# Will Market-Oriented Reforms Propel Technology Progress?

## Empirical Evidence from China's High-Tech Sectors

Dai Kuizao (戴魁早)[1*] and Liu Youjin (刘友金)[2]
[1,2] *Business School, Hunan University of Science and Technology, Xiangtan, China*

***Abstract:*** *This paper aims to explore the effects of market-oriented reforms on industrial technology progress. Based on a theoretical analysis, we performed an empirical study with a marketization index and panel data of high-tech sectors in China. We found that market-oriented reforms had significantly propelled technology progress in China's high-tech sectors, and the effects became more evident after China's WTO entry. Market-oriented reforms induced technology progress by increasing capital allocation efficiency, R&D input, and technology diffusion. Among various aspects of market-oriented reforms, the institutional environment exerted the most significant effects, followed by the economy's non-state sector, product market development, and factor market development; the government-market relationship index influenced technology's progress the least. The effects are heterogeneous across sectors with different technology attributes and more significant for technology-intensive sectors. Our findings offer policy implications for China's ongoing market-oriented reforms and policy design for technology progress in high-tech sectors.*

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## 1. Introduction

China's economy is shifting from rapid growth to quality-oriented development. In this new stage, the transition of economic growth patterns and economic structure improvement top the policy agenda. With their heft and strong correlation with other sectors, high-tech industries are both the drivers of economic growth and vital forces behind industrial upgrades and evolving growth patterns. Their development underpins China's economic health, industrial modernization, and growth quality. High-tech industries rely on technology progress for sustained development as a high ground for international competition in the era of the knowledge-based economy. According to the endogenous economic growth theory and industrial development experience in developed countries, R&D is a key driver of technological progress (Wu, 2008).

For China as a developing country, technology progress may derive from either innovation, importation (Coe and Helpman, 1995; Lin and Zhang, 2005; Acemoglu *et al*.,

[*] CONTACT: Dai Kuizao, email: daikz2007@sina.com.
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2007; Tang *et al*., 2014), or international technology spillover from trade and investment (He *et al*., 2014). Other factors of technology progress include financial structure (Jing *et al*., 2017), banking sector market structure (Cai, 2019), reverse technology spillover from outward foreign direct investment (OFDI) (Shen and Zheng, 2019), and market segmentation (Wang and Zhao, 2019; Huang and Yao, 2020).

Over the past four decades since 1978, China has launched market-oriented economic reforms. In response to the economic challenges after the global financial crisis, the 18th CPC National Congress, the Third Plenum of the 18th CPC Central Committee, the 19th CPC National Congress, and the Fourth Plenum of the 19th CPC Central Committee have identified priorities for further deepening reforms in the new era. An objective of market-based reform is to boost productivity, which is primarily driven by technological progress. Hence, successful market-oriented reforms must promote technological progress. In this sense, market-oriented reforms are likely to be a key factor underpinning high-tech industries' progress in China. In the context of the ongoing supply-side structural reforms and high-quality economic development, the following questions must be answered: Did China's market-oriented reforms contribute to industrial technological progress, especially in the high-tech sectors? If so, what is the mechanism that caused market-oriented reforms to facilitate technological progress? Is there any difference in such effects from various aspects of market-oriented reforms as well as sectors with different technology levels?

Very few studies have touched upon the total factor productivity (TFP) effects of market-oriented reforms. For instance, Jiang and Zhang (2008) discussed the effects of China's economic transition on technology spillovers from foreign direct investment (FDI). Zhang *et al*. (2011), Ma (2014), and Wang (2016) explored the effects of market-oriented reforms on the productivity of regional industrial enterprises. Mao and Xu (2015) investigated how market-oriented reforms had influenced regional TFP through employment reallocation. Li and Liu (2015) explored the mechanism in which evolving regional market-based systems had influenced the TFP.

These studies have focused on the effects of market-oriented reforms at the regional level without elucidating whether market-oriented reforms led to sector-level technological progress, thus failing to address the last three questions. China has carried out market-oriented reforms for its monopolistic sectors and state-owned enterprises (SOEs) in various stages. Given the sectoral attributes, for instance, that SOEs are different from non-state enterprises in performing state-mandated functions, market-oriented reforms have been carried out at an uneven pace and with variable intensity in various sectors. Unlike reforms at the regional level, market-oriented reforms have been differentiated in terms of sectoral marketization process and reform characteristics (Wu, 2006; Cheng and Sun, 2012; Dai and Liu, 2013). Hence, the effects of market-oriented reforms on technological progress should be discussed at the sectoral level. Based on the existing literature, this paper attempts to identify the mechanism in which market-oriented reforms influence technology's progress and employs the sectoral marketization index as well as the 1995-2014 panel data of China's high-tech sectors to verify the conclusions of theoretical analysis for an answer to the above questions.

Compared with the existing literature, this paper offers the following contributions. (i) For the first time, it reveals how market-oriented reforms have influenced technological progress in China's high-tech sectors and arrives at inspiring conclusions. (ii) It employs a recursive model to discuss how market-oriented reforms have induced technological progress by increasing capital allocation efficiency, R&D input, and technology diffusion. Discussions about how market-oriented reforms have influenced industrial technological progress provide insights and policy implications. (iii) While existing literature only discussed how market-oriented reforms had influenced technology's progress, this paper further investigates the differentiated effects from five aspects of market-oriented reforms, as well as the differentiated effects on the progress of technology in sectors with different technological attributes. In this manner, the effects of various aspects of market-oriented reforms and the sectoral heterogeneity are verified. Lastly, this paper puts forth specific policy recommendations on propelling progress in industrial technology.

## 2. Theoretical Analysis and Research Hypotheses

China's economic institutional transition at the regional marketization level is primarily reflected in the government-market relationship, non-state sector development, product market, and factor market sophistication, as well as the institutional environment (Fan *et al*., 2011; Dai and Liu, 2013).[1] Based on a summary of existing literature, it can be found that market-oriented reforms may have propelled sectoral technological progress by increasing capital allocation efficiency, R&D input, and technology diffusion. In other words, market-oriented reforms may facilitate sectoral technological progress through its effects on capital efficiency, R&D input, and technology diffusion (as shown in Figure 1).

