Technology Progress Path and Catch-up Strategy for Late-Moving Large Countries

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Abstract: *Based on the endogenous technology progress framework for late-moving large countries, this paper simulates the effects of market size on technology progress path and technology catch-up, and finds that under the strategy of combining innovation with imitation, the increase of market size will restrain the convergence of economies towards technology frontier and deepen their reliance on imitation. Under the strategy of replacing imitation with innovation, there is a non-uniform U-shaped threshold effect for market size to influence technology progress path and catch-up, and the threshold for the shift of technology progress path lags behind that for technology catch-up. Hence, we should follow technology catch-up as the benchmark and timely adjust our innovation strategy to unleash the advantages of economies of scale for innovation. The innovation-driven development strategy is a choice compatible with China's changing market size. However, since China remains in a transition from a super-large economy to a super-strong one, the contribution of innovation will decrease at first before increasing afterwards.*

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1. Introduction

As a populous and large country, China has formed a broad and expanding domestic market with a super-large market advantage (Research Group of the State Council Development Research Center, 2020). To give full play to China's super-large market advantage, as noted at the Fifth Plenary Session of the 19th CPC Central Committee, "We should adhere to the strategic fulcrum of expanding domestic demand, race to create a complete domestic demand system, implement the strategy of expanding domestic consumption while deepening supply-side structural reforms, and steer and create new demand." To achieve a dynamic supply-demand equilibrium at a high level, it takes not only demand-side efforts to stimulate supply based on the huge domestic demand, but also a higher quality of supply to meet and create domestic demand. The key to supply-side improvement lies in technology innovation.

As shown in the world history of technological transitions, most early-moving countries relied on innovations while late-moving countries resorted to technology importation and imitation (Lin and Zhang, 2005). As a late-moving large country, China is both a "late-moving country" and a "large country" (Ouyang *et al*., 2016): Over the past 40 years, China has acquired advanced technology

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from developed countries through technology trade and foreign direct investment (FDI) and created an economic growth miracle. With its increasing technological advancement, however, the space for technology imitation is narrowing. Technology importation and imitation have become insufficient to maintain economic growth at the current pace. More importantly, China cannot buy, ask for or beg for core technologies from developed countries. In the context of diminishing dividends from globalization and major-power conflict, it is urgent for China to shift from imitation to innovation based on domestic circulation to break through foreign control of critical technologies (Liu, 2020). While China's market heft may induce endogenous technology innovation, it is also necessary for the government to make top-down design and overall arrangements (Liu, 2020).

For such reasons, the transition of technology progress path and technology catch-up for China as a late-moving large country is of great value for research and is a focal question for policy makers. As such, China has been adjusting and advancing its national innovation strategy, shifting the focus of attention from technology importation to innovation. Thanks to the pro-innovation national strategy and policy incentive, China's innovation input has surged. For instance, China's R&D personnel per million people have increased substantially from 443 persons in 1996 to 1,177 persons in 2015, which exceeds the world average of 1,151 persons. China's R&D funds as a share of GDP have increased steadily over the years from 0.56% in 1996 to 2.07% by 2015, which has reached the level for innovative countries.[1] However, the substantial increase in R&D spending did not make innovation output more efficient. Instead of facilitating China's transition from factor-driven to innovation-driven growth, it has inhibited China's TFP and TFP's contribution to economic growth, and as a result, China ranked only the 17th on the list of the world's most innovative countries (Ye and Liu, 2018). Moreover, Chinese enterprises are still plagued by a lack of innovation strengths and efficiency. They have yet to acquire critical technologies in various domains, and still have a long way to go to reach global technology frontiers. Adjustment in the national innovation-driven development strategy and input of R&D resources seem to fall short of expected effects in terms of a shift in technology innovation pattern at the firm level and a shift of technology progress path and technology catch-up at the national level.

Based on the above empirical facts, this paper attempts to answer the following three questions: First, what is the role of China's market heft in promoting the country's economies of scale advantage with respect to technology innovation? Does it help or hurt the transition of China's technology progress path in its technology catch-up process?

Second, does China's expanding domestic market size play a heterogeneous role in its technology progress path and technology catch-up under different innovation strategies? If the answer is yes, there would be non-uniform market size thresholds and time points for adjusting the innovation development strategy to achieve the goals of shifting technology progress path and achieving technology catch-up. Then, China's seemingly ineffective adjustment of the innovation strategy could have stemmed from the choice of different strategic objectives, as well as the lagged effect of market size on the shift of technology progress path.

Third, China should rely on domestic economic circulation as the basis for the transition of its technology progress path. Breakthrough in critical technologies is also a key driver of domestic circulation and the creation of a new development pattern. This interaction process also requires the support of national innovation strategies. The question is how should China adjust its innovation development strategy according to its changing domestic market size, shift its technology progress path, and achieve technology catch-up at a dynamic equilibrium?

