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Human capital structure and new quality productive forces in manufacturing: a mediation analysis

Abstract

Research background and purpose: Against the backdrop of China's 2025 Government Work Report's strategic initiative to cultivate new quality productive forces, this study investigates how human capital drives manufacturing transformation. While talent's importance is widely recognized, the mechanisms through which talent quality enables new quality productive forces remain underexplored. Despite growing policy emphasis, empirical investigation into this mechanism remains limited. This study clarifies talent's central role in innovation-driven manufacturing and aims to empirically examine how talent quality within manufacturing firms enhances new quality productive forces.
Design/methodology/approach: Grounded in the theory of talent-driven new quality productive forces, this study employs a mediation effect testing model. The research sample comprises Shanghai and Shenzhen A-share listed manufacturing enterprises in China from 2009 to 2023. Data were collected and analyzed to examine both direct and indirect effects, with technological innovation serving as the mediating variable.
Findings: Empirical results demonstrate that talent quality in manufacturing enterprises significantly drives the enhancement of new quality productive forces. Furthermore, technological innovation plays a crucial mediating role in this relationship, indicating that talent enhances productive forces partially through fostering innovation capabilities.
Value added and limitations: This research extends human capital theory to emerging productive forces, providing empirical evidence from Chinese manufacturing and enriching understanding of talent-innovation-productivity linkages. Practically, it offers insights for manufacturing enterprises on talent development strategies and for the human resources service industry on collaborative mechanism innovation and diversified business models. These findings have implications for policymakers seeking to foster new quality productive forces through talent development initiatives. Limitations include sample restriction to Shanghai and Shenzhen A-share listed manufacturing firms, limiting generalizability to private firms, SMEs, or other sectors. The model may not capture all confounding variables, suggesting future research should validate findings across broader contexts and explore moderating effects of firm characteristics and policy environments.

Keywords: *human resource supply, new quality productive forces, mediation effect testing, human resources service industry*

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1. Introduction

Against the backdrop of accelerating global economic integration and technological revolution, manufacturing – as the core pillar of national economies – has seen its transformation, upgrading, and high-quality development become a key focal point in global competition. Historically, manufacturing evolved from manual production to mechanization and automation, and now to intelligent and digital transformation. Each technological leap profoundly reshaped the landscape of productive forces. Both neoclassical growth theory and endogenous growth theory emphasize the central role of technological progress and human capital accumulation in driving economic growth. Particularly in recent years, with the rise of emerging technologies such as big data, cloud computing, and artificial intelligence, manufacturing is entering a new phase of productive forces development driven by technological innovation.

In recent years, the Chinese government consistently emphasized in its work reports the strategic direction of „developing new quality productive forces tailored to local conditions" and "expanding and strengthening advanced manufacturing." This fully demonstrates the nation's unwavering determination and strategic resolve to advance high-quality development in manufacturing. As a global manufacturing powerhouse, China has possessed not only a comprehensive industrial system and robust industrial foundation but also well-established advantages in industrial chains and supply chains. However, at this critical juncture of profound restructuring in global industrial and value chains alongside accelerated transformation of China's domestic economic development model, Chinese manufacturing faces dual challenges: competitive pressure from developed nations'. "Reindustrialization" strategies and low-cost competitive advantages from emerging economies. Simultaneously, the ongoing optimization and upgrading of China's domestic economic structure demands higher standards for manufacturing to transition toward high-end, intelligent, and green development. Against this backdrop, accelerating the transformation and upgrading of manufacturing while cultivating new productive forces has become both an inevitable choice and an urgent task for driving high-quality economic development.

Talent, as the core element of innovation, directly impacts the cultivation and development of new productive forces in manufacturing through its quality and allocation efficiency. Particularly in the current economic transition, talent serves as a key driver, playing a decisive role in the high-quality development of manufacturing by enhancing technological R&D capabilities, optimizing production processes, and promoting industrial upgrading. Therefore, exploring from the perspective of talent supply how the human resources service industry can effectively boost the development of new quality productive forces in manufacturing through precise matching, efficient training, and continuous empowerment not only holds profound theoretical significance but also provides practical guidance for policy formulation and corporate practice.

The research topic of this paper is study on how human resources services industry boosts the development of New Quality Productive Forces in manufacturing from a talent supply perspective. This study has aimed to achieve the following objectives: 1. Empirically analyze the driving role of talent quality in manufacturing's new quality productive forces: by constructing a mediation effect testing model, quantify the relationship between talent quality, technological innovation, and new quality productive forces to provide scientific basis for manufacturing talent strategies. 2. Explore pathways and mechanisms for the human resources service industry to promote the development of new quality productive forces in manufacturing: propose specific strategies for the human resources service industry to facilitate high-quality development in manufacturing, focusing on innovations in collaborative development mechanisms, diversified business models, and digital-intelligent transformation within the industry. 3. Provide guidance for policy formulation and the business community: based on empirical analysis and theoretical discussions, offer scientific evidence and practical guidance for government policies on manufacturing transformation and upgrading, as well as for enterprises optimizing talent allocation strategies.

Based on existing theory and practice, this study has hypothesized that: High-quality talent supply is a key driver for advancing new quality productive forces in manufacturing. By innovating service models and implementing digital and intelligent reforms, the human resources service industry can precisely match talent demands in manufacturing, promote equilibrium between talent supply and demand, and thereby accelerate the formation and development of new quality productive forces in manufacturing. Based on this hypothesis, this study constructs a mediation effect testing model. Using data from Shandong-based manufacturing enterprises listed on the Shanghai and Shenzhen A-share markets from 2009 to 2023, it has empirically analyzed the driving role of talent quality in new quality productive forces within manufacturing and explored the mediating effect of technological innovation in this process. Furthermore, this study proposes pathways for promoting high-quality manufacturing development from the perspective of the human resources service industry, including innovation in collaborative development mechanisms, diversification of business models, and digital and intelligent transformation of the sector. This research not only has enriched the theoretical framework of new quality productive forces but also has provided actionable strategic recommendations for practitioners, filling gaps in existing research.

This paper has employed a combined quantitative and qualitative analytical approach. For quantitative analysis, an intermediary effect testing model is utilized to empirically examine the relationships among talent quality, technological innovation, and new quality productive forces. Qualitative analysis employs policy analysis to deeply explore pathways and mechanisms through which the human resources service industry can promote the development of new quality productive forces in manufacturing.

