultural and leisure activities). According to expert forecasts, this could create new jobs, stimulate innovation, and ensure economic growth.

### **The impact of population aging on economic growth**

In recent decades, population aging has transformed from a “long-term prospect” into an immediate factor reshaping the economic trajectories of most countries, and China is no exception. The peculiarity of China’s situation lies in the fact that rapid population aging coincides with an unprecedented scale of regional economic disparities, making the analysis of its interrelationships with labor productivity particularly complex. Researchers have long noted that age structure directly affects the economy through the quantity and quality of labor – a key element of productivity (Solow, 1956; Bloom et al., 2001). The “demographic dividend”, which explained 15% of China’s GDP per capita growth in 1982–2000, was precisely the result of an increase in the working-age share of the population and its efficiency (Bloom, Williamson, 1998; Wang, Mason, 2008). Current data show that

when the share of elderly (65+) exceeds 15%, this effect transforms into a “demographic burden”, manifested in a shrinking workforce, reduced innovation, and slowing productivity, particularly in poorer regions (Bloom et al., 2010; Kotschy, Bloom, 2023; Maestas et al., 2023).

Analysis at the regional level is necessary not only because of spatial effects but also due to the tangible mechanisms through which aging exerts influence, related to migration, infrastructure, and human resource practices. For Russia, R.V. Kulagin identified the following feature: weighted indicators of employment in older age groups do not have a uniform impact on regional labor productivity indicators (Kulagin, 2024). Similarly, in other countries, researchers note that aging reduces adaptability to technology in moderately developed regions, but in wealthy ones, this is offset by investments in human capital and the “silver economy” (Hu et al., 2012; Li, 2013; Kudinsh et al., 2022). In China, these differences reach extreme proportions: eastern provinces leverage aging as a driver, attracting workers through services for the elderly and experienced specialists (Han, Wang, 2018; Lin, 2025), while western regions suffer from increasingly acute resource shortages and youth out-migration (Man et al., 2021; Antipova, Chen, 2023). This is why such analysis at the regional level is not a luxury but a necessity: without it, policy risks being ineffective.

It should be noted that methodological approaches in studying this topic have been evolving and improving for over half a century. Early work relied on classical production functions and panel data without accounting for spatial interdependence, which was logical and acceptable for the national level but insufficient for a global perspective, as modern world regions are closely interconnected (Solow, 1956; Van Groezen et al., 2005; Wang, Mason, 2008).

Contemporary models already incorporate space: for example, one study used a spatial lag model (SLM) to analyze the age structure of the population and the increasing share of elderly people in Russian regions (Belyakov et al., 2025). However, that study focused on total factor productivity rather than labor productivity. Labor productivity is not only a direct driver of economic growth but also the “primary point of impact” of population aging on the economic system. Yet existing research does not focus on the key mechanisms through which aging directly affects labor productivity via the quantity, quality, and structure of the workforce.

One study brought researchers closer to this problem by demonstrating that aging affects productivity through human capital and innovation (Wu et al., 2025). Other scholars concluded that aging reduces productivity in the United States by 0.9% annually (Maestas et al., 2023). However, their model does not account for two key features of China: migration and spillover effects, without which estimates remain static, while the reality of Chinese regions is dynamic. T.A. Burtseva and colleagues emphasized the importance of regional specificity in Russia but did not employ spatial models; therefore, their conclusions about the “impact of aging” remained general, lacking quantitative assessment of how neighboring regions influence each other (Burtseva et al., 2021).

Despite the extensive body of literature, there are gaps that directly pertain to the practice of analyzing Chinese realities. First, most studies at the national and regional level have been conducted without synthesizing aging theory and spatial economics. Second, aging is rarely considered as an independent factor in modified production functions incorporating spatial effects. A recent study noted that precisely this disconnect between

demography and spatial economics hinders the development of adequate policy. This problem is particularly acute in China, where aging is progressing faster than in most countries (Goldin et al., 2024).

