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Does Human Capital Agglomeration Increase Firm Productivity?

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Abstract: Human capital has become one of the most important indicators of a country's overall strength and development process in recent years. Based on the samples of listed companies from 2006 to 2020, this paper uses a fixed-effects model to explore the impact and mechanism of human capital agglomeration on firms' productivity. The study results show that human capital agglomeration significantly enhances the productivity of firms, i.e., the higher the level of human capital agglomeration in the city, the higher the productivity of firms. After the robustness test, the research conclusions are reliable. The mechanism shows that knowledge spillover and technological innovation, skill matching, and specialized production are the mechanisms through which human capital affects firms' productivity. Heterogeneity analysis shows regional, enterprise, and industry heterogeneity in the impact of human capital agglomeration on the productivity of firms. Accordingly, this paper provides exploratory suggestions on maximizing the positive effects of human capital agglomeration on firms' productive activities.

Keywords: Human capital, Productive efficiency, Knowledge spillovers, Market liberalization.

1. Introduction

Human capital plays an important role in promoting innovative development and increasing the economic resilience of cities. After the first endogenous growth models emerged in the late 1980s, human capital became an important explanatory factor in economic growth (Buendía et al., 2015) [1]. Human capital theorists such as Schultz have also emphasized the indispensable role of human knowledge and skills in the production process. At the end of 2019, hundreds of cities in China introduced talent policies and settlement policies one after another, actively promoting the transformation from "population dividend" to "talent dividend". Talent is an important support and "engine" for regional economic growth, and human capital has become the focus of talent strategy construction in Chinese cities. As China's economy moves from a phase of rapid growth to a phase of high-quality development, the development goals of the new normal require enterprises to actively innovate and continuously accumulate intellectual capital through learning and technological advances, thereby increasing productivity. It can be seen that the improvement of the productivity of human capital enterprises and the resulting diffusion and spillover effects is directly related to the improvement of the overall productivity of the city and even the country. Total Factor Productivity (TFP) measures production efficiency from multiple perspectives and was first derived from the Solow production function proposed by Solow (1957), reflecting the effective role that factors of production such as labor and capital can play in economic growth [2].

Human capital makes an important contribution to the process of economic growth. The conceptual discussion of human capital was first introduced and explained by Schultz (1961) regarding its impact on economic growth [3]. Becker (2009) proposed a new perspective in exploring the externalities of human capital by viewing human capital as an investment that individuals make in themselves, i.e., they invest their time and resources in acquiring competencies by investing in education, training, and health, etc., to increase the returns to expected employment, income [4]. Mincer (1958) used investment in education as a proxy for human capital and explored the return on investment of human capital. Academic research on the economic effects of human capital agglomeration has focused more on the macro provincial and city level [5]. Differences in the level of human capital across cities must affect local innovation behavior and economic growth (Mincer, 1958; Gennaioli et al., 2013) [6]. Concerning the study of the relationship between human capital and productivity, early economists have recognized the strong link between human capital and productivity, i.e., the interconnections and exchanges between workers can reflect the formation of human capital, which in turn affects productivity. Mankiw (1992), Arnold et al. (2007) and Liu (2014) point out that human capital has a direct impact on the level of growth or productivity, including the process of technological progress and innovation that is dependent on human capital, which generates economic effects [7-9]. The greater the concentration of human capital, the higher the productivity that tends to be exhibited in the relevant industrial sector (Rauch, 1993) [10]. As a result of advanced technology, potential employment opportunities, and higher salaries, the population moves between cities, which gradually creates an uneven distribution and human capital agglomeration. According to modern economic theory, population mobility and industrial development can generate agglomeration and economies of scale, driving innovative behavior and economic growth through sharing, matching, and learning. When the economy moves from decentralization to agglomeration, the rate of innovation increases (Duranton & Puga, 2004; Fujita & Thisse, 2003) [11-12]. However, it has been argued that the innovation effect of human capital agglomeration promotes economic growth, but the impact is lagging. Moreover, talents are mobile and there is a possibility of spillover, thus restricting regional economic development. In recent years, some scholars have focused on the economic effect of human capital agglomeration on enterprise development, so it is important to study the correlation between human capital

agglomeration and enterprise productivity to promote the effective combination of knowledge-based economic growth and real economic development, and to enhance the overall economic strength of the city.