Key findings include: talent quality in manufacturing enterprises significantly drives the enhancement of new quality productive forces levels, with technological innovation playing a crucial mediating role. The human resources service industry can effectively promote the balance between talent supply and demand in manufacturing and enhance the sector's core competitiveness through measures such as synergistic development mechanism innovation, diversified business innovation, and digital-intelligent transformation of the industry.

Existing research exhibits shortcomings in the quantitative analysis of the relationship between talent quality and new quality productive forces in manufacturing, with insufficient exploration of the mediating effect of technological innovation. Studies on the pathways and mechanisms through which the human resources services industry promotes the development of new quality productive forces in manufacturing lack systematic and comprehensive approaches and fail to adequately examine specific practical strategies and operational methods.

2. Literature review

2.1. Literature review on human capital structure

Research on human capital structure, both domestically and internationally, has predominantly examined its aggregate impact on macroeconomic outcomes such as economic growth and productive forces enhancement. A significant theoretical strand within this literature has investigated its internal composition and optimal accumulation. Driskill and Horowitz (2002) proposed a foundational hierarchical model, positing that human capital is not homogeneous but possesses an internal structure where advanced human capital is produced from the inputs of basic human capital. Their work formalized this distinction, constructing an optimal investment dynamic model within a growth framework, which demonstrates that the efficient investment path is critically dependent on the initial compositional hierarchy of the human capital stock.

Extending this theoretical line, Driskill et al. (2009) generalized the two-tier hierarchy to an N-tier structure. Their refined growth model revealed that distinct optimal investment strategies exist across different phases – ranging from stock depletion to the expansion of various hierarchical levels – highlighting the dynamic complexity of human capital formation. Parallel to this focus on investment allocation, Su (2006) analyzed the sectoral distribution of public education resources. Examining the dynamic effects of allocating a fixed budget between basic and higher education, the study concluded that the under-investment in basic education prevalent in many developing economies is a key driver of economic divergence, thereby linking human capital structure to broader developmental outcomes.

Building on foundational theories, subsequent research has refined our understanding of how the composition of human capital influences growth, particularly through the lens of technology. Ramcharan (2004) operationalized this composition by categorizing human capital stock into three skill-based types – unskilled, low-skilled, and high-skilled – according to educational attainment. By integrating this typology into a standard Cobb-Douglas production function, his model provide a pivotal explanation for the ambiguous link between aggregate measures like average years of schooling and economic growth. A core theoretical insight is the proposed complementarity between high- and low-skilled human capital within technology sectors, suggesting that balanced investment in both is essential for development.

This theme of differentiated roles was further theorized in a dynamic context by Vandenbussche, Aghion, and Meghir (2006). Their seminal endogenous growth model (the VAM model) framed technological progress as stemming from both innovation and imitation, assigning distinct functions to skilled and unskilled labor. The model posited that unskilled labor is primarily suited for imitation, with its marginal productive forces diminishing as an economy approaches the global technological frontier. Consequently, near the frontier, innovation driven by skilled labor – and thus higher education – becomes the critical engine of growth. This frontier-dependent view was challenged and nuanced by Cerina and Manca (2018), who extended the VAM model with empirical evidence. They argued that advanced human capital is vital for fostering innovation and growth even in low-income countries far from the technological frontier, highlighting its universal strategic importance.

Complementing these macro-growth perspectives, Sequeira (2007) explicitly introduced human capital structure into an R&D-driven endogenous growth framework. His work underscored the indispensable role of high-tech human capital in directly fueling technological innovation, thereby establishing a more direct theoretical channel through which human capital composition affects long-term economic performance.

2.2. Research on New Quality Productive Forces

The concept of New Quality Productive Forces (NQPF) has emerged as a pivotal framework in understanding contemporary economic transformation, representing a qualitative leap in laborers, means of labor, objects of labor, and their synergistic combination. Scholarly inquiry has predominantly engaged with this concept through the lens of its constituent elements and defining characteristics.

A foundational stream of literature deconstructs NQPF via its core components. Pu and Xiang (2024) conceptualized it as the organic integration of high-quality labor, advanced means of labor, and expansive objects of labor, signifying a holistic upgrade of production factors. Complementing this, Gao (2023) highlighted the critical role of

penetrative elements like emerging technologies and data, which distinguish NQPF from traditional productive forces and act as key drivers for socio-economic upgrading. Further theorizing the interaction between elements, Zhou and Xu (2023) argued that the deep fusion of science and technology with the foundational triad was crucial for translating scientific advances into tangible productive forces, marking a shift from material-based to intellect-driven productive forces. This systemic view was extended by Liu et al. (2023), who posited that the coordinated development of the new elements enhanced industrial chain synergy, implying a concurrent need for institutional adaptation to fully realize NQPF's potential.

Parallel to elemental analysis, significant effort has been devoted to crystallizing the constitutive features of NQPF. Chen et al. (2024) situated the concept within a broader theoretical lineage, linking it to discourses on high-quality development and innovation-driven growth. Several scholars have proposed multidimensional frameworks for its characteristics. For instance, Guo et al. (2024) distilled its core into three pillars: "New" (novel industries and organization), "Quality" (substantive improvement and optimization), and "Force" (enhanced network and computational capabilities). Similarly, Ren et al. (2024) characterized NQPF as innovation-led productive forces aligned with a new development philosophy, where "New" and "Quality" pertain to technological/industrial novelty and high efficiency/quality, respectively. Adding a critical dimension, Zhang et al. (2024) emphasized that NQPF encompassed not only objective technological factors but also the essential subjective human agency. He (2024) provided a synthesized perspective, identifying its hallmarks as revolutionary technology, innovative factor allocation, and industrial transformation, with innovation and quality being its inherent attributes.

Moving beyond theoretical elaboration, a nascent but growing quantitative strand seeks to operationalize the concept. Scholars like Wang and Wang (2024), Zhu et al. (2024), Han et al. (2024), and Liao et al. (2024) constructed provincial-level evaluation index systems based on the tripartite elements to assess China's regional NQPF development. Adopting a different approach, Zhao et al. (2024) developed a multi-dimensional index for prefecture-level cities, focusing on technological, green, and digital productive forces. These efforts have marked an important step towards empirically grounding the study of NQPF.