For such reasons, this paper creates an endogenous technology progress model for late-moving

[1] In the interest of length, we have omitted the illustrated international comparisons of R&D personnel per million population and R&D spending as a share of GDP, which will be provided upon request.

large countries to explain the economies of scale advantage of the market from a technology innovation perspective for a quantitative simulation of the heterogeneous effects of market size on the shift of technology progress path and technology catch-up under different innovation strategies. Based on China's empirical data, we perform a numerical simulation of the dynamic mechanism of the effects of China's expanding domestic market on technology catch-up and the transition of technology progress path for late-moving countries. The remainder of this paper is structured as follows: Part 2 offers a literature review, Part 3 is theoretical model specification, Part 4 presents a numerical simulation, the final section is conclusions and policy recommendations.

2. Literature Review

As shown in the history of the rise and fall of technology powers and the catch-up history of late-moving countries, there is certain continuity and leapfrogging in the path of technology transition, in which innovation and technology importation play a pivotal role. As for the choice of technology progress path for late-moving countries, there is a controversy over whether technology importation or innovation should hold sway (Fang and Xing, 2017): First, based on the comparative advantage theory, the technology importation pattern suggests that late-moving countries choose their path of technology progress according to their respective factor endowments. Generally speaking, significant technological gaps exist between late-moving and developed countries. Compared with innovation, technology imitation tends to be less time-consuming and take fewer human and material resources to avoid the uncertainty of indigenous R&D and the risk of failure. As such, technology importation and imitation may allow countries to leverage their late-mover advantage to upgrade and catch up with leading nations (Keller and Yeaple, 2009). Brezis *et al*. (1993) considered that technology importation and imitation would allow late-moving countries to learn frontier technology, and that after the accumulation of imitation reaches a certain level, the imitating country may also experience a technological leapfrog and emerge as a leader of the next round of innovation. By introducing technology diffusion into the new growth model, Acemoglu *et al*. (2006) investigated the technology interaction mechanism of developed and developing countries, and identified technology progress of developing countries as a result of technology importation.

Second, the innovation pattern considers that if late-moving countries are excessively dependent on technology importation, they would fall into a comparative advantage trap, become locked up at a low level of technology and unable to innovate, and ultimately develop insurmountable "equilibrium technology gaps" with early-moving countries that condemn them into permanent followers (Krugman, 2003). Significant productivity gaps between countries also suggest that the imitation and absorption of frontier technologies from developed countries are a slow and costly process, which makes it unlikely to achieve economic growth convergence through spillover effects (Los and Timmer, 2005). In China's transition and upgrade, many enterprises have gained a foothold in the international market through imitation, but many others have fallen into a vicious cycle in which more focus on technology importation has led to even more backwardness (Lyu *et al*., 2017). Firms may become technology leaders by giving play to innovation and seeking critical technology innovations. In fact, international competition is underpinned by core technologies, which developed countries will not sell, and innovation is the only way for late-moving countries to achieve technological breakthroughs and catch up with developed countries, as can be evidenced in the development history of the United States, Germany, among other developed countries.

Normally, late-moving countries have to go through a process of technology importation, absorption, imitation and innovation, and over-emphasis on any single mode of innovation is biased. Technology importation and innovation are not completely independent from one another. Their relationship has been explained by academics with the "hypothesis of substitution" and "hypothesis of complementarity" (Zhang *et al*., 2020). On one hand, Lee (1996) uncovered a substitution effect of technology importation on innovation in South Korea's manufacturing industry, and some empirical studies by Chinese academics also arrived at similar conclusions (Xiao and Xie, 2016).

On the other hand, empirical research on late-moving countries like China and India also identified a relationship of substitution between technology importation and innovation (Zhang *et al.*, 2020). Fu and Wu (2013) created an endogenous growth model for late-moving countries and introduced the CES innovation possibility frontier encompassing innovation and technology importation to depict their relationships of complementarity and substitution using the elasticity of substitution between the two types of innovation results to simulate the critical role of technology gaps in knowledge production and technology catch-up.

In various stages of economic development, the two modes of innovation under various conditions may alternatively dominate technology progress (Basu and Weil, 1998). The mode of technology innovation and the path of technology progress should evolve amid changing technology gaps. When a country is significantly less innovative than developed countries, it is more appropriate to pursue imitation, but when it closes its innovation gaps, the shift from imitation to innovation becomes necessary (Caselli and Coleman, 2006; Ouyang and Tang, 2017). Moreover, empirical research suggests that technology innovation decisions are subject to a multitude of factors such as technology gaps and the level of openness, factor endowment structure, institutional environment, the protection of intellectual property rights, the degree of market competition, income gaps, financial development and economic volatility, which also influence the transition of technology progress path (Yu and Zhang, 2015; Huang and Song, 2017; Fang and Xing, 2017; Wang and Yuan, 2018). However, very few studies have incorporated market size into the technology gap convergence framework to examine their effects on the transition of technology progress path.