Firstly, market-based reforms may have induced sector technology progress by raising capital allocation efficiency. According to the economic growth theory, there is an inseparable relationship between technological progress and TFP, where technological progress often finds expression in TFP growth (Grossman and Helpman, 1991). Sustainable growth in TFP as the overall productivity of input factors is subject to the efficiency change of capital and other factors. Thus, it can be deduced that more efficient capital allocation resulting from market-oriented reforms will propel TFP improvement and the progress of technology.

Theoretically, market-oriented reforms may raise capital allocation efficiency in the following ways. (i) A high degree of market-based operations is reflected in a smaller scope and within the intensity of governmental intervention via industrial polices and control of scarce resources. In terms of capital allocation efficiency, less government intervention will slash capital allocation distortions resulting from administrative monopoly and optimize the market-based capital allocation of various ownership types (Fang, 2007; Ma, 2014). Better diversion of capital to production and R&D activities will raise both of their efficiencies (Dai and Liu, 2013). (ii) A high degree of market-based operations also finds expression in a vibrant non-state sector and a sophisticated product market. Competition between firms will optimize sectoral capital allocation efficiency (Dai and Liu, 2013), thus improving the overall level of sector technology. With the emergence of more efficient non-state firms, the factors of production will flow to the more productive firms, contributing to TFP (Ma, 2014; Wang and Zhang, 2019; Huang and Yao, 2020). (iii) A high degree of market-based operations is also manifested in sophisticated capital markets, which not only reflect a real picture of factor price but facilitate the free flow of factors across firms, projects between firms, and projects of the same sector. Capital migration to more efficient firms or projects within a sector helps improve capital allocation efficiency within the sector (Cai, 2019).

Secondly, market-oriented reforms may induce sectoral technological progress by nudging firms to spend more on R&D. Theoretically, sectoral market-oriented reforms may induce growth in sectoral R&D input in the following aspects. (i) A higher level of market-based operations suggests a higher degree of factor and product market sophistication. A well-developed factor market may enhance a sector's capacity to absorb R&D funds and R&D personnel, and facilitate the flow of R&D resources across firms and projects in a sector, thus inducing growth in sectoral R&D input (Liu, 2011; Cai, 2019). A well-developed product market disseminates information about new products in a sector, incentivizing firms to undertake R&D to meet the rising demands (Chen and Yu, 2007). (ii) A higher level of market-based operations indicates a more vibrant non-state sector or clearer ownership systems for various economic sectors. In a vibrant non-state sector, new businesses emerge, and the product market becomes less monopolized and more competitive, thus nudging firms to stay competitive by increasing R&D spending. Soft budgetary constraints under an inexplicit ownership system impede innovation input (Qian

[1] For detailed discussions, please refer to Dai and Liu (2013).

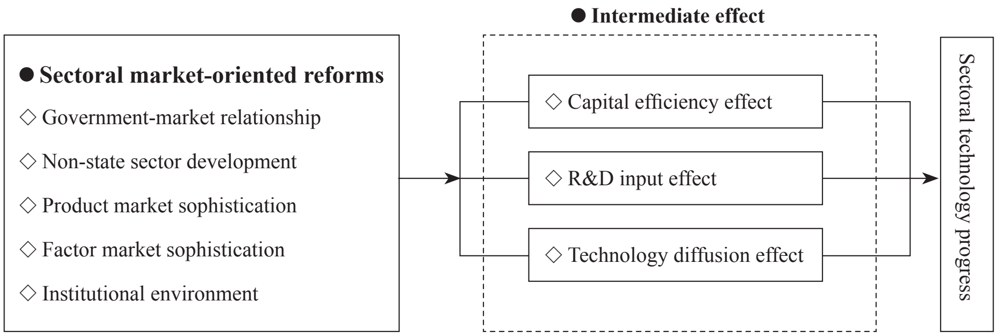


**Figure 1: Effects of Market-Oriented Reforms on Sectoral Technology Progress**

and Xu, 1998). By contrast, a clear ownership system rewards innovative firms, allowing them to invest more in R&D (Baumol, 2002). (iii) An increase in market-based operations suggests an improvement in a sector's access to capital and the legal environment. Studies on China found that the lack of funds was a key barrier to R&D growth (Xie and Fang, 2011; Yu *et al*., 2019). Better access to capital allows firms to raise more R&D funds from various sources and at lower costs. A sound legal environment offers a conducive institutional environment for firm innovation (Fan *et al.*, 2011) and induces growth in firm R&D input. For instance, a higher intensity of law enforcement on intellectual property rights (IPR) will incentivize R&D input (Zhang and Lu, 2012).

The endogenous economic growth theory incorporates R&D into the analytical framework for economic growth and reveals the important effects of R&D on technological progress (Aghion and Howitt, 1992; Grossman and Helpman, 1991). Chinese and international empirical studies have also identified growth in R&D input as a key driver of technological progress (Jefferson *et al*., 2006; Wu, 2006; Tang *et al*., 2014; Shen and Zheng, 2019). Thus, it can be deduced that market-oriented reforms may have induced sectoral technological progress by nudging firms to spend more on R&D.

Thirdly, market-oriented reforms may have propelled sectoral technological progress via technology diffusion. Both theoretical research and empirical evidence suggest that technology diffusion is a key driver of technological progress (Coe and Helpman, 1995; Lin and Zhang, 2005; Acemoglu *et al*., 2007; Shen and Zheng, 2019). An increase in sectoral market-based operations may encourage technology transactions, facilitate the flow of people, and expedite the diffusion or spillover of advanced technology. It can be deduced that market-based reforms may promote technological progress in a sector via technology diffusion.

