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Article

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Directors' IT expertise and firms' total factor productivity

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ABSTRACT

Using a hand-collected data set of Chinese A-share non-financial listed companies spanning years 2005–2020, this study examines whether directors' information technology expertise influences firms' total factor productivity. Our findings indicate a significant and positive effect. The positive effect is more salient for firms with lower capital intensity and firms in non-competitive product markets. Furthermore, two mechanisms through which directors' information technology expertise improves total factor productivity have been identified: one is the increase in information technology investments; the other one is the enhancement in operating efficiency of fixed assets. Our study not only sheds new lights on the effects of directors' information technology expertise, but also provides convergent evidence on the determinants of firm-level total factor productivity.

KEYWORDS

Information technology expertise; total factor productivity; information technology investment; operating efficiency

JEL CLASSIFICATION

G30; G34; D24; M10

1. Introduction

Total factor productivity (TFP), which refers to the level of output transformed from input (Baier et al., 2006) and usually interpreted as the 'surplus', has been long recognised as a crucial measure to reflect the overall efficiency of using resources (Şeker & Saliola, 2018). In recent years, numerous studies have established the importance of TFP. For instance, it has a positive impact on labour productivity (Prados De La Escosura & Rosés, 2021), investment efficiency (Kong et al., 2021), and the level of sustainability development (Markowska-Przybyła, 2020).

Besides that, researchers have longstanding interest on the determinants of TFP. Existing literature on this question mainly laid emphasis on two aspects: external environment and the firms' specific characteristics. For example, Aghion et al. (2015) find that if industrial policies are promoted fairly among companies in the same industry, instead of focusing on supporting individual company, it can promote the improvement of overall corporate TFP. Similarly, external market discipline (Tian & Twite, 2011), stricter

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environmental regulation (Ai et al., 2020; He et al., 2020; Lee & Lee, 2020; Yang et al., 2012) and labour market regulation (Bellocchi et al., 2020) can also significantly enhance industrial competition and subsequently increase TFP. In terms of firms' characteristics, management efficiency in general (Bloom & Van Reenen, 2010), board efficiency in particular (Giannetti et al., 2015; Tian & Twite, 2011) have been claimed as important factors affecting product quality and TFP.

The current study attempts to propose a new factor that influences firm-level TFP. It is well known and confirmed by previous studies that deficiency in information technology (hereafter IT) investment and IT expertise of employees are detrimental for firms (Kleis et al., 2012; Pavlou & El Sawy, 2006). When shifting the focus to IT adoption and employment of IT specialists, there appears to be very little emerging evidence concerning the question whether the employees' IT expertise can influence firm-level TFP. The current study aims to fill this void and take a step further by specifically examining directors' IT expertise, a group of people who is often regarded as the most significant mechanism for corporate decision-making by having the most discourse right and executive power in the organisation (Jiang & Kim, 2015).

IT expertise helps board directors promoting IT to corporate strategy level and greatly improving the possibility of IT adoption. Besides, IT knowledge and skills will facilitate board directors to better comprehend how to use equipment to make the operation more competitive, intelligently exercise their supervision and advisory functions and correct the risks in a timely manner. IT directors contributes to the increase of TFP by bringing superior technology and promoting the updates of IT systems. It is noteworthy that advanced technology may not only create technology progress but also advanced operational management that contributes to efficiency improvement.

Using a hand-collected data set of directors' IT expertise of China's listed firms over the period 2005–2020, we find that directors' IT expertise can increase firms' TFP. Moreover, we conduct a series of robustness checks to validate our primary findings, including performing firm fixed effect estimations and instrumental variable estimations, controlling for additional variables in terms of characteristics of directors, and considering the impact of some specific industries. Further analyses reveal that the positive effect of directors' IT expertise on TFP is more significant for firms with lower capital intensity and firms in less competitive product markets. Finally, we provide evidence for two potential channels through which directors' IT expertise has a positive impact on firms' TFP. We strongly believe that China's institutional environment can successfully facilitate us to solve our research question in the following two aspects. First of all, China, as the second largest economy in the world, is at an important stage of transition. The core feature of China's New Normal is the pursuit of high ROIC at the industry and capital levels and TFP improvements at the micro firm level.¹ Secondly, China has unique corporate governance features, where the board has more power and authority than those in western countries (Jiang & Kim, 2015).

Our findings contribute to the literature in the several ways. First, we contribute to the literature on the determinants of TFP. This study explores the effect of firms' specific characteristics by examining the relation between directors' IT expertise and firm-level TFP based on a data set from China, where directors' characteristics can be extremely important. The mechanisms through which the aforementioned above effect works are

¹Please refer to http://www.gov.cn/guowuyuan/2015-03/16/content_2835101.htm.

also investigated. Our paper is different but related to Cette et al. (2021), who mainly relies on the survey responses in 2018 of 1,065 French manufacturing firms and find the employment of information and communication technology (ICT) specialists can greatly improve a firm's TFP by about 17%. The employment data in Cette et al. (2021)'s study bears some noises, for instance it includes both in-house and outsourced personal, and it does not differentiate between their rankings within the firms. Our study clarifies and provides convergent evidence by empirically examining directors' IT expertise only.

By viewing the board of directors as an important part of corporate governance, the composition and its working mechanism are critical to the long-term development of the company and the interests of all shareholders. To that end, we also contribute to extant work on directors' personal factors, such as oversea experience. Extant literature has noted that IT expertise can help firms improve information quality and innovation efficiency. In particular, management's IT expertise is associated with high efficiency of firm's internal information environment (Haislip & Richardson, 2018) and improved innovation (Mattta et al., 2019). Ashraf et al. (2019) highlights the IT expertise of audit committee can decrease financial restatements, meanwhile increase the timeliness of earnings announcements disclosure. Considered alongside these findings from previous studies, our study sheds some light on the question of whether directors' IT expertise plays a role in firms' TFP, introducing TFP as a new economic consequence.

The remainder of this paper is organised as follows. Section 2 discusses the hypothesis development. Section 3 describes the research design, including sample selection, model specification, and variable measurement. The empirical results including robustness checks and heterogeneities in the effect of directors' IT expertise are presented and discussed in Section 4. Section 5 examines economic channels underlying the effect of directors' IT expertise. We conclude in Section 6.

2. Literature review and hypothesis development

2.1. Total factor productivity

TFP reflects the overall transformation efficiency of the input resources into the final output (Şeker & Saliola, 2018). Findings from extant literature suggest TFP is the result of a cumulative accumulation of many factors. While under the premise of other factors, TFP is positively related to labour quality, human capital investment, high quality products and high market demand. In addition, lenders' greater access to the collateral in the financial crisis can also enhance the TFP by changing the composition of their investments and their workforce towards newer capital and more skilled labour (Ersahin & Strahan, 2020). At the firm-level, Bloom and Van Reenen (2010) both demonstrate that management efficiency is an important factor affecting product quality and TFP. More specifically, when board members have overseas experience, it helps to improve the company's governance efficiency and thereby improving TFP (Giannetti et al., 2015).

2.2. IT expertise

IT encompasses "automated [and computerized] means of originating, processing, storing, and communicating information" (AICPA 2006, AU 314). Accordingly, IT is of great

importance because of the significant reliance of business operations and financial reporting on computerised information systems. Both practitioners and academic researchers have shown that effective implementation of IT can significantly improve corporates' performance in various fields, such as firms' information quality (Brazel & Dang, 2008; Dorantes et al., 2013; Li & Nwaeze, 2015), internal control effectiveness (Li et al., 2012; Morris, 2011), innovation (Kleis et al., 2012), business operations (Kobelsky et al., 2008; Kobelsky et al., 2008) and the quality of their financial reporting (Dehning & Richardson, 2002; Dehning et al., 2003). In addition, IT can also guarantee customer relations by dynamically observing customer demands (Rai et al., 2009), thus helping enterprises to better maintain existing markets and develop new markets. From the financial reporting point of view, successful IT implementation, in particular the application of XBRL can provide more comprehensive and reliable information (Dorantes et al., 2013; Li et al., 2012), and reduce information processing costs (Blankespoor, 2019).

However, when IT cannot be applied properly, it may bring risks to the company. The weakness of IT is more likely to be associated with lower efficiency in operations, volatile internal control structure, a greater number of financial misstatements and consequently a failure to pursue organisation strategic objectives (Klamm & Watson, 2009; Klamm et al., 2012; Li et al., 2012). Overall, the evidence suggests that companies, who are adequately investing and successfully implementing IT, often receive benefits; if not, it can be detrimental (Kobelsky et al., 2008).