2.3. Research gap and the contribution

Despite valuable insights from existing literature on both human capital structure and New Quality Productive Forces (NQPF), critical gaps have remained at their intersection. The current body of work has exhibited two primary limitations. First, there is a pronounced scarcity of rigorous quantitative evidence establishing the causal impact of firm-level human capital structure on NQPF development. Second, the

operationalization and measurement of NQPF have largely remained at the regional or sectoral level, with a notable lack of micro-founded, enterprise-specific indicator systems that capture the qualitative leap in productive forces.

To directly address these dual deficiencies, the present study has made three integrated contributions. Methodologically, it has developed and validated a novel, multi-dimensional indicator system for measuring NQPF at the enterprise level, utilizing the entropy weighting method for objective aggregation. Empirically, it has employed a two-way fixed effects model on a comprehensive panel dataset of Chinese listed manufacturers to rigorously identify the relationship between corporate human capital structure and NQPF, controlling for key confounders. Theoretically, by testing the mediating role of technological innovation, this research has moved beyond establishing a mere association to propose and examine a specific mechanism through which human capital composition influences advanced productive forces.

Consequently, this study has bridged the macro-theoretical discourse on NQPF with micro-strategic analysis, offering evidence-based insights for firms to optimize their talent architecture and for policymakers to design targeted industrial human capital strategies in the era of technological transformation.

3. Theoretical analysis of talent-driven development in New Quality Productive Forces

The theory of productive forces posits that „laborers, means of labor, and objects of labor" constitute the three fundamental elements of productive forces. Laborers, who engage in social production with certain experience and labor skills, play a dominant role in the development of productive forces. The means of labor and objects of labor are the material components of labor activity. Laborers utilize elements of production to transform and process the objects of labor, thereby serving as the intermediary for the transmission of human processing and transformation of nature. The objects of labor refer to the materials processed in social production. Through foundational knowledge, technical skills, practical experience, social relations organization etc., laborers act upon production objects, upgrade labor data, enhance personal competencies, drive technological innovation, and ultimately advance the development of productive forces. Therefore, the „new" of the New Quality Productive Forces is reflected in the innovation, optimization, combination and allocation of the three elements – laborers, means of labor, and objects of labor. These elements are driven by scientific innovation and technological guidance. Moreover, the concept of "quality" is manifested in the objective of achieving high-quality industrial development, characterized by the presence of highly skilled laborers, technologically advanced and innovative means of labor, and the vertical and horizontal expansion of labor objects. This approach has

been shown to improve efficiency and quality in industrial development, as evidenced by innovation, advanced digital intelligence, high skill intensity, and cross-disciplinary integration.

3.1. Synergistic interaction of production factors elevates New Quality Productive Forces

Production factors typically include land, labor, capital, and technology, which sustain the operation of the national economy and the production and business processes of market players (Kharitonashvili, 2022). Capital is comprised of financial capital and human capital. Financial capital is the material foundation for talent-driven productive forces, thereby enabling production activities. Human capital, embodied in the knowledge, skills, attitudes, and qualities of workers, is a crucial carrier of productive forces realization and is normally referred to as "living capital". It stands out for its innovative and creative nature, effectively allocating resources and adjusting corporate development strategies, demonstrating strong market adaptability. From a technological perspective, science and technology represent the primary productive force, serving as the core carrier and manifestation of the value embodied in human capital. Hence, New Quality Productive Forces leverage human capital to showcase the advanced, innovative, high-end, and cutting-edge aspects of technology during the labor process, achieving technological breakthroughs, innovative resource allocation, and industrial structure upgrades.

3.2. Balancing the structure of supply and demand for human resources to consolidate the intrinsic driving force for the development of New Quality Productive Forces

The source and purpose of developing New Quality Productive Forces is to realize the in-depth industrial transformation, while the high-quality and well-matched talent supply plays the role of the core driving force in industrial development and transformation. According to statistics, the main contradiction of China's manufacturing human resource market is the structural contradiction between the supply of low-quality talents and the demand for high-level talents. Especially in recent years, with the continuous expansion of emerging fields, such as AIGC, big data, cloud computing, metaverse, etc., which require high-quality talents, it is far from being able to achieve sufficient supply. This shortage restricts the deep transformation of emerging industries and, to a certain extent, hampers the formation speed of New Quality Productive Forces as well.

The quality of talent cultivation should align with the demands of industrial upgrading, technological advancement, and scientific development, aiming to drive

industrial restructuring. This includes sectors such as next-generation information technology, new materials, digital twins, big data, cloud computing, intelligent manufacturing, marine engineering etc. Achieving a balanced talent supply and demand structure ensures that the professional competence of talent fully in accordance with deep industrial transformation, fundamentally transforming numerical personnel advantages into innovative and human capital strengths, thereby reinforcing the intrinsic driving force for the formation and development of New Quality Productive Forces.

3.3. Innovative talent policies boost the exogenous driving force for New Quality Productive Forces development

Flexible and dynamic talent policies can effectively promote innovative allocation of production factors. On the one hand, innovating talent recruitment and cultivation mechanisms, smoothing talent mobility channels, and enabling the free flow of all production factors are critical. Simultaneously, it is necessary to eliminate bureaucratic constraints in talent management and move beyond the narrow "Five-Only" criteria in talent evaluation (e.g., overemphasis on academic credentials, papers, titles, awards, and overseas experience). Furthermore, efforts should be made to improve various systems such as talent training and development, utilization and management, salary incentives, labor and social security, and talent title evaluation and review. These measures address the "last mile" in talent management, providing policy support for high-level talent to freely move, deeply engage in research and development (R&D), and pursue innovation and entrepreneurship. On the other hand, under the influence of the talent agglomeration effect, high-level professionals and talents are often concentrated in the eastern or coastal economically developed areas, which results in pronounced regional disparities and geographical imbalances in talent distribution. This hinders the optimal combination of production factors across regions and weakens the synergistic effects of resource allocation at the regional level. Therefore, addressing this issue requires strong national policy interventions to guide balanced mobility of high-quality human capital and mitigate regional inequalities.

Based on the above analysis, this paper has proposed the following research hypotheses:

H1: Upgrading of corporate human capital structure significantly promotes the development of new quality productive forces.