Another stream of literature has fully recognized the positive effects of market size on technology innovation based on the "demand-induced innovation" theory. Theoretical studies discussed the intensity of economies of scale in the process of technology innovation under the framework of endogenous economic growth (Romer, 1990; Jones, 1995; Lucas and Moll, 2014), and empirically tested the economies of scale effect with cross-national empirical data or verified the technology innovation effect of market size with sectoral data (Barro and Sala-i-Martin, 2003; Acemoglu and Linn, 2004; Hermosilla and Wu, 2018). With China's growing market size, academics have turned their eyes to the mechanisms and conditions of its effects on innovation, productivity and global value chains (Chen and Xu, 2012; Huang and Zhang, 2019; Zheng and Zheng, 2020).

In summary, existing studies provide theoretical inspirations for late-moving countries to pursue a suitable path of technology progress for technology catch-up, but most of those studies have analyzed the transition of technology progress path from an R&D input perspective. Research from the perspective of R&D output remains limited. More research has yet to be carried out to uncover the dynamic effect of market expansion on the mode of technology innovation and technology catch-up. This paper's possible contributions are twofold: First, under the framework of technology gap convergence, this paper defines the relative contribution rates of innovation and imitation outputs as proxies for technology progress paths to simulate the non-uniform threshold effect of market size on the technology progress path and technology catch-up for late-moving countries and interpret the economies of scale advantage of market size from an innovation perspective as the new theoretical basis for unleashing China's large market advantage. Second, by depicting the substitution or complementarity effects of imitation and innovation on technology improvement, this paper introduces different innovation strategies for a numerical simulation of the evolving trajectory of technology progress path and technology catch-up amid continuous domestic market growth. The dynamic correlation between the market expansion, the shift of technology progress and technology catch-up is analyzed for a new theoretical explanation on the exploration of an innovation path with Chinese characteristics.

3. Model Specification

3.1 Basic Model Framework

Based on the framework of technology gap convergence, this paper creates an endogenous technology progress model for late-moving large countries to simulate how market size influences the shift of technology progress path and technology catch-up under various innovation strategies. It is assumed that the preferences of the representative household in a late-moving economy satisfy the CRRA utility function for a continuous period of time.

$$U=\int_0^{\infty} exp(-\rho t)\frac{C(t)^{1-\theta}-1}{1-\theta}dt$$

Where, ρ is the discount rate, θ is the risk aversion coefficient, and $C(t)$ is total consumption at t. To maximize utility, the representative household's consumption decision satisfies Euler equation: $\dot{C}/C=(r-\rho)/\theta$.

The late-moving country is a closed economy, which employs labor in its production process. Let total labor input be a constant L, and labor supply is inelastic. Thus, the economy is faced with the following resource constraint at time point :

$$C(t) + Z(t) \leq Y(t)$$

Where, $Z(t)$ is the economy's total R&D spending at time, and $Y(t)$ is total output.

The late-moving country's final product $Y(t)$ is manufactured with a continuous intermediate product $y_i(t)$. The intermediate product category is standardized as 1, and the form of production function is specified as the C-D production function:

$$1\text{n}Y(t)=\int_0^1 1\text{n}y_i(t)di \tag{1}$$

Final product $Y(t)$ is specified as the value standard, and $p_i(t)$ is the price of intermediate product $y_i(t)$. In a final product market of perfect competition, the demand function for the intermediate product may be obtained according to equation (1):

$$y_i(t) = Y(t)/p_i(t)$$

Technology of intermediate product $y_i(t)$ manufacturer i is specified as follows:

$$y_i(t) = q_i(t)\, 1_i(t) \tag{2}$$

Where, $q_i(t)$ is the most advanced technology on the production line of the product, i.e. the highest level of productivity, and $1_i(t)$ is the labor input employed by the enterprise i, which pays a wage compensation of $w(t)$. Aggregate labor input of the late-moving economy satisfies $1\text{n}L=\int 1\text{n}1_i(t)di$.