2.3. Directors' IT expertise and TFP

When shifting the focus to personal characteristics, previous studies have noted the important role played by individuals' IT expertise. Specifically, Haislip and Richardson (2018) find that CEO IT expertise has significant firm benefits (i.e. fewer IT material weaknesses and more accurate forecasts, respectively). Further, Higgs et al. (2016) demonstrate IT expertise at the board level (i.e. a technology committee) will mitigate the negative market reactions related to security breach disclosures. As is known to all, board directors are extremely critical in corporate governance, and thus being regarded as the most significant mechanism for corporate decision-making (Jiang & Kim, 2015). Various personal characteristics and skills of board directors have been examined previously, such as directors' overseas experience (Cao et al., 2019; Giannetti et al., 2015), accounting and auditing expertise (Naiker & Sharma, 2009), legal background (Litov et al., 2014), bank affiliation (Erkens et al., 2014; Gunner et al., 2008; Sisli-Ciamarra, 2012) and so on. Building upon prior research, we explicitly posit that the directors' IT expertise can positively influence firms' TFP by promoting the adoption of IT and improving the efficiency. That is, these mechanisms allow the directors' IT expertise to benefit the IT investment and operating efficiency of fixed assets, consequently translating to higher firm-level TFP.

First, IT expertise helps board directors promoting IT to corporate strategy level and greatly improving the possibility of IT adoption. Given the fact that the board is the core mechanism for corporate strategy formulation and supervision, decisions of board directors should have a direct impact on corporate strategy (Sharma & Yetton, 2003). By setting up the tone at the top and increasing the commitment of the entire organisation, firms can create an environment of valuing IT implementation and innovation (Bassellier et al.,

2003; Enns et al., 2003). To be specific, compared to that lacks of IT knowledge and skills, board directors with IT expertise are better able to identify areas of information risks, observe the necessities to launch the technology innovation and have a better understanding of the role that IT platforms play with respect to business operations. Since agency problems are important factors that affecting IT investment decisions (Turedi, 2020), the more directors with IT expertise in a board, the higher the frequency of the board's positive responses to IT-related plans and activities, and the higher level of IT management (Kambil & Lucas, 2002). Meanwhile, to decrease employees' reluctance that may be brought by adopting new technologies, the professional IT work experience will facilitate the directors to select a more qualified IT management team, better communicate the effectiveness of IT implementations with employees and enhance the board's IT-related credibility.

Secondly, board directors with IT expertise can better discover and solve the problems in the fixed assets utilisation, thus improving its operating efficiency. After the adoption of technological systems, the company's ability to integrate and utilise IT and IT-related managerial talent are the key determinants of operating efficiency (Martínez-Núñez & Pérez-Aguar, 2014; Syverson, 2011). IT knowledge and skills will facilitate board directors to better comprehend how to use equipment to make the operation more competitive, intelligently exercise their supervision and advisory functions and correct the risks in a timely manner. Previous studies have provided ample evidence supporting this notion (Benaroch & Chernobai, 2017; Jewer & Mckay, 2012; Valentine & Stewart, 2015; Valentine & Stewart, 2013) and almost 74% of board directors believe that having IT-related expertise is very important for improving the company's governance level (Valentine & Stewart, 2013).

Finally, directors' IT expertise can greatly enhance firm-level TFP through promoting the adoption of IT and improving the operating efficiency. Considering the fact that technology change and efficiency change are the main sources of TFP growth (Sari et al., 2016), IT investment contributes to the increase of TFP by bringing superior technology and promoting the updates of IT systems. Those technology benefits will be reflected in the upward shift of the firms' production technology. It is also noteworthy that advanced technology may not only create technology progress but also advanced operational management that contributes to efficiency improvement. By taking advantage of new technologies and efficient operation procedures, firms will learn about the ways to produce more output with the certain combination of inputs, or to produce a given amount of output using less input combinations, which consequently translate to higher TFP.

Based on the discussion above, we predict that directors' IT expertise encourages IT investment and improves operating efficiency, thereby enhancing TFP for firms. More formally, we hypothesise that:

H1: *Ceteris paribus*, directors' IT expertise has a positive impact on TFP.

2.4. Directors' IT expertise, capital intensity and TFP

Capital intensity has been traditionally defined as the ratio of capital to labour (Dobb, 1956). Kaldor (1939) deems that increasing the degree of capital intensity implies the

installation of superior equipment with a greater labour-saving capacity. Firms with lower capital intensity have fewer fixed assets relative to labour, and the utilisation of machinery and equipment in daily production is less compared to those with higher capital intensity. Directors with IT expertise can improve the efficiency of existing machinery and equipment. In addition, they may introduce new technology and equipment, and change the manufacturing and management mode. Therefore, directors' IT expertise may bring more incremental impact on TFP of firms with lower capital intensity, and we predict that the effect of directors' IT expertise on increasing TFP is stronger for firms with lower capital intensity. Accordingly, we hypothesise that:

H2: Ceteris paribus, the positive relationship between directors' IT expertise and TFP is more salient in firms with lower capital intensity.

2.5. Directors' IT expertise, product market competition and TFP

Schmidt (1997) finds that increasing product market competition unambiguously reduces managerial slack and induces high effort. Firms in non-competitive product markets benefit more from good governance relative to those in competitive markets, because the lack of competitive pressure fails to enforce discipline on managers (Giroud & Mueller, 2011). As Giroud and Mueller (2011) claimed that, only in non-competitive industries, weak governance firms have lower productivity and higher input costs. Directors' IT expertise can play a greater role in non-competitive industries through improving efficiency and increasing investment. Thus, we expect that firms in non-competitive industries are more likely to be beneficial from directors' IT expertise. We therefore hypothesise that:

H3: Ceteris paribus, the positive relationship between directors' IT expertise and TFP is more significant for firms in non-competitive product markets.

3. Research design

3.1. Sample and data sources

Our sample is initially comprised of all A-share firms listed on the Shanghai Stock Exchange (SHSE) and Shenzhen Stock Exchange (SZSE) from 2005 to 2020. We exclude financial firms (e.g. banks, insurance companies and investment trusts) as they account and report under special rules and have different capital structures. We then exclude observations with missing variables. Finally, we have a usable sample of 35,898 observations, representing 3,800 firms.

We manually collect the data of directors' IT expertise from their biographies in A-share firms listed on SHSE and SZSE. Following Haislip and Richardson (2018), we define that a director has IT expertise if he or she has an IT-related academic degree or is working or once worked in IT-related positions of employment. Based on the *Catalogue of Undergraduate Majors in Colleges issued by the Ministry of*

Education issued in 2012, IT-related academic degrees include academic degrees in electronic information, computer, e-commerce, information and computing science, information management and information system, and information resource management. According to Enns et al. (2003) and Haislip and Richardson (2018), IT-related positions refer to positions related with IT, information management, information system, information construction, ERP construction, software development, Internet development, computer, electronic engineering, system engineering, system construction, e-commerce and e-government, Internet of things, cloud computing, etc.

Other financial and corporate governance data used in this study are obtained from the China Stock Market & Accounting Research (CSMAR) system.

3.2. Models

To examine the relation between IT expertise and TFP, we estimate the following Model (1). To mitigate the potential endogeneity, we regress the contemporaneous TFP measures on the one period lag values of directors with IT expertise and other explanatory variables. The lag allows for the effect of change in having IT directors for a company to show up in future. A similar approach is also used in Helwege and Liang (1996), Coles et al. (2006), and Yuan and Wen (2018).

$$\begin{aligned}
 TFP_{i,t} = & \alpha_0 + \alpha_1 IT(IT_ratio)_{i,t-1} + \alpha_2 ROA_{i,t-1} + \alpha_3 Leverage_{i,t-1} + \alpha_4 FirmSize_{i,t-1} \\
 & + \alpha_5 FirmAge_{i,t-1} + \alpha_6 FreeCashFlow_{i,t-1} + \alpha_7 Capital_{i,t-1} + \alpha_8 BoardSize_{i,t-1} \\
 & + \alpha_9 Top1_{i,t-1} + \alpha_{10} SOE_{i,t-1} + \alpha_{11} IndepDirRatio_{i,t-1} + \alpha_{12} GDP_{i,t-1} \\
 & + \alpha_{13} Population_{i,t-1} + Year + Industry + \varepsilon
 \end{aligned} \tag{1}$$

where α_i represents regression coefficients, ε is an error term. The dependent variable *TFP* measures total factor productivity, while *IT* and *IT_ratio* measure directors' IT expertise. Control variables include *ROA*, *Leverage*, *FirmSize*, *FirmAge*, *FreeCashFlow*, *Capital*, *BoardSize*, *Top1*, *SOE*, *IndepDirRatio*, *GDP*, *Population*, *Year* and *Industry*. All the main variables are defined in Appendix.

