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Can Internet construction promote enterprise upgrading?

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ABSTRACT

This paper investigates the impact of Internet infrastructure construction on enterprise transformation and upgrading and the underlying mechanisms using a progressive double difference model based on a quasi-natural experiment of the Chinese government's "broadband China" policy by matching A-share listed companies and city panel data from 2008–2019 in Shanghai and Shenzhen. The conclusions show that the "broadband China" policy can significantly promote the transformation and upgrading of enterprises in pilot cities. However, its effect shows a diminishing marginal contribution, and the policy is more effective for traditional manufacturing industries during the implementation period. Enhancing human capital and reducing internal transaction costs are two important channels for Internet infrastructure construction to help enterprises transform and upgrade. Combined with the life cycle theory, we find that the "broadband China" policy has the most significant impact on changing and upgrading enterprises in the growth and maturity stages, especially those in the manufacturing industry, but not those in the maturity and decline stages of the service industry. Finally, a series of robustness tests using Monte Carlo simulation, entropy balance method, and instrumental variables method, excluding other factors, show that the findings are still robust.

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1. Introduction

Currently, international competition is intensifying, waves of counter-globalization are emerging, the world economy is sluggish due to the impact of the epidemic, and the world is facing profound adjustments in economic, technological, political, and security aspects(Butzbach et al., 2020; Duan & Jiang, 2021; Egger & Fischer, 2020; Wu & Lee, 2021). In this context, the development of manufacturing in many developing countries faces the "double pressure" of returning high-end industries to developed countries and relocating low-end industries to poorer countries with lower

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labor costs(Sefidkar et al., 2021; Tang et al., 2018; Teece, 2018; Valentina & Robert, 2015). In addition, numerous governments have explicitly proposed accelerating digital development and fostering new digital industries (Bacache-Beauvallet & Bloch, 2018; Landini, 2016; Teece, 2018). On the one hand, the adjustment and upgrading of the industrial structure depend on the organizational changes of micro-enterprises. However, the integration and penetration of the digital economy to empower traditional industries and digital technology with the real economy is precisely the "creative destruction" of conventional enterprises' production methods and operation modes (Mcafee & Brynjolfsson, 2012).

Modern information networks have to carry out the emergence of the digital economy. Therefore, the role of data as a new factor in production is always limited. However, its value as a factor of production is greatly enhanced if it is connected to networks, shared by other external networks, and interfaced with production practices (Silva & Martins, 2014). From this, we cannot help but ask whether the full rollout of network broadband, the foundation of all information economies, whether the internet or digital, can substantially impact business transformation and upgrading? If so, what are the mechanisms underlying this impact? The formulation and implementation of the R&D (Broadband China) policy has become the critical point and breakthrough to answer the above questions.

As broadband network coverage expands, transmission speed and access capacity continue to improve in countries worldwide. Broadband technology innovation has made remarkable progress (Castaldo et al., 2018; Gawer & Cusumano, 2014; Nambisan et al., 2019). However, broadband networks still suffer from unclear positioning of public infrastructure, unbalanced regional and urban-rural development, the insufficient richness of application services, and an imperfect development environment during the construction process (Roost & Alisa, 2016; Tu et al., 2019). In China, for example, to strengthen the strategic guidance and systematic deployment and promote the rapid and healthy development of broadband infrastructure, the Chinese government issued the Notice of the State Council on the Issuance of "Broadband China" Policy and Implementation Plan in August 2013, aiming to accelerate the optimization and upgrading of broadband networks, help SMEs to utilize the penetration and integration of broadband technologies To promote collaborative innovation in the industry (Chen et al., 2020; Liu, 2017). Over the past two decades, telecommunications infrastructure investments and broadband Internet access have profoundly changed various aspects of the Chinese economy, including economic growth (Chu, 2013; Koutroumpis, 2009), foreign trade (Freund & Weinhold, 2004; Venables, 2002), technological progress (Daido & Tabata, 2013; Hulten et al., 2006), but there is little literature examining the impact of network infrastructure development on the structural transformation and upgrading of Chinese industries, especially at the micro-level to explore the mechanisms underlying the transformation and upgrading of firms. The few studies remain based on qualitative analysis of the theoretical framework for constructing the internet and industrial structure (Olson et al., 2015; Yuan et al., 2012). (Joseph & Zhu, 2018) empirically analyzed the impact of Internet infrastructure construction characterized by telecommunication fixed asset investment on the transformation and upgrading of China's manufacturing industry and regional differences based on provincial panel data in China. Due to the lack of an analytical framework for policy experiments, using a single indicator to measure network infrastructure alone is susceptible to endogeneity, leading to questionable reliability of the findings. In this paper, we combine these two shortcomings and assess the impact of network infrastructure construction on enterprise transformation and upgrading using a natural experiment of the "Broadband China" policy based on the theoretical mechanism of network infrastructure and micro-enterprise transformation and upgrading. This research idea has a sufficient theoretical and practical basis.

However, another thorny issue, in reality, is that the definition and metrics of enterprise transformation and upgrading have not been uniformly asserted. Most of the existing studies have focused on macro and meso levels, and relatively few studies have been conducted on micro-level enterprises. Moreover, they are mainly based on case studies (Xu, 2000; Yaseen, 2020). A few scholars have started to adopt empirical studies to explore enterprise transformation and upgrading (Aghion et al., 2015; Du & Zhang, 2018; Giannetti et al., 2015), but they are also limited to weighing single indicators. At the theoretical level, firms generally transform through two paths, one is a cross-industry change in which firms enter new industries to engage in production and business activities (Poon, 2004); the other is transformation at the level of firm organization and management (Humphrey & Schmitz, 2002), both of which are manifested as factor investments in R&D and innovation. Upgrading refers to the process of transforming one's factor input structure and improving the competitive conditions by increasing the level of technology or marketability, usually by moving up the industrial or value chain to a higher value-added position (Humphrey & Schmitz, 2002; Schmitz, 2004). There are various enterprise upgrading forms, including process upgrading, product upgrading, functional upgrading, and value chain upgrading. Based on the definition of enterprise transformation and upgrading in the existing literature, this paper defines the transformation and upgrading of micro-enterprises as horizontal transformation and vertical upgrading of enterprises. Among them, horizontal transformation is mainly manifested in the transformation of the development strategy, business type, and organizational model of enterprises, which require the continuous enhancement of their innovation and organizational coordination capabilities; vertical upgrading is mainly manifested in the improvement of the productivity level of enterprises and the transformation of production from low-technology labor-intensive to medium- and high-technology capital- and technology-intensive.

This paper seeks to contribute to the following aspects: first, on the research theme, this paper is the first to explore the impact of the development of the digital economy at the macro level on the transformation and upgrading of micro-enterprises from multiple perspectives using the "broadband China" policy of the Chinese government, which not only enriches the theories related to industrial restructuring in the industrial organization but also provides a new perspective for studying the transformation and upgrading of micro-enterprises. This enriches the theory of industrial restructuring in industrial organizations and offers a unique perspective for studying the transformation and upgrading of micro-enterprises. Second, in terms of mechanism analysis, this paper breaks through the existing research mainly from the viewpoint of human capital quality and transaction cost saving on analyzing the role mechanism of factors influencing enterprise transformation and upgrading from the perspectives of innovation and industrial agglomeration, which completes the existing research framework on the path of enterprise transformation and upgrading. Third, in terms of the theoretical approach, the life cycle theory is added to the process of enterprise transformation and upgrading, which makes up for the potential heterogeneity of existing studies that only consider the cross-sectional differences of enterprises and ignore the time dimension, further deepening the research on this topic. Fourth, identifying empirical strategies, using progressive double-difference method, entropy balance method, two-stage least squares method, and placebo test combined with Monte Carlo simulation, identifies the causal relationship between digital economy development and enterprise transformation and upgrading in a more "clean" way. In addition, a series of other robustness tests are conducted to strengthen the credibility of the findings.