The novelty of this study lies in the synthesis of population aging theory and spatial economics, as well as the inclusion of population aging as an independent explanatory factor in modified production functions that account for spatial effects. This allows for filling the existing scholarly gap in analyzing the situation in China at the regional level.

### Construction of the theoretical model

To construct a theoretical model, it is important to identify the key factors influencing labor productivity. These include human capital (knowledge and skills of employees), physical capital (industrial equipment and infrastructure), as well as other resources necessary for organizing the production process. Over the past few years, due to population aging worldwide, much attention has been devoted to assessing the impact of the old-age dependency ratio (ODR) on economic growth. Many studies have shown that ODR affects not only labor supply but also average labor productivity, thereby influencing its efficiency (Bloom et al., 2010).

Let us consider the following production function:

$$Y = BL^{1-\alpha}, \quad (1)$$

where:  $Y$  – output;  $B$  – labor efficiency;  $L$  – labor.

Dividing both sides of equation (1) by  $L$ , we obtain the average labor productivity function:

$$y = \frac{Y}{L} = BL^{-\alpha}, \quad (2)$$

where  $y$  – average labor productivity.

The old-age dependency ratio is defined by the following relation:

$$ODR = \frac{N_{old-age}}{N_{working-age}},$$

where:

$N_{old-age}$  – number of elderly people (65 years and older);

$N_{working-age}$  – number of working-age population (15–64 years).

It is worth noting that population aging entails certain negative consequences. In particular, as the share of elderly people in the age structure increases, the working-age population shrinks, which likely reduces labor efficiency. Furthermore, labor efficiency is closely related to capital. Consequently, labor efficiency  $B$  can be expressed as:

$$B = f(ODR, K, X),$$

where:

$X$  – vector of variables explaining the level of labor productivity;

$K$  – capital.

Combining these elements, equation (2) can be represented as:

$$y = \frac{Y}{L} = BL^{-\alpha} = f(ODR, K, X)L^{-\alpha}. \quad (3)$$

This means that average labor productivity  $y$  depends on labor efficiency, which is influenced by  $ODR$ ,  $K$ , and other variables.

Taking logarithms of both sides of equation (3) yields:

$$\ln y = \ln f(ODR, K, X) - \alpha \ln L. \quad (4)$$

Differentiating equation (4) with respect to time gives:

$$g_y = -\alpha g_L + \beta g_{ODR} + \gamma g_K + \theta g_X, \quad (5)$$

where:

$g_y$  – growth rate of average labor productivity;

$g_L$  – growth rate of employment;

$g_K$  – growth rate of physical capital;

$g_{ODR}$  – growth rate of the old-age dependency ratio.

Let us consider the growth rate of physical capital  $g_K$ . Within the framework of the classical Solow model (Solow, 1956), the dynamic change in capital equals new investment minus capital depreciation. The model assumes that new investment equals the product of the saving rate and output:

$$\dot{K} = sY - \delta K, \quad (6)$$

where:

$s$  – saving rate;

$\delta$  – depreciation rate.

For further analysis of factors affecting  $g_K$ , we divide both sides of equation (6) by the capital stock:

$$g_K = \frac{\dot{K}}{K} = s \frac{Y}{K} - \delta. \quad (7)$$

From this, it is evident that  $g_K$  is positively correlated with  $\frac{Y}{K}$ , i.e., the average capital productivity ( $ACP$ ). Based on this close relationship, in this study we can approximately use capital productivity to characterize the growth rate of capital.

Thus, equation (5) can be represented as:

$$g_y = -\alpha g_L + \beta g_{ODR} + \gamma ACP + \theta g_X. \quad (8)$$

Expression (8) will serve as the empirical basis for constructing econometric models.