Compared with the existing studies, our marginal contributions may be as follows: first, we study from the perspective of micro-enterprises and use the fixed effects model to study the relationship between human capital agglomeration and enterprise productivity; second, compared with the previous literature that focuses on the spatial spillover effect of human capital, this paper analyzes the influence mechanism of human capital and enterprise productivity, providing a new research perspective.

2. Theoretical Analysis and Research Hypotheses

Human capital formation is an important driver of macro- and microeconomic development. According to the neoclassical growth model. Labor is one of the basic production elements and can contribute to productivity [13]. Lucas (1988) modified the standard neoclassical model of growth and international trade theory to include human capital accumulation in the research framework [14]. He emphasizes that human capital is a social activity of a group, and through the analysis of three theoretical models emphasizes the important role of physical capital accumulation and technological change, the accumulation of human capital through schooling, and the accumulation of specialized human capital through secondary schooling for sustained economic growth. Human capital is formed by the potential labor force through education, training, and learning. As Kuznets (1962) mentioned in his book, creative endeavors are produced in a strong intellectual atmosphere [15]. Population growth is the basis for labor force growth and when workers with education and training are involved in the labor force, more products will be able to be produced. Based on the neoclassical theory of production, Chang (2016) explicitly considers the effects of internal human capital represented by internal labor quality and external human capital determined by the size of technology on factory productivity, where interaction and exchange between skilled workers are responsible for increasing human capital spillovers [16].

Academic research on the relationship between urban human capital and productivity has been partially focused on the micro-enterprise level, but there is still a relative lack of relevant research. Combes et al.(2012) include human capital in the study of agglomeration economies, and in examining whether agglomeration economies contribute to the formation of productivity advantages in large cities, they propose that the main source of knowledge spillovers is the intensive interaction of highly skilled people, emphasizing that the knowledge externalities of human capital, as a high-quality workforce, are the key to the productivity gains brought about by agglomeration economies, indirectly demonstrating its relationship with firm productivity [17]. Whether an enterprise can sustain value creation and continuous development depends largely on the size of production efficiency. Based on the above analysis, this paper puts forward the hypothesis 1.

H1: Higher human capital agglomeration in the city contributes to higher firm productivity.

2.1. Knowledge Spillovers and Technological Innovation

The agglomeration of human capital in cities helps to promote R&D and innovation activities within firms, thus increasing productivity. Most scholars follow a relatively consistent pattern of explaining the principles of education: the 3Rs of education, vocational training, and higher education, i.e., the development of the ability of the educated person to perform a skill or action effectively (Nelson & Phelps, 1966) [18]. Education helps individuals to accept, understand, and interpret things and information and improves their efficiency in solving all kinds of word-processing problems. The agglomeration of human capital in cities provides opportunities for talented people to communicate with each other, exchange learning and imitation, and create knowledge overflow. Darby (1998) identified entrepreneurs' skills, knowledge competencies, and core team members as decisive elements for industrial start-ups [19]. Human capital reserves determine whether a city can reasonably meet the innovation needs of local firms and industrial development goals. From an enterprise's perspective, R&D personnel with a higher level of education are more capable of learning new knowledge and technology, have a higher ability to assess and understand productive innovation activities, and can adapt as quickly as possible to the operation and operation of new equipment and technology. The production and management activities required in technological progress are constantly adapted to changes in the market environment, and the more educated an enterprise manager is, the more he or she can introduce innovative technologies to improve competitiveness under the actual situation. The rise in the level of knowledge and expertise in the Nielsen population helps enterprises to innovate and accelerate technological progress. Therefore, when the degree of human capital agglomeration in cities rises, people have more opportunities to communicate and share knowledge, and more R&D personnel matching the innovative behaviors related to local enterprises will appear, thus promoting the level of innovation of enterprises, which in turn improves the productivity of enterprises. Based on the above analysis, this paper puts forward the hypothesis 2.

H2: Human capital agglomeration improves firm productivity by increasing the level of firm innovation.