Theoretically, market-oriented reforms induce technology diffusion in the following ways: (i) A higher level of market-based operations indicates higher sophistication in technology and other factor markets, where technology suppliers are matched with buyers (Dai, 2018). An increase in technology transactions allows firms to apply advanced technology to transform their production methods, thus enhancing the effects of technology diffusion or spillover (Dai and Liu, 2016). After acquiring a basic technology, a technology buyer may re-engineer, imitate, and innovate, shortening the cycle of secondary innovation (Dai, 2018). (ii) A higher degree of market-based operations suggests lower barriers to the free flow of people, which is conducive to the cross-regional flow of educated workforce across firms and regions (Mao and Xu, 2015). The flow of the educated workforce as a technology diffusion vehicle or spillover (He *et al*., 2014) induces the diffusion or spillover of advanced technology (Mao and Xu, 2015; Dai, 2018). Lower barriers to the flow of people make it easier for workers to receive training, education, and earn higher wages, contributing to a human capital improvement in the sector. By shortening the time, it takes for workers to acquire new skills, a higher level of human capital expedites advanced technology adoption (Costinot, 2009). The more frequent flow of people increases technology diffusion (Sun *et al*., 2014).

The above theoretical analysis suggests that market-oriented reforms may boost technological progress by increasing capital allocation efficiency, R&D input, and technology diffusion. There may be a certain degree of correlation among these three mechanisms, which are not entirely independent from each other. They reflect an increase in market-based operations in China's high-tech sectors (Cheng and Sun, 2012; Dai and Liu, 2013) and may act as a key force behind China's technological progress. In other words, the level of technology should be relatively high in more market-based sectors. To verify these assumptions, we put forth two hypotheses to be tested.

Hypothesis 1: Market-oriented reforms have significantly propelled technological progress in China's high-tech sectors; in other words, the level of technology is more likely to be higher in more market-based sectors.

Hypothesis 2: Market-oriented reforms have propelled technological progress in China's high-tech sectors by increasing capital allocation efficiency, R&D input, and technology diffusion.

## 3. Econometric Model, Variables and Data Explanations

### 3.1 Econometric Model

Referencing common practices for research on technology progress, this paper specifies the following form of the production function to examine the effects of market-oriented reforms on sectoral technology progress (Wu, 2008; Li and Liu, 2015):

$$Y_{it} = A_{it}(Mark_{it})F(K_{it}, L_{it}) = A_{it}(Mark_{it})K_{it}^{\alpha}L_{it}^{\beta} \quad (1)$$

In equation (1), $Y_{it}$ is total output, $Y_{it}$ is a function of $K_{it}$ (material capital stock) and $L_{it}$ (labor input volume), and $\alpha$ and $\beta$ are the output elasticities of capital and labor, respectively. $A_{it}$ is sectoral technology level as a function of market-based operations ($Mark_{it}$). $A_{it}$ can be specified in the following form of total factor productivity (TFP):

$$TFP_{it} = A_{it} = A_0 Mark_{it}{}^{\eta} Z_{it}^{\gamma} \quad (2)$$

In equation (2), $A_{it}$ is the level of sectoral technology, and $TFP_{it}$ is sectoral TFP as a function of market-oriented reforms. $Mark_{it}$ is sectoral marketization index, $A_0$ is the level of sectoral technology in the initial state, and $Z_{it}$ respresents other factors that influence the level of sectoral technology or TFP. The following econometric model can be obtained by taking the natural logarithm for equation (2).

$$\ln TFP_{it} = \ln A_{it} = \ln A_0 + \eta \ln Mark_{it} + \gamma \ln Z_{it} \quad (3)$$

By differentiating t on both sides of equation (3), we have:

$$\Delta TFP_{it} / TFP_{i,t-1} = \Delta A_{it} / A_{i,t-1} = \eta\, \Delta Mark_{it} / Mark_{i,t-1} + \gamma\, \Delta Z_{it} / Z_{i,t-1} \quad (4)$$

For simplicity, we use symbols $TG_{it}$, $MG_{it}$ and $ZG_{it}$ to denote $\Delta TFP_{it} / TFP_{i,t-1}$, $\Delta Mark_{it} / Mark_{i,t-1}$ and $\Delta Z_{it} / Z_{i,t-1}$, respectively. In this manner, change in the level of sectoral technology $TG_{it}$ (technology progress) is a function of change in the level of market-based operations $MG_{it}$. Equation (4) implicitly assumes that sectoral technology progress $TG_{it}$ will change with various factors. The current level of sectoral technology is influenced by the level in the previous period. This lag effect can be briefly explained with the following regional adjustment model:

$$(TG_{it})^{e} = \eta MG_{it} + \gamma ZG_{it} + \lambda_{it} + \varepsilon_{it} \quad (5)$$

In equation (5), $(TG_{it})^{e}$ is the expected level of sectoral technology progress. Equation (5) indicates the expected level of sectoral technology progress under the influence of the current level of the explanatory variable. Due to the limitations of the institutional environment, the expected level of sectoral technology progress cannot be achieved in the short run. Hence, the actual change in technology progress ($TG_{it} - TG_{i,t-1}$) is only part of expected change [$(TG_{it})^e - TG_{i,t-1}$], and the following relationship exists:

$$TG_{it} \text{-} TG_{i,t-1} = (1-\zeta)[(TG_{it})^e - TG_{i,t-1}] \quad (6)$$

In equation (6), $1-\zeta(0<\zeta<1)$ is the adjustment coefficient for the expected value of sectoral technology progress, and a higher value means more rapid adjustment; when $\zeta=0$, actual technology progress equals the expected value; when $\zeta=1$, the current level of technology is the same as the previous period without any adjustment in the level of technology in period *t*. That is to say, the gap between $TG_{i,t-1}$ and the level of expected technology progress $(TG_{it})^e$ is $(TG_{it})^e - TG_{i,t-1}$, and adjustment in period *t* is $(1-\zeta)[(TG_{it})^e - TG_{i,t-1}]$. After substituting equation (6) into equation (5), we have:

$$TG_{it} \text{-} TG_{i,t-1} = (1-\zeta)[\eta MG_{it} + \gamma ZG_{it} + \lambda_{it} + \varepsilon_{it} - TG_{i,t-1}] \quad (7)$$