To examine the moderating effects of capital intensity, we divide the initial sample into two groups, firms with higher capital intensity and those with lower capital intensity. Then, we re-estimate the baseline regression (1) for the two groups, respectively. Similarly, based on the Herfindahl-Hirschman Index (HHI), we divide the initial sample into two groups, firms in higher competitive market and those in lower competitive market, to observe the moderating effect of product market competition.

3.3. Variables

3.3.1. Dependent variable: TFP

We employ the methodology developed by Levinsohn and Petrin (2003) to measure a firm's TFP. This methodology makes use of an intermediate input as a proxy variable for productivity. Following Levinsohn and Petrin (2003), we use a two-step procedure to estimate productivity based on a Cobb – Douglas production function as Equation (2):

$$y_{it} = \beta_0 + \beta_L L_{it} + \beta_K K_{it} + \beta_M M_{it} + \omega_{it} + \eta_{it}, \tag{2}$$

where y_{it} is the output variable. L_{it} , K_{it} , M_{it} represent the labour input, capital stock and intermediate inputs, respectively. ω_{it} is the TFP and is a state variable impacting the firm's decision rules. η_{it} is an independent and identically distributed component. In this study, the labour input is measured using the number of employees in a listed firm. Capital stock includes property, plant and equipment net of depreciation. As for intermediate inputs, unlike the manufacturing sector, the use of electricity as a proxy variable does not seem to be warranted as we consider various industries in our sample. We therefore take expenses for material and other inputs as the proxy for intermediate inputs. The output is measured as total sales of a firm.

In the first step, according to Levinsohn and Petrin (2003), the intermediate input is just a function of the two state variables in their model, K_t and ω_t . In addition, the intermediate input is supposed to be strictly increasing in ω . Thus, we get Equation (3):

$$\omega_t = \omega_t(M_t, K_t). \quad (3)$$

By replacing Equation (2) with Equation (3), we control for ω in the estimation as Equation (4) and Equation (5):

$$y_{it} = \beta_l L_{it} + \phi_t(M_{it}, K_{it}) + \eta_{it}, \quad (4)$$

where

$$\phi_t(M_{it}, K_{it}) = \beta_0 + \beta_k K_{it} + \beta_m M_{it} + \omega_t(M_{it}, K_{it}). \quad (5)$$

The first-stage estimator is the identification of the input variable coefficient β_l . Then, the second step in the estimation allows the identification of β_k and β_m , which assumes ω_t follows a first-order Markov process as Equation (6):

$$\omega_t = E(\omega_t | \omega_{t-1}) + \xi_t, \quad (6)$$

where ξ_t is the innovation in ω_t .

Then Equation (4) is estimated as Equation (7):

$$y_{it} - \beta_l L_{it} = \beta_0 + \beta_k K_{it} + \beta_m M_{it} + E(\omega_t | \omega_{t-1}) + \xi_t + \eta_{it}. \quad (7)$$

For any value of (β_k, β_m) , we estimate $E(\omega_t | \omega_{t-1})$. Equation (7) is further used to estimate β_k and β_m . After the two-step procedure, we get the consistent estimation of TFP ω_t .

3.3.2. Test variable: directors' IT expertise

We use two variables to measure directors' IT expertise. The first is *IT*, a dummy variable that equals one if a listed firm has at least one director with IT expertise on its board in year t and zero otherwise. The second is *IT_ratio*, which is the percentage of directors with IT expertise on a firm's board in year t .

3.3.3. Control variables

Following prior studies (Giannetti et al., 2015; Jiang et al., 2016), we control for several firm characteristics that have been shown to affect TFP. The control variables include *ROA* (the ratio of net profit divided by total assets), *Leverage* (total debts divided by total assets), *FirmSize* (the natural logarithm of total assets), *FirmAge* (the difference between year t and the year of establishment of a firm plus one), *FreeCashFlow* (the net income plus depreciation and amortisation minus cash paid to acquire fixed assets, intangible assets, and other

long-term assets, scaled by total assets), *Capital* (fixed assets divided by total number of employees), *BoardSize* (the natural logarithm of the number of directors), *Top1* (the percentage of shares held by the largest shareholder), *IndepDirRatio* (the percentage of independent directors on a firm's board). Additionally, we include a variable reflecting the unique characteristics of the Chinese market that may affect TFP, *SOE* (a dummy variable that equals one if a firm's ultimate controlling shareholder is the state and zero otherwise). We also include *GDP* (the natural logarithm of GDP per capita of a province) and *Population* (the natural logarithm of total population of a province) to control for potential confounding regional effects. Finally, we include year and industry fixed effects to control for the industrial fixed effect and dynamic changes in the macroeconomic environment common to all firms over the sample period, respectively. Industry fixed effects are defined at 2-digit industry code for manufacturing firms and 1-digit industry code for other industries. Detailed variable definitions are listed in [Appendix](#). We winsorise all continuous variables at 1% at both tails.

4. Empirical analyses

4.1. Descriptive statistics and correlation analysis

Panel A of [Table 1](#) presents the summary statistics of the main variables in this study. The mean of *TFP* is 15.499. The mean of the test variable *IT* is 0.307, indicating that 30.7% of firm-year sample observations have at least one director with IT expertise on the board account. The percentage of directors with IT expertise on a firm's board (*IT_ratio*) has a mean of 0.055.

In Panel B of [Table 1](#), we compare the mean of *TFP* between the group with IT expertise and the one without IT expertise. The mean of *TFP* is 15.552 for firms whose directors have IT expertise and 15.475 for firm whose directors have no IT expertise, and the differences are statistically significant at the 1% level, suggesting that firms having board directors with IT expertise have higher TFP than those without IT expertise.

In [Table 2](#), we calculate the correlation coefficients among variables. The results suggest that our main variable of interest, *IT*, is significantly positive related with TFP. In addition, the correlations between the independent variables are relatively low.

4.2. Regression results of TFP on directors' IT expertise

[Table 3](#) presents the results of the impact of directors' IT expertise on TFP. Columns (1) and (3) only include the key variables of interest, *IT* and *IT_ratio*, and several firm basic financial proxies, whereas Columns (2) and (4) also include corporate governance features. In all four columns, the coefficients estimated in *IT* and *IT_ratio* are significantly positive. The coefficient on *IT* in Column (2) indicates that TFP of firms that having IT-expertise directors is increased by 0.041, representing about 0.3% of the sample mean. The coefficient on *IT_ratio* in Column (4) is 0.262, indicating that one standard deviation increase in the percentage of directors with IT expertise on a firm's board results in an increase in TFP by 2.71%.² The finding is consistent with our prediction that board directors with IT expertise is associated with higher TFP.

²We also use (1) TFP calculated based on industry-adjusted output and (2) TFP calculated based on industry-adjusted inputs and output to re-regress, and find that our findings are still statistically and economically significant.

Table 1. Summary Statistics.

Variables	N	Mean	S.D.	25%	Median	75%	95%
Panel A: Descriptive statistics for the main variables used in this study							
TFP_t	35,898	15.499	1.075	14.784	15.422	16.138	17.458
IT_{t-1}	35,898	0.307	0.461	0.000	0.000	1.000	1.000
IT_ratio_{t-1}	35,898	0.055	0.103	0.000	0.000	0.111	0.286
ROA_{t-1}	35,898	0.038	0.062	0.014	0.037	0.067	0.128
$Leverage_{t-1}$	35,898	0.439	0.208	0.273	0.438	0.599	0.786
$FirmSize_{t-1}$	35,898	21.909	1.287	20.975	21.746	22.641	24.335
$FirmAge_{t-1}$	35,898	16.513	5.798	12.000	16.000	20.000	26.000
$FreeCashFlow_{t-1}$	35,898	0.007	0.073	-0.021	0.016	0.047	0.108
$Capital_{t-1}$	35,898	53.920	94.819	13.400	25.762	51.716	192.022
$BoardSize_{t-1}$	35,898	2.154	0.206	2.079	2.197	2.197	2.485
$Top1_{t-1}$	35,898	0.357	0.152	0.236	0.335	0.463	0.635
SOE_{t-1}	35,898	0.423	0.494	0.000	0.000	1.000	1.000
$IndepDirRatio_{t-1}$	35,898	0.370	0.053	0.333	0.333	0.400	0.455
GDP_{t-1}	35,898	10.857	0.648	10.507	10.960	11.349	11.725
$Population_{t-1}$	35,898	8.498	0.670	7.916	8.641	9.010	9.306
Panel B: Univariate results							
	$IT_t = 1$ (N = 11012)	$IT_t = 0$ (N = 24886)	Differences				
	Mean	Mean	T test				
TFP_t	15.552	15.475	t-value				
			6.235***				

Panel A of Table 1 reports descriptive statistics on TFP , IT , IT_ratio and control variables for the sample during 2005–2020. Panel B presents the results of univariate analysis on the mean differences of TFP between firms whose directors have IT expertise and firms whose directors have no IT expertise. The t -values for differences in means are based on t -tests. *** denotes significance at the 1% level (two-tailed). All variables are defined in the Appendix.