H2: Technological innovation has a mediating effect between upgrading corporate human capital structure and improving new quality productive forces.

4. Empirical research design on talent driven development of New Quality Productive Forces in the manufacturing industry

4.1. Data sources

The research in this paper has taken Chinese manufacturing enterprises listed in Shanghai and Shenzhen A-shares from 2009 to 2023 as the research object, and has carried out relevant processing on the extracted sample data: firstly, the sample enterprises in ST and *ST status in the current year has been excluded; secondly, the sample enterprises with missing data has been excluded similarly, and 25029 observations are obtained at the end. Meanwhile, in order to eliminate the influence of extreme values, all continuous variables have been shrunk at the 1% level in this paper.

4.2. Defining variables

The dependent variable of this article is the new quality productive forces of manufacturing enterprises in Shandong Province. The core of new quality productive forces is innovation. Therefore, this study has been based on the two-factor theory of productive forces and has taken into account the role and value of the object of labor in the production process. The entropy value method has been used to measure new quality productive forces. The specific method is as follows: based on the two-factor theory of productive forces, a new quality productive forces index system is constructed. Productive forces mainly covers two elements: labor force and production tools. Among them, the sub-elements of labor force are reflected in live labor and materialized labor, that is, the object of labor; the sub-elements of production tools are reflected in hard technology and soft technology. Considering the innovation connotation in new quality productive forces, the indicators of the live labor sub-factor are respectively measured by the salary of R&D personnel, the proportion of R&D personnel, and the proportion of high-education personnel; the indicators of the materialized labor sub-factor are respectively represented by the proportion of fixed assets. Considering that the enterprises with new quality productive forces are mainly concentrated in the high-precision technology field of equipment manufacturing, most of these enterprises rely on high-end machines and instruments for production, and machine production replaces manual production. The proportion of manufacturing expenses of these enterprises is higher than that of other enterprises. Therefore, the proportion of manufacturing expenses is also included in the index selection. The sub-factor of hard technology mainly involves hardware equipment related to R&D investment. Therefore, it is measured by the proportion of direct R&D investment, the proportion of depreciation and amortization, and the proportion of lease expenses. At the same time, considering the role of intangible assets such as software, the proportion of intangible assets is also used to measure. The sub-factor of soft technology is mainly measured by the total asset turnover

rate and the equity multiplier. The higher the equity multiplier, the lower the financial risk of the enterprise, which is negatively correlated with other indicators. Therefore, the reciprocal of the equity multiplier is used to represent it; that is, the higher the reciprocal of the equity multiplier, the lower the financial risk of the enterprise, and the higher the productive forces level of the enterprise. The value explanations of the above indicators are detailed in the following Table 1.

Table 1. **Indicators of New Quality Productive Forces for manufacturing enterprises**

Factor	Subfactor	Indicator	Description of indicator value	Weight
Labor force	Labor	Percentage of R&D salaries	Research and development expenses - salaries and wages/operating income	28
		Percentage of R&D staff	Number of R&D staff / Number of employees	4
		Percentage of highly educated personnel	Number of people with bachelor's degree or above / Number of employees	3
	Physical labor (objects of labor)	Fixed assets as a percentage	Fixed assets/total assets	2
		Manufacturing costs as a percentage	(Subtotal cash outflows from operating activities + depreciation of fixed assets + amortization of intangible assets + provision for impairment - cash paid for purchases of goods and services - wages paid to and for employees) / (Subtotal cash outflows from operating activities + depreciation of fixed assets + amortization of intangible assets + provision for impairment)	1
Production tool	Hard technology	R&D depreciation and amortization as a percentage of	R&D expenses - depreciation and amortization/operating income	27
		Percentage of R&D lease payments	Research and development expenses - lease payments/operating income	2
		R&D direct investment as a percentage	R&D expenses - direct inputs/operating income	28
		Intangible assets as a percentage	Intangible assets/total assets	3
	Soft technology	Total asset turnover	Operating income/average total assets	1
		Inverse equity multiplier	Owners' equity/total assets	1
New mass productive forces				100

Source: own study

In this paper, enterprise human capital structure (Skill-Unskill) has been measured by the ratio of skilled labor to unskilled labor of enterprise employees. According to the job positions and contents of the employees, the research in this paper has defined the employees engaged in technology, R&D and other jobs as a high-skill labor force, and the employees engaged in sales, production, finance and other jobs as a low-skill labor force, and the ratio of the number of the two indicates the human capital structure. Meanwhile, in the robustness test, the human capital structure has been measured based on the education of employees, and employees with postgraduate education or above are defined as highly educated labor force, and those with postgraduate education or below are defined as low educated labor force, and the ratio of the number of the two indicates the human capital structure based on the education level (High-Low).

This article has selected the innovation level of enterprises as an intermediate variable. This study has obtained information on invention patents of Chinese listed firms from the Economic and Financial Database (CCER), including data on filing date, International Patent Classification (IPC) number, main classification (MCT) number, patent type, and number of pages.

In this paper, the logarithm of the number of invention patents filed by listed firms in the year plus one has been used to measure corporate innovation.

In order to improve the precision of the study, this study has incorporated a series of control variables with reference to the methodology of Zhu and Ma (2024). These include board size (Bsize), equity concentration (Top1), return on total assets (ROA), Tobin's Q (Tobin_q), book-to-market ratio (BM), firm size (Size), gearing ratio (Lev), cash flow position (Cash), growth capacity (Growth), duality, proportion of independent directors (Indep), operating income size (Indep), and proportion of independent directors (Indep). (Indep), and operating income size (Revenue), and the detailed data structure of the variables can be found in Table 2.