2.2. Skill Matching and Specialized Production

The concentration of human capital in the city improves the overall quality of the workforce and helps to reasonably match workers with different skills with corresponding positions in enterprises, which not only improves the overall employment rate in the city, but also strengthens the industries in which enterprises have an advantage, promotes specialized production and division of labor, and thus improves the efficiency of production. Workers who have received higher education can utilize their professional strengths more quickly after vocational training, which greatly reduces the hiring costs of enterprises in different industries. At the same time, the quantitative and qualitative expansion of the labor market facilitates the formation of industrial agglomerations and specialization in a city (Glaeser et al., 1992) [20]. Adam Smith's “The Wealth of Nations” elaborates on the connotation of specialization and division of labor, and emphasizes the importance of specialization and division of labor to improve labor productivity. Enterprises that form

industrial clusters due to the agglomeration of the market division of labor and establish industrialized links with each other will benefit from the convenience brought by the larger industrial division of labor, and thus be able to devote themselves more exclusively to their fields of specialization, and continuously improve the degree of specialization and industry competitiveness. Therefore, the accumulation of human capital in cities can reduce the waste of human resources caused by frictional unemployment in the labor market, provide suitable workers for the specialized division of labor and production of enterprises, and promote the enhancement of enterprise production efficiency.

H3: Human capital agglomeration improves firm productivity by facilitating labor skill matching.

H4: Human capital agglomeration increases the productivity of firms by promoting specialization.

3. Methodology

3.1. Sample and Data Source

The empirical research data of this paper is based on matching urban macro data with enterprise microdata. For the enterprise data, the CSMAR database of Chinese listed companies from 2006 to 2020 is used as the initial research sample. The samples are processed as follows: (1) Considering the existence of the specificity of the financial industry, we first exclude the samples of listed companies in the financial and insurance industry as well as those in the ST and ST*; (2) We exclude samples of listed companies with missing and abnormal financial indicators and those that have been delisted from the stock market. After screening, we finally obtained the balanced panel data of 9,690 listed companies, and to avoid the impact of extreme values on the empirical results, the continuous variables of listed companies are winsorized up and down by 1%. The macro-level data of prefecture-level cities come from the China Statistical Yearbook, China Urban Statistical Yearbook, and Statistical Yearbook of City Population Counts in previous years, and local statistical bulletins and yearbooks fill in some missing values.

3.2. Variable Explanation and Descriptive Statistics

3.2.1. Explained variable: firm productivity (TFP)

Productive efficiency covers a wide range, including changes in production technology, management, and manpower of enterprises (Kong et al,2021) [21]. At present, there are various indicators in the academic world to measure the production efficiency of enterprises, among which total factor productivity (TFP) can reflect the output efficiency of enterprise resources in general. Total Factor Productivity (TFP) is an enterprise's calculation of its additional production efficiency, i.e., a measure of the overall efficiency from inputs to final outputs, under the condition that the inputs of all types of production factors (e.g., labor and capital) are established. Therefore, this paper chooses total factor productivity (TFP) to measure the production efficiency of enterprises. Total factor productivity measurement methods mainly include the OLS method, OP method, LP method, GMM method, and so on. Among them, the consistent semiparametric estimation method developed by Olley and Pakes (1996) uses the current investment proxy variable, which can overcome the endogeneity and sample selection bias problems caused by mutual decision bias in the sample data [22]. The LP method proposed by Levinsohn and Petrin (2003) uses the intermediate goods input indicator as a proxy variable to avoid the sample loss problem when the investment variable has a negative sign in the OP method [23]. Therefore, this paper finally chooses the OP method to measure the total factor productivity of enterprises, and at the same time uses the results of the LP method as a proxy variable for the robustness test.

3.2.2. Core explanatory variable: human capital agglomeration (HC)

The core explanatory variable of this paper is urban human capital agglomeration, which is measured by the population with tertiary education and above in each city, and the degree of human capital agglomeration is measured by the calculation of locational entropy. The specific calculation formula is as follows:

$$HC_{it} = \frac{PC_{it} / P_{it}}{PC_t / C_t} \tag{1}$$

Where i denotes city, t denotes year, HC_{it} is the human capital agglomeration of the city i, PC_{it} and P_{it} denote the population with tertiary and higher education in the city i in year t, and the resident population in the city i in year t, respectively; and PC_{it} and P_{it} denote the total number of people with tertiary and higher education in the national population and the total population in the country, respectively.

3.2.3. Control variables

Considering that the sample includes both macro and micro data, this paper firstly introduces indicators that can reflect the economic characteristics of enterprises, including the listing age of listed enterprises (Listdt), property rights (PR), equity concentration (OC), institutional shareholding ratio (PSII), gearing ratio (Lev), net profitability ratio of total assets (ROA), board of directors' size (BS), and Tobin'sQ (TobinQ), etc. as micro control variables, and secondly, GDP per capita (lnpgdp) and fiscal size (lngorv) at the city level are selected as macro control variables. Table 1 reports the variable descriptions and descriptive statistics.