### Method for calculating ACP

Since official statistical data on the capital stock in China are not published (only data on fixed capital investment volumes are available), the dynamics of the capital stock within the Solow model framework are as follows:

$$\dot{K}(t) = I(t) - \delta K(t). \quad (9)$$

Solving the differential equation (9) yields:

$$K(t) = K_0 e^{-\delta(t_0-t)} + e^{-\delta t} \int_{t_0}^t I(\tau) e^{-\delta \tau} d\tau, \quad (10)$$

where:

$t_0$  – base year;

$K_0$  – capital stock in that year, approximated by the volume of fixed capital investment in that year.

When the time interval between the base year  $t_0$  and the study year is sufficiently large, the first part of equation (10) approaches zero, which reduces the error caused by inaccurate estimation of  $K_0$ .

The base year in this study is taken as 1982. For the provinces of Hainan and Chongqing, which were established later, the base years are 1988 and 1997, respectively. The analysis period covers 2001–2022.

### Data and econometric model

For the purpose of regression analysis, panel data from the official website of the National Bureau of Statistics of China for 31 provinces over the period 2001–2022 were used.

To avoid endogeneity problems associated with using the number of employed persons

as a regressor, this study employs the share of employed persons in the total population.

In accordance with equation (8), the baseline regression model takes the form:

$$\begin{aligned} Gr_{ALP_{i,t}} = & Gr_{L_{i,t}} + Gr_{ODR_{i,t}} + \\ & + ACP_{i,t} + Gr_{N_{i,t}} + Gr_{ODR_{i,t}} * Gr_{L_{i,t}}. \end{aligned} \quad (11)$$

The proposed model allows for assessing the impact of various factors on the dynamics of labor productivity in region  $i$  during period  $t$ . The dependent variable ( $Gr_{ALP_{i,t}}$ ) is the growth rate of real average labor productivity. The main predictors include indicators characterizing the demographic situation (growth rate of the old-age dependency ratio,  $Gr_{L_{i,t}}$ ) employment (growth rate of the employment share,  $Gr_{ODR_{i,t}}$ ), and capital use efficiency (growth rate of capital productivity,  $ACP_{i,t}$ ). The model also includes control variables, such as the growth rate of the total population ( $Gr_{N_{i,t}}$ ) and an interaction term reflecting the joint influence of demographic factors and employment ( $Gr_{ODR_{i,t}} * Gr_{L_{i,t}}$ ). To account for unobserved factors affecting labor productivity, fixed effects ( $\mu_i$ ) and time effects ( $\rho_t$ ) are introduced, along with a random error term ( $\varepsilon_{it}$ ).

To control for a number of other economic development factors, additional variables were included in the model: the growth rate of total exports and imports in GRP, the growth rate of domestic patent applications filed, the growth rate of real deposit rates, and the growth rate of real oil prices. However, most of the additional variables did not have a significant impact on the results. A complete list of variables and their characteristics is presented in *Tables 1 and 2*.

Table 1. List of regression variables

Indicator	Notation in models
Growth rate of real average labor productivity	$Gr_{ALP_{i,t}}$
Real average labor productivity (in 2000 prices), yuan/person	$ALP$
Growth rate of the old-age dependency ratio	$Gr_{ODR_{i,t}}$
Growth rate of the employment share	$Gr_{L_{i,t}}$
Average capital productivity, Y/K	$ACP$
Growth rate of total population	$Gr_{N_{i,t}}$
Interaction term: growth rate of aging × growth rate of employment	$Gr_{ODR_{i,t}} * Gr_{L_{i,t}}$

Table 2. Descriptive statistics

	Mean	Median	Maximum	Minimum	SD	Observations
Gr_ALP	0.0860	0.0852	0.3073	-0.1437	0.0493	682
Gr_ODR	0.0354	0.0358	0.3247	-0.3678	0.0851	682
Gr_L	0.0078	0.0056	0.9709	-0.3015	0.0492	682
ACP	0.3494	0.3404	0.8330	0.1030	0.1534	682
Gr_N	0.0061	0.0053	0.0562	-0.0571	0.0119	682