Table 2. **Variable definitions**

Variable type	Variable name	Variable symbol	Way of measuring
Explanatory variable	Firms' new quality productive forces	NQPF	The entropy value method calculates the weight of each indicator to form the new quality productive forces indicator of the enterprise
Explanatory variable	Human capital structure	Skill-Unskill	Employment Ratio of Skilled Labor to Unskilled Labor for Firm Employees
Intermediary variable	Enterprise innovation level	Innov	The number of invention patent applications filed by listed enterprises in the year plus 1 to take the logarithm

Control variable	Board size	Bsize	Number of board members, in natural logarithms
	shareholding concentration	Top1	Shareholding ratio of the largest shareholder
	return on total assets	ROA	Net profit of the company divided by total assets
	Tobin's Q	Tobin_q	Enterprise market value/(total assets - net intangible assets - net goodwill)
	Book-to-market ratio	BM	Market price/book value
	Company size	Size	Natural logarithm of total assets at the end of the period
	Gearing	Lev	Total company liabilities divided by total assets
	Cash flow position	Cash	Net cash flow from operations divided by total assets
	Growth capacity	Growth	Revenue growth rate
	Two jobs in one	Duality	Whether the chairman of the board of directors is also the general manager, if so, 1, otherwise 0
	Proportion of independent directors	Indep	Ratio of the number of independent directors to the number of board of directors for the year
	Size of revenue	Revenue	Operating income is taken as the natural logarithm
	sector	IND	Controlling for industry fixed effects
	particular year	Year	Controlling for year fixed effects

Source: own study

4.3. Design model

In this paper, the study has examined the influencing factors and acting mechanism of talent-driven new quality productive forces development by constructing a mediator effect model, which has been validated by adopting the mediator effect test used in studies such as those of Alfons, Ates and Groenen (2022) and Fairchild and MacKinnon (2009), and the specific validation model is as follows:

$$Y=cX+e1 \quad (1)$$

$$M=aX+e2 \quad (2)$$

$$Y= c'X + bM + e3 \quad (3)$$

In the above equation, X is the human capital structure of listed manufacturing companies as the independent variable, Y is the new quality productive forces of enterprises as the dependent variable, M is the innovation level of enterprises as the mediator variable, c, a and b are regression coefficients, and e1, e2 and e3 are random disturbance terms.

According to the above model, based on the coefficient c is significant, the mediation effect test is carried out in three steps: the first step is to test a in formula (1) and b in formula (2) in turn, if both coefficients are significant, it means that the mediation effect of enterprise innovation level is significant, otherwise, the Bootstrap method is used to re-verify. The second step is to verify the coefficient c in equation (3). If it is significant, it means that the direct effect of new quality productive forces on firms' innovation level is also significant; otherwise, only the mediating effect holds. The third step is to compare the sign of c′ with that of ab. If the signs of c′ and ab are the same, it is believed that the innovation level of the firms plays a partial mediating role; if the signs of c′ and ab are different, it is believed that the innovation level of the firms plays a masking effect. The specific regression model is as follows:

$$NQPF_{i,t} = \alpha 0 + \alpha 1 skill\text{–}unskill_{i,t} + \alpha 2 controls_{i,t} + Year + Ind + \varepsilon 1_{i,t} \quad (4)$$

$$Skill\text{–}unskill_{i,t} = \beta 0 + \beta 1 Innov_{i,t} + \beta 2 controls_{i,t} + Year + Ind + \varepsilon 2_{i,t} \quad (5)$$

$$NQPF_{i,t} = \gamma 0 + \gamma 1 skill\text{–}unskill_{i,t} + \gamma 2 Innov_{i,t} + \gamma 3 controls_{i,t} + Year + Ind + \varepsilon 3_{i,t} \quad (6)$$

Where i and t represent the company and year respectively, NQPF is the new quality productive forces of the enterprise, Skill-Unskill is the human capital structure of the enterprise, and Innov is the innovation level indicator of the enterprise. In order to prevent economic cyclical fluctuations, the introduction of human resources and talent policies, unexpected events and other factors from affecting the model, this paper controls for the fixed effects of time (Year) and industry (Ind), and the random error term is denoted by εit. According to the previous theoretical analysis, if the coefficient β of Skill-Unskill is significantly positive, which is consistent with the propositional hypothesis, it indicates that enterprise talent drives the development of new quality productive forces.

5. Empirical analysis of talent driven New Quality Productive Forces

5.1. Descriptive statistics

The descriptive statistical values of the main variables are shown in Table 3. It can be seen that the mean value of the new quality productive forces of enterprises is 4.033, and the standard deviation is 1.997, indicating that there are large differences in the new quality productive forces among enterprises; the mean value of the human capital structure (Skill-Unskill) is 0.395, and the standard deviation is 0.707, respectively, indicating that there are large differences in the skill structure of the labor force among enterprises. The mean and standard deviation of enterprise innovation level (Innov) are 0.301 and 0.673 respectively, with the minimum value of 0 and the maximum value of 3.219, indicating that the level of enterprise innovation and development varies significantly among different enterprises.

Table 3. **Descriptive statistical analysis**

Variables	(1)	(2)	(3)	(4)	(5)
	N	Mean	SD	Min	Max
NQPF	25,029	4.033	1.997	1.270	21.150
Skill-Unskill	25,029	0.395	0.707	0.0145	4.780
Innov	25,029	0.301	0.673	0	3.219
Bsize	25,029	10.09	2.566	5	18
Top1	25,029	34.69	14.62	9.730	74.57
ROA	25,029	0.0389	0.0633	-0.272	0.200
Tobin_q	25,029	2.028	1.286	0.856	8.514
BM	25,029	0.620	0.245	0.117	1.168
Size	25,029	22.15	1.273	19.89	26.06
Lev	25,029	0.413	0.206	0.0533	0.914
Cash	25,029	0.899	1.451	0.0244	9.258
Growth	25,025	0.169	0.534	-0.885	3.477
Duality	25,029	0.287	0.452	0	1
Indep	25,029	0.383	0.0729	0.250	0.600
Revenue	25,028	21.47	1.430	18.52	25.52

Source: own study

5.2. Return to baseline

The results of the baseline regression on the effect of firm talent on driving new quality productive forces are shown in Table 4. Column (1) controls for time and industry fixed effects but does not include control variables, while column (2) includes control variables while controlling for fixed effects. The results have shown that the regression coefficients of the human capital structure of enterprises are all significantly positive at the 1% level, indicating that the higher the ratio of high-skilled personnel in an enterprise, the higher the level of new quality productive forces, that is to say, high-skilled personnel promote the development of new quality productive forces in enterprises. Specifically, the results in column (2) have shown that for every unit of growth in the human capital structure of the enterprise, the new quality productive forces increase by 0.092 (t=9.96) units. Combining the results of empirical and theoretical analyses, the development of enterprise talent is conducive to improving the level of new quality productive forces, and the research hypothesis of this paper has been verified by the mathematical model.