The coefficients of the control variables are generally consistent with prior studies (Giannetti et al., 2015). That is, firms with higher ROA, higher leverage, higher free cash flow and larger sizes are associated with higher TFP. We also regress TFP calculated by OP method on IT expertise, the significant positive relationship remains robust.

4.3. Endogeneity

In this section, we conduct a battery of robustness checks to address potential endogeneity issues, including firm fixed effects estimations, controlling for additional characteristics of board directors, considering the impact of some specific industries, and instrumental variable estimations.

4.3.1. Firm fixed effect estimations

To control for selection on time-invariant firm-specific unobservable variables that are related with both directors' IT expertise and TFP, we re-estimate the regression of Model (1) using firm fixed effect models. The results are presented in Table 4, and the coefficients on the four columns are significantly positive. This implies that our results are not driven by time-invariant firm-specific characteristics.

4.3.2. Controlling for some candidates of omitted variables in terms of characteristics of board directors

The effect of directors' IT expertise on TFP may suffer from omitting some time variant variables that are correlated with both directors' IT expertise and TFP. That is because



Table 2. Correlation Matrix.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
<i>TFP_t</i>	1													
<i>IT_{t-1}</i>	0.033 ^a	1												
<i>ROA_{t-1}</i>	0.118 ^a	0.025 ^a	1											
<i>Leverage_{t-1}</i>	0.388 ^a	-0.086 ^a	-0.351 ^a	1										
<i>FirmSize_{t-1}</i>	0.768 ^a	0.011 ^b	0.000	0.415 ^a	1									
<i>FirmAge_{t-1}</i>	0.162 ^a	-0.012 ^b	-0.087 ^a	0.114 ^a	0.222 ^a	1								
<i>FreeCashFlow_{t-1}</i>	0.154 ^a	0.021 ^a	0.725 ^a	-0.252 ^a	0.018 ^a	0.065 ^a	1							
<i>Capital_{t-1}</i>	0.081 ^a	-0.066 ^a	-0.053 ^a	0.138 ^a	0.287 ^a	0.059 ^a	-0.062 ^a	1						
<i>BoardSize_{t-1}</i>	0.138 ^a	0.050 ^a	0.014 ^a	0.140 ^a	0.203 ^a	-0.069 ^a	-0.018 ^a	0.116 ^a	1					
<i>Top1_{t-1}</i>	0.185 ^a	-0.063 ^a	0.136 ^a	0.053 ^a	0.183 ^a	-0.173 ^a	0.086 ^a	0.081 ^a	0.034 ^a	1				
<i>SOE_{t-1}</i>	0.207 ^a	-0.049 ^a	-0.101 ^a	0.285 ^a	0.278 ^a	0.025 ^a	-0.022 ^a	0.183 ^a	0.266 ^a	0.234 ^a	1			
<i>IndepDirRatio_{t-1}</i>	0.028 ^a	0.020 ^a	-0.009 ^c	-0.030 ^a	0.037 ^a	0.056 ^a	-0.002	-0.021 ^a	-0.472 ^a	0.021 ^a	-0.100 ^a	1		
<i>GDP_{t-1}</i>	0.205 ^a	0.107 ^a	0.061 ^a	-0.149 ^a	0.194 ^a	0.364 ^a	0.102 ^a	-0.012 ^b	-0.169 ^a	-0.061 ^a	-0.247 ^a	0.134 ^a	1	
<i>Population_{t-1}</i>	-0.005	0.044 ^a	0.045 ^a	-0.061 ^a	-0.047 ^a	0.038 ^a	0.003	-0.086 ^a	-0.050 ^a	-0.048 ^a	-0.175 ^a	0.006	-0.033 ^a	1

This table reports the correlation coefficients on the main variables defined in the Appendix. c, b and a indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively.

Table 3. Directors' IT Expertise and TFP.

VARIABLES	(1) TFP_t	(2) TFP_t	(3) TFP_t	(4) TFP_t
IT_{t-1}	0.042*** (2.99)	0.041*** (2.97)		
IT_ratio_{t-1}			0.278*** (3.84)	0.262*** (3.74)
ROA_{t-1}	1.551*** (11.26)	1.403*** (10.28)	1.553*** (11.28)	1.403*** (10.29)
$Leverage_{t-1}$	0.766*** (15.15)	0.807*** (16.34)	0.767*** (15.19)	0.808*** (16.37)
$FirmSize_{t-1}$	0.627*** (80.53)	0.613*** (77.18)	0.627*** (80.55)	0.613*** (77.10)
$FirmAge_{t-1}$	-0.004** (-2.51)	-0.003* (-1.78)	-0.004** (-2.44)	-0.003* (-1.70)
$FreeCashFlow_{t-1}$	1.461*** (14.34)	1.455*** (14.38)	1.456*** (14.31)	1.449*** (14.35)
$Capital_{t-1}$	-0.001*** (-8.27)	-0.001*** (-8.55)	-0.001*** (-8.23)	-0.001*** (-8.51)
$BoardSize_{t-1}$		-0.047 (-1.10)		-0.039 (-0.91)
$Top1_{t-1}$		0.323*** (6.01)		0.328*** (6.10)
SOE_{t-1}		0.041** (2.05)		0.041** (2.05)
$IndepDirRatio_{t-1}$		-0.106 (-0.77)		-0.108 (-0.79)
GDP_{t-1}		0.201*** (9.77)		0.200*** (9.72)
$Population_{t-1}$		0.064*** (4.77)		0.064*** (4.74)
Constant	1.069*** (6.30)	-1.113*** (-3.73)	1.067*** (6.29)	-1.111*** (-3.73)
Year FEs	Yes	Yes	Yes	Yes
Industry FEs	Yes	Yes	Yes	Yes
N	35,898	35,898	35,898	35,898
Adj-R ²	0.682	0.691	0.682	0.691

This table presents the results of the impact of directors' IT expertise on TFP. The dependent variable is TFP , and the test variables are IT and IT_ratio . The t -statistics in the brackets are based on standard errors adjusted for clustering at the firm level. *, **, and *** indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively. All variables are defined in the Appendix.

directors with IT expertise may change the structure of the board along other dimensions known to affect TFP. In this section, we add to the baseline model some candidates of omitted variables in terms of characteristics of board directors.

Green and Homroy (2018) find that female representation on board committees has economically meaningful effects on firm performance. Therefore, we control for the gender diversity of the board ($FemDir$). Giannetti et al. (2015) documented that TFP will be increased after firms hire directors with foreign experience, and we thus control for directors with overseas experiences ($ForeignExpDir$). Following Giannetti et al. (2015), we also control for the average age of board members ($DirectorAge$). Furthermore, we control for the average tenure of board members ($DirectorTenure$), directors with academic background ($AcademiaDir$), and directors with work experiences in finance ($FinWorkExpDir$).

We add these additional control variables to Model (1) and re-estimate the regressions. The results are reported in Table 5. It shows that the coefficients on IT and IT_ratio continue to be significantly positive at the 5% level or better. In

Table 4. Directors' IT Expertise and TFP: Firm Fixed Effect Models.