Calculated from: <https://data.stats.gov.cn/english>

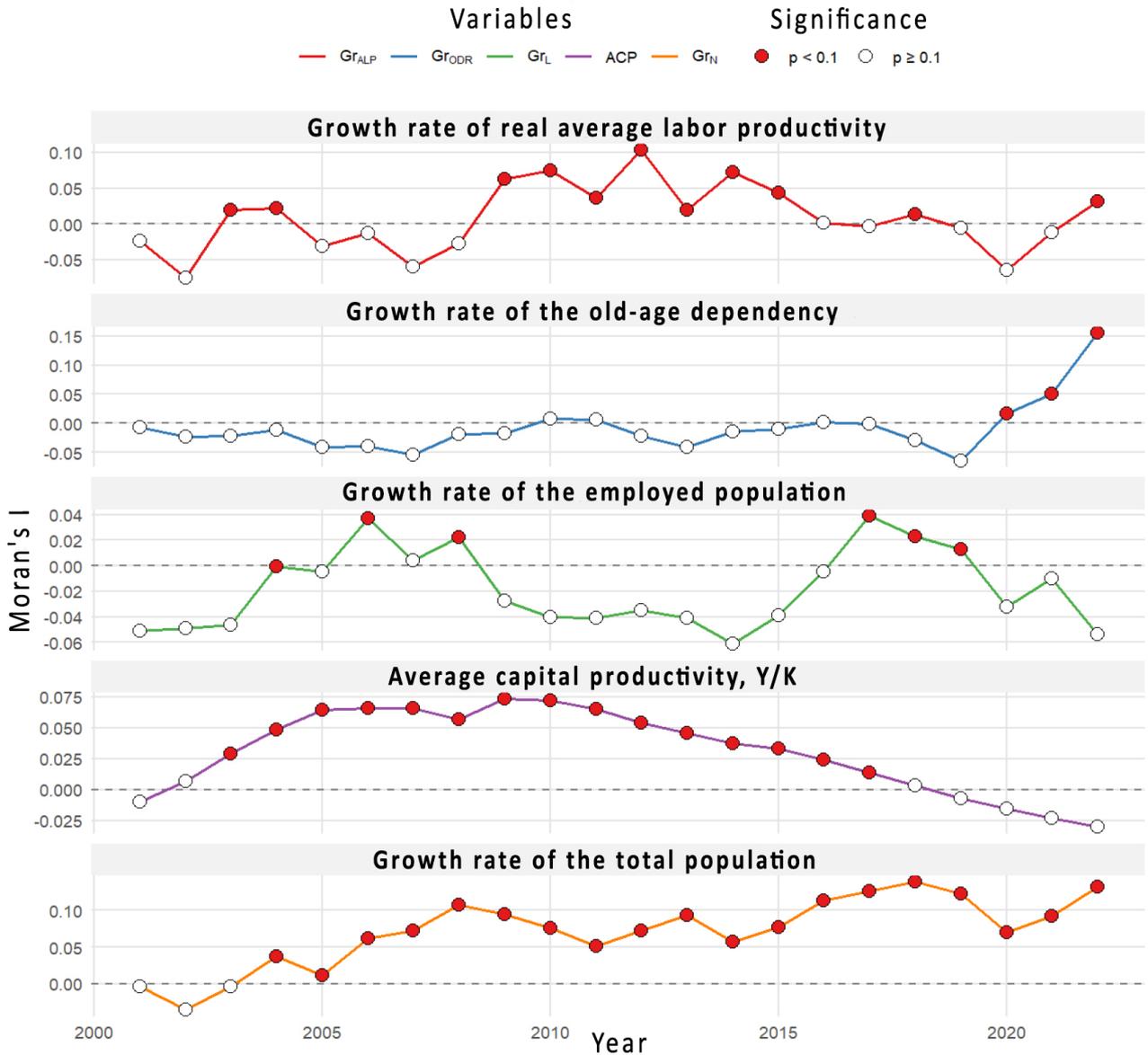
**Test for spatial correlation**

Ignoring spatial dependence in regional economic development leads to biases in model specification and reduces the validity of conclusions (Anselin, 1988). To test for spatial autocorrelation of variables, this study employs Moran's I index, with values ranging from -1 to 1. Positive values indicate positive spatial autocorrelation, negative values indicate negative autocorrelation, and values close to zero suggest the absence of such autocorrelation (Moran, 1950).