In addition, in terms of control variables, corporate return on total assets, firm size, and cash flow position has a significant positive impact on corporate new quality productive forces. The size of the corporate board of directors, Tobin's Q, book-to-market ratio, and operating income size have a significant negative effect on corporate new quality productive forces.

Table 4. **Research on the impact of corporate talent on new quality productive forces**

Variables	(1)	(2)
	No control variable	With control variable
Skill-Unskill	0.093***	0.092***
	(10.13)	(9.96)
Bsize		-0.004***
		(-2.88)
Top1		-0.000
		(-0.87)
ROA		0.224***
		(3.19)

Tobin_q		-0.016***
		(-3.09)
BM		-0.195***
		(-6.69)
Size		0.069***
		(8.66)
Lev		-0.033
		(-1.29)
Cash		0.016***
		(4.28)
Growth		0.012
		(1.58)
Duality		-0.008
		(-1.00)
Indep		-0.023
		(-0.47)
Revenue		-0.047***
		(-6.78)
Constant	-0.120*	-0.411***
	(-1.87)	(-4.39)
Observations	25,029	25,024
R-squared	0.430	0.434
IND FE	YES	YES
Year FE	YES	YES
r2_a	0.427	0.432

Robust t-statistics in parentheses
*** p<0.01 ** p<0.05 * p<0.13.3 Mediation effect test

Source: own study

According to the mediation effect step-by-step regression method, after the benchmark regression was significant, the mediator variable enterprise innovation level was further added to the regression, in order to analyze the mechanism of talent-driven development of new quality productive forces, the empirical results are shown in Table 5. Model (1) is the regression of the mediator variable on the dependent variable, and the regression coefficient of human capital structure was 0.006, which was significant at 1% significance level, proving that the increase in the proportion of high-skilled personnel in enterprises promotes enterprise innovation. Model (2) has shown the regression results after introducing intermediary variables, and it can be seen that the innovation level of enterprises (Innov) is significant at 1% significance level, and the human capital structure of enterprises is significant at 1% significance level, which proves that the intermediary effect exists. In the process of talent-driven new quality productive forces enhancement, enterprise innovation plays a part in the intermediary effect, that is, the enterprise's high-skilled talents drive the enterprise's innovation ability, thus increasing the enterprise's new quality productive forces development level.

Table 5. **Path analysis of talent-driven new quality productive forces development in enterprises**

Variables	(1)	(2)
	Innov	NQPF
Innov		0.808***
		(30.81)
Skill-Unskill	0.006**	0.096***
	(2.44)	(9.42)
Bsize	-0.362***	-0.002***
	(-5.26)	(-2.12)
Top1	-0.103***	-0.000
	(-14.64)	(-0.43)
ROA	0.386**	0.229***
	(2.29)	(3.23)
Tobin_q	-0.000	-0.017***
	(-0.02)	(-3.12)

BM	0.001***	-0.182***
	(4.09)	(-6.21)
Size	0.302***	0.061***
	(15.08)	(8.01)
Lev	-0.000	-0.032
	(-0.00)	(-1.12)
Cash	0.003	0.014***
	(1.05)	(4.20)
Growth	0.011***	0.014
	(4.81)	(1.43)
Duality	-0.001	-0.007
	(-0.09)	(-1.00)
Indep	0.016**	-0.037
	(2.29)	(-0.47)
Revenue	-0.003	-0.042***
	(-1.57)	(-6.38)
Constant	0.228**	-0.401***
	(2.28)	(-4.23)
Observations	25,024	25,024
R-squared	0.148	0.434
IND FE	YES	YES
Year FE	YES	YES
r2_a	0.145	0.432

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: own study

5.3. Robustness check

In this paper, the core explanatory variables and the explanatory variables have been replaced separately for robustness testing. For the substitution of the explanatory variables, this paper has examined the level of human capital structure (high-low) constructed by academic qualifications. In this paper, "total factor productive forces" has been used as a substitute explanatory variable to measure the level of new quality productive forces of enterprises. In this study, total factor productive forces has been calculated by the ACF method and then regressed. From the regression results in column (1) of Table 6, the high-low coefficient is significantly positive at the 1% level, indicating that after replacing the explanatory variables, the quality of enterprise talent has a significant positive impact on the improvement of the level of enterprise's new quality productive forces, indicating that high-educated talents drive the formation of enterprise's new quality productive forces, and the hypothesis of this paper's research, H1, has been preliminary verified. The test results in column (2) show that the regression coefficients of the two measures still pass the significance test at the 1% level after replacing the measure of new quality productive forces, which is consistent with the results of the previous basic regression.

Table 6. **Robustness test**

Variables	(1)	(2)
	NQPF	TFP
Skill-Unskill		0.009***
		(11.47)
High-low	26.692***	
	(9.83)	
Bsize	-0.004***	0.001***
	(-2.86)	(5.96)
Top1	-0.000	0.000***
	(-0.88)	(5.57)
ROA	0.222***	0.006
	(3.15)	(1.01)

Tobin_q	-0.016***	0.003***
	(-3.02)	(4.64)
BM	-0.193***	-0.021***
	(-6.64)	(-6.71)
Size	0.068***	0.016***
	(8.53)	(21.27)
Lev	-0.029	-0.007***
	(-1.14)	(-3.07)
Cash	0.016***	0.003***
	(4.33)	(7.95)
Growth	0.011	0.003***
	(1.57)	(4.30)
Duality	-0.009	-0.003***
	(-1.10)	(-4.49)
Indep	-0.025	-0.013***
	(-0.53)	(-2.92)
Revenue	-0.045***	-0.009***
	(-6.45)	(-14.05)
Constant	-0.454***	-0.138***
	(-4.91)	(-12.86)
Observations	25,008	25,024
R-squared	0.437	0.227
IND FE	YES	YES
Year FE	YES	YES
r2_a	0.435	0.223

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: own study

The empirical analysis has demonstrated that the quality of talent in manufacturing firms drives the level of new quality productive forces, in which technological innovation plays a mediation effect.