2. Theoretical analysis and research hypothesis

Enterprise digitization is how enterprises use digital technologies to penetrate business capabilities and thus enhance productivity(Eller et al., 2020; Lo et al., 2020). As the most basic and core content of digital technology, network infrastructure can characterize the digitalization degree of enterprises in a certain sense. This paper considers the impact of human capital aggregation effect, knowledge spillover effect, network externality effect, and scale the impact of network infrastructure construction transaction cost on enterprise transformation and upgrading, respectively, and proposes corresponding theoretical hypotheses accordingly.

2.1. Human capital aggregation effect and knowledge spillover effect of network infrastructure

The "broadband China" policy, as a core development strategy for network infrastructure construction, promotes enterprise transformation and upgrading through human capital aggregation and accelerated knowledge spillover. As a factor of production that cannot be ignored, human capital plays a crucial role in promoting enterprise innovation and transformation and upgrading (Alon et al., 2018). Regarding human capital characteristics (Theg et al., 1964) argues that human capital is first and foremost a personalized wealth, expressed as human capabilities and qualities, which cannot be separated from the person itself. The productivity of human capital depends on the degree of effort and learning ability of the people who possess it, so appropriate and effective stimulation and incentive can improve the efficiency of human capital use. On the one hand, the "Broadband China" policy insists on combining network upgrading and industrial innovation, accelerates the establishment of an enterprise-oriented, market-oriented, and closely integrated technological innovation system between industry, academia, research, and application, and promotes the integration and utilization of domestic and foreign advantageous resources. The network infrastructure has improved the traditional way of knowledge acquisition and absorption, allowing workers to learn and communicate more conveniently through the internet, accelerating the "learning by doing" of human capital, and speeding up the knowledge acquisition process, transmission and sharing.

The network infrastructure can disseminate information across space and time, allowing two cities that were not close to each other to be more closely connected through the internet and broadband, reducing the "physical distance" between cities. Metcalfe's law in the Internet field allows the connection of network nodes to generate powerful knowledge and information spillover effects, improving the efficiency of knowledge dissemination and saving workers' learning costs (Pisano et al., 2015), thus contributing to the improvement of the quality of human capital in enterprises. In addition, the mechanism by which firms benefit from the development of the internet can be reflected in the critical role of the aggregation effect, which is mainly reflected in the aggregation of skilled workers in the local labor market (Oliver et al., 2014), where the rapid development of network infrastructure and the increasing digitization of enterprises make them hire more high-level labor to adapt to the transformation and upgrading of enterprises footsteps, passively raising the level of corporate human capital. Network infrastructure can also influence regional economic growth through the Hicks efficiency channel. The externalities of network infrastructure make it produce positive spillover effects on other factors such as infrastructure capital and labor, shifting the production possibility curve outward and producing increasing returns to scale (Rokicki & Stępniak, 2018; Zhou et al., 2021). In addition, Internet technology can effectively improve the productivity of emerging markets, and inclusive finance such as Internet finance can also help the poor get out of poverty(Bayar et al., 2021; Kireyeva et al., 2021; Máté et al., 2020). Based on the above analysis, this paper proposes the following research hypothesis.

> Hypothesis 1: The "Broadband China" policy, as the core development strategy of network infrastructure construction, promotes the transformation and upgrading of enterprises by improving human capital.

2.2. Transaction cost scale effects and network externalities of network infrastructure

As a quasi-public good, network infrastructure has a strong externality. It will have an important impact on the economic growth of enterprises after being included in the aggregate production function (Zhou et al., 2021). The growth or transformation and upgrading of the enterprise economy are expressed in the increase of efficiency in the production process and the increase of efficiency and cost reduction of all processes that do not occur in the material means of production. Costall and Still (1989) proposed the theory of transaction costs, defining them as the costs of obtaining market information, negotiating and concluding transaction contracts, monitoring them in their implementation, and, if necessary, mediation and arbitration. At the same time, he points out that the transaction costs of the firm can be viewed from two perspectives: on the one hand, the firm as a form of the transaction allows the owners of several factors of production and products to form a unit to participate in market transactions, thus reducing the number of traders and the frictions in the transaction process; within the firm, market transactions are eliminated, and the complex structure that accompanies them is replaced by the entrepreneur, whom The entrepreneur directs the production, and thus the firm replaces the market. The former can be seen as the market-based transaction costs of the firm, closely related to the number of market transactions in which the firm participates; the latter can be seen as the internal transaction costs of the firm, inextricably linked to the internal organizational structure and management efficiency of the firm. Calamel et al. (2012) found that the construction of network facilities plays a large degree of influence on the production, R&D activities, and even consumer behavior choices of firms at the micro-level, and its development has led to a significant reduction in search and transportation costs of industrial firms, effectively increasing their revenues and reducing information asymmetry in different production sectors. Greene et al. (2009) found that U.S. firms are organized to use network technologies more effectively compared to EU countries, which better demonstrates the crucial role of capital and organizational structure in the effective use of investments in network technologies. In addition to this, network infrastructure development reduces firms' transaction costs. It is also accompanied by network externality effects (Gil, 2007), i.e., the incremental utility gained by a given user in consuming the same product when the number of other users consuming the product increases. However, network externalities are not always positive, and beyond a certain point, the increase in network size may reduce the effect of network users, thus generating negative network externalities. Thus, there are significant positive network externalities in the early stage of network infrastructure construction that make transactions between firms and consumers and firms and enterprises more convenient, with a significant increase in transaction size and decreased transaction costs. In the later stage of network infrastructure construction, network congestion due to the high internet application may generate certain negative network externalities, which increase the transaction costs of enterprises. Based on the above analysis, this paper proposes the following research hypothesis.

> Hypothesis 2a: The "Broadband China" policy, as the core development strategy of network infrastructure construction, promotes the transformation and upgrading of enterprises by reducing their internal transaction costs.

> Hypothesis 2b: The "Broadband China" policy, as the core development strategy of network infrastructure construction, promotes the transformation and upgrading of enterprises by reducing their market-based transaction costs.

2.3. Heterogeneity analysis of enterprise characteristics

The analysis of heterogeneity at the firm level includes studying the cross-section of firms, such as firm size, strong nature, and firm property rights, and the study of the dynamics of firms in the time dimension - the healthy life cycle perspective (Reynolds et al., 2018). Firms are living organisms with three stages of survival and development: the growth stage, regeneration and maturity stage, and aging stage. There are significant differences in firms' profitability, investment strategies, R&D capabilities, and transformation and upgrading dynamics in different life cycle stages. A & B, (2013) investigated the impact of R&D investment intensity from the perspective of enterprise life cycle and found that the R&D investment intensity of enterprises in the entrepreneurial and growth stages is significantly higher than that in the maturity stage. In contrast, the decline stage is significantly lower than that in the maturity stage.

On the one hand, enterprises in the growth period tend to have less investment in fixed assets such as network infrastructure and relatively low sunk costs. According to the producer theory, the investment in network infrastructure construction will significantly impact the R&D, innovation, transformation, and upgrading of enterprises in the growth period. Enterprises in the mature stage have often formed their production model and economic growth, are in a steady development stage, and hold a particular market share, there are more considerable sales revenue and economies of scale, and may show some inertia and conservative thinking (Alon et al., 2018), and the more basic network facilities construction may have a minor impact, or no significant effect. In terms of internal structure and management awareness, enterprises in decline tend to have rigid internal institutional structures risk-averse managers and are willing to make minor repairs to their existing technologies and products rather than invest in breakthrough innovations (B & D, 2018), therefore, the improvement of network facilities does not significantly influence the decision and process of upgrading. Based on the above analysis, this paper proposes the following research hypothesis.