Table 1. Variable explanation and descriptive analysis

Name of Variables	Description	Mean	SD	Min	Max
TFP	Enterprise productivity	1.9746	0.1383	1.0484	2.4337
HC	Human capital agglomeration	4.9095	0.9067	1.2969	6.7289
Listdt	Age of listing	2.6055	0.4613	0	3.4012
PR	Nature of property rights	0.7314	0.4433	0	1
OC	Shareholding concentration	36.6191	14.7833	3.6211	89.0930
PSII	Institutional shareholding	56.0337	19.9104	0.0970	152.5042
Lev	Asset-liability ratio	0.5080	0.2151	0.0207	6.2808
ROA	Net profit margin on total assets	0.0384	0.0703	-0.9183	2.3010
BS	Size of the Board	2.0447	0.2110	1	3
TobinQ	Tobin Q	1.9574	1.8478	0.6735	69.8757
lnpgdp	GDP per capita	8.4639	1.1959	4.3176	10.5636
lngorv	Fiscal expenditure on science and technology /GDP	15.7268	1.3369	10.9619	18.2405

3.3. Model Setup

This paper examines the relationship between human capital agglomeration and enterprise productivity through a fixed effects model to test the previous hypothesis. The specific model is set as follows:

$$TFP_{ijt} = \beta_0 + \beta_1 HC_{it} + Controls_{it} + Controls_{jt} + Year + City + \varepsilon_{ijt}$$

Where i denotes the city where the listed company is located, t denotes the year, and j denotes the listed company. denotes the listed company. TFP_{ijt} is the explanatory variable of this paper, which is the firm's production efficiency, measured by total factor productivity, and indicates the production efficiency of firm j in city i in year t. HC_{it} is the core explanatory variable that indicates the degree of human capital agglomeration in the city where firm j is located. $Control_{it}$ and $Control_{jt}$ denote city-level and firm-level control variables, respectively. In addition, both the degree of human capital concentration (HC) and firm productivity (TFP) are treated logarithmically in the regressions that follow. The model controls for time (Year), region (City), and industry (Ind) fixed effects, and standard errors are clustered at the firm level with robust standard errors.

4. Results and Discussion

4.1. Benchmark Regression Results

This paper constructs a year-region fixed-effects model to regress human capital agglomeration and enterprise productivity, and the results of the baseline regression analysis are shown in Table 2, where column (1) presents the results of the analysis with the introduction of the fixed effects of time and region only and without any control variables, and columns (2) and (3) represent the estimation results of the sequential inclusion of the control variables at the enterprise level and the city level, respectively. the results of the estimations performed. The results reported in column (3) all show that the estimated coefficients on human capital agglomeration are significantly positive and pass the 5% significance test. Moreover, the regression coefficients and signs of the control variables are consistent with the results of related literature, and the signs and estimated sizes of the coefficients of human capital agglomeration do not change significantly after the addition of the control variables, which indicates that urban human capital agglomeration significantly contributes to the improvement of the productivity of local enterprises.

Table 2. Impact of human capital agglomeration on enterprise productivity

Variables	TFP_OP		
	(1)	(2)	(3)
HC	0.0256***	0.0251***	0.0232***
	(0.0068)	(0.0067)	(0.0065)
Listdt		0.0055	0.0050
		(0.0116)	(0.0116)
PR		-0.0024	-0.0023
		(0.0081)	(0.0081)
OC		0.0004	0.0004
		(0.0002)	(0.0002)
PSII		0.0012***	0.0012***
		(0.0002)	(0.0002)
Lev		0.1527***	0.1527***
		(0.0244)	(0.0243)
ROA		0.4397***	0.4391***
		(0.1029)	(0.1026)
BS		0.0258**	0.0258**
		(0.0109)	(0.0109)
TobinQ		-0.0152***	-0.0153***
		(0.0031)	(0.0030)
lnpgdp			-0.0079
			(0.0081)
lngorv			0.0301**
			(0.0117)
_cons			
Year FE	YES	YES	YES
City FE	YES	YES	YES
Ind FE	YES	YES	YES
N	9630	9630	9630
R^2	0.4662	0.5781	0.5787