After rearranging equation (7) and making $\eta^*=(1-\zeta)\eta$, $\gamma^*=(1-\zeta)\gamma$, $\lambda_{it}^*=(1-\zeta)\lambda_{it}$ and $\varepsilon_{it}^*=(1-\zeta)\varepsilon_{it}$, we have:

$$TG_{it} = \zeta TG_{i,t-1} + \eta^* MG_{it} + \gamma^* ZG_{it} + \lambda_i^* + \varepsilon_{it}^* \quad (8)$$

In equation (8), the coefficients $\eta^*$ and $\gamma^*$ are short-term multipliers, and reflect the short-term effects of explanatory variables and on technology progress; $\eta$ and $\gamma$ are long-term multipliers, reflecting the long-term effects of the above explanatory variables on technology progress. $\zeta$ is the lag multiplier, and reflects the impact of technology progress in the previous period on the current period. Equation (8) dynamic panel model is a basic test model. According to relevant research literature, $Z_{it}$ includes technology importation, trade dependence, capital deepening and the level of human capital, and can be expressed by the following equation:

$$Z_{it} = \gamma_1 TI_{it} + \gamma_2 DT_{it} + \gamma_3 CS_{it} + \gamma_4 HC_{it} \quad (9)$$

In equation (9), *TI*, *DT*, *CS* and *HC* denote technology importation in high-tech sectors, trade dependence, per capita capital stock, and the level of human capital, respectively. $ZG_{it}$ in equation (9) is estimated with the growth rate equation of the explanatory variables in equation (8). Growth rates of these variables are denoted by *TIG*, *DTG*, *CSG* and *HCG*.

According to the theoretical mechanism analysis, market-oriented reforms may induce sectoral technology progress via such mechanisms as more efficient capital allocation. After verifying Hypothesis 1, we create the following recursive model based on equation (8) referencing the intermediate effect test method (Wen *et al*., 2014) to verify the existence of such mechanisms (i.e. verify Hypothesis 2). Based on equation (8), we may create the following recursive model:

$$TG_{it} = \zeta TG_{i,t-1} + \eta^* MG_{it} + \gamma^* ZG_{it} + \lambda_i + \varepsilon_{it} \quad (10)$$

$$W_{it} = \theta_0 + \theta_1 W_{i,t-1} + \theta_2 MG_{it} + \vartheta ZG_{it} + \varepsilon_{it} \quad (11)$$

$$TG_{it} = \psi_1 TG_{i,t-1} + \psi_2 MG_{it} + \psi_3 W_{it} + \kappa ZG_{it} + \lambda_i + \varepsilon_{it} \quad (12)$$

In the above equation, *W* is the intermediate variable, and includes the proxy variables for the three intermediate effects (as in the previous section, each variable's change ratio is followed in the empirical test). The lag term may, to some extent, control for the possible impact of missing variables. To increase the robustness of analysis results, we introduce the intermediate variable with a one-phase lag into equation (11). If the capital efficiency effect, R&D input effect or technology diffusion effect is the intermediate effect through which market-oriented reforms influence industrial technology progress, the symbols of $\theta_2\psi_3$ and $\eta^*$ should all be positive or negative. Moreover, the intermediate effect as a share of aggregate effect can be calculated with equation $\theta_2\psi_3/\eta^*$. We follow the same approach of Cai and Xu (2017), Jing *et al*. (2017) and Cai (2019) in testing the intermediate effect.

**3.2 Variables and Data**

*3.2.1 Market-oriented reforms*

The measurement of market-oriented reforms as a systematic project with quantitative indicators is highly complex. Based on the "China marketization index" by Fan *et al*. (2011), Dai and Liu (2013) created a set of indicators to measure the process of market-oriented reforms. These indicators cover five aspects of market-oriented reforms, and are backed by available and continuous data. Hence, this paper employs this index to measure the level of market-based operations in China's high-tech sectors. This index consists of the five aspects of government-market relationship (*Mark*01), non-state sector development (*Mark*02), product market development (*Mark*03), factor market development (*Mark*04), and institutional environment (*Mark*05). Change in sectoral marketization (*MG*) is then estimated with the growth rate equation.

*3.2.2 Sectoral technology progress*

This paper employs TFP for measuring the level of sectoral technology, and change in TFP reflects technology progress (*TG*). Similar to He *et al*. (2014) and others, this paper estimates TFP in high-tech sectors based on DEA's Malmquist index method. We make $x^t$ and $Y^t$ denote the input vector (including capital and manpower) and output vector at time $t$, respectively. With the distance function, we may create the Malmquist index based on output:

$$TFP_i = M_i(x^{t+1}, y^{t+1}; x^t, y^t) = \left\{\left[D_i^t(x^t, y^t)\big/D_i^t(x^{t+1}, y^{t+1})\right]\left[D_i^{t+1}(x^t, y^t)\big/D_i^{t+1}(x^{t+1}, y^{t+1})\right]\right\}^{1/2}$$

$$= \frac{D_i^t(x^t, y^t)}{D_i^{t+1}(x^{t+1}, y^{t+1})}\left[\frac{D_i^{t+1}(x^t, y^t)}{D_i^t(x^{t+1}, y^{t+1})} \times \frac{D_i^{t+1}(x^t, y^t)}{D_i^t(x^{t+1}, y^{t+1})}\right]^{1/2} \quad (13)$$

In estimating TFP in equation (13), we should determine the input and output variables. Similar to most literature (He *et al*., 2014), the output variable in this paper is reflected by the total output value of China's high-tech sectors. Labor input is denoted by employment data. Capital input is denoted by actual capital stock, which needs to be estimated. For the simplicity of calculation, our estimation is conducted with equation $K_t = I_t/P_t + (1-\delta_t)K_{t-1}$; where, $K_t$ is the actual capital stock of a high-tech sector in year $t$, $K_{t-1}$ is the actual capital stock in year *t-1*, $P_t$ is the price index of fixed asset investment, $I_t$ is the nominal investment in year $t$, and $\delta_t$ is the depreciation rate of fixed assets in year $t$.