> Hypothesis 3: Network infrastructure development will have a differential impact on the transformation and upgrading of enterprises at different life cycle stages.

3. Model construction and data description

3.1. Variable definition

1. Measurement of enterprise transformation and upgrading. In this paper, enterprise R&D innovation *(RD*) and total factor productivity (*TFP*) are used as proxies for measuring enterprise transformation and upgrading for a comprehensive comparative analysis. For enterprise's R&D innovation, this paper adopts the proportion of enterprise's R&D expenditure to primary business income as a proxy for R&D expenditure intensity. To calculate total factor productivity, this paper chooses the semi-parametric method to measure the total factor productivity of enterprises. Considering that the samples used in this paper are data of listed companies and the OP (Olley-Pakes) method requires that the actual investment of enterprises must be more significant than zero in the first stage, this restriction may lead to the loss of much sample information in the estimation process, so this paper chooses the LP (Levinsohn-Petrin) method to measure the total factor productivity of enterprises.
2. Measurements of network infrastructure construction. In this paper, the dummy variable of "broadband China" policy (*DID*) is selected as a proxy for network infrastructure construction, and the dummy variable of policy grouping is based on whether the registered address of the parent company of the listed company is rated as a "broadband China" demonstration city in the sample period. This

variable is an interaction term between the policy grouping dummy variable and the time dummy variable.

3. Control variables. In this paper, we control for the effects of controllable factors from both regional and firm levels. The firm-level control variables include firm size, leverage, fixed asset ratio, operating cash flow, management shareholding, capital intensity, capital expenditure, endogenous financing, equity debt ratio, Tobin's Q, whether the chairman and general manager are the same people, and the proportion of independent directors; the city-level control variables include the level of regional economic development, foreign direct investment, and the degree of government intervention.

The pilot list of "broadband China" used in this paper comes from the official announcement of the Chinese government. Since the pilot list of "broadband China" policy has been published since 2013, A-share listed companies from 2008 to 2019 are selected as the initial sample. The sample is measured by year, that is, the data of all listed companies each year. From 2008 to 2019, the number of listed companies increased from 2500 to 4140. We counted a total of 298490 samples within the research time range. The city-level data are obtained from the China City Statistical Yearbook and EPS database, and the corporate-level financial indicators are obtained from the CSMAR database. In addition, this paper excludes financial and insurance, ST, and *ST category companies, as well as outliers with severe missing samples and asset-to-liability ratios greater than 1. Finally, when matching prefecture-level cities with the registered addresses of listed companies, some towns do not have corresponding listed companies, so the samples of listed companies located in urban areas of municipalities directly under the central government and pilot areas of county-level cities are also excluded, and finally, all continuous variables are subjected to a 1% upper and lower tail reduction. The definitions and descriptive statistics of all variables are given in Table 1.

3.2. Model construction

This paper uses the progressive double-difference method, entropy balance method, two-stage least squares method, and placebo test combined with Monte Carlo simulation to more "cleanly" identify the causality of the impact of digital economy development on business transformation and upgrading. In addition, a series of other robustness tests are conducted to strengthen the credibility of the findings. The following considerations are the main reasons for constructing the model based on the "quasi-natural experiment" approach with the double difference method. First, there is a two-way causal relationship between the construction of network infrastructure and the transformation and upgrading of enterprises in China, which may lead to the transformation and upgrading of enterprises. Still, the successful transformation and upgrading of enterprises in the region may require higher quality network infrastructure and thus promote the construction of network infrastructure in turn, thus creating a two-way causal problem. Therefore, this paper adopts the "quasi-natural experiment" method and constructs a double-difference model to solve this problem. This paper considers the "Broadband China" policy implemented in 2013 as an

Table 1. Definition of variables and descriptive statistics.

Variable	Variable Definition	Observations	Mean	Standard deviation	Minimum	Maximum
RD	R&D expenses/primary business income	17335	0.13	0.08	0.06	0.22
TFP	Calculated using semi-parametric LP method	23959	12.67	0.45	10.21	13.49
Scale	Total assets, taking the logarithm	24650	21.39	1.49	19.23	26.34
lev	Total liabilities/total assets	24650	0.54	0.28	0.11	1.02
Fixasset	Net fixed assets/total assets	24650	0.63	0.24	0.06	0.8
Cashflow	Net cash flow from operating activities	19108	19.16	1.722	14.58	23.33
Pershare	Number of shares held by management/ total number of shares	23870	0.25	0.48	0.06	0.11
Capintense	Net fixed assets/number of employees	24626	12.57	1.55	9.09	15.23
Capexpend	Capital expenditure/total assets	24641	0.16	0.12	0.06	0.32
Innerfinance	Net profit/net fixed assets	24650	0.94	2.81	−1.97	18.6
Ratiodebt	Owner's equity/total liabilities	24650	2.66	3.38	0.12	20.16
Duality	Whether the chairman and general manager are the same people	24327	1.85	0.21	1.06	2.08
Tobin	Market value/total assets, take the logarithm	24649	1.08	0.11	0.09	1.08
Mshare	Number of independent directors/ number of directors	24575	0.48	0.12	0.39	0.65
GDP	Real GDP per capita, take the logarithm	24647	11.6	0.89	8.57	13.27
FDI	Percentage of actual foreign investment utilized in the current year	24469	3.06	1.86	0.15	9.09
Govsupport	Fiscal expenditure/regional GDP	24647	0.26	0.12	0.13	0.39

Source: drawn by the author.

exogenous shock to accurately identify the causal relationship between network infrastructure construction and enterprise transformation and upgrading. Considering that the policy pilot is set up gradually, the classical DID (Differences-in-Differences) model is only applicable to assessing one-off policies' effects. Specifically, the Ministry of Industry and Information Technology (MIIT) and the National Development and Reform Commission (NDRC) has released a total of three batches of "Broadband China" pilot cities, with the first batch starting in 2014 and including a total of 39 cities (and city clusters) in Beijing, Tianjin, and Shanghai; the second batch has been implemented since 2015, with 39 new towns established on top of the original set; the third batch of pilot cities, including Shenyang and Hangzhou, was established in 2016. Accordingly, the benchmark model is constructed in this paper as shown in Equation 1 below.

$$RD/TFP = \beta_0 + \beta_1 DID_{i,t} + \sum Controls + v_i + u_t + \varepsilon_{it} \tag{1}$$

In Equation (1), *RD* denotes firm R&D innovation, *TFP* denotes total factor productivity, i denotes the enterprise, and t denotes the year. DID denote the "Broadband China" pilot policy. The coefficient β_1 is the variable of interest in this paper, which indicates the difference between the enterprises in the pilot city and those of the non-pilot town before and after the pilot city implementation of the policy. Controls denote a set of control variables that may affect regional and firm characteristics; v_i denotes individual fixed effects; $u_t$denotes time fixed effects, and ε_{it} Denotes the random error term.

Given the possible sample selection bias leading to random errors in the treatment and control groups that do not satisfy the homogeneous distribution assumption, this paper considers choosing the propensity score matching (PSM) method to eliminate the sample selection bias. However, PSM is highly dependent on the setting of the first-stage Logit model. To this end, drawing on the entropy balance method proposed by Hainmueller (2012) to select those characteristic variables that may lead to biased policy evaluation, a set of weights is obtained by higher-order matching so that the means and variances of all distinct variables of the samples in the experimental and control groups are the same. Then samples closer to the experimental group are found from the control group to be assigned higher weights. Next, a weighted regression is used to estimate the regression model and re-estimate the double-difference using the matched samples. Finally, model (2) is further constructed based on model (1).

$$(RD/TFP)^{EBA} = \beta_0 + \beta_1 DID_{i,t} + \sum Controls + v_i + u_t + \varepsilon_{it} \tag{2}$$

The covariates selected in this paper mainly include two dimensions, city, and firm, as detailed in the variable definitions and descriptive statistics. The other setting forms remain consistent with the baseline regression model.