Based on equation (2), the marginal cost of the intermediate product is:

$$MC_i(t) = w(t)/q_i(t) \tag{3}$$

Technology progress is manifested in the improvement of the most advanced technology $q_i(t)$ for the intermediate product, whose manufacturers are engaged in the R&D of new technologies. Once an R&D program succeeds, the most advanced technology $q_i(t)$ for the intermediate product will increase to $(1+\lambda) q_i(t)$. On this production line, an enterprise with the latest technology $q_i(t)$ competes with the incumbent enterprise $q_i(t)/(1+\lambda)$ with originally the most advanced technology. Under the Bertrand competition, the enterprise with the latest technology will set the price of the intermediate product according to the marginal cost of the incumbent enterprise:

$$p_i(t) = (1+\lambda)w(t)/q_i(t) \tag{4}$$

If the actual price is higher than the above price, the incumbent enterprise remains profitable, and the intermediate product market will be occupied by the incumbent enterprise; if the actual price is below the above price, although the incumbent enterprise still finds it hard to profit, there is still room for the enterprise with the latest technology to increase its profitability.

Based on equations (2)-(4), the profit function of the intermediate product manufacturer can be obtained as follows:

$$\pi_i(t)=\lambda Y(t)/(1+\lambda) \qquad (5)$$

While market size is determined by such factors as household income and population, total output (income) $Y(t)$ denotes the total purchasing power of households in the country and may represent the market size of a country (Alesina *et al*., 2000; Acemoglu and Linn, 2004; Aghion and Howitt, 2008). As can be learned from the above equation, market size has a positive effect on the profitability of intermediate input manufacturers, i.e. larger market size means greater profit from innovation and more incentives for enterprises to innovate. This virtuous cycle also reflects the scale advantage of innovation.

Of course, R&D and innovation are risky. If an enterprise succeeds in its R&D program, it will acquire a more advanced patent technology and employ the new technology for the manufacturing of intermediate product to earn more profits; if it fails in its R&D program, it will not be able to upgrade technology, leaving the manufacturing of the intermediate product to any incumbent enterprise (Aghion and Howitt, 2008).

It is assumed that the manufacturer of the intermediate product may improve technology for the intermediate product in category *i* through innovation and imitation. It is specified that after the manufacturer succeeds in innovation and imitation at time point *t*, it may upgrade the level of technology in phase t+1 to the following, respectively:

$$q_{Di}(t+1)=(1+\lambda_D)\cdot q_i(t),\ q_{Fi}(t+1)=(1+\tfrac{\lambda_F}{a(t)})\cdot q_i(t) \qquad (6)$$

Where, λ_D and λ_F are the levels of technology improvement for innovation and imitation, and $a(t)=A(t)/\overline{A}(t)$ is the relative level of technology or technology gaps of a late-moving country, i.e. the ratio between the late-moving country $A(t)$'s level of technology and the level of global frontier technology $\overline{A}(t)$. Higher value of $a(t)$ means that the country is closer to the global technology frontier and has smaller technology gaps with developed countries (Acemoglu *et al*., 2006). Obviously, the level of technology improvement achieved by late-moving large countries with imitation $\lambda_F/a(t)$ is subject to technology gaps since greater technology gaps suggest a broader space for late-moving countries to import foreign technology and benefit from the spillover effects (Keller and Yeaple, 2009). As late-moving countries approach the global technology frontier, there are fewer technologies to imitate, and remaining advanced technologies are highly sophisticated with diminishing spillover effects. At this moment, technology importation and imitation play a limited role in their technological advancement. Meanwhile, the progress rate of global frontier technology is $\overline{g}$, i.e. $\overline{A}(t)=\overline{A}(0)\cdot e^{\overline{g}t}$.

Given the high-risk characteristic of firm innovation, we introduce the innovation success rate to measure R&D risk, i.e. higher success rate means a smaller R&D risk, and vice versa. The success rates of innovation and imitation are specified as the increasing functions of their respective R&D input:

$$p_{Di}(t)=z_{Di}(t)/\tfrac{\zeta_D}{\varphi(\lambda_D z_{Di}(t))},\ p_{Fi}(t)=z_{Fi}(t)/\tfrac{\zeta_F}{\varphi(\lambda_F/a(t),\ z_{Fi}(t))} \qquad (7)$$

Where, ζ_D and ζ_F respectively denote the cost parameters of innovation and imitation. Since innovation is costlier than imitation, we specify $\zeta_F \leq \zeta_D \leq Y$. A reasonable hypothesis is that the marginal effect of R&D input on the success rate of innovation decreases with the increase of R&D input, i.e. R&D cost increases with R&D spending. When R&D inputs $z_{Di}(t)$ and $z_{Fi}(t)$ remain constant, the success rate of innovation is also subject to the goal of R&D, i.e. the degrees of improvement in new technology λ_D and $\lambda_F/a(t)$ after successful innovation. Greater improvement in new technology suggests a smaller possibility for such technological breakthrough to be achieved through R&D innovation. Function φ reflects the increase of R&D cost with the increasing degrees of technology improvement λ_D and $\lambda_F/a(t)$, as well as the increasing R&D inputs $z_{Di}(t)$ and $z_{Fi}(t)$.