Calculations are based on a spatial weight matrix constructed using inverse geographic

distances ( $W_{i,j} = \frac{1}{d_{i,j}}$ , where  $d_{i,j}$  is the distance between regions  $i$  and  $j$ ). The results (Fig. 2) confirm significant spatial clustering of key indicators. These include the growth rate of real average labor productivity, average capital productivity, and population growth rates. At the same time, the growth rate of the old-age dependency ratio exhibits statistically insignificant autocorrelation in most periods. However, visual analysis of its spatial distribution (Fig. 3) reveals a different picture. The patterns on the map allow for the identification of spatial relationships.

Dynamics of spatial autocorrelation of the main variables (2001–2022)

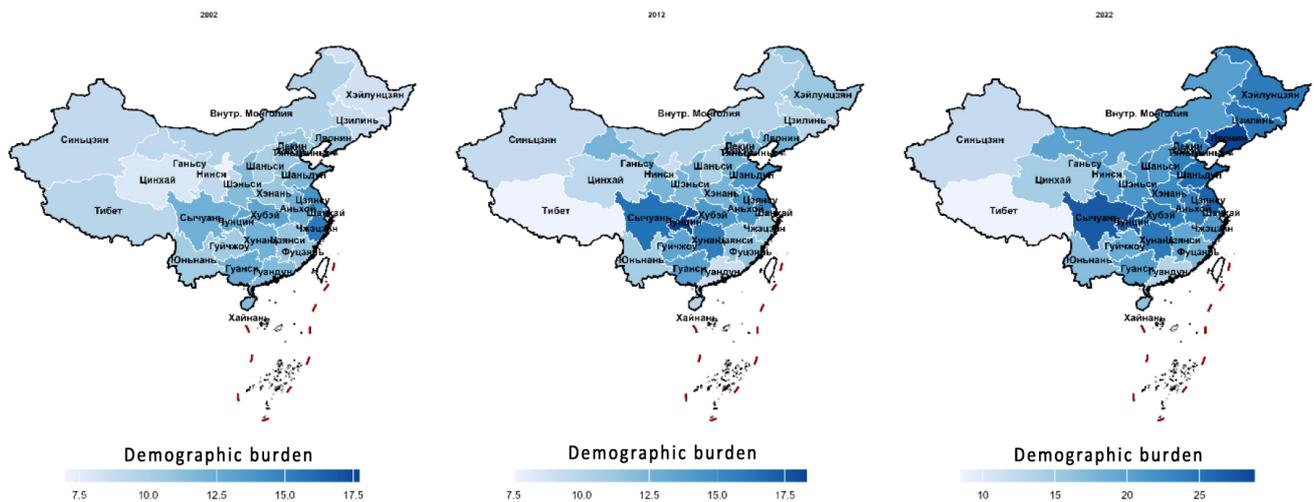


Note: Color lines denote variables; red dots – statistically significant values

Figure 2. Dynamics of Moran's I for variables  
 Calculated from: <https://data.stats.gov.cn/english>