VARIABLES	(1) TFP_t	(2) TFP_t	(3) TFP_t	(4) TFP_t
IT_{t-1}	0.031*** (2.88)	0.030*** (2.80)		
IT_ratio_{t-1}			0.141** (2.20)	0.141** (2.21)
ROA_{t-1}	0.906*** (8.50)	0.881*** (8.17)	0.907*** (8.51)	0.881*** (8.17)
$Leverage_{t-1}$	0.401*** (8.90)	0.401*** (8.89)	0.400*** (8.88)	0.401*** (8.88)
$FirmSize_{t-1}$	0.470*** (43.03)	0.468*** (42.81)	0.470*** (43.01)	0.468*** (42.77)
$FirmAge_{t-1}$	0.001 (0.05)	-0.001 (-0.07)	0.000 (0.03)	-0.001 (-0.09)
$FreeCashFlow_{t-1}$	0.783*** (10.69)	0.793*** (10.81)	0.782*** (10.68)	0.793*** (10.80)
$Capital_{t-1}$	-0.000*** (-3.94)	-0.000*** (-3.97)	-0.000*** (-3.95)	-0.000*** (-3.98)
$BoardSize_{t-1}$		0.029 (0.83)		0.035 (1.00)
$Top1_{t-1}$		0.072 (1.02)		0.073 (1.02)
SOE_{t-1}		-0.020 (-0.66)		-0.021 (-0.67)
$IndepDirRatio_{t-1}$		0.012 (0.12)		0.012 (0.11)
GDP_{t-1}		0.066 (1.37)		0.066 (1.37)
$Population_{t-1}$		-0.059 (-0.77)		-0.059 (-0.77)
Constant	4.466*** (16.05)	4.273*** (4.40)	4.467*** (16.05)	4.266*** (4.39)
Year FEs	Yes	Yes	Yes	Yes
Industry FEs	Yes	Yes	Yes	Yes
Firm FEs	Yes	Yes	Yes	Yes
N	35,898	35,898	35,898	35,898
No. of Firms	3,800	3,800	3,800	3,800
Adj-R ²	0.518	0.519	0.518	0.519

This table presents the results of the impact of directors' IT expertise on TFP using firm fixed effects model. The dependent variable is TFP , and the test variables are IT and IT_ratio . The t -statistics in the brackets are based on standard errors adjusted for clustering at the firm level. *, **, and *** indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively. All variables are defined in the Appendix.

addition, consistent with Giannetti et al. (2015), the coefficients of $ForeignExpDir$ are significantly positive, indicating directors with foreign experience are associated with higher TFP.

4.3.3. Controlling for specific industries

There is a concern that firms operating in high technology industries are more likely to employ directors with IT expertise and have higher TFP. To address this concern, first, we exclude observations belonging to IT-related industries, including science and technology promotion and application service industry (M75), computer, communication, and other electronic equipment manufacturing industry (C39), software and information technology service industry (I65), and Internet and related service industry (I64). Second, following Haislip and Richardson (2018), we include $isITind$, a dummy variable that equals one if a firm belongs to one of the industries

Table 5. Directors' IT Expertise and TFP: Controlling for Some Possible Omitted Variables.

VARIABLES	(1) TFP_t	(2) TFP_t
IT_{t-1}	0.033** (2.38)	
IT_ratio_{t-1}		0.220*** (3.12)
ROA_{t-1}	1.274*** (9.11)	1.272*** (9.11)
$Leverage_{t-1}$	0.824*** (16.74)	0.824*** (16.76)
$FirmSize_{t-1}$	0.614*** (74.27)	0.614*** (74.25)
$FirmAge_{t-1}$	-0.003 (-1.57)	-0.003 (-1.50)
$FreeCashFlow_{t-1}$	1.526*** (14.38)	1.522*** (14.36)
$Capital_{t-1}$	-0.001*** (-10.27)	-0.001*** (-10.23)
$BoardSize_{t-1}$	-0.074 (-1.64)	-0.067 (-1.49)
$Top1_{t-1}$	0.293*** (5.46)	0.298*** (5.55)
SOE_{t-1}	0.041** (1.98)	0.040** (1.97)
$IndepDirRatio_{t-1}$	-0.177 (-1.25)	-0.179 (-1.27)
GDP_{t-1}	0.201*** (9.52)	0.200*** (9.48)
$Population_{t-1}$	0.068*** (5.17)	0.067*** (5.15)
$AcademiaDir_{t-1}$	0.010 (0.33)	0.009 (0.30)
$FinWorkExpDir_{t-1}$	-0.020* (-1.68)	-0.019 (-1.64)
$ForeignExpDir_{t-1}$	0.032** (2.45)	0.031** (2.37)
$FemDir_{t-1}$	-0.032** (-2.36)	-0.032** (-2.36)
$DirectorAge_{t-1}$	-0.000 (-0.04)	-0.000 (-0.11)
$DirectorTenure_{t-1}$	-0.001*** (-2.79)	-0.001*** (-2.86)
Constant	-1.023*** (-3.33)	-1.019*** (-3.32)
Year FEs	Yes	Yes
Industry FEs	Yes	Yes
N	32,707	32,707
Adj-R ²	0.695	0.695

This table presents the results of the effect of directors' IT expertise on TFP controlling for some possible omitted variables in terms of characteristics of board directors. The dependent variable is TFP . The test variables are IT and IT_ratio . In addition to the control variables in the baseline model, we also include $AcademiaDir$, $FinWorkExpDir$, $ForeignExpDir$ to proxy for various board backgrounds, $FemDir$ to proxy for board gender composition, and $DirectorAge$ and $DirectorTenure$ to proxy for board average age and average tenure respectively. The sample in this table is from 2009 to 2020 because the data of characteristics of the board are only available since 2008. The t -statistics in the brackets are based on standard errors adjusted for clustering at the firm level. *, **, and *** indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively. All variables are defined in the Appendix.

Table 6. Directors' IT Expertise and TFP: Specific Industries.

VARIABLES	(1) TFP_t	(2) TFP_t	(3) TFP_t	(4) TFP_t
IT_{t-1}	0.040*** (2.74)		0.037*** (2.76)	
IT_ratio_{t-1}		0.265*** (3.02)		0.247*** (3.55)
$isITind_{t-1}$			0.030 (1.11)	0.021 (0.77)
ROA_{t-1}	1.666*** (10.99)	1.666*** (11.00)	1.403*** (10.28)	1.403*** (10.29)
$Leverage_{t-1}$	0.747*** (14.05)	0.747*** (14.05)	0.809*** (16.31)	0.809*** (16.33)
$FirmSize_{t-1}$	0.616*** (72.67)	0.616*** (72.63)	0.613*** (77.32)	0.613*** (77.20)
$FirmAge_{t-1}$	-0.003 (-1.61)	-0.003 (-1.56)	-0.003* (-1.76)	-0.003* (-1.69)
$FreeCashFlow_{t-1}$	1.324*** (12.34)	1.322*** (12.34)	1.458*** (14.42)	1.452*** (14.39)
$Capital_{t-1}$	-0.001*** (-7.59)	-0.001*** (-7.58)	-0.001*** (-8.54)	-0.001*** (-8.50)
$BoardSize_{t-1}$	-0.030 (-0.66)	-0.023 (-0.49)	-0.045 (-1.05)	-0.038 (-0.89)
$Top1_{t-1}$	0.325*** (5.56)	0.328*** (5.59)	0.325*** (6.05)	0.329*** (6.12)
SOE_{t-1}	0.034 (1.58)	0.035 (1.60)	0.041** (2.04)	0.041** (2.04)
$IndepDirRatio_{t-1}$	-0.064 (-0.43)	-0.066 (-0.45)	-0.109 (-0.79)	-0.111 (-0.80)
GDP_{t-1}	0.192*** (8.80)	0.191*** (8.77)	0.200*** (9.73)	0.199*** (9.70)
$Population_{t-1}$	0.062*** (4.28)	0.062*** (4.26)	0.064*** (4.72)	0.063*** (4.71)
Constant	-1.111*** (-3.53)	-1.117*** (-3.56)	-1.106*** (-3.71)	-1.106*** (-3.71)
Year Fes	Yes	Yes	Yes	Yes
Industry Fes	Yes	Yes	Yes	Yes
N	30,899	30,899	35,898	35,898
Adj-R ²	0.697	0.697	0.691	0.691

This table presents the results from the ordinary least squares regressions of the effect of directors' IT expertise on TFP considering specific industries, including Science and technology promotion and application service industry (M75), computer, communication and other electronic equipment manufacturing industry (C39), software and information technology service industry (I65), and Internet and related service industry (I64). The dependent variable is TFP . The test variables are IT and IT_ratio . Columns (1) and (2) report the results after dropping the observations belonging to one of the industries. Columns (3) and (4) report the regression results controlling for $isITind$, a dummy variable which equals 1 if a firm belongs to one of the industries mentioned above and 0 otherwise. The t -statistics in the brackets are based on standard errors adjusted for clustering at the firm level. *, **, and *** indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively. All variables are defined in the Appendix.

mentioned above, zero otherwise, in Model (1), and re-estimate the regressions. Reported in Table 6, the coefficients on IT and IT_ratio in the four columns are positive and significant, and the magnitudes are comparable to those reported in Table 3, indicating that the effects of directors' IT expertise on TFP are not driven by specific industries.