4. Results and discussion

4.1. Baseline regression results

Before conducting the regression, we first performed a multicollinearity test. The variance inflation factor test of the explanatory variables showed that the most significant value of VIF among all variables was 1.63, which was much smaller than the critical value of 10 required by the rule of thumb, so there was no need to worry about the multicollinearity among variables. In addition, to ensure that the model setting is reasonable, we introduce two dummy variables, "policy1" and "policy2," into the model before the regression, and the conditions for them to take the value of 1 are "the region is a test area after two years" and "the region is a test area after two years", respectively. If the coefficients of "policy1" and "policy2" coefficients are not significant simultaneously, it indicates that the parallel hypothesis is valid. According to the estimation results of the similar trend test in Table 2, both coefficients were insignificant, and the parallel trend hypothesis holds. This paper examines the impact of the "broadband China" policy on transforming and upgrading enterprises by using the progressive double-difference method. The estimation results of the benchmark regression model are given in Table 2.

Models 1 and 2 consider the bivariate fixed effects and firm-level control variables and find that the intensity of R&D expenditures and the firm's total factor productivity show significant positive coefficients at the 1% confidence level. Models 3 and 4 add city-level control variables on top of this. It can be seen that the coefficients and significance of R&D expenditure intensity have decreased. The coefficient of total factor productivity level of enterprises has also reduced significantly. However, it is still considered positive at 1% confidence level, which indicates that network infrastructure construction can substantially improve R&D innovation level and total factor productivity of enterprises in the pilot cities. Productivity growth.

Table 2. Network infrastructure development and enterprise transformation and upgrading: benchmark regression.

	RD	TFP	RD	TFP	Entropy balance	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
policy1	−0.015	−0.034	−0.048	−0.038	−0.067	−0.057
	(0.030)	(0.028)	(0.014)	(0.031)	(0.063)	(0.028)
policy2	−0.037	−0.028	−0.040	−0.058	−0.034	−0.054
	(0.057)	(0.026)	(0.056)	(0.017)	(0.026)	(0.057)
DID	0.0056***	0.0545***	0.0085**	0.0448***	0.0045***	0.0323***
	(0.0008)	(0.0104)	(0.0026)	(0.0152)	(0.0521)	(0.0052)
Scale	0.0004	−0.0021	0.0015	0.0042	0.0052	0.0048
	(0.0003)	(0.0057)	(0.0026)	(0.0023)	(0.0026)	(0.056)
Lev	0.0015	−0.0682*	0.0056	−0.0645**	0.0042	−0.05526
	(0.0021)	(0.0353)	(0.0026)	(0.0565)	(0.0052)	(0.0352)
Fixasset	−0.0084***	0.0493	−0.0026***	0.0645	−0.0015***	0.0225
	(0.0019)	(0.0413)	(0.0052)	(0.0352)	(0.0056)	(0.0426)
Cashflow	−0.0008***	0.0069**	−0.0052***	0.0026	−0.0005**	0.0527*
	(0.0002)	(0.0031)	(0.0002)	(0.0029)	(0.0002)	(0.0035)
Pershare	−0.0022	−0.0212	−0.0021	−0.0505**	−0.0031	−0.0147
	(0.0021)	(0.0248)	(0.0021)	(0.0235)	(0.0023)	(0.0230)
Capintense	0.0014***	0.0111*	0.0014***	0.0084	0.0018***	0.0003
	(0.0004)	(0.0061)	(0.0004)	(0.0057)	(0.0005)	(0.0063)
Capexpend	0.0255***	−0.1023	0.0263***	−0.1494**	0.0208***	−0.1187
	(0.0047)	(0.0715)	(0.0047)	(0.0668)	(0.0065)	(0.0780)
Innerfinance	0.0001	0.0037**	0.0001	0.0033**	0.0001	0.0006
	(0.0001)	(0.0017)	(0.0001)	(0.0016)	(0.0001)	(0.0017)
Ratiodebt	0.0006***	−0.0039**	0.0006***	−0.0033*	0.0008***	−0.0050***
	(0.0002)	(0.0019)	(0.0002)	(0.0018)	(0.0003)	(0.0018)
Duality	−0.0015**	0.0018	−0.0015**	0.0069	−0.0030***	0.0211**
	(0.0007)	(0.0093)	(0.0007)	(0.0087)	(0.0010)	(0.0089)
Tobin	−0.0021	0.1638	−0.0003	0.1089	0.0077	0.1719
	(0.0058)	(0.1408)	(0.0059)	(0.1294)	(0.0061)	(0.1541)
Mshare	0.0065	−0.1141	0.0058	−0.1076	−0.0056	−0.0584
	(0.0054)	(0.0795)	(0.0053)	(0.0755)	(0.0073)	(0.0737)
FDI			−0.0000	0.0142***	−0.0004*	0.0165***
			(0.0002)	(0.0027)	(0.0002)	(0.0026)
Govsupport			0.0164**	−1.6924***	0.0133*	−1.5981***
			(0.0069)	(0.0873)	(0.0072)	(0.1008)
GDP			0.0004	0.0459***	−0.0001	0.0585***
			(0.0005)	(0.0065)	(0.0005)	(0.0074)
Constant	−0.0070	11.8529***	−0.0136	11.5485***	−0.0094	11.3749***
	(0.0086)	(0.1856)	(0.0108)	(0.1805)	(0.0129)	(0.2128)
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.2151	0.1490	0.2171	0.2377	0.2201	0.2439
N	12585	17661	12533	17533	12533	17533

Note: ***, **, and * denote 1%, 5%, and 10% significance levels, respectively, and robust standard errors after using corrected heteroskedasticity are in parentheses; all models are clustered to the firm group, and the following table is identical.
Source: drawn by the author.

To solve the possible self-selection problem of the experimental group sample, this paper uses the entropy balancing method to re-estimate the double-difference to obtain the robustness results. Model 5 and 6 are the entropy matching results for the corresponding R&D expenditure intensity and total factor productivity, respectively. As a result, it can be seen that the explanatory variables are both significantly positive at the 1% confidence level. The coefficient of total factor productivity decreases further. At the same time, the significance of R&D expenditure intensity increases significantly. The estimation of the entropy matched equilibrium results again indicates that network infrastructure construction can substantially promote the transformation and upgrading of enterprises within the pilot cities.