### Dynamics of the old-age dependency ratio in China (2002–2022)

#### Old-age dependency ratio



#### Growth rate of the old-age dependency ratio

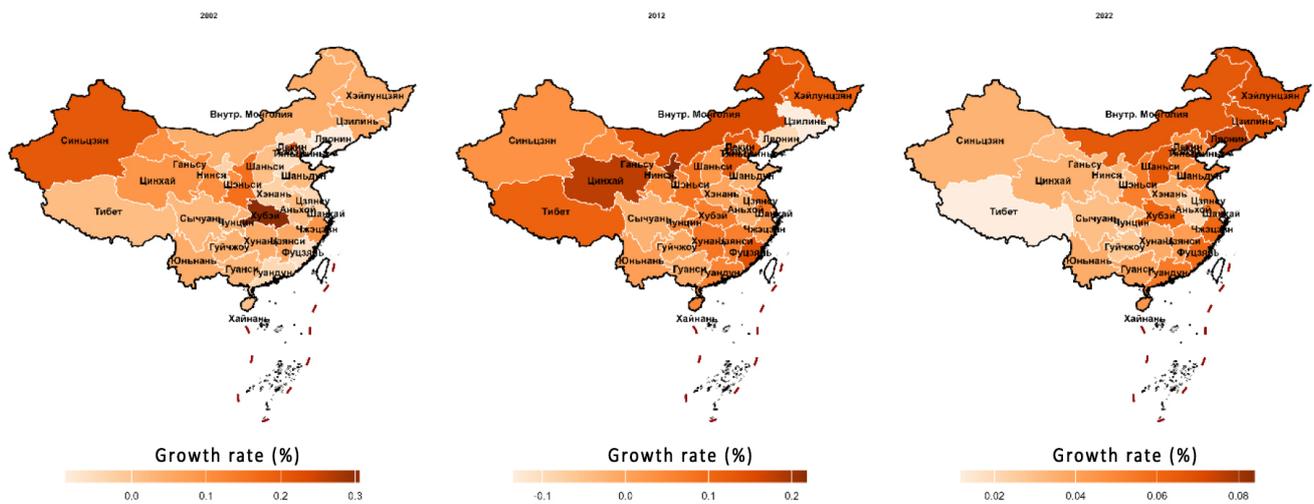


Figure 3. Dynamics of the old-age dependency ratio in China

Calculated from: <https://data.stats.gov.cn/english>

## Results and discussion

Table 3 presents the results of the regression estimates. To test for multicollinearity, the variance inflation factor (VIF) was calculated. All obtained VIF values do not exceed 10, indicating the absence of substantial multicollinearity. The selection of the optimal model specification was based on robust Lagrange multiplier (LM) tests, the results of which indicate the preference for the spatial autoregressive model (SAR) over the spatial error model (SEM). To control for unobserved regional heterogeneity and time effects affecting labor productivity, estimation was carried out based on the SAR model with fixed effects. Thus, a spatial lag model with fixed effects should be specified:

$$Gr_{ALP_{i,t}} = \lambda (W * Gr_{ALP_{j,t}}) + \beta Gr_{ODR_{i,t}} + \alpha_1 Gr_{L_{i,t}} + \alpha_2 ACP_{i,t} + \alpha_3 Gr_{N_{i,t}} + \alpha_4 Gr_{ODR_{i,t}} * Gr_{L_{i,t}} + \mu_i + \rho_t + \varepsilon_{it} \quad (12)$$

where:

$\lambda$  – spatial autoregressive coefficient;

$W$  – normalized weight matrix;

$(\mu_i)$  – individual effects;

$(\rho_t)$  – time effects;

$(\varepsilon_{it})$  – random errors of the model.

Models 1 and 2 include a spatial lag (SAR) with individual and time effects, respectively. Models 3 and 4 represent standard panel regressions with the same effects for comparison. The stability of the key coefficients across different specifications confirms the robustness of the main findings.

The statistically significant spatial autocorrelation coefficient  $\lambda$  (0.72\*\*\*, Model 1) confirms a strong positive spatial dependence among regions, reflecting a spillover effect – the diffusion of technologies and capital from coastal clusters to inland provinces. When controlling for time effects,  $\lambda$  decreases (0.19\*, Model 2) but remains significant. This underscores the importance of regional clustering, particularly in the context of the “Go West” policy, necessitating coordinated interregional approaches.

The impact of demographic factors demonstrates complex dynamics. The coefficient for the growth rate of the old-age dependency ratio ( $Gr_{ODR_{i,t}}$ ) is consistently negative across all specifications. This result confirms the constraining effect of population aging on labor productivity. Concurrently, employment growth ( $Gr_{L_{i,t}}$ ) also exhibits a negative effect, likely due to “capital dilution” associated with an influx of low-skilled labor.