4.3.4. Instrumental variable estimations

A threat to our inference on the effect of directors' IT expertise on TFP is that with one or more directors with IT expertise on the board is a firm's choice, and hence, the main

results have the concern of endogeneity. To address this concern, we perform instrumental variable (IV) estimations. The instrument we use is the average of IT/IT_ratio in a year-province-industry (IT_avg/IT_ratio_avg). We expect the increase in the average of IT directors in a certain region-industry to increase the chance for firms to have directors with IT expertise on their boards. Therefore, the relevance condition for the instrument is satisfied.

The IV results are presented in Table 7. Columns (1) and (3) tabulate the results of the first-stage regression. The coefficients on IT_avg and IT_ratio_avg are both positive and significant at the 1% level, confirming that the firm is more likely to have directors

Table 7. Directors' IT Expertise and TFP: Using the Instrumental Variable Approach.

	(1) First stage	(2) Second stage	(3) First stage	(4) Second stage
VARIABLES	$InstrumentedIT_{t-1}$	TFP_t	$InstrumentedIT_ratio_{t-1}$	TFP_t
$InstrumentedIT_{t-1}$		0.100*** (5.12)		
$InstrumentedIT_ratio_{t-1}$				0.410*** (4.20)
IT_avg_{t-1}	3.725*** (37.16)			
$IT_ratio_avg_{t-1}$			0.996*** (32.38)	
ROA_{t-1}	-0.134 (-0.40)	1.332*** (15.34)	0.000 (0.01)	1.331*** (15.34)
$Leverage_{t-1}$	-0.378*** (-3.65)	0.814*** (37.63)	-0.016** (-2.44)	0.810*** (37.56)
$FirmSize_{t-1}$	0.053*** (2.89)	0.613*** (170.95)	0.003*** (2.65)	0.613*** (171.05)
$FirmAge_{t-1}$	-0.009** (-2.10)	-0.003*** (-3.57)	-0.001*** (-2.94)	-0.003*** (-3.41)
$FreeCashFlow_{t-1}$	0.000 (0.00)	1.466*** (20.93)	0.021 (1.48)	1.454*** (20.78)
$Capital_{t-1}$	-0.000* (-1.85)	-0.001*** (-23.67)	-0.000*** (-4.40)	-0.001*** (-23.54)
$BoardSize_{t-1}$	0.797*** (7.68)	-0.083*** (-3.95)	0.004 (0.59)	-0.060*** (-2.96)
$Top1_{t-1}$	-0.003*** (-2.78)	0.003*** (13.92)	-0.000*** (-4.12)	0.003*** (14.01)
SOE_{t-1}	0.064 (1.43)	0.043*** (5.31)	0.003 (1.18)	0.044*** (5.33)
$IndepDirRatio_{t-1}$	1.151*** (3.26)	-0.150** (-2.04)	0.046* (1.96)	-0.137* (-1.86)
GDP_{t-1}	0.071 (1.52)	0.192*** (23.50)	-0.000 (-0.12)	0.191*** (23.26)
$Population_{t-1}$	0.053* (1.76)	0.062*** (11.62)	0.001 (0.65)	0.062*** (11.66)
Constant	-5.922*** (-8.22)	-0.881*** (-6.72)	-0.071* (-1.76)	-0.923*** (-7.09)
Year Fes	Yes	Yes	Yes	Yes
Industry Fes	Yes	Yes	Yes	Yes
N	32,162	32,162	32,162	32,162
R ²	0.234	0.689	0.353	0.690

This table shows the results from the ordinary least squares regressions of the effect of directors' IT expertise on TFP using the instrumental variable approach. The dependent variable is TFP . The test variables are $InstrumentedIT$ and $InstrumentedIT_ratio$. The instrumental variables are IT_avg and IT_ratio_avg , respectively, calculated as the average of IT/IT_ratio in a year-province-industry. The t -statistics in the brackets are based on standard errors adjusted for clustering at the firm level. *, **, and *** indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively. All variables are defined in the Appendix.

with IT expertise on its board when the firm is in a region-industry where there are more IT directors. The results from the second-stage regressions are presented in Columns (2) and (4). The coefficients on *InstrumentedIT* and *InstrumentedIT_ratio* are both significantly positive at the 1% level. An *F*-test of excluded instruments support the relevance of the instrument (*F*-statistics are both above 10, significant at the 1% level).

4.4. The moderating effects of capital intensity

Based on the year-industry specific median of *Capital*, we divide the initial sample into two groups, firms with higher capital intensity and those with lower capital intensity. Then, we re-estimate the baseline regression for the two groups, respectively, and the results are presented in Table 8. Consistent with our expectation, the coefficients on *IT* and *IT_ratio* in the groups of lower capital intensity in Columns (2) and (4) are both significantly positive at the 1% level, while they are positive but insignificant for higher-level groups in Columns (1) and (3). In addition, the tests of the difference in coefficients on *IT* and *IT_ratio* between higher and lower groups yield *p*-values of 0.009 and 0.0005, respectively. These results suggest that the positive effect of directors' IT expertise on TFP is more effective for firms with lower capital intensity.

4.5. The moderating effects of product market competition

We use Herfindahl-Hirschman Index (HHI) as a proxy for product market competition. We divide the sample into higher and lower groups based on whether the HHI is below or above the corresponding year-specific median. We re-estimate Model (1) with the two subsamples separately. The regression results are reported in Table 9. The coefficients on *IT* and *IT_ratio* in the groups of lower level of competition in Columns (1) and (3) are 0.098 and 0.394, both significantly positive at the 1% level, whereas the coefficient on *IT* is not significant Column (2), and the coefficient on *IT_ratio* is 0.137 significantly positive at the 1% level in Column (4). The tests of the difference in coefficients on *IT* and *IT_ratio* between lower and higher groups are both significant at 1% level. These results are consistent with our expectation, suggesting that the positive effect of directors' IT expertise on TFP is more significant for firms in non-competitive product markets.

5. Economic mechanisms

Our evidence indicates that directors' IT expertise can increase TFP. In this section, we try to explore the economic mechanisms underlying this relation. As discussed in the previous parts, directors' IT expertise may affect IT investment and operating efficiency of a firm, thereby increasing TFP. We examine the potential mechanisms from two aspects: (1) whether firms having directors with IT expertise are more likely to invest more in IT; and (2) whether directors' IT expertise improves the operating efficiency of fixed assets.

Table 8. The Moderating Effects of Capital Intensity.

	(1) Higher	(2) Lower	(3) Higher	(4) Lower
IT_{t-1}	0.011 (1.07)	0.049*** (4.96)		
IT_ratio_{t-1}			0.046 (0.82)	0.295*** (6.58)
ROA_{t-1}	1.363*** (12.29)	1.320*** (11.36)	1.363*** (12.29)	1.325*** (11.41)
$Leverage_{t-1}$	0.663*** (22.98)	0.899*** (33.45)	0.662*** (22.97)	0.899*** (33.50)
$FirmSize_{t-1}$	0.621*** (134.45)	0.611*** (129.31)	0.621*** (134.44)	0.611*** (129.17)
$FirmAge_{t-1}$	-0.003*** (-2.59)	-0.003*** (-3.55)	-0.003** (-2.57)	-0.003*** (-3.39)
$FreeCashFlow_{t-1}$	1.391*** (16.09)	1.378*** (14.23)	1.390*** (16.08)	1.370*** (14.15)
$BoardSize_{t-1}$	-0.030 (-1.12)	-0.043* (-1.65)	-0.027 (-1.03)	-0.033 (-1.27)
$Top1_{t-1}$	0.393*** (12.12)	0.226*** (7.29)	0.393*** (12.12)	0.233*** (7.48)
SOE_{t-1}	0.077*** (7.01)	0.024** (2.22)	0.077*** (7.02)	0.023** (2.17)
$IndepDirRatio_{t-1}$	-0.245** (-2.53)	0.016 (0.17)	-0.244** (-2.51)	0.013 (0.13)
GDP_{t-1}	0.210*** (19.63)	0.171*** (16.07)	0.210*** (19.63)	0.169*** (15.91)
$Population_{t-1}$	0.076*** (10.74)	0.060*** (8.62)	0.076*** (10.76)	0.059*** (8.54)
Constant	-1.504*** (-9.05)	-0.818*** (-4.85)	-1.512*** (-9.11)	-0.805*** (-4.78)
Year Fes	Yes	Yes	Yes	Yes
Industry Fes	Yes	Yes	Yes	Yes
p -value of test of difference between (1) and (2)		0.009***		
p -value of test of difference between (3) and (4)				0.0005***
N	18,036	17,862	18,036	17,862
Adj-R ²	0.706	0.689	0.706	0.689

This table presents the results of the moderating effects of capital intensity on the relationship between directors' IT expertise and TFP. The dependent variable is TFP , and the test variables are IT and IT_ratio . The t -statistics in the brackets are based on standard errors adjusted for clustering at the firm level. *, **, and *** indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively. All variables are defined in the Appendix.