Note: Standard errors in parentheses (* p < 0.1, ** p < 0.05, *** p < 0.01)

4.2. Robustness Test

4.2.1. Examination of endogeneity issues

Table 3. Handling endogeneity: IV

Variables	2SLS First stage (1)	2SLS Second stage (2)
	HC	TFP_OP
HC		0.0744**
		(0.0367)
Geo×pop_rate	-0.6353***	
	(0.0951)	
Year FE	YES	YES
City FE	YES	YES
Ind FE	YES	YES
Cragg-Donald Wald F statistic	189.58	
Kleibergen-Paap Wald rk F statistic	44.32	
N	9630	9630

The benchmark regression in this paper may have endogeneity problems. First, large, well-developed, and highly productive firms may tend to choose their addresses in cities with human capital agglomeration based on talent demand, thus the possibility of reverse causality exists. Moreover, the higher the productivity of local enterprises, the more specialized talents they need to carry out activities such as innovation and R&D, thus attracting the inflow of talent from the surrounding cities and enhancing urban human capital agglomeration. At the same time, the model may also have problems such as omitting important variables and estimation bias caused by unobservable factors. Therefore, this paper draws on Goldsmith-Pinkham et al. (2020) and uses the instrumental variable method (2SLS) for the endogeneity problem by using the degree of terrain relief (Relief) as an instrumental variable [24]. The degree of topographical relief characterizes the geography of an area. With hundreds or even thousands of years of historical population migration, regions gradually formed population concentrations of different sizes, which eventually developed into villages and towns, leading to differences in population density among regions. Therefore, the degree of topographic relief affects regional population distribution, and cities with high levels of relief have relatively low population densities, which inhibit the concentration of human capital to a certain extent, thus affecting the productivity of local enterprises. At the same time, an instrumental variable indicator is constructed using the interaction term between the city's topographic relief and the national annual population growth rate (Relief×pop_rate). Since the topographic relief of the city is not prone to significant changes over time, it does not directly affect the production scale of local firms and satisfies the exogeneity condition. The regression results of the instrumental variable approach are presented in Table 3. The regression results at the first stage show that the instrumental variable indicator Geo×pop_rate has a significantly negative effect on human capital agglomeration, satisfying the correlation assumption for this instrumental variable. and the Cragg-Donald Wald F statistic is higher than the empirical threshold, indicating that the model has no weak instrumental variable problem. Human capital concentration in the two-stage regression shows a significant positive relationship with firm productivity. The coefficient is slightly larger than the benchmark regression results, indicating that the endogeneity problem underestimates the extent of the impact of human capital concentration.

4.2.2. Other robustness tests

Total Factor Productivity (TFP) calculated by the LP method is used as the explanatory variable. The previous analysis used enterprises' total factor productivity (TFP) calculated based on the OP method. To verify whether the estimation results of the benchmark regression rely on the way this indicator is measured, this paper uses the LP method to calculate the total factor productivity (TFP) of enterprises to re-estimate it, and the estimation results are shown in Table Column (1) of Table 4. The regression results show that the impact of human capital agglomeration on firms' productivity is still significantly positive, which is consistent with the benchmark regression results. It shows that the conclusions of this paper are still robust after changing the core explanatory variable measures.

The explanatory variable lagged one period. Use human capital agglomeration lagged one period as an explanatory variable. The human capital agglomeration of a city may experience a period before it has an impact on the productivity of local firms. To address the possibility of time lag when firms' productivity is affected, this paper uses a one-period lag of the explanatory variables to regress total factor productivity. The results reported in tabular column (3) show that the effect of human capital agglomeration on firms' productivity is significantly positive at the 1% level, indicating that the robustness of the regression results is not affected by substituting explanatory variables. c. Random effects (RE). After re-estimation by switching to the random effect model (RE), the results are shown in Table Column (3). The effect of human capital level on productivity remains significantly positive at the 1% level, indicating that the results of the benchmark regression are robust.