Table 3. Regression estimation results

Explanatory variables	Model 1	Model 2	Model 3	Model 4
Spatial autoregressive coefficient ( $\lambda$ )	0.72***	0.19*		
$Gr_{ODR_{i,t}}$	-0.05***	-0.04**	-0.10***	-0.04**
$Gr_{L_{i,t}}$	-0.34***	-0.37***	-0.32***	-0.37***
$ACP_{i,t}$	0.06***	0.03**	0.14***	0.03**
$Gr_{N_{i,t}}$	-0.29*	-0.35***	-0.2	-0.35***
$Gr_{ODR_{i,t}} * Gr_{L_{i,t}}$	1.83**	1.99***	1.97***	2.02***
Individual effects	Yes		Yes	
Time effects		Yes		Yes

Note: \*\*\*, \*\*, \* – significance at the 1%, 5%, and 10% levels, respectively.

Source: own compilation.

Of particular interest is the interaction of demographic factors. The positive coefficient for the product term  $Gr_{ODR_{i,t}} * Gr_{L_{i,t}}$  indicates a compensatory mechanism: employment growth mitigates the negative impact of aging. However, current demographic dynamics (shrinking workforce coupled with accelerated aging) have neutralized this buffering effect.

Furthermore, the coefficient for  $Gr_{N_{i,t}}$  is substantially negative in most models. This implies that under current economic and social conditions, rapid population growth will constrain labor productivity growth. This dampening effect may be attributed to factors such as increased strain on resource allocation caused by population growth and a reduction in per capita resources.

Average capital productivity ( $ACP_{i,t}$ ) remains a powerful driver: the significant positive coefficient aligns with China's investment-oriented growth model.

The study confirms the fundamental dependence of average labor productivity in China on demographic shifts. Accelerated population aging, which has lost the compensation previously provided by the demographic dividend, represents a serious structural challenge. At the same time, accounting for spatial interdependencies remains a critical condition for correctly modeling regional economic dynamics.

These findings necessitate strategic measures. Intensification of investment in R&D and digitalization must be accompanied by strengthening spatial interactions for the diffusion of innovations; simultaneously, the quality of human capital should be enhanced. Such a comprehensive approach underscores the need for a transition from the traditional extensive growth model, based on cheap labor

and substantial investment, to an intensive model. The new paradigm must be founded on technological innovation and efficient resource utilization.

### Conclusion

Thus, the study employing spatial econometric methods has made it possible to identify the key drivers and constraints of regional labor productivity in China. The empirical results confirm three principal findings.

First, spatial dependence significantly influences the economic landscape. Consistently positive and statistically significant autoregressive coefficients indicate pronounced effects of technological diffusion and interregional capital flows.

Second, demographic changes impose a dual burden on productivity. Population aging consistently reduces labor productivity growth through the contraction of labor resources and increased social expenditures, as confirmed by all models. Simultaneously, extensive employment expansion provokes "capital dilution", reflecting the constraining influence of low-skilled labor. Critically, the compensatory effect of the interaction between aging and employment growth persists under current conditions.

Third, capital productivity remains the most consistently positive factor. This result confirms the effectiveness of the investment-oriented model but exposes risks to its sustainability.

The study's findings dictate the need for a dual transformation of policy: technological modernization requires overcoming administrative barriers through the creation of "coast-to-inland" innovation corridors, and investment in human capital must replace the focus on quantitative indicators. Targeted retraining of older age groups and flexible pension mechanisms could partially mitigate demographic pressure.

A limitation of the study is the lack of differentiation of the elderly population by skill level, which requires further investigation using microdata. Nevertheless, the results unequivocally indicate that the transition from an extensive model to an economy of innovation and cooperation – optimizing resources through spatial integration and human potential development – becomes an imperative for overcoming the structural challenges of accelerated population aging.

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