4.2. Quantification and decomposition of mechanisms

1. Quantification of mechanisms. To test the hypothesis proposed in the theoretical part, i.e., to examine the intrinsic mechanism behind the impact of network infrastructure construction on enterprise transformation and upgrading, drawing on the research method of (Schmitz 2004), this paper constructs the regression models shown in Equations (3) and (4). It combines the regression results of Equation (1) to determine the impact of network infrastructure construction on enterprise transformation and upgrading and its intrinsic logic.

$$Human/Cost = \alpha_0 + \alpha_1 DID_{i,t} + \sum Controls + v_i + u_t + \varepsilon_{it} \quad (3)$$

$$RD/TFP = \gamma_0 + \gamma_1 DID_{i,t} + \gamma_2 (Human/Cost) + \sum Controls + v_i + u_t + \varepsilon_{it} \quad (4)$$

   Equation (3) tests the impact of network infrastructure construction on firms' human capital and transaction costs. Equation (4) tests the effects of network infrastructure construction and mediating variables on firms' transformation and upgrading.*Human* denotes the human capital of an enterprise. This paper uses the proportion of the number of people with bachelor's degrees or above in the enterprise to the total number of employees in the enterprise to measure the human capital structure of the enterprise. *The cost* denotes the transaction cost of the enterprise, and the paper further subdivides the transaction cost of micro-enterprises into internal transaction cost and external transaction cost. Among them, the inner transaction cost (*Innermost)* is measured by the proportion of management expense to total assets, which indicates the management transaction cost of the enterprise; the external transaction cost (*Extercost*) is measured by the ratio of selling expense to the central business revenue, which indicates the market transaction cost of the enterprise.
2. Mechanism test and decomposition. Based on the previous results, this paper applies the mediating effect model to regress Equations (1), (3) and (4) sequentially to first test whether the mediating effect of corporate human capital exists, and the results are shown in Table 3. In the total effect regression, model 1 and model 4 test the impact of network infrastructure construction on firms' R&D innovation and total factor productivity, respectively. The regression results are consistent with the findings of the benchmark model. Model 2 tests the impact of network infrastructure construction on firms' human capital, and the results show that network infrastructure construction significantly promotes the level of firms' human capital. The reason may include two aspects: First, the direct effect is that the network infrastructure improves the traditional way of knowledge acquisition and absorption and allows workers to learn and communicate more conveniently through the internet, which accelerates the "learning by doing" of human capital and speeds up the process of knowledge acquisition, transmission,

Table 3. Network infrastructure and enterprise transformation and upgrading: human capital mechanisms.

	R&D expenditure		Human Capital	TFP	
	Model 1	Model 2	Model 3	Model 4	Model 5
DID	0.0056**	0.0456*	0.0596***	0.0355***	0.03748***
	(0.0009)	(0.0009)	(0.0045)	(0.0112)	(0.0112)
Human		0.0597***			0.0359
		(0.0052)			(0.0296)
Corporate Control Variables	YES	YES	YES	YES	YES
City control variables	YES	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES
Constant	−0.0159	−0.018	−0.2962***	11.559***	11.5659***
	(0.0122)	(0.0122)	(0.0982)	(0.1951)	(0.1944)
R^2	0.2189	0.2159	0.5095	0.2485	0.24852
N	9657	9657	14224	13787	13787

Source: drawn by the author.

and sharing. Second, the indirect effect is that the network infrastructure construction has brought two cities that were not close to each other closer together through the internet and broadband, reducing the "spatial distance" between cities. Metcalfe's law in the Internet field allows the connection of network nodes to generate powerful knowledge and information spillover effects, which indirectly accelerates the sharing of knowledge and achievements and promotes the enhancement of human enterprise capital. Model 3 tests the impact of network infrastructure construction and human capital on enterprise R&D innovation, and it can be seen that the impact of human capital on enterprise R&D innovation is significantly positive at the 1% confidence level, indicating that the enhancement of human capital level provides fundamental support for sustained innovation. When a human capital intermediary is added, the regression coefficients of policy dummy variables are further reduced. The significance is also reduced to 10%. Combined with the three-part method of mediating effect, the confidence level can be judged that human capital plays an essential mediating role in network infrastructure construction to promote enterprise R&D innovation. Its mediating effect size is about 11.1% $(1-\gamma_1/\beta_1)$. Similarly, Model 5 tests the effects of network infrastructure construction and human capital on firms' total factor productivity. Again, the regression coefficients of the policy dummy variables are further reduced when human capital intermediation is added. The Sobel test results show the significant presence of the human capital intermediation effect. Therefore, network infrastructure construction can significantly promote the transformation and upgrading of enterprises through a human capital intermediation mechanism. Hypothesis H1 of the theoretical part is verified.

Similarly, Table 4 shows the test results of the mediation mechanism of transaction costs. Firstly, the intermediary agency is tested on the internal transaction cost of enterprises. The results of model 1 show that the network infrastructure construction can significantly reduce the interior transaction cost of enterprises. Model 2 is to test the influence of network infrastructure construction and interior transaction cost on

Table 4. Network infrastructure and business transformation and upgrading: transaction cost intermediation.

	Intra-company transaction costs			External transaction costs of enterprises		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
DID	−0.0085* (0.0085)	0.00526** (0.0008)	0.0854*** (0.018)	0.0085*** (0.005)	0.00123** (0.0598)	0.04485*** (0.0126)
Innercost		−0.0248*** (0.0026)	−0.1185* (0.0689)			
Extercost					−0.0096 (0.0052)	0.1485 (0.0969)
Corporate Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
City control variables	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.0359 (0.0259)	−0.0185 (0.0108)	11.5559*** (0.1806)	0.1593*** (0.0137)	−0.0189 (0.0110)	11.5858*** (0.1802)
R^2	0.3989	0.2289	0.2315	0.5548	0.2156	0.2326
N	18071	12533	17533	18071	12533	17533

Source: drawn by the author.

the R&D innovation of enterprises. It can be seen that the coefficients of policy dummy variables are reduced when the intermediary effect variable is added. The internal transaction cost on the R&D innovation of enterprises The effect of interior transaction cost on enterprise R&D innovation is significantly negative at 1% confidence level, indicating that reducing interior transaction cost can especially promote enterprise innovation enhancement. Combining model 1 and model 2, we find that interior transaction cost plays a part in the mediating mechanism in network infrastructure construction to promote enterprise R&D innovation.

Similarly, model 3 tests the influence of network infrastructure construction and internal transaction cost on enterprise total factor productivity. The conclusion shows that the coefficient of DID decreases when adding enterprise internal transaction costs. The influence of interior transaction cost on enterprise total factor productivity passes the 10% confidence level test, indicating that enterprise interior transaction cost plays a partial mediating role in network infrastructure construction promoting enterprise total factor productivity enhancement. The coefficient of DID decreases, and the effect of interior transaction cost on the total factor productivity of enterprises pass the 10% confidence level test, indicating that the interior transaction cost plays a partial mediating role in network infrastructure construction to promote enterprise total factor productivity. Thus, hypothesis 2a of the theoretical part is tested; that is, the network infrastructure construction promotes the transformation and upgrading enterprises by reducing enterprises' internal transaction costs.

Model 4 estimates the effect of network infrastructure construction on firms' external transaction costs, and it can be seen that the regression coefficient of DID is significantly positive at 1% confidence level, implying that network infrastructure raises firms' external transaction costs, which is the opposite of the theoretical hypothesis H2b of this paper. The possible explanation given in this paper is that the network infrastructure construction increases the sales volume of enterprises, consumers, and producers can be seamlessly connected through the network, improving matching efficiency. At the same time, the reduction of search cost can seek more market shares for enterprises in the commodity trading market, which further increases the cost of sales of enterprises. Model 5 and 6 test the influence of network infrastructure construction and external transaction cost on the transformation and upgrading of enterprises. When the external transaction cost of enterprises is added, the regression coefficients of enterprise R&D innovation and total factor productivity decrease, but none of the coefficients of external transaction cost is significant. With the help of the Sobel test of mediation effect, it is found that the mediation effect of external transaction cost of enterprises does not exist. Therefore, hypothesis 2b of the theoretical part is not confirmed. Based on the above mechanism decomposition, it can be found that the network infrastructure construction can only promote the transformation and upgrading of enterprises within the pilot cities by reducing their internal transaction costs.