6. Development pathways for the human resources service industry to promote the development of New Quality Productive Forces in the manufacturing industry from the talent supply perspective

6.1. Innovation in collaborative development mechanism

In order to promote the establishment and operation of the Industry-Education Integration Community and Municipal Industry-Education Association, it is necessary to integrate the resources of the government, scientific research institutes, industry associations, human resources service enterprises, universities, and manufacturing enterprises, as well as other relevant parties. Meanwhile, leveraging the advantageous resources in the "Two Wings" (socialist transformation of individual agriculture, handicrafts, and capitalist industry and commerce) to form an integrated cooperation mechanism of "Industry-University Research and Application" in order to provide policy support, technical support and market support for the platform. Additionally, align with the job requirements of manufacturing enterprises, accurately grasping the demands for knowledge, skills, and competencies, while deepening school-enterprise cooperation.

Based on the regional talent demand, the cooperation mode of "risk sharing and benefit sharing" is designed. Meanwhile, exploring the modern apprenticeship system with Chinese characteristics, industrial colleges, enterprise colleges, etc., in which human resource service enterprises, universities and advanced manufacturing companies jointly participate. In addition, the implementation of integrated teaching models that combine theory and practice is critical. These models should prioritize emerging fields such as intelligent manufacturing and industrial internet to cultivate specialized and customized talent.

Human resource service enterprises are advised to establish a dynamic monitoring system for talent demand in the manufacturing industry. The utilization of big data and artificial intelligence technology facilitates the real-time analysis of labor demand fluctuations within the industry, the prediction of future skill-demand trends, and the provision of accurate service support to human resources service institutions.

Human resources service institutions should engage deeply with manufacturing enterprises, and communicate extensively with HR and technical departments in the company so as to clarify specific requirements for talent, including expertise, skill

levels, and project experience. Simultaneously, a detailed list of job requirements should be drawn up and shared with the co-operative colleges and training institutions promptly.

Setting up a regional "manufacturing" big data information platform to release real-time enterprise employment demand, talent supply information and industry trends. At the same time, integrating multi-source data and applying intelligent algorithms, it realizes regular docking between manufacturing enterprises and human resource service organizations, and dynamically updates the skills demand mapping through research and data analysis. Moreover, real time matching of job demand and talent supply provides dynamic and accurate human resources support for the development of New Quality Productive Forces in the manufacturing industry. For example, it could publish an annual talent shortage index report for the "Top Ten Industries" (e.g., high-end equipment, new energy materials).

6.2. Diversified innovative business models

Human resource service institutions focus on creating customized outsourcing services, which are embedded in the entire production process of the manufacturing industry. According to the specific needs of enterprises, it provides customized human resource management solutions. At first, Human resources service enterprises conduct in-depth research on the business process, production process, and other business operations of the enterprise. This research enables the enterprises to understand the existing production process, equipment status, and personnel skill level. Then, the enterprises can formulate an intelligent transformation plan in accordance with the actual situation of the enterprise. This plan encompasses not only the enhancement of technical suggestions, but also the integration of human resource management content, such as personnel training and post adjustment.

Building an integrated service ecosystem including recruitment, training, outsourcing and consulting, which covers the demand of the entire manufacturing value chain. Centered on the human resource services industry, it integrates upstream and downstream industrial resources to create a complete manufacturing industrial ecosystem. For instance, in the electronic information manufacturing industry, human resources service institutions not only provide basic services such as recruitment and training for enterprises, but also establish cooperative relationships with raw material suppliers, parts manufacturers, logistics distribution enterprises, etc., to form a collaborative development of the whole process service of the industrial chain. Through optimizing resource allocation across all industrial chain segments, it improves the overall operational efficiency and competitiveness of the industry, promoting the development of New Quality Productive Forces in manufacturing.

The manufacturing industry is comprised of numerous subdivisions, each of which possesses distinct characteristics and requirements. As proof, the equipment manufacturing industry pays attention to high-precision production processes and strict quality control, which requires extremely high skills and experience of workers. Electronic equipment emphasizes technological innovation and rapid product development cycle, which requires a large number of professionals with cutting-edge scientific and technological knowledge. In the domain of aerospace manufacturing, professionals need to possess specialized knowledge in disciplines such as mechanical design, material science, and the understanding of unique specifications and standards that are specific to the field. Thus, in the realm of human resources, prominent and mid-sized enterprises typically delineate the organizational frameworks according to distinct service domains, thereby establishing specialized service teams. Similarly, it conducts a comprehensive and detailed analysis of market dynamics, technology development trends, talent supply and demand in different manufacturing segments, and provides "counterpart" services.

6.3. Data-driven optimization of human-position matching

It is imperative for the human resources service industry to closely monitor the development trends and technological innovations in manufacturing, paying particular attention to technological advancements and the resulting changes in talent requirements. Through conducting a comprehensive investigation into manufacturing enterprises, involving questionnaires, interviews and other methods, it is possible to accurately ascertain the actual talent requirements across the R&D, production, and sales processes. Accordingly, key positions such as R&D engineers, production managers, and quality control experts could be identified, and the job capability model could be constructed likewise. Correspondingly, the machine learning algorithm is used to strengthen the prediction capability concerning industry talent demand. Through the in-depth analysis of the talent structure, skill distribution and flow trend of the manufacturing industry, a dynamic capability model is constructed.

The human resources service industry has occasion to collaborate deeply with manufacturing enterprises, educational institutions, government departments, and other stakeholders to build a comprehensive database covering multiple dimensions such as skills, job requirements, and career development paths.

For one thing, the talent database should be equipped with the functionality to facilitate dynamic updates and the provision of real-time feedback. Through seamless integration with enterprise HR systems, recruitment platforms, and training institutions, real-time updates on job requirements, talent flow, and skill enhancement are provided to ensure the accuracy and practicality of data. On this basis, the human resources service industry can provide enterprises with talent recruitment, training,

and career planning services that are both precise and effective. These services help enterprises optimize human resource allocation, reduce labor costs, and improve production efficiency.

For another thing, making use of big data and artificial intelligence technologies can intelligently analyze and process collected talent information. Specifically, through data cleansing, de-duplication, classification and labeling, it builds an accurate talent portrait and realizes quantitative assessment of talent skills and dynamic matching of job requirements. Concurrently, the combination of career development path data enables the provision of personalized career planning suggestions and skill enhancement plans for manufacturing practitioners, thus contributing to career advancement.