Table 4. Robustness testing

Variables	Replacement of explained variables	Replacing the explanatory	Random effect (RE)
	TFP_LP	TFP_OP	TFP_OP
	(1)	(2)	(3)
HC	0.0096*	0.0234***	0.0102***
	(0.0056)	(0.0062)	(0.0039)
Control_company	YES	YES	YES
Control_city	YES	YES	YES
Year FE	YES	YES	YES
City FE	YES	YES	YES
Ind FE	YES	YES	YES
N	9630	8,346	9,630
R^2	0.6008	0.5826	0.2741

5. Analysis of Heterogeneity

The research hypothesis that human capital agglomeration contributes to the enhancement of enterprise productivity has been confirmed, but the question of whether its enhancement effect varies according to the location and enterprise characteristics remains to be analyzed in depth. Therefore, this paper analyzes the heterogeneity of the relationship between human capital agglomeration and enterprise productivity based on differences in location and differences in enterprise characteristics.

5.1. Regional Heterogeneity

In China, there are differences in geographic advantages, resource endowment, economic development foundation, and market maturity among the eastern, central, and western regions. To further examine the degree of influence of human capital agglomeration effect in different regions, this paper divides the city into two sub-samples of the east and the central and western regions for group regression, and the results are shown in Table 5. The results show that human capital agglomeration significantly improves the productivity of firms in the eastern and central and western regions, and the degree of agglomeration in the eastern region has a greater effect on productivity than in the central and western regions. The possible explanation for the above results lies in the fact that firms benefit from the positive impact of the effects of knowledge accumulation, skill matching, and specialized production brought about by human capital agglomeration, whether they are in the eastern or western regions. In addition, in the eastern region, the human capital accumulation is relatively strong, the manufacturing structure and industrial chain are more complete, and a certain scale of enterprise agglomeration has been formed, so local enterprises can absorb the inflow of high-quality human capital more quickly and form large-scale and specialized production, so their productivity is improved more quickly.

Table 5. Regional heterogeneity

Variables	East	Central+West
	(1)	(2)
HC	0.0314**	0.0122**
	(0.0151)	(0.0060)
Control_company	YES	YES
Control_city	YES	YES
Year FE	YES	YES
City FE	YES	YES
Ind FE	YES	YES
N	6555	3075
R^2	0.5685	0.6754

5.2. Enterprise Heterogeneity

There are differences in the production and operation process of enterprises in different growth stages, different property rights nature, and different industries. In this paper, group regressions of human capital agglomeration and enterprise productivity are conducted based on the age of enterprises, the nature of property rights, and industry characteristics. First, for the age of enterprises, enterprises are categorized into young and mature enterprises based on the area-year median of the age of establishment of enterprises; second, enterprises are categorized into state-owned and non-state-owned enterprises based on the nature of ownership of enterprises.

Table 6 reports the results of the heterogeneity analysis of firm characteristics, and the results in columns (1) and (2) show that the productivity of mature firms is sensitive to human capital to a higher degree compared to young firms. Young firms are mostly in the growth and early maturity stages, while firms in the growth stage place more emphasis on investment in R&D programs to stimulate product innovation, as well as the need to absorb capital investment to expand production capacity and market share, and have a higher degree of demand for human capital. However, these enterprises generally have limitations such as relatively imperfect internal business structure, weak competitive ability, and exogenous financing ability, and their attraction to talents and utilization rate of human resources are weaker than those of mature enterprises. When a company enters the mature stage, its operating conditions are relatively stable and its reputation in the market will be gradually accumulated. Although mature enterprises face the real problems of rigid organizational structure, overly conservative business style, and insufficient innovation vitality, they have already formed a relatively perfect management system and business structure, and have a higher status in the market, so they are more attractive to and utilize innovative human capital, and their productivity is more sensitive to the influence of human capital than that of young enterprises. For the nature of firm ownership, according to the results reported in columns (3) and (4) of Table 6, human capital agglomeration is significant for the productivity of both local state-owned and non-state-owned firms, but non-state-owned firms are higher than state-owned firms. SOEs have certain financing advantages, while more non-state private firms often face certain financing constraints, leading to differences in productivity improvement, and non-state firms often need to absorb talent to enhance their market share to expand their financing. Private firms are more flexible in human resource deployment, operational systems, and implementation of innovative strategies, and leaders have a stronger sense of innovation and sensitivity to market opportunities, so they are more affected by regional human capital agglomeration.