4.3. Heterogeneity analysis

1. Criteria for identification of high-tech enterprises. Compared with traditional manufacturing enterprises, it is still an open question whether high-tech enterprises with higher technology levels can improve quality and efficiency and achieve higher quality upgrading activities. For this reason, this paper divides the sample enterprises into high-tech enterprises and non-high-tech enterprises (from now on referred to as "traditional enterprises") according to the "Management Measures for the Recognition of High-tech Enterprises" jointly issued by the Ministry of Science and Technology, the Ministry of Finance and the State Administration of Taxation in 2016. The specific classification of high-tech enterprises is based on the following criteria: when the sales revenue is less than RMB 50 million, the ratio of total R&D expenses to total sales revenue for the same period is greater than or equal to 5%; when the sales revenue is between RMB 50 million and RMB 200 million, the ratio of total R&D expenses to total sales revenue for the same period is greater than or equal to 4%; when the sales revenue is more significant than RMB 200 million, the ratio of total R&D expenses to total sales revenue for the same period is greater than or equal to 3%. The ratio is greater than or equal to 3%. Table 6 gives the regression results of transforming and upgrading different enterprises according to the high-tech enterprise recognition criteria.

   As shown in Table 5, both with R&D expenditure intensity and total factor productivity of enterprises as the explanatory variables, network infrastructure construction significantly enhances the transformation and upgrading of traditional enterprises, especially accelerating the R&D innovation of conventional enterprises. However, in terms of purely technological upgrading, the total factor productivity of high-tech firms is significantly higher than that of traditional firms due to network infrastructure construction. On the one hand, compared with high-tech enterprises, traditional enterprises themselves contain a low level of information technology, and according to the producer theory, when the degree of information technology within traditional enterprises does not reach the threshold expectations, the marginal output generated by each unit of input factors is incremental. Therefore, when faced with the continuous improvement of network infrastructure within the pilot city, traditional enterprises can more fully utilize the internet to innovate technology and achieve transformation and upgrading. High-tech

Table 5. Regression of grouping based on high-tech enterprise recognition criteria.

	R&D expenditure		TFP	
	High-tech Enterprises	Traditional Enterprises	High-tech Enterprises	Traditional Enterprises
DID	0.0005	0.0017***	0.0567**	0.0395***
	(0.0037)	(0.0006)	(0.0285)	(0.0111)
Corporate Control Variables	YES	YES	YES	YES
City control variables	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Constant	−0.0257	−0.0128	10.9746***	11.5914***
	(0.0455)	(0.0108)	(0.3826)	(0.1952)
R^2	0.1897	0.2196	0.3055	0.2339
N	1803	10730	2456	15077

Source: drawn by the author.

Table 6. Based on industry classification criteria for listed companies.

	R&D expenditure		TFP	
	manufacturing industries	Service Industry	manufacturing industries	Service Industry
DID	0.0089*	0.0599**	0.0564***	0.0857*
	(0.0009)	(0.0013)	(0.0126)	(0.0205)
Corporate Control Variables	YES	YES	YES	YES
City control variables	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Constant	−0.0274	0.0061	11.5896***	11.1744***
	(0.0149)	(0.0095)	(0.2271)	(0.3473)
R^2	0.1959	0.3089	0.2174	0.2885
N	8298	3070	11517	4331

Source: drawn by the author.

enterprises' endowment determines that their transformation and upgrading is not a quick fix; however, the construction of network infrastructure can also promote further improvement of their technology level; the law of diminishing marginal returns makes high-tech enterprises produce a decreasing marginal contribution to technological change after increasing a small amount of information technology investment. Therefore, high-tech enterprises want to achieve a more profound transformation and upgrading and need a stronger technology impact.

2. Analysis based on the industry classification standard of listed companies. The new generation of information technology with the internet as the core drives fundamental changes in the traditional manufacturing industry's production mode and industrial form. It has become the main direction of global modern industrial transformation and upgrading. Then we cannot help but ask, does the formulation of the "Broadband China" policy boost China's manufacturing industry's? If the manufacturing and service industries apply digital technology simultaneously, which industry will have a higher probability of achieving change and upgrading? To this end, this paper divides the sample of listed companies into manufacturing industries and service industries according to the Industry Classification Guidelines for Listed Companies (2012 Edition) of the Securities and Futures Commission. The regression results of sub-samples are given in Table 6.

Overall, implementing the "Broadband China" policy can significantly promote the transformation and upgrading of enterprises in both types of industries. However, by indicators, the network infrastructure construction is more potent for R&D innovation in the service industry than in the manufacturing industry; and the network infrastructure construction is more rapid for total factor productivity improvement in the manufacturing industry than in the service industry. This is because the current integration of the Internet and service industry is closer than that of the manufacturing industry. The new economic forms that appear with the help of the internet, such as online medical care, virtual campus, virtual classroom, and digital government, all belong to the service industry, which is inseparable from the attributes of the service industry itself, so the transformation and innovation ability of network infrastructure construction to service industry will be more robust; meanwhile, manufacturing industry, as the pillar industry of the national economy, needs technology to transform and upgrade itself. At the same time, the transformation and upgrading of the manufacturing industry, as a pillar industry of the national economy, requires continuous improvement of technology and productivity level, and the network infrastructure is also part of the infrastructure, compared with the development of the manufacturing industry, which needs more excellent infrastructure than the service industry. Therefore, the network infrastructure's marginal effect on improving the manufacturing industry's technology level is slightly better than that of the service industry.

In addition, to explore in-depth whether the integration and development of Internet and manufacturing industries will be systematically different by different manufacturing industries, the article further subdivides manufacturing industries into equipment manufacturing and consumer goods manufacturing. According to Marx's two-sector theory of social production, social production is mainly divided into sectors that produce means of production and industries that have means of consumption. The regression results of further subdivision by the manufacturing industry show that network infrastructure does not promote the level of innovation in equipment manufacturing and consumer goods manufacturing but significantly increases the total factor productivity of these two types of sectors, and the marginal contribution to consumer goods manufacturing is considerably higher than that of equipment manufacturing. This regression result illustrates two issues: first, overall, network infrastructure construction has a limited effect on the innovation capacity of manufacturing (and subsectors), which echoes the regression results of the manufacturing subsample in Table 7; second, the marginal contribution of network infrastructure construction to productivity improvement is relatively low for enterprises with higher technological requirements. Combined with the above empirical results, it can be seen that the implementation of the "broadband China" policy has a positive boost to the transformation and upgrading of both manufacturing and service industries. However, the marginal contribution of network infrastructure construction gradually decreases with the continuous improvement of the technological endowment.

5. Further research: corporate life cycle theory

5.1. Life cycle division

Most existing studies only consider the impact of cross-sectional differences in enterprises, ignoring the potential heterogeneity in the enterprise life cycle's time

Table 7. Network infrastructure and enterprise transformation and upgrading: a life-cycle perspective.

	R&D expenditure			TFP		
	Growth period	Maturity	Recession	Growth period	Maturity	Recession
DID	0.0028***	0.0001	0.0020	0.0539***	0.0314**	0.0323
	(0.0010)	(0.0010)	(0.0015)	(0.0127)	(0.0140)	(0.0227)
Corporate Control Variables	YES	YES	YES	YES	YES	YES
City control variables	YES	YES	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Constant	−0.0158	−0.0141	0.0025	11.6513***	11.5047***	11.4875***
	(0.0174)	(0.0118)	(0.0135)	(0.2225)	(0.2148)	(0.3497)
R^2	0.2085	0.2443	0.2773	0.2473	0.2576	0.2166
N	5649	5444	1427	7890	7495	2135

Source: drawn by the author.

dimension. The current evaluation of the effects of the "broadband China" policy needs to be further developed. Life-cycle theory suggests that firms differ significantly in size, profitability, investment and financing strategies, and willingness to transform at different stages of development (Costall & Still, 1989). In this paper, we expect that the incentive effects of network infrastructure construction will be other depending on the life-cycle stages.