In order for the model to have an explicit solution without losing generality, we assume the function form of φ to be:

$$\varphi(\lambda_D, z_{Di}(t))=(1+\lambda_D^{-1})(1+z_{Di}(t)^{-1}),$$
$$\varphi(\lambda_F/a(t), z_{Fi}(t))=(1+(\lambda_F/a(t))^{-1})(1+z_{Fi}(t)^{-1}) \quad (8)$$

R&D inputs for innovation and imitation $Z_D(t)$ and $Z_F(t)$ at time point t, together with aggregate R&D input $Z(t)$, are:

$$Z_D(t)=\int_0^1 z_{Di}(t)di,\ Z_F(t)=\int_0^1 z_{Fi}(t)di,\ Z(t)=\int_0^1 (z_{Di}(t)+z_{Fi}(t))di \quad (9)$$

3.2 Technology Progress Path under the Constraint of Innovation Strategy

In this section, we further analyze the technology progress path for late-moving countries under the constraint of different innovation strategies. As for the manifestations of various innovation strategies, Acemoglu *et al*. (2006) believed that heterogeneous innovation strategies were reflected in the differences of productivity under various decisions. In contrast, Huang and Song (2017) defined technology progress based on technology gaps and technology spillover effects as catch-up oriented and technology progress driven by competitive innovation as competition-oriented.

Hence, this paper defines different innovation strategies by the respective goals of the two patterns of innovation, i.e. the relative degrees of technology improvement λ_D and $\lambda_F/a(t)$: When $\lambda_D>\lambda_F/a(t)$, the results of innovation may cover and substitute those of imitation, allowing the late-moving large country to pursue innovation in lieu of imitation. When $\lambda_D\leq\lambda_F/a(t)$, however, innovation and imitation are complementary with each other, prompting the late-moving large country to combine innovation with imitation.

Classification of the two innovation strategies responds to the controversy over the complementarity and substitution between innovation and imitation at the theoretical level (Zhang, 2020). Moreover, it also reflects the evolving trajectory of China's innovation-driven development strategy in various stages. While China vowed to develop into an "innovative country" in 2006, for instance, it also encouraged enterprises to import advanced technology, which is in effect a strategy of combining innovation with imitation ("Imitation Plus Innovation Strategy" for short); the 18th CPC National Congress called for pursuing innovation with Chinese characteristics and implementing an innovation-driven development strategy, which is consistent with the strategy of replacing imitation with innovation ("Innovation Instead of Imitation Strategy" for short).

Under different innovation strategies, the degrees to which the two types of innovation contribute to technology improvement remain constant, and the technology progress rate of the economy is correlated with the success rate of technology innovation. As such, the R&D inputs $Z_D(t)$ and $Z_F(t)$ for innovation and imitation should be determined at first. Manufacturer i of the intermediate product will determine the R&D inputs $z_{Di}(t)$ and $z_{Fi}(t)$ for innovation and imitation according to the following expected profit $E\pi_i(t+1)$:

$$E\pi_i(t+1)=\begin{cases} p_{Di}(t)\cdot E\pi_{Di}(t+1)+(1-p_{Di}(t))\cdot p_{Fi}(t)\cdot E\pi_{Fi}(t+1)-z_{Di}(t)-z_{Fi}(t), & \text{if } \lambda_D>\lambda_F/a(t) \\ p_{Fi}(t)\cdot E\pi_{Fi}(t+1)+(1-p_{Fi}(t))\cdot p_{Di}(t)\cdot E\pi_{Di}(t+1)-z_{Di}(t)-z_{Fi}(t), & \text{if } \lambda_D\leq\lambda_F/a(t) \end{cases} \quad (10)$$

Where, $E\pi_{Di}(t+1)$ and $E\pi_{Fi}(t+1)$ are the expected profits from successful innovation and imitation, respectively, and the enterprise forecasts its profit in the next phase according to market performance in the current phase. From equation (5), we have: $E\pi_{Fi}(t+1)=(\lambda_F/a(t))Y(t)/(1+\lambda_F/a(t))$ and $E\pi_{Di}(t+1)=\lambda_D Y(t)/(1+\lambda_D)$. As can be learned from the above equations, expected profit from technology innovation by the manufacturer of the intermediate input is jointly influenced by market size, the degrees of technology improvement from innovation and imitation, and their respective success rates of innovation.

As can be learned from equations (7) and (10), enterprises commit a limited amount of R&D input under the high-risk and high-cost constraints of new technology development. When an economy boasts a large market, however, R&D risk in the innovation success rate is offset by the market size implicit in the profit function, i.e. the high R&D input of innovation is spread by a large market. The absorption and scattering of firm innovation risk by market heft reflect the scale advantage of market heft for R&D.