Table 6. Enterprise heterogeneity

Variables	TFP_OP			
	life-cycle		Nature of Property	
	Young Enterprise	Mature Business	State-owned enterprises	non-state-owned enterprise
	(1)	(2)	(3)	(4)
HC	0.0152**	0.0419**	0.0133**	0.0220*
	(0.0064)	(0.0167)	(0.0060)	(0.0117)
Control_company	YES	YES	YES	YES
Control_city	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Ind FE	YES	YES	YES	YES
N	6330	3,300	7041	2579
R^2	0.6912	0.5876	0.6086	0.7039

For the heterogeneity analysis of industry and factor intensity, this paper first takes the Classification and Codes of Listed Companies (2012 Edition) issued by the China Securities Regulatory Commission (CSRC) as the basis, and treats the enterprises with the first letter of the industry code C as manufacturing industries, and the rest of the enterprises as non-manufacturing industries. Secondly, according to the industry in which the enterprise is located, the enterprise is divided into labor-intensive, capital-intensive, and technology-intensive industries, and the results of the heterogeneity of the industry division are shown in Table 7.According to the regression results of Column (1) and Column (2), the degree of the impact of human capital agglomeration on the productivity of non-manufacturing

industries is sensitive to the degree of the enterprises in the manufacturing industry. Although the manufacturing industry has more room for innovation in technology and R&D, its independent R&D capability is weak compared to developed countries, and the input-output efficiency of innovation is low. Therefore, compared with the high cost of independent R&D, manufacturing enterprises are more inclined to imitate and introduction of advanced technology, and the quality of R&D personnel demand is relatively low. In recent years, some enterprises in non-manufacturing industries such as “Internet+”, information industry, software service, etc., have been continuously upgrading their R&D level with a series of national policies and financial support, making R&D the main path for enterprises to improve, and thus their productivity is more susceptible to the influence of human capital agglomeration. The results in columns (4) to (6) show that the effect of human capital agglomeration on productivity enhancement is more prominent in labor-intensive enterprises, followed by capital-intensive enterprises, with a weaker significance in technology-intensive enterprises. One of the possible reasons for this is that labor-intensive firms have a large share of employees, and employee compensation increases the firm's labor cost, which makes managers more motivated to undertake innovation and R&D projects in pursuit of productivity returns to fill the huge labor cost.

Table 7. Industry heterogeneity

Variables	TFP_OP				
	Manufacturing	Non-manufacturing	labor-intensive	Capital-intensive	Technology-intensive
	(1)	(2)	(3)	(4)	(5)
HC	0.0116*	0.0425***	0.0466***	0.0182**	0.0077
	(0.0065)	(0.0149)	(0.0120)	(0.0083)	(0.0082)
Control_company	YES	YES	YES	YES	YES
Control_city	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES
Ind FE	YES	YES	YES	YES	YES
N	5835	3795	3308	3056	3259
R^2	0.6401	0.5840	0.6784	0.7237	0.6385

6. Analysis of Impact Mechanisms

6.1. Knowledge Spillovers and Technological Innovation

An increase in the degree of urban human capital agglomeration will promote the occurrence of innovative behaviors in enterprises, thus enhancing their productivity. People with higher education have higher independent innovation ability than those with lower education, and are more capable of accepting and learning new knowledge and skills, thus better promoting R&D innovation and technological progress of enterprises. At the same time, the gathering of talents accelerates the sharing of knowledge and information between people, so that geographically nearby enterprises can learn from each other in terms of technology, management, and production methods, and realize the complementary advantages in all aspects. Based on the above analysis, this paper takes the invention patent application situation as the mechanism variable of knowledge and innovation effect. IApply1 is the logarithm of the number of invention patent applications per year in the city, and IApply2 is the logarithm of the number of invention patent applications per year in the enterprise. The results reported in column (1) of Table 8 show that the coefficients of urban human capital agglomeration are all significantly positive, indicating that human capital agglomeration generates knowledge spillovers to the innovation environments of both cities and firms, stimulates urban innovation vitality, promotes technological innovation of firms, and then enhances the productivity of firms.