5.1. Directors' IT expertise and IT investment

We examine the channel role of IT investment in the relationship between IT expertise and TFP. First, we run the regression model with the dependent variable $ITInvestment$, calculated as the natural logarithm of the IT equipment and software plus one in a firm in year t . The variables of interest are IT and IT_ratio . We then conduct a regression with TFP as the dependent variable, director' IT expertise and IT investment as explanatory variables to test the mediating effect of IT investment.

The empirical results are reported in Table 10. The coefficients on IT and IT_ratio in Columns (1) and (3) are positive and significant at the 1% level, suggesting that directors' IT expertise can increase IT investment. The coefficient on $ITInvestment$ in Columns (2) and (4) are both significantly positive at the 1% level, indicating that IT investment can increase TFP. The Sobel Z values are 4.348 and 5.267, respectively, proving that IT investment may be one of the channels through which directors' IT expertise influences TFP.

Table 9. The Moderating Effects of Product Market Competition.

	(1) Lower	(2) Higher	(3) Lower	(4) Higher
IT_{t-1}	0.098*** (7.31)	0.004 (0.43)		
IT_ratio_{t-1}			0.394*** (6.97)	0.137*** (3.13)
ROA_{t-1}	1.869*** (11.62)	1.302*** (12.97)	1.846*** (11.48)	1.310*** (13.05)
$Leverage_{t-1}$	1.232*** (34.71)	0.618*** (24.53)	1.233*** (34.72)	0.621*** (24.67)
$FirmSize_{t-1}$	0.575*** (95.91)	0.624*** (142.18)	0.576*** (95.98)	0.624*** (141.94)
$FirmAge_{t-1}$	-0.009*** (-6.87)	0.002** (2.29)	-0.009*** (-6.62)	0.002** (2.42)
$FreeCashFlow_{t-1}$	1.437*** (11.83)	1.637*** (20.44)	1.436*** (11.81)	1.633*** (20.38)
$Capital_{t-1}$	-0.001*** (-28.84)	-0.001*** (-13.16)	-0.001*** (-28.72)	-0.001*** (-12.85)
$BoardSize_{t-1}$	-0.279*** (-8.25)	0.142*** (5.87)	-0.260*** (-7.71)	0.143*** (5.93)
$Top1_{t-1}$	0.190*** (4.49)	0.339*** (11.89)	0.207*** (4.86)	0.343*** (12.02)
SOE_{t-1}	-0.005 (-0.33)	0.049*** (4.88)	-0.002 (-0.15)	0.048*** (4.82)
$IndepDirRatio_{t-1}$	-0.382*** (-3.02)	0.106 (1.22)	-0.379*** (-2.99)	0.101 (1.16)
GDP_{t-1}	0.295*** (21.59)	0.167*** (17.35)	0.292*** (21.29)	0.165*** (17.09)
$Population_{t-1}$	0.053*** (5.90)	0.085*** (12.91)	0.055*** (6.11)	0.083*** (12.70)
Constant	-0.422** (-2.00)	-1.431*** (-9.23)	-0.469** (-2.22)	-1.391*** (-8.97)
Year Fes	Yes	Yes	Yes	Yes
p-value of test of difference between (1) and (2)	0.0001***			
p-value of test of difference between (3) and (4)			0.0001**	
N	14,335	17,836	14,335	17,836
Adj-R ²	0.629	0.699	0.628	0.699

This table presents the results of the moderating effects of product market competition on the relationship between directors' IT expertise and TFP. The dependent variable is *TFP*, and the test variables are *IT* and *IT_ratio*. Herfindahl-Hirschman Index (HHI) is proxy for product market competition. The *t*-statistics in the brackets are based on standard errors adjusted for clustering at the firm level. *, **, and *** indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively. All variables are defined in the Appendix.

5.2. Directors' IT expertise and operating efficiency

Next, we examine the effect of directors' IT expertise on operating efficiency of a firm using fixed asset turnover (*PPETurnover*) as a proxy. The dependent variable, *PPETurnover*, is calculated as sales divided by net average fixed assets of a firm in year *t*. The variables of interest are *IT* and *IT_ratio*. We then run the regression model with TFP as the dependent variable, and director' IT expertise and fixed asset turnover as explanatory variables. The results are presented in Table 11. The coefficients on *IT* and *IT_ratio* are positively related with fixed asset turnover and significantly at the 1% level, suggesting that directors' IT expertise can improve the utilisation efficiency of plant and equipment and operating efficiency. The coefficients of *PPETurnover* in Columns (2) and (4) are both significantly positive at the 1% level. The Sobel Z values are 4.046 and 7.183, respectively, indicating that directors' IT expertise may increase TFP by improving operational efficiency.

Table 10. Possible Channel: IT Investment.

Variables	(1) <i>ITInvestment</i> _{<i>t</i>-1}	(2) <i>TFP</i> _{<i>t</i>}	(3) <i>ITInvestment</i> _{<i>t</i>-1}	(4) <i>TFP</i> _{<i>t</i>}
<i>IT</i> _{<i>t</i>-1}	0.621*** (6.82)	0.039*** (5.37)		
<i>IT_ratio</i> _{<i>t</i>-1}			4.024*** (9.15)	0.253*** (7.17)
<i>ITInvestment</i> _{<i>t</i>-1}		0.002*** (5.72)		0.002*** (5.57)
<i>ROA</i> _{<i>t</i>-1}	-1.829* (-1.84)	1.403*** (17.42)	-1.836* (-1.85)	1.403*** (17.43)
<i>Leverage</i> _{<i>t</i>-1}	0.500** (2.04)	0.805*** (40.51)	0.517** (2.11)	0.806*** (40.59)
<i>FirmSize</i> _{<i>t</i>-1}	0.706*** (17.19)	0.611*** (183.67)	0.701*** (17.07)	0.611*** (183.64)
<i>FirmAge</i> _{<i>t</i>-1}	0.026*** (2.99)	-0.003*** (-4.46)	0.028*** (3.23)	-0.003*** (-4.26)
<i>FreeCashFlow</i> _{<i>t</i>-1}	3.283*** (4.06)	1.450*** (22.33)	3.197*** (3.95)	1.445*** (22.26)
<i>Capital</i> _{<i>t</i>-1}	-0.002*** (-3.43)	-0.001*** (-24.92)	-0.002*** (-3.24)	-0.001*** (-24.78)
<i>BoardSize</i> _{<i>t</i>-1}	-0.191 (-0.82)	-0.047** (-2.48)	-0.067 (-0.29)	-0.039** (-2.07)
<i>Top1</i> _{<i>t</i>-1}	-0.282 (-1.00)	0.323*** (14.27)	-0.203 (-0.72)	0.328*** (14.47)
<i>SOE</i> _{<i>t</i>-1}	0.558*** (5.77)	0.040*** (5.14)	0.556*** (5.75)	0.040*** (5.13)
<i>IndepDirRatio</i> _{<i>t</i>-1}	0.845 (0.99)	-0.108 (-1.58)	0.803 (0.95)	-0.110 (-1.61)
<i>GDP</i> _{<i>t</i>-1}	-0.380*** (-4.02)	0.202*** (26.60)	-0.399*** (-4.22)	0.201*** (26.44)
<i>Population</i> _{<i>t</i>-1}	0.320*** (5.15)	0.063*** (12.65)	0.313*** (5.05)	0.063*** (12.57)
Constant	-13.503*** (-9.13)	-1.080*** (-9.05)	-13.452*** (-9.11)	-1.079*** (-9.05)
Year Fes	Yes	Yes	Yes	Yes
Industry Fes	Yes	Yes	Yes	Yes
N	36,287	35,893	36,287	35,893
Adj-R ²	0.101	0.691	0.102	0.691
Sobel Z	4.348***		5.267***	

This table presents the results of the impact of directors' IT expertise on IT investment. The dependent variable is *ITInvestment*, and the test variables are *IT* and *IT_ratio*. *ITInvestment* is calculated as the natural logarithm of IT equipment and software plus 1 in a firm in year *t*. The *t*-statistics in the brackets are based on standard errors adjusted for clustering at the firm level. *, **, and *** indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively.