(1) When a late-moving large country pursues the Innovation Instead of Imitation Strategy (the strategy of replacing imitation with innovation), i.e. $\lambda_D>\lambda_F/a(t)$, if its enterprise succeeds in innovation but fails in imitation, the level of new technology in phase $t+1$ will increase to $(1+\lambda_D)\cdot q_i(t)$, and there is a probability of $p_{Di}(t)\cdot(1-p_{Fi}(t))$ for the enterprise to earn an expected profit $E\pi_{Di}(t+1)$; if the enterprise fails in its innovation, but manages to improve the level of its new technology to $(1+\lambda_F/a(t))\cdot q_i(t)$ by means of imitation, there is a probability of $p_{Fi}(t)\cdot(1-p_{Di}(t))$ for the enterprise to earn an expected profit of $E\pi_{Fi}(t+1)$; if the enterprise successfully achieves technological breakthroughs in both innovation and imitation at the same time, since innovation contributes more to technology improvement than does imitation, the results of innovation will cover and substitute those of imitation, the level of new technology will still increase to $(1+\lambda_D)\cdot q_i(t)$, and there is a probability of $p_{Di}(t)\cdot p_{Fi}(t)$ for the enterprise to earn an expected profit of $E\pi_{Di}(t+1)$; however, if the enterprise fails to achieve any technological breakthrough in neither innovation nor imitation, there is a probability of $(1-p_{Fi}(t))\cdot(1-p_{Di}(t))$ for the enterprise to end up with zero profit.

According to the first-order condition of equation (10), the enterprise's R&D inputs for innovation and imitation can be determined in relation to equations (5)-(7):

$$z_{Di}(t)=\left((\zeta_D\lambda_D-1-\lambda_D)-\frac{\zeta_D\zeta_F\lambda_D}{Y(t)}\right)\Big/(1+\lambda_D)$$
$$z_{Fi}(t)=\left((\zeta_F\lambda_D-1-\lambda_D)-\frac{\zeta_D\zeta_F\lambda_D}{Y(t)}\right)\Big/(1+\lambda_D) \qquad (11)$$

Obviously, the expansion of market size $Y(t)$ helps raise profit for the manufacturer of the intermediate product, and R&D inputs will increase for both innovation and imitation under the profit incentive. Since R&D input is subject to the level of technology improvement λ_D, the enterprise will increase its the level of R&D input for innovation and imitation when the level of its technology improvement increases. The distribution of R&D resources for innovation and imitation within the enterprise is subject to innovation cost coefficients ζ_D and ζ_F, and the two types of R&D input will increase with cost.

As can be learned from equations (9) and (11), the society-wide aggregate R&D input is as follows:

$$Z(t)=\left((\zeta_F+\zeta_D)\lambda_D-2(1+\lambda_D)-\frac{2\zeta_D\zeta_F\lambda_D}{Y(t)}\right)\Big/(1+\lambda_D) \qquad (12)$$

As can be learned from the above equation, corporate R&D input can be spread over a large market $Y(t)$, so that market expansion helps increase overall R&D input, which reflects the scale advantage of late-moving countries for innovation. Furthermore, there is a preference for R&D investment to be made in new technical field with great growth potentials, and the enterprise will focus on major technological breakthroughs that can be achieved with innovation, i.e. the level of technology improvement λ_D, and thus determine the amount of R&D input. A higher level of technology improvement will encourage the enterprise to invest more in R&D.

In relation to equations (7), (8) and (11), the success rates of innovation and imitation can be calculated as follows:

$$p_{Di}(t)=1-\frac{\zeta_F}{Y(t)}\ ,\ p_{Fi}(t)=\left(1-\frac{\zeta_D}{Y(t)}\right)\cdot\left(\frac{1+(\lambda_F/a(t))^{-1}}{1+\lambda_D^{-1}}\right) \qquad (13)$$

Success rates of both types of innovation are subject to the innovation cost parameter, the level of technology improvement, market size, among other factors. By heightening innovation risk, an increase in the innovation cost parameter will make the enterprise more scrupulous and cut back on R&D spending, dimming the prospect of successful innovation. A large domestic market, however, will reinforce the motivation of enterprises to innovate, invest more in R&D, spread the exorbitant innovation cost, and thus reduce the risk of R&D innovation and increase the success rates of innovation and imitation by giving play to the economies of scale advantage. Moreover, the success rate of imitation is also correlated with the degree of technology improvement and the relative level of technology. A higher success rate of imitation is associated with a smaller technology improvement achieved with imitation and a higher relative level of technology of the late-moving country.