6.2. Skill Matching and Specialized Production

Human capital agglomeration facilitates the matching of labor and the specialization of firms. On the one hand, human capital agglomeration reduces search costs for firms, making it easier for firms to obtain a workforce that matches their production needs. At the same time, workers also have more potential employment opportunities and are more likely to find desired jobs that match their skills, which reduces the probability of frictional unemployment in the local labor market. On the other hand, the rich human resources in the city provide a good external environment for the competition and division of labor of local enterprises. The mobility of highly skilled people in different fields in the labor market encourages firms to focus more on improving their specialization to gain a competitive advantage. At the same time, enterprises can obtain more timely information on market dynamics and technological updates through cooperation. Specialized division of labor helps to accelerate the improvement of enterprise production efficiency. Therefore, this paper uses the ratio of urban employed population and resident population as the employment rate to measure the degree of urban labor force matching (Emp) and the enterprise Herfindahl-Hirschman Index (HHI) to measure the degree of specialization. The regression results in columns (3) and (4) of Table 8 show that the coefficients of human capital agglomeration on the degree of labor force matching and the degree of specialization are both significantly dominant at the 5% level. Thus, urban human capital agglomeration promotes skill matching in the labor market and the degree of specialization of local firms, which in turn increases firms' productivity.

Table 8. Analysis of impact mechanisms

Variables	Knowledge spillovers and technological innovation		Skill matching and specialized production	
	IApply1	IApply2	Emp	HHI
	(1)	(2)	(3)	(4)
HC	0.3038***	0.1672**	0.0282**	0.0199**
	(0.0496)	(0.0694)	(0.0113)	(0.0086)
Control_company	YES	YES	YES	YES
Control_city	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
N	9615	9615	7560	9,591
R^2	0.9760	0.4410	0.5379	0.5346

7. Conclusions

Based on a sample of listed enterprises from 2006 to 2020, this paper investigates the impact of human capital agglomeration in cities on the production efficiency of enterprises through a fixed-effects model. It analyzes how human capital enhances the total factor productivity of enterprises in terms of the mechanisms of knowledge spillover and technological innovation, skill matching, and specialized production. The results of empirical analysis show that human capital agglomeration has a significant role in promoting the productivity of enterprises. The findings remain reliable after a series of robustness tests. Heterogeneity analysis shows that there are differences in the extent to which human capital agglomeration affects the productivity of enterprises in different regions, stages, ownerships, and industries. Among them, the productivity of eastern regions, young enterprises, non-state-owned enterprises, and manufacturing enterprises are more sensitive to the promotional impact of human capital agglomeration. Mechanism analysis shows that urban human capital agglomeration enhances firms' productivity by promoting knowledge spillovers and technological innovation in the R&D sector, facilitating the efficiency of skill matching in the labor market, and increasing the degree of firm specialization.

The conclusions of the study have theoretical and practical significance for the development of cities and enterprises, which can provide a reference for the development of the knowledge environment and job market in cities, and also help enterprises to discover effective ways to improve their productivity. Therefore, this paper puts forward the following suggestions: (1) Focus on regional talent cultivation. The government should take into account both the introduction and cultivation, and emphasize the investment in education and scientific research while formulating policies related to the introduction of talents, to improve the talent cultivation and innovation level of local universities, and create a favorable atmosphere for the development of the local market and the production of enterprises. In addition, the enterprise level should improve the talent management system, improve the personnel structure of management, R&D, and technical departments within the enterprise, improve the utilization efficiency of personnel with different skills, and provide human resources support for the production and operation of the enterprise; (2) Based on the differences in the degree of the role of human capital in different regions, flexible talent policies should be formulated according to local conditions. The eastern region with a higher degree of human capital concentration should pay more attention to the demand of the labor market to prevent the phenomenon of “saturation” and the excess competition for talent. At the same time, to strengthen exchanges between the eastern and western regions, the establishment of an open platform for the exchange of talent, and enhance the efficiency of human capital utilization. In addition, the western region should carry out appropriate policy adjustments, such as education investment, infrastructure, corporate tax burden, etc., to create a good business environment for the cities in the western region, attract foreign talent, and promote the degree of match between human capital and enterprises. (3) In terms of enterprise development, relevant departments should focus on mature enterprises and state-owned enterprises and encourage mature enterprises to change. Increase the support of innovation funds, assist in building innovation platforms for schools and enterprises, and encourage the flow of talents and the transformation of technical cooperation results. Mature enterprises should embrace the cultural value of trial and error, appropriately transform their business processes in combination with new technologies such as big data, improve incentives for innovation, weaken management control, and enhance the initiative and creativity of talents. In addition, sound and open industrial innovation platforms, pooling industry and technology quality resources, and strengthening intellectual property protection provide favorable conditions for independent R&D in the manufacturing industry.

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