*3.2.3 Control variables*

Technology importation (*TI*): as a key source of industrial technology progress in China, technology importation is denoted by the spending on foreign technology importation in high-tech sectors referencing Wu (2008). Trade dependence (*DT*): Measured by the export shipment value of high-tech sectors as a share of total output value referencing Dai and Liu (2013). Capital stock per capita (*CS*): Measured by the ratio between the current-year total fixed asset value and the size of the workforce in each high-tech sector referencing He *et al*. (2014). Human capital (*HC*): measured by R&D personnel as a share of total workforce referencing He *et al*. (2014).

*3.2.4 Intermediate variables*

(i) R&D input (*RD*) is the proxy variable for the R&D input effect, and equals the sum of internal and external R&D spending in each sector. (ii) Capital output ratio (*CO*) is the proxy variable for the capital efficiency effect. Referencing Cai *et al.* (2009), the capital-output ratio equals the year-end net value of fixed assets for each high-tech sector / total output value of the high-tech sector. (iii) Technology transaction volume (*TR*) is the proxy variable of the technology diffusion effect, and is depicted by the technology transaction volume in each high-tech sector referencing Dai and Liu (2016). In the empirical test, all the three intermediate variables are converted into growth rates denoted by *COG*, *RDG,* and *TRG,* respectively.

## 4. Empirical Test and Results

### 4.1 Impact of Market-Oriented Reforms on Sectoral Technology Progress

Considering data availability, our sample range is between 1995 and 2014. Our samples include the following 17 high-tech sectors: chemical pharmaceuticals manufacturing, traditional Chinese medicine (TCM) herb and product processing, biological product manufacturing, aircraft manufacturing and maintenance, spacecraft manufacturing, communication equipment manufacturing, radar and auxiliary equipment manufacturing, broadcasting and TV equipment manufacturing, electronic devices manufacturing, electronic component manufacturing, home audiovisual equipment manufacturing, other electronic equipment manufacturing, complete computer manufacturing, external computer equipment manufacturing, office equipment manufacturing, medical equipment and apparatus manufacturing, and instrument and apparatus manufacturing. Data is primarily from the *Statistical Yearbook of High-Tech Industries in China*, *China Statistical Yearbook* and the *China Economy Information Net (CEInet)*. Data of the sectoral marketization process in 1995-2010 are from Dai and Liu (2013). Data for estimating the sectoral marketization index in 2011-2014 are from the *Statistical Yearbook of High-Tech Sectors in China* for relevant years. In this paper, we have winsorized continuous variables to reduce the impact of outliers.

Model 1 in Table 1 reports the results of two-step SYS-GMM estimation in equation (8). Both the Hansen test and AB test satisfy the requirements of GMM estimation, i.e., the first-order autocorrelation significantly exists in the residual error, the second-order autocorrelation does not exist, and the Hansen statistic is insignificant. These results suggest that the instrumental variable employed in Model 1 is reasonable, valid and free from the problem of over-identification. As can be learned from the dynamic POLS and FE estimation results reported by Model 2 and Model 3, the coefficient $TG_{t-1}$ of Model 1 is 0.216, which is between coefficients 0.225 and 0.189 of Model 2 and Model 3, indicating relatively good robustness of SYS-GMM estimation results in Model 1. Judging by the results of parametric estimation, the coefficient of the change ratio of the sectoral marketization process (MG) is significantly positive with a value of 0.135, which suggests that market-oriented reforms have significantly propelled technology progress in high-tech sectors, verifying Hypothesis 1.

China's WTO entry is a milestone in the nation's market-oriented reforms. Market-oriented reforms before and after China's WTO entry may have influenced technology progress in China's high-tech sectors in different ways. Here, the dummy variable of time *T* is introduced for verification (the value is 0 for 1995-2001 and 1 for 2002-2014). As can be seen from Model 4, the coefficient of $T \times Mark$ is significantly positive at 1% (value is 0.069). That is to say, market-oriented reforms after the WTO entry have induced technology progress in China's high-tech sectors in a more significant way. A possible explanation is that the WTO entry marks a milestone in China's market-oriented reforms, which led to a sharp increase in market-based operations conducive to such intermediate effects as R&D inputs and technology transactions in high-tech sectors. International competition after the WTO entry would also encourage high-tech firms to spend more on R&D, upgrade equipment, and apply more advanced technologies to stay competitive, contributing to better technological performance in their respective

**Table 1: Estimated Results of Overall Impact**

| Explanatory variable | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
|---|---|---|---|---|---|---|
| $TG_{t-1}$ | 0.216***<br>(2.74) | 0.225***<br>(4.12) | 0.189***<br>(3.12) | 0.249***<br>(4.16) | 0.295***<br>(5.63) | 0.233***<br>(5.15) |
| *MG* | 0.135***<br>(4.01) | 0.125***<br>(2.88) | 0.109***<br>(3.25) | 0.127***<br>(2.95) | 0.107***<br>(3.25) | 0.116***<br>(4.51) |
| $T\times MG$ | - | - | - | 0.069***<br>(2.64) | 0.078<br>(1.35) | 0.102**<br>(2.18) |
| *TIG* | 0.077**<br>(2.31) | 0.181*<br>(1.93) | 0.197<br>(0.65) | 0.057*<br>(1.91) | 0.051<br>(0.44) | 0.053<br>(1.23) |
| *DTG* | 0.041**<br>(2.11) | 0.096***<br>(2.76) | 0.075<br>(1.53) | 0.033***<br>(3.32) | 0.042*<br>(1.91) | 0.038<br>(1.53) |
| *CSG* | 0.152***<br>(2.73) | 0.056<br>(0.88) | 0.161**<br>(2.22) | 0.138***<br>(2.77) | 0.114<br>(1.33) | 0.127**<br>(2.21) |
| *HCG* | 0.188***<br>(3.19) | 0.242***<br>(3.53) | 0.215<br>(1.46) | 0.159***<br>(3.11) | 0.142***<br>(2.73) | 0.163<br>(1.48) |
| Estimation method | Two-step system GMM | Dynamic POLS | Dynamic FE | Two-step system GMM | Dynamic POLS | Dynamic FE |
| Observations | 306 | 306 | 306 | 306 | 306 | 306 |
| $R^2$ value | - | 0.789 | 0.713 | - | 0.821 | 0.806 |
| AR(2) -test P value | 0.532 | - | - | 0.193 | - | - |
| Hansen-test P value | 0.457 | - | - | 0.735 | - | - |