6. Conclusions

Using manually collected data on directors' IT expertise in China's listed firms over the period 2005–2020, we find that directors' IT expertise is positively associated with TFP. Our findings further show that the effect of directors' IT expertise is more significant for firms with lower capital intensity and firms in non-competitive product markets. In addition, directors' IT expertise contributes to higher TFP by increasing IT investment and fixed asset turnover.

This study is of great theoretical and practical significance. In theory, this study enriches the literature on the influencing factors of TFP and the economic consequences of directors' IT expertise. To the best of our knowledge, the present study is one of the first to investigate the association between these two factors in

Table 11. Possible channel: fixed asset turnover.

Variables	(1) <i>PPETurnover</i> _{<i>t</i>-1}	(2) <i>TFP</i> _{<i>t</i>}	(3) <i>PPETurnover</i> _{<i>t</i>-1}	(4) <i>TFP</i> _{<i>t</i>}
<i>IT</i> _{<i>t</i>-1}	4.628*** (4.22)	0.039*** (5.15)		
<i>IT_ratio</i> _{<i>t</i>-1}			31.000*** (5.86)	0.243*** (6.59)
<i>PPETurnover</i> _{<i>t</i>-1}		0.001*** (28.21)		0.001*** (28.11)
<i>ROA</i> _{<i>t</i>-1}	-4.912 (-0.40)	1.339*** (15.61)	-5.070 (-0.42)	1.338*** (15.61)
<i>Leverage</i> _{<i>t</i>-1}	32.840*** (10.88)	0.770*** (36.19)	32.952*** (10.92)	0.771*** (36.24)
<i>FirmSize</i> _{<i>t</i>-1}	-1.956*** (-3.89)	0.616*** (174.56)	-1.989*** (-3.96)	0.616*** (174.53)
<i>FirmAge</i> _{<i>t</i>-1}	-0.088 (-0.83)	-0.003*** (-3.70)	-0.070 (-0.66)	-0.003*** (-3.53)
<i>FreeCashFlow</i> _{<i>t</i>-1}	50.327*** (5.08)	1.404*** (20.29)	49.659*** (5.01)	1.399*** (20.22)
<i>Capital</i> _{<i>t</i>-1}	-0.046*** (-7.86)	-0.001*** (-23.07)	-0.046*** (-7.73)	-0.001*** (-22.95)
<i>BoardSize</i> _{<i>t</i>-1}	-5.803** (-2.01)	-0.062*** (-3.06)	-4.894* (-1.71)	-0.054*** (-2.68)
<i>Top1</i> _{<i>t</i>-1}	10.994*** (3.19)	0.323*** (13.41)	11.609*** (3.36)	0.328*** (13.58)
<i>SOE</i> _{<i>t</i>-1}	-6.779*** (-5.87)	0.052*** (6.41)	-6.792*** (-5.89)	0.052*** (6.40)
<i>IndepDirRatio</i> _{<i>t</i>-1}	-9.851 (-0.95)	-0.112 (-1.54)	-10.320 (-1.00)	-0.114 (-1.57)
<i>GDP</i> _{<i>t</i>-1}	2.362** (2.05)	0.191*** (23.71)	2.192* (1.90)	0.190*** (23.55)
<i>Population</i> _{<i>t</i>-1}	2.260*** (3.02)	0.062*** (11.86)	2.190*** (2.92)	0.062*** (11.77)
Constant	1.150 (0.06)	-0.966*** (-7.61)	1.961 (0.11)	-0.964*** (-7.60)
Year Fes	Yes	Yes	Yes	Yes
Industry Fes	Yes	Yes	Yes	Yes
N	32,492	32,160	32,492	32,160
Adj-R ²	0.0373	0.697	0.0378	0.697
Sobel Z		4.046***		7.183***

This table presents the results of the impact of directors' IT expertise on fixed asset turnover. The dependent variable is *PPETurnover*, and the test variables are *IT* and *IT_ratio*. *PPETurnover* is calculated as sales divided by net fixed assets of a firm in year *t*. The *t*-statistics in the brackets are based on standard errors adjusted for clustering at the firm level. *, **, and *** indicate significance at the 0.10, 0.05 and 0.01 levels (two-tailed), respectively. All variables are defined in the Appendix.

the emerging market and reveals the mechanisms by which IT expertise affects firm-level TFP. Besides that, the findings are beneficial to firms and investors who are interested in promoting TFP. That is, when firms appoint individuals with IT expertise as members of a board, IT investment and fixed asset turnover tend to be increased, therefore, their TFP can be improved.

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Appendix Variable Definitions

Variable Definitions.

Variables	Definitions
Dependent Variable	
<i>TFP</i>	Total factor productivity, calculated following Levinsohn and Petrin (2003)
Independent Variable	
<i>IT</i>	A dummy variable that equals one if a listed firm has at least one director with IT expertise on its board in year t and zero otherwise
<i>IT_ratio</i>	The percentage of directors with IT expertise on a firm's board in year t
Control Variables	
<i>AcademiaDir</i>	A dummy variable that equals one if a listed firm has at least one director with academic background on its board in year t and zero otherwise (since 2008)
<i>BoardSize</i>	Board size, natural logarithm of the number of directors on a firm's board in year t
<i>Capital</i>	Capital intensity, calculated as fixed assets (divided by 10,000) divided by a firm's total number of employees in year t
<i>DirectoAge</i>	The average age of directors in a firm in year t (since 2008)
<i>DirectorTenure</i>	The average tenure of directors in a firm in year t (month) (since 2008)
<i>FemDir</i>	A dummy variable that equals one if a listed firm has at least one female director on its board in year t and zero otherwise (since 2008)
<i>FinWorkExpDir</i>	A dummy variable that equals one if a listed firm has at least one director with working experiences in finance on its board in year t and zero otherwise (since 2008)
<i>FirmAge</i>	The difference between year t and the year of establishment of a firm plus one
<i>FirmSize</i>	Natural logarithm of total assets in year t
<i>ForeignExpDir</i>	A dummy variable that equals one if a listed firm has at least one director with overseas experiences on its board in year t and zero otherwise (since 2008)
<i>FreeCashFlow</i>	The net income plus depreciation and amortisation minus cash paid to acquire fixed assets, intangible assets, and other long-term assets, scaled by total assets in year t
<i>GDP</i>	Natural logarithm of GDP per capita (RMB, yuan) of the province where the listed firm is registered in year t
<i>Growth</i>	The difference in sales between year t and year $t-1$ divided by revenue in year $t-1$
<i>IndepDirRatio</i>	The percentage of independent directors on a firm's board in year t
<i>isITind</i>	A dummy variable which equals one if a firm belongs to one of the following industries, including Science and technology promotion and application service industry (M75), computer, communication, and other electronic equipment manufacturing industry (C39), software and information technology service industry (I65), and Internet and related service industry (I64) in year t and zero otherwise
<i>ITInvestment</i>	Natural logarithm of the increase of IT equipment plus one in a firm in year t
<i>Leverage</i>	Financial leverage, calculated by the book value of total debts divided by the book value of total assets in year t
<i>Population</i>	Natural logarithm of total population (divided by 10,000) of the province where the listed firm is registered in year t
<i>PPETurnover</i>	The ratio of sales divided by net fixed assets of a firm in year t
<i>ROA</i>	Return on assets, calculated as the ratio of net profit divided by the book value of total assets in year t
<i>SOE</i>	A dummy variable that equals one if the ultimate controlling shareholder of a listed firm is the state in year t and zero otherwise
<i>Top1</i>	The percentage of shares held by the largest shareholder in year t

This table contains the definitions of variables used in our analysis.