In relation to equation (13), the enterprise may raise the level of production technology for the intermediate product *i* at time point *t*+1 by means of innovation and imitation:

$$q_i(t+1)=G(Y(t+1),a(t))\cdot q_i(t)$$

$$G(Y(t),a(t))==\left(\frac{\zeta_F}{Y(t)}\right)\cdot\left(1-\frac{\zeta_D}{Y(t)}\right)\cdot\left(\frac{1+(\lambda_F/a(t))^{-1}}{1+\lambda_D^{-1}}\right)\left(1+\frac{\lambda_F}{a(t)}\right)+\left(1-\frac{\zeta_F}{Y(t)}\right)\cdot\left(1+\lambda_D\right)$$
$$+\left(\frac{\zeta_F}{Y(t)}\right)\cdot\left(\frac{\lambda_D^{-1}-(\lambda_F/a(t))^{-1}+\zeta_D(1+(\lambda_F/a(t))^{-1})/Y(t)}{1+\lambda_D^{-1}}\right) \tag{14}$$

Based on equation (1), the aggregate level of technology is defined as the aggregation of the highest levels of production technologies possessed by all enterprises, i.e. $1\text{n}A(t)=\int_0^1 1\text{n}q_i(t)di$. On such a basis, we may obtain the technology progress rate of the late-moving large country at time point *t* by aggregating all enterprises after taking logarithm of equation (14):

$$g(t)=\ln\left[1+\underbrace{\left(1-\frac{\zeta_F}{Y(t-1)}\right)\cdot\lambda_D}_{\text{Innovation } g_D}+\underbrace{\left(\frac{\zeta_F}{Y(t-1)}\right)\cdot\left(1-\frac{\zeta_D}{Y(t-1)}\right)\cdot\left(\frac{1+(\lambda_F/a(t-1))^{-1}}{1+\lambda_D^{-1}}\right)\frac{\lambda_F}{a(t-1)}}_{\text{Imitation } g_F}\right] \tag{15}$$

As can be learned from equation (15), the late-moving large country achieves technology progress by means of innovation and imitation. First, the technology progress rate $g(t)$ is subject to the level of technology improvement and the country's relative level of technology. The more the country achieves technology improvement λ_D and λ_F by means of innovation and imitation, the faster it will make technology progress.

For the late-moving country and the early-moving country, their relative levels of technology in the previous phase have both positive and negative inter-temporal effects on technology progress in the current phase: On one hand, the relative level of technology in the previous phase $a(t-1)$ has a negative effect on technology progress rate in the current phase $g(t)$ as technology spillover effects diminish with narrowing technology gaps, and technology improvement that can be achieved through imitation also starts to decrease, causing technology progress to slow. On the other, the relative level of technology $a(t-1)$ has a positive effect on the technology progress rate. As technology gaps narrow, barriers to technology assimilation start to wane, making imitation more likely to succeed. As such, how the relative level of technology influences technology progress rate is subject to the relative magnitude of those two effects:

$$\frac{\partial g(t)}{\partial a(t-1)}=-\frac{1}{G}\left(\frac{\zeta_F}{Y(t)}\right)\cdot\left(1-\frac{\zeta_D}{Y(t)}\right)\cdot\left(\frac{\lambda_F}{(1+\lambda_D^{-1})a(t-1)^2}\right)<0$$

As can be learned from the above equation, as the late-moving large country approaches the global technology frontier, the positive effect of increasing success rate of imitation is insufficient as to offset the negative effect of decreasing technology improvement, and the technology progress rate will decrease with the increasing relative level of technology.

On such a basis, the relative contributions of innovation and imitation to technology progress rate $g(t)$ is examined in relation to equation (15). Thus, the evolving trajectory of technology progress path is examined from the perspective of innovation output:

$$\frac{g_D(t)}{g_F(t)}=\frac{Y(t-1)-\zeta_F}{Y(t-1)-\zeta_D}\frac{1+\lambda_D}{1+\frac{\lambda_F}{a(t-1)}}\frac{Y(t-1)}{\zeta_F} \tag{16}$$

If $\partial(g_D(t)/g_F(t))>0$, innovation will lead to a faster pace of technology progress compared with imitation, so that a shift of technology progress path towards innovation is consistent with the expected strategic goal; if $\partial(g_D(t)/g_F(t))<0$, imitation will lead to a faster pace of technology progress compared with innovation, which means that the technology progress path is skewed towards imitation, and the Innovation Instead of Imitation Strategy has failed to achieve the expected effect.

As can be learned from equations (16), $\partial(g_D(t)/g_F(t))/\partial a(t-1)>0$, i.e. the growth rate of imitation $g_F(t)$ slows amid narrowing technology gaps, and innovation plays a more prominent role. Then, technology progress naturally leans towards innovation.