Notes: (1) ***, ** and * denote significance at 1%, 5% and 10% levels.
(2) Numbers in parentheses are t values;
(3) Given the limitation of sample observations, the first-order lag of the explanatory variable is defined as the instrumental variable.
(4) The fixed effect of sector and the fixed effect of time are controlled for when performing the estimation.
(5) GMM method employed Stata/MP14.0 software pack, and ran xtabond2 program.
(6) For the convenience of comparison between various models, we have standardized the variables when performing the estimation. The same is for Tables 2-4.

sectors.[2]

## 4.2 A Mechanism Analysis

Based on the above-mentioned theoretical mechanism analysis, market-oriented reforms may have expedited sectoral technology progress by increasing capital allocation efficiency, R&D input, and technology diffusion. In this section, we take a further step to test the existence of the three intermediate effects. Model 1 in Table 1 in the above section reported the result of the first-step estimation of the recursive model (estimated with equation (10)), and the coefficient $\eta^*$ is significant. Therefore, we only need to test the intermediate effect from Step 2 to Step 4. Table 2 reports the two-step SYS-GMM estimation results of equations (11) and (12) for the three intermediate effects, and the Hansen test and AB test suggest that the results of Models 1-6 are robust. As can be learned from Table 2, the coefficients $\theta_2$ and $\psi_3$ of both intermediate effects in the step-two test are both significant, and the coefficient $\psi_2$ of the step-three test is also significant. That is to say, both intermediate effects exist. Following the practices

[2] In the interest of length, the analysis of control variable effects is omitted to highlight the theme of this paper.

**Table 2: Test Results of Intermediate Effects**

| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
|---|---|---|---|---|---|---|
| Intermediate effect | Capital efficiency effect | | R&D input effect | | Technology diffusion effect | |
| Explained variable | *COG* | *TG* | *RDG* | *TG* | *TRG* | *TG* |
| Explained variable with a one-phase lag | -0.166*** (-3.91) | 0.283*** (4.17) | 0.327*** (3.55) | 0.215*** (3.17) | 0.249*** (5.34) | 0.286*** (4.55) |
| *MG* | -0.224*** (-3.44) | 0.104*** (4.68) | 0.168*** (2.83) | 0.093*** (4.27) | 0.314*** (4.66) | 0.081*** (3.29) |
| *TIG* | -0.077 (-0.56) | 0.128*** (4.33) | 0.225 (1.22) | 0.113*** (2.74) | 0.071** (2.23) | 0.064* (1.94) |
| *DTG* | 0.146 (1.33) | 0.067* (1.95) | 0.114 (1.22) | 0.048* (1.97) | 0.047 (1.13) | 0.025*** (3.43) |
| *CSG* | -0.027* (-1.83) | 0.132** (2.27) | 0.217*** (3.78) | 0.151** (2.24) | 0.114 (0.65) | 0.077** (2.19) |
| *HCG* | -0.103*** (-4.50) | 0.186*** (2.85) | 0.077* (1.82) | 0.148*** (2.64) | 0.066*** (2.85) | 0.123*** (3.37) |
| *W* | - | -0.138*** (-2.64) | - | 0.249*** (3.58) | - | 0.172*** (3.79) |
| Observations | 306 | 306 | 306 | 306 | 306 | 306 |
| AR(2) -test P value | 0.645 | 0.182 | 0.212 | 0.137 | 0.268 | 0.216 |
| Hansen-test P value | 0.563 | 0.419 | 0.797 | 0.697 | 0.554 | 0.547 |
| Sobel test | $\theta_2$, $\psi_3$ are significant and require no Sobel test | | $\theta_2$, $\psi_3$ are significant and require no Sobel test | | $\theta_2$, $\psi_3$ are significant and require no Sobel test | |
| Intermediate effect | Significant | | Significant | | Significant | |
| Intermediate effect / aggregate effect | 22.96% | | 31.11% | | 40.01% | |

of Cai and Xu (2017), Jing *et al*. (2017) and Cai (2019), the Sobel test is not required.

*4.2.1 Analysis of capital efficiency effect*

In Model 1 of Table 2, the influence coefficient of the sector marketization process's (*MG*) effect on change in the capital-output ratio (*COG*) is significantly negative at 1%. The implication is that market-oriented reforms have reduced the capital-output ratio, making capital allocation more efficient in China's high-tech sectors. In Model 2, the coefficient of change in the capital-output ratio is significantly negative at 1%, indicating that a reduction in the capital-output ratio has propelled technology progress in high-tech sectors. Meanwhile, the coefficient of market-oriented reforms is significantly positive, and the value of coefficient $\psi_2$ (0.104) is smaller than the estimated coefficient of the benchmark estimation model $\eta^*$ (0.135), which verifies that market-oriented reforms may have induced technology progress in high-tech sectors by reducing the capital-output ratio (or raising capital allocation efficiency), which verifies the theoretical expectations in Ma (2014).

*4.2.2 Analysis of R&D input effect*

As shown in the estimation results of Model 3 of Table 2, the coefficient of sectoral marketization process (*MG*) with respect to change in R&D input (*RDG*) is significantly positive at 1%, which indicates that the sectoral marketization process has induced growth in R&D spending in high-tech sectors, which is consistent with the conclusions of Dai and Liu (2013b). As shown in the estimation results of Model 4, the estimated coefficients of sectoral marketization process and change in R&D input are significantly positive at 1%, and the coefficient of sectoral marketization process $\psi_2$ (0.093) is smaller than the estimated coefficient $\eta^*$ (0.135) of the benchmark estimation model (Model 1 in Table 1), which verifies the partial intermediate effect of R&D input. The implication is that the sectoral marketization process has induced technology progress in high-tech sectors via its effects on R&D input.