Firstly, based on the digital reform of the human resources service industry, digital and intelligent recommendation is realized. On this occasion, using artificial intelligence technology such as machine learning and deep learning to develop intelligent recommendation algorithms. According to the post portrait and talent portrait, the accurate matching of people and posts is achieved. Furthermore, developing intelligent search and screening modules to explore new modes of digital-intelligent employment. It offers multifaceted and intelligent search and screening functionalities to assist enterprises in expeditiously identifying target talents and enhancing recruitment efficiency.

Secondly, developing a human resource intelligent management system based on the recruitment and employee training of manufacturing enterprises. The application of artificial intelligence (AI) interview, online evaluations, and other technologies aims to accomplish resume screening, interview arrangement, etc., and improve recruitment efficiency. In addition, analyzing and predicting talent mobility trends through big data to support corporate decision-making. Building a skill enhancement online learning resource module while establishing a rich online course library. It covers all kinds of professional competencies and management expertise, offering employees the flexibility to acquire knowledge at their discretion and in a flexible manner.

7. Conclusion

This study has adopted a talent supply perspective, focusing on the mechanism through which the human resources service industry propels new quality productive forces in manufacturing. By constructing a mediation effect testing model and conducting empirical analysis using panel data from Shanghai and Shenzhen A-share listed manufacturing enterprises in Shandong Province from 2009 to 2023, this study has produced research findings that are both innovative and practically valuable. The core empirical findings have revealed a transmission mechanism

linking "talent quality-technological innovation-new quality productive forces": firstly, the quality of talent in manufacturing enterprises exerts a significant positive driving effect on the level of new quality productive forces. This discovery has confirmed that enhancing talent quality is the core foundation for developing new quality productive forces in manufacturing, providing direct empirical support for addressing the key question of "how talent empowers new quality productive forces". Secondly, technological innovation plays a fully mediating role between talent quality and new quality productive forces. This indicates that talent quality does not directly impact the enhancement of new quality productive forces but instead indirectly boosts it through intermediate pathways such as stimulating corporate technological innovation vitality and optimizing the allocation of innovation factors. This clearly delineates the chain of actions through which talent empowers new quality productive forces.

This research has held significant theoretical and practical implications. Theoretically, it has filled a gap in the interdisciplinary field of human resources services and new quality productive forces. Addressing the academic debate on "how human resources services specifically boost new quality productive forces in manufacturing," it provides a systematic empirical answer by clarifying the core driving role of talent quality and the mediating role of technological innovation. This research has supplemented the theoretical framework of new quality productive forces with the micro-level mechanism of "talent empowerment," simultaneously overcoming previous studies' ambiguous understanding of the relationship between human resources and new quality productive forces. It has constructed an analytical framework of "supply-side talent quality → intermediary-level technological innovation → output-side new quality productive forces," offering a reference theoretical perspective for subsequent related research. At the practical level, the findings have offered precise guidance for manufacturing transformation and upgrading. For governments, they clarify the central role of talent strategies in cultivating new quality productive forces within manufacturing, enabling targeted policy development – such as optimizing support for human resources services and establishing talent quality enhancement systems. For enterprises, they reveal the intermediary value of technological innovation, helping companies refine talent allocation strategies and build operational frameworks for "talent-innovation" conversion platforms. This addresses the real-world challenges of "difficulty in attracting talent and weak conversion capabilities" faced by manufacturing firms. transformation platforms, thereby addressing the practical challenges of "difficulty in attracting talent and weak conversion" faced by manufacturing enterprises.

The core contributions of this study are threefold: firstly, it has innovated the research perspective by focusing on the talent supply dimension, examining the linkage mechanism between the human resources service industry and new quality productive

forces in manufacturing, thereby moving beyond previous macro-level, generalized analyses of the role of the human resources service industry. Secondly, it has employed robust methodological and data foundations, utilizing mediation effect testing models for empirical analysis. The selection of 15 years of panel data from listed enterprises in Shandong Province enhances the reliability and timeliness of the findings. Thirdly, the conclusions have represented a breakthrough, being the first to explicitly validate the full mediating role of technological innovation between talent quality and new quality productive forces, thereby refining the transmission pathways through which human resources empower new quality productive forces.

However, this study has retained two notable limitations: firstly, sample representativeness is constrained. The data exclusively covers manufacturing enterprises listed on the Shanghai and Shenzhen A-share markets in Shandong Province. While reflecting characteristics of leading regional firms, it fails to encompass small and medium-sized manufacturing enterprises, non-listed companies, or enterprises in other provinces. Consequently, the generalizability of findings across manufacturing firms of varying scales and regions nationwide requires further validation. Secondly, the precision of variable measurement is insufficient. Constrained by research methodology and data availability, the assessment of talent quality, technological innovation, and new-type productive forces primarily relies on established proxy indicators from existing literature (e.g., talent educational structure, R&D intensity, total factor productive forces). This approach fails to fully capture the inherent complexity of each variable, potentially introducing measurement errors.

Based on these limitations and core findings, the following future research directions are proposed: firstly, expand the scope and types of samples. Subsequent studies should broaden regional data coverage to include manufacturing enterprises from eastern, central, and western provinces, incorporate small, medium, and micro enterprises as well as non-listed companies into the sample, and distinguish between labor-intensive, technology-intensive, and capital-intensive manufacturing enterprises to analyze the heterogeneity of research conclusions and enhance their generalizability. Secondly, deepen variable measurement and mechanism analysis. Combine surveys to construct a more comprehensive evaluation system for talent quality, technological innovation, and new productive forces. Simultaneously, explore the differentiated mechanisms through which various segments of the human resources industry (e.g., talent training, headhunting services, HR outsourcing) contribute to new productive forces. Third, broaden research contexts by focusing on emerging areas like green transformation and smart manufacturing within manufacturing. Explore specialized pathways for the human resources services industry to optimize talent supply and accelerate new quality productive forces development in these scenarios, thereby providing more targeted theoretical support for high-quality manufacturing development.

Authors' contribution

S.H.: draft manuscript preparation. **Z.L.:** article conception, theoretical content of the article. **M.L.:** research methods applied, conducting the research. **H.W.:** data collection, analysis and interpretation of results.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors did not use Generative AI and AI-assisted technologies in the writing process.

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