This paper chooses (Dickinson, 2011) to propose an operational and objective cash flow model method to divide the sample into three stages: growth, maturity, and decline. The positive and negative combinations of three indicators, net cash flow from operating activities, net cash flow from investing activities, and net cash flow from financing activities, are used to reflect the operational risk, profitability, and growth rate of different life cycles.

Combined with the enterprise life cycle criteria, firstly, the complete sample information is used to classify different types of enterprises into three stages: growth stage, maturity stage, and decline stage, and the estimation results are shown in Table 7. It can be seen that the network infrastructure construction significantly promotes the transformation and upgrading of enterprises in the growth period characterized by the increase of R&D expenditure intensity and total productivity level. The real factor productivity growth of enterprises in the maturity period is also significantly positive at the 5% confidence level. However, it fails to promote the transformation and upgrading of enterprises in the recession period. This paper argues that enterprises in the growth period are significantly more dynamic than those in the maturity and recession periods in terms of their ability to receive new things and innovation.

Moreover, since enterprises in the growth period have just entered the industry, their sunk costs are relatively low. Therefore, the cost of network infrastructure construction to facilitate their transformation and upgrading is acceptable, so they are more conducive to achieving transformation and upgrading. The more mature the development, the higher the cost of change and upgrading enterprises, and therefore will not be easily transformed. After reaching the recession period, firms' sales start to decline, their market share gradually declines, their financial situation deteriorates, and it is tough to transform and upgrade due to aging technology and lack of financial support(Wahba & Elsayed, 2014), the declining firms' R&D results conversion

Table 8. Business life cycle by within manufacturing.

	R&D expenditure			TFP		
	Growth period	Maturity	Recession	Growth period	Maturity	Recession
DID	0.0032***	0.0001	0.0015	0.0627***	0.0281	0.0429
	(0.0012)	(0.0013)	(0.0020)	(0.0154)	(0.0173)	(0.0275)
Corporate Control Variables	YES	YES	YES	YES	YES	YES
City control variables	YES	YES	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Constant	−0.0252	−0.0214	−0.0045	11.8701***	11.4505***	10.7519***
	(0.0233)	(0.0153)	(0.0202)	(0.2909)	(0.2643)	(0.4393)
R^2	0.2114	0.2031	0.2021	0.2212	0.2324	0.2106
N	3825	3653	819	5294	4979	1243

Source: drawn by the author.

rate keeps decreasing, coupled with the continuous disconnection from frontier technology. This validates the hypothesis proposed in the theoretical section3.

5.2. Business life cycle by manufacturing and within the service industry

The overall level of manufacturing enterprises in China is low overall compared with developed countries in Europe and the United States, so within manufacturing enterprises, are there differences in transformation and upgrading for enterprises with different life cycles? This paper further subdivides the manufacturing industry by enterprise life cycle within the listed companies based on the industry classification criteria. The estimation results are shown in Table 8. it can be seen that for the manufacturing life cycle, enterprises in the mature stage are more conducive to transformation and upgrading, whether using R&D expenditure or total factor productivity as the explanatory variables, the "broadband China The regression coefficients of the "broadband China" policy pass the 1% confidence level test, however, for the mature and declining stage enterprises, the policy does not promote the transformation and upgrading of enterprises. Similarly, the regression coefficients of the "broadband China" policy pass the 1% confidence level test only in the mature stage enterprises, i.e., the policy only promotes the R&D innovation of the adult stage enterprises in the service industry and does not significantly promote the transformation and upgrading of the adult and declining stage enterprises. In summary, whether we divide the life cycle by the total sample or by industry classification, the network infrastructure construction plays a significant role in promoting the transformation and upgrading of enterprises in the growth period. However, it does not promote the transformation and upgrading of enterprises' maturity and recession periods.

6. Discussion of endogeneity issues

6.1. Robustness test

1. Placebo test. In order to exclude the interference of other policies and prove that the transformation and upgrading of enterprises are indeed caused by the implementation of the "Broadband China" pilot policy, this paper randomly sets the experimental group to conduct an indirect placebo test. Specifically, the

expression of the estimated coefficient of DID (Differences-in-Differences) β is obtained according to Equation (1) as follows.

$$\hat{\beta} = \beta + \lambda \frac{cov(DID_{ct}, \varepsilon_{it}|X)}{var(DID_{ct}|X)} \tag{5}$$

X denotes all observable control variables and fixed effects, and λ is the effect of unobservables on the explanatory variables. If we want to obtain an unbiased estimate of $\hat{\beta}$, we must ensure that $\lambda = 0$, but this cannot be directly verified. To this end, this paper finds an error variable that theoretically does not affect the outcome variable using computer simulation to replace *DID*. If $\hat{\beta} = 0$ can still be estimated under this premise, then $\lambda = 0$ can be inferred. Specifically, this paper uses Monte Carlo simulation to randomly select a "Broadband China" pilot city from the total sample. "The list of pilot cities is set as a "pseudo-experimental group" (the distribution of selected prefecture-level cities in each year is also consistent with the real distribution), and the remaining sample is used as the control group. In this paper, this process is repeated 1000 times to generate 1000 β^{random}.It is easy to find that the distribution of β^{random} is around zero and follows a normal distribution. This result not only greatly reduces the effect of other policy interference on the explanatory variables but also indirectly proves that the transformation and upgrading of enterprises in the pilot cities are indeed significantly affected by the formulation of the "Broadband China" policy, and the conclusions of this paper are robust and reliable.

2. Sample selection process: PSM-DID (Propensity Score Matching- Differences-in-Differences), where the PSM-DID method is further used to re-run the robustness test. Before PSM-DID estimation, it is necessary to pass the "balance test" and satisfy the "common support test" to ensure the matching quality. To this end, the propensity scores are first estimated using a logit model.

$$Logit(Treat_i = 1) = \alpha_i + \sum Controls + \varepsilon_{it} \tag{6}$$

*Treat*y indicates whether the sample belongs to the treatment group as a dummy variable; other control variables are kept consistent with the baseline regression model. Next, three matching methods, caliper matching, nearest-neighbor matching, and kernel matching, are used in this paper. After excluding the samples that reject the common support hypothesis, the double-difference method is used again to re-estimate the results, as shown in Table 9. It can be seen that whether using its strict caliper radius or choosing one-to-one nearest neighbor matching that would lose a large number of samples, the network infrastructure construction significantly contributes to the transformation and upgrading of enterprises characterized by R&D (Research and Development) expenditure intensity and total factor productivity.

3. Excluding other policy interference. Made in China 2025, an industrial policy involving support for innovation released by the Chinese government in 2015, can significantly promote the transformation and upgrading of firms. Unfortunately, the implementation interval of this policy happens to be within

Table 9. Robustness test (I): PSM-DID.

	Radius Matching		One-to-one near-neighbor matching	
	R&D expenditure	TFP	R&D expenditure	TFP
DID	0.0016*	0.0571***	0.0016**	0.0427***
	(0.0010)	(0.0112)	(0.0008)	(0.0102)
Corporate Control Variables	YES	YES	YES	YES
City control variables	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Constant	−0.0109	11.6608***	−0.0136	11.5485***
	(0.0110)	(0.1949)	(0.0108)	(0.1805)
R^2	0.2083	0.2483	0.2171	0.2377
N	7568	12027	12533	17533

Source: drawn by the author.

the sample of this paper. To avoid the possibility that the transformation and upgrading of firms in this paper may be due to the industrial policy interference of Made in China 2025 encountered during the policy implementation period, the robustness test further controls for Made in China 2025, an industrial policy supporting innovation. The results find that network infrastructure development still significantly drives firms' transformation and upgrading. Therefore, made in China 2025, a supportive policy can significantly affect firms' R&D innovation and total factor productivity.