*4.2.3 Analysis of technology diffusion effects*

As can be learned from the estimated results of Model 5 in Table 2, the coefficients of sectoral marketization process (*MG*) and change in technology transactions (*TRG*) are significantly positive at 1% (value is 0.314), which indicates that an increase in the sectoral marketization level has induced technology transactions in high-tech sectors and thus enhanced technology diffusion. As revealed by the estimated results of Model 6, the estimated coefficients of the sectoral marketization process and change in technology transactions are all significantly positive, and the coefficient $\psi_2$ of the sectoral marketization process (0.081) is smaller than the estimated coefficient $\eta^*$ of the benchmark estimation model (0.135). This verifies the partial intermediate effect of technology transactions, and indicates that the sectoral marketization process may propel technology progress via technology diffusion. That is to say, it is of great significance to promote technology diffusion in such sectors as spacecraft manufacturing where the effects of technology diffusion are poor.

In summary, the test results of intermediate effects show that the sectoral marketization process has induced technology progress in China's high-tech sectors by such means as raising capital allocation efficiency, which verifies Hypothesis 2. In the comparison of the three intermediate effects as a share of the aggregate effect, it can be found that technology diffusion is the most effective (as a share of 40.01%), followed by R&D input (as a share of 31.11%), and the capital efficiency effect comes last (22.96%).

### 4.3 Robustness Test

Aside from controlling for variables and the inter-variable endogeneity problem in the above estimations, the sectoral technology progress is re-estimated in the section for a robustness test to ensure valid results.

In the above section, we performed estimations using the Malmquist index. Consistent with Li and Liu (2015), the Solow residual is employed to estimate sectoral technology progress (denoted by simple *STG*) with the following equation:

$$\Delta TFP_{it}/TFP_{i,t-1}=(A_{it}-A_{i,t-1})/A_{it}=(Y_{it}-Y_{i,t-1})/Y_{it}-\alpha(K_{it}-K_{i,t-1})/K_{it}-\beta(L_{it}-L_{i,t-1})/L_{it} \quad (14)$$

Where, $Y$ is the aggregate output value of high-tech sectors, $L$ is labor input (denoted by the workforce size of each high-tech sector), and $K$ is capital input (denoted by actual capital stock). Data treatment for these three indicators is the same as the above estimation of the Malmquist index. According to the C-D production function, the output elasticities $\alpha$ and $\beta$ of capital ($K$) and labor ($L$) are estimated with the fixed effects; according to the estimated output elasticities, we may calculate the change in Solow residual in each high-tech sector as a sign of sectoral technology progress. With the change in Solow residual as the explained variable, we re-estimated the above key conclusions. In the robustness test, the two-step system-GMM estimated results suggested that the conclusions from Table 1 and Table 2 are relatively robust.

## 5. Further Discussions: Heterogeneity of Market-Oriented Reforms' Effects

### 5.1 Five Differences in Sectoral Market-Oriented Reforms

China's market-oriented reforms comprise the following five aspects: Government-market relationship, non-state sector development, product market development, factor market development, and institutional environment (Fan *et al.*, 2011; Dai and Liu, 2013), which may create differentiated effects. Referencing Fan *et al*. (2011) and Dai and Liu (2013), the ratio of change in the sectoral marketization process (*MG*) in equation (8) is replaced by the ratio of change in the five aspects of sectoral market-oriented reforms. Model 1 in Table 3 reports the estimated results of two-step SYS-GMM for the five aspects of the sectoral marketization index, and Models 2 and 3 are POLS and FE estimations accordingly.

As shown in the estimated results of Model 1 in Table 3, the estimated coefficients for the five aspects of marketization are all positive. Among them, the estimated coefficients for the ratio of change in non-state sector development (*MG*02), the ratio of change in product market development (*MG*03), the ratio of change in factor market development (*MG*04), and the ratio of change in institutional environment (*MG*05) are significant at 1%, and the values of the four coefficients are 0.128, 0.093, 0.059 and 0.148, respectively. The estimated coefficient of the ratio of change in the government-market relationship (*MG*01) is insignificant at 10% (significance level is close to 10%) with a value of 0.037. That is to say, the first four aspects of the sectoral marketization index have significantly induced technology progress in China's high-tech sectors, and the effect of the government-market relationship index is insignificant. To some extent, this result has verified the conclusions of Fan *et al*. (2011) on the "different contributions of the five aspects of marketization to economic growth."

The above conclusions suggest that among the five aspects of the sectoral marketization index, a further improvement in non-state sector development and institutional environment may effectively propel technology progress in high-tech sectors. Since the two marketization indexes of market development and government-market relationship are relatively low (mean values are 0.083 and 0.153, respectively, which are far below the mean values of the other three indexes), market-based reforms in these two aspects are of great potentials and practical significance. Factor market development, in particular, should be a key direction in the market-oriented reforms of China's high-tech sectors.

### 5.2 Differentiated Effects of Market-Oriented Reforms on Sectors with Different Technology Attributes

Sectors with different technology densities are sensitive to or dependent on R&D input (or

**Table 3: Estimated Effects of the Five Aspects of the Sectoral Marketization Index**

| Explanatory variable | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| $TG_{t-1}$ | 0.195***<br>(4.17) | 0.218***<br>(3.44) | 0.172***<br>(3.54) |
| *MG01* | 0.037<br>(1.63) | 0.035<br>(0.81) | 0.033<br>(1.44) |
| *MG02* | 0.126***<br>(3.95) | 0.138***<br>(3.32) | 0.133***<br>(3.19) |
| *MG03* | 0.093***<br>(3.24) | 0.104*<br>(1.95) | 0.095<br>(1.29) |
| *MG04* | 0.059***<br>(2.77) | 0.062***<br>(3.33) | 0.053***<br>(2.78) |
| *MG05* | 0.148***<br>(3.41) | 0.143**<br>(2.10) | 0.141***<br>(2.95) |
| Observations | 306 | 306 | 306 |
| $R^2$ value | - | 0.732 | 0.671 |
| AR(2) -test P value | 0.137 | - | - |
| Hansen-test P value | 0.891 | - | - |