6.2. Endogenous treatment: instrumental variables approach

Considering that the approval of the pilot cities for the "Broadband China" policy is not a completely exogenous event, the selection of the pilot cities for "Broadband China" and the structural transformation of the Chinese economy may be decided at the same time, and the estimation results may be endogenously biased. In this paper, an instrumental variables approach is used to correct for the possible endogeneity bias.

In this paper, the standard deviation of the elevation of each city (from now on referred to as "city slope") is chosen as the instrumental variable of the "Broadband China" pilot policy. There are two main reasons: first, the slope of a city will affect the construction of network infrastructure, and a more significant slope will not only increase the construction cost of network infrastructure but also affect the signal quality of broadband network and thus the operational efficiency of network infrastructure, while the establishment of "broadband China" pilot cities must be made after fully considering the local The choice of the "Broadband China" pilot cities must be made after fully considering the conditions of the local telecommunication infrastructure, thus satisfying the correlation assumption of the instrumental variables. Second, the slope of the city is a typical natural geographic variable. Whether the R&D innovation and total factor productivity level of enterprises are improved or not can hardly be linked to the topography and geology of the city, and if there is a link, then the only way is to influence the "Broadband China" pilot policy and thus the transformation and upgrading of enterprises. Thus the assumption of exogeneity of instrumental variables is satisfied.

Table 10. Robustness test (II): Instrumental variables.

	Instrumental variable method test	
	Model 1	Model 2
DID	0.0080***	0.2292**
	(0.0027)	(0.1066)
Corporate Control Variables	YES	YES
City control variables	YES	YES
Individual fixed effects	YES	YES
Time fixed effects	YES	YES
Constant	−0.0141	11.5608***
	(0.0108)	(0.1801)
Phase I F-value	414.95	578.10
KP-rk Wald F	489.385	624.031
R^2	0.0218	0.9001
N	12531	17686

Source: drawn by the author.

In addition, since the urban slope is cross-sectional, it cannot be directly applied as an instrumental variable in the panel data fixed-effects model. Based on the existing studies, this paper constructs an interaction term between cross-sectional instrumental variables and time variables as an instrumental variable for the pilot policy of "broadband China." Table 10 reports the two-stage least squares regressions of R&D expenditure intensity and total factor productivity using the instrumental variables method, and it can be seen that the second-stage DID regression coefficients still contribute significantly to enterprise transformation and upgrading at least at the 5% confidence level. In addition, the first-stage F-value test is significantly larger than the rule of thumb after the inclusion of all control variables, and the KP-rk Wald F-statistic is larger than the critical value at the 10% level of bias validated, ruling out the hypothesis of under-identification of instrumental variables. In summary, the network infrastructure did have a boosting effect on the transformation and upgrading of firms within the pilot cities, again proving the reliability of the previous study's findings.

7. Conclusions and policy recommendations

VII.1 Research findings

Based on the institutional background and theoretical analysis, this paper empirically examines the impact of network infrastructure construction on enterprise transformation and upgrading and its mechanism of action by using various models and methods, such as progressive double-difference method, entropy equilibrium method, and two-stage least squares method, with the quasi-natural experiment of national "broadband China" policy pilot construction.

The findings: First, overall, network infrastructure development significantly improves firm transformation and upgrading as characterized by R&D expenditure intensity and firm total factor productivity, and this finding still holds after a series of robustness tests, and the slope of each city is selected as an instrumental variable. Second, the results of the mechanism analysis show that network infrastructure development contributes to firm transformation and upgrading mainly through the dualchannel of enhancing human educational capital and reducing internal transaction costs. Thus, the effect of the human capital mediating mechanism is the strongest. Third, based on the theory of enterprise heterogeneity, whether the intensity of R&D expenditure or total factor productivity is used as the explanatory variable, network infrastructure construction significantly enhances the transformation and upgrading of traditional enterprises, especially accelerates the R&D innovation of traditional enterprises. However, in terms of simple technology level improvement, the total factor productivity of high-tech enterprises is slightly higher than that of traditional enterprises by network infrastructure construction. Fourth, based on the industry heterogeneity analysis, it is found that network infrastructure construction can positively promote the transformation and upgrading of enterprises in both manufacturing and service industries. However, network infrastructure construction on the innovation capacity enhancement of manufacturing industries is more limited. Finally, the marginal contribution of network infrastructure construction to the two types of industries gradually decreases with the continuous improvement of the technological endowment. Fifth, after considering the enterprise life cycle perspective, it is found that the incentive effect of network infrastructure construction will have different performances depending on the differences of each life cycle stage. The transformation and upgrading of enterprises in the growth period characterized by increased R&D expenditure intensity and total productivity level are significantly positive. The total factor productivity growth of enterprises in the maturity period is also significantly positive at a 5% confidence level. In contrast, The effect of transformation and upgrading is not significant for enterprises in the recession period.

VII.2 Policy Recommendations

Based on the above findings, this paper puts forward the following policy recommendations: First, further, increase the investment in network infrastructure construction and Internet-related applications, insist on promoting the development process of industrial digitization and digital industrialization, and accelerate the pace of construction of digital China. Create a comprehensive interconnection of human-machine and material industrial internet and continue to promote industrial Internet enterprise extranet construction while vigorously building and renovating enterprise intranet. Second, develop a differentiated and dynamic network infrastructure development strategy based on local conditions. Universal, secure and affordable network connectivity is a fundamental enabler of the digital economy and a catalyst for inclusive growth and sustainable development. Third, we should increase efforts to introduce high-quality human capital to break the human capital bottleneck in enterprise transformation and upgrading. Firstly, we should establish flexible and diversified talent introduction mechanisms according to the nature and type of enterprises and improve the existing high-tech talent introduction mechanism to guide the inflow of high-quality human capital to high-tech industries while considering the digital development of traditional industries. Secondly, focus on the "secondary training" of talents, improve the training and reward mechanism of talents, promote the integration and utilization of domestic and foreign advantageous resources with the development of digital technology, create a more standardized and convenient knowledge transfer and exchange environment, and allow human capital to further improve its knowledge and skills in the process of labor, realize its value and create higher social value at the same time. At the same time, it creates higher social value. Fourthly, respect the law of enterprises' development and improve the effectiveness and precision of broadband incentive policies. Finally, the government should consider the life cycle of enterprises when formulating network facilities development strategies and appropriately and flexibly make differentiated arrangements for network facilities development strategies.

VII.3 Limitations and Prospects

1. The theoretical analysis of the relationship between Internet capabilities and the Internet strategic transformation of traditional manufacturing enterprises needs to be further deepened. It is not enough to study the relationship between the new competitive advantage and the Internet capability after the transformation. Still, it is also necessary to learn how the Internet capability affects the transformation of enterprises in the four aspects of customer interaction, iterative innovation, organizational learning, and resource management when implementing the Internet strategic transformation.
2. The empirical analysis of the relationship between Internet capabilities and Internet strategic transformation of enterprises needs to further consider the influence of intermediaries. Furthermore, the empirical evidence of the relationship between Internet capabilities and corporate Internet strategic transformation can mediate dynamic competitive capabilities, which requires selecting more appropriate research methods and research lines for a more in-depth empirical study of them.

Ethical statement

This article does not contain any studies with human participants or animals performed by any authors. Therefore, I certify that this manuscript is original and has not been published, and will not be submitted elsewhere for publication. Moreover, the study is not split into several parts to increase submissions and submit to various journals or one journal over time.

Conflict of interest

The authors declare that they have no conflict of interest.

Data availability statement

The submitted article appears all data, models, and code generated or used during the study.

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