Note: Unreported control variables include technology importation (*TIG*), trade dependence (*DTG*), capital deepening (*CSG*) and human capital level (*HCG*). The same is for Table 4.

technology diffusion) by different degrees (Xu and Zhang, 2014). Since market-based reforms may induce sectoral technology progress and increasing R&D input and technology diffusion, the question is whether the effects of market-oriented reforms vary across sectors with different technology attributes? To test the above question, we performed a test using the product term method referencing Dai and Liu (2013), i.e. the following econometric model is created based on equation (8):

$$TG_{it} = \rho_1 TG_{i,t-1} + \rho_2 MG_{it} + \rho_3 (MG_{it} \times TIN_{it}) + \rho_4 ZG_{it} + \lambda_i^* + \varepsilon_{it}^* \tag{15}$$

In equation (15), $TIN_{it}$ is sectoral technology density, and $MG_{it} \times TIN_{it}$ is the product term between marketization process and sectoral technology density. Regarding the measurement of technology density ($TIN_{it}$), two common indicators are the R&D personnel as a share of the workforce and R&D spending as a share of total output value (Xu and Zhang, 2014). In this paper, these two indicators are denoted by R&D personnel as a share of the workforce and R&D spending in high-tech sectors as a share of total R&D spending, and referred to briefly as R&D personnel density and R&D spending density.

The estimated results of both Model 1 and Model 4 in Table 4 suggest that the coefficient of the product term ($MG_{it} \times TIN_{it}$) between sectoral technology density, no matter whether measured by R&D personnel density or R&D spending density, and marketization process is significantly positive, and the values are 0.205 and 0.226, respectively. This explains that in sectors with high technology densities, market-oriented reforms played a bigger role in inducing technology progress. A possible explanation is that with higher shares of R&D input, sectors with higher technology densities are more dependent on the diffusion of advanced technology. Hence, technology progress in sectors with higher technology densities is more dependent on the growth of R&D input and the diffusion of advanced technology, as manifested in the more significant effects of market-oriented reforms on technology progress in sectors with high technology densities. The implication is that market-oriented reforms have induced technology progress in sectors with high technology densities such as aircraft manufacturing and maintenance. For sectors like electronic component manufacturing, relevant measures should be taken to increase sectoral technology density for market-oriented reforms to propel sectoral technology progress.

**Table 4: Estimated Effects of Market-Oriented Reforms on Technology Progress in Sectors with Different Technology Attributes**

| Explanatory variable | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
|---|---|---|---|---|---|---|
| | Density of R&D personnel | | | Density of R&D spending | | |
| $TG_{t-1}$ | 0.221*** (3.15) | 0.282*** (4.37) | 0.147*** (3.11) | 0.309*** (3.88) | 0.492*** (5.11) | 0.245*** (4.39) |
| $MG$ | 0.084*** (2.84) | 0.101*** (3.75) | 0.105*** (3.36) | 0.137*** (4.16) | 0.122*** (4.16) | 0.193*** (3.75) |
| $TIN \times MG$ | 0.205*** (4.16) | -0.043 (1.35) | 0.413*** (5.17) | 0.226*** (5.21) | 0.105 (0.88) | 0.315** (2.22) |
| Method of estimation | Two-step system GMM | Dynamic POLS | Dynamic FE | Two-step system GMM | Dynamic POLS | Dynamic FE |
| Observations | 306 | 306 | 306 | 306 | 306 | 306 |
| $R^2$ value | - | 0.806 | 0.783 | - | 0.659 | 0.702 |
| AR(2)- test P value | 0.140 | - | - | 0.253 | - | - |
| Hansen-test P value | 0.657 | - | - | 0.842 | - | - |

## 6. Research Conclusions and Policy Implications

How does China's ongoing market-oriented reforms propel industrial technological progress? This paper offers a theoretical analysis on how market-oriented reforms may influence sectoral technological progress. It employs the sectoral marketization index and the sectoral panel data of China's high-tech sectors during 1995-2014 to test of the conclusions of the theoretical analysis.

Our empirical results support the theoretical analysis expectations, i.e., market-oriented reforms have propelled technological progress in China's high-tech sectors. The effects of market-oriented reforms have increased after China's WTO entry. Market-oriented reforms have propelled technological progress primarily with higher capital allocation efficiency, R&D input, and technology diffusion. Further research found that the five aspects of market-oriented reforms have influenced technological progress in China's high-tech sectors in different ways. The effects of the institutional environment are the most significant, followed by those of private sector development, product market development, factor market development, and government-market relationship. Among sectors with high technology densities, market-oriented reforms have played a more prominent role in inducing technological progress.

At the policy level, this paper's conclusions offer the following implications for China's ongoing market-oriented reforms and technological progress, especially in high-tech sectors.

(1) Policymakers should coordinate market-oriented reforms (especially the classified reforms for state-owned enterprises) with industrial technology and industry development polices to promote the development of high-tech sectors. In deepening market-based reforms, the priority is to continue reforming the factor market, especially to develop and improve the R&D risk investment system for high-tech firms and the market-based free flow of high-tech R&D personnel. Furthermore, market-oriented reforms should be carried out in various sectors according to the level of market-based operations therein, giving prominence to sectors with low levels of market-based operations such as aircraft manufacturing, maintenance, and radar and auxiliary equipment manufacturing.

(2) China's ongoing market-oriented reforms should be coordinated with policies to promote capital efficiency improvement, R&D, and technology transactions to induce technology progress more effectively. China should further improve fiscal incentives, and pre-tax deductions to encourage firm R&D, as well as improve legal and policy assurances, technology market regulations, and technology market services thus, developing technology market professionals, and offering tax incentives to technology based transactions. CE

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