Lastly, in observing the degrees to which technology improvement λ_D and λ_F can be achieved by means of innovation and imitation may influence technology progress path, we find that $\partial(g_D(t)/g_F(t))/\partial\lambda_D>0$, and $\partial(g_D(t)/g_F(t))/\partial\lambda_F<0$, i.e. λ_D has a positive effect on the growth rate of innovation $g_D(t)$, shifting the technology progress path towards innovation; λ_F has a positive effect on imitation $g_F(t)$, causing the technology progress path to be more dependent on imitation.

(2) If the late-moving large country pursues an Imitation Plus Innovation Strategy (strategy of combining innovation with imitation), we have $\lambda_D \leq \lambda_F/a(t)$. The success rates of innovation and imitation are derived according to the first-order condition of equation (10), with which the technology progress rate and path of the late-moving large country can be obtained:

$$g(t)=\ln\left[1+\underbrace{\left(1-\frac{\zeta_D}{Y(t-1)}\right)\cdot\frac{\lambda_F}{a(t-1)}}_{\text{Imitation } g_F}+\underbrace{\left(\frac{\zeta_D}{Y(t-1)}\right)\cdot\left(1-\frac{\zeta_F}{Y(t-1)}\right)\cdot\left(\frac{1+\lambda_D^{-1}}{1+(\lambda_F/a(t-1))^{-1}}\right)\lambda_D}_{\text{Innovation } g_D}\right] \tag{17}$$

$$\frac{g_D(t)}{g_F(t)}=\frac{Y(t-1)-\zeta_F}{Y(t-1)-\zeta_D}\frac{1+\lambda_D}{1+\frac{\lambda_F}{a(t-1)}}\frac{\zeta_D}{Y(t-1)} \tag{18}$$

As can be learned from equations (17)-(18), first, when the late-moving country approaches to the global technology frontier, i.e. technology gaps narrow and the technology progress rate $g(t)$ and the innovation and imitation rates $g_D(t)$ and $g_F(t)$ will decrease. Since imitation slows more substantially than innovation, technology progress will shift towards innovation.

Second, the greater degrees of technology improvement λ_D and λ_F achieved by means of innovation and imitation, the faster the pace of technology progress.

Third, the degree of technology improvement λ_D achieved by means of innovation is positively correlated with the innovation rate $g_D(t)$, causing technology progress to move towards innovation; the degree of technology improvement λ_F achieved by means of imitation has positive effects on both innovation and imitation, but the effect on imitation is stronger, causing technology progress to move towards imitation. Obviously, there is a non-uniformity in their effects on the growth rates of innovation $g_D(t)$ and imitation $g_F(t)$.

3.3 Market Size, Innovation Strategy and Technology Progress Path

Massive and expanding domestic market is a prominent strength of late-moving large countries. In this section, we will further reveal the heterogeneous effects of market size on innovation and imitation under different innovation strategies, as well as effects on the transition of technology progress path and technology catch-up:

(1) When the late-moving country pursues the Innovation Instead of Imitation Strategy, i.e. $\lambda_D>\lambda_F/a(t)$, based on equation (15), the effects of market size on the growth rates of innovation and imitation are shown as follows:

$$\frac{\partial g_D(t)}{\partial Y(t-1)}=\frac{\lambda_D\zeta_F}{Y(t-1)^2}>0$$

$$\frac{\partial g_F(t)}{\partial Y(t-1)}=\frac{1+\lambda_F/a(t-1)}{1+\lambda_D^{-1}}\frac{\zeta_F}{Y(t-1)^2}\left(\frac{2\zeta_D}{Y(t-1)}-1\right)$$

On one hand, $\partial g_D(t)/\partial Y(t-1)>0$, indicating that growth in market size helps increase the growth rate of innovation $g_D(t)$. The reason is that a large market may spread R&D cost and scatter the risk of innovation. On the other hand, the effect of market size on imitation is subject to the threshold effect. Although market size may increase the success rates of innovation and imitation at the same time, innovation has a substitutive effect on imitation, and whether technology improvement can be achieved by means of imitation is subject to the results of innovation. As such, the effect of market size on the growth rate of imitation is subject to the magnitude of its effect on the success rates of innovation and imitation.

Let $Y_1=2\zeta_D$ be the threshold, when the large country's market size is smaller than the threshold, i.e. $Y(t-1)\leq Y_1$, $\partial g_F(t)/\partial Y(t-1)>0$, and an increase in market size will speed up imitation, i.e. market size contributes to the success rate of imitation more than it defuses the risk of innovation; when market size crosses the threshold $Y(t-1)>Y_1$, $\partial g_F(t)/\partial Y(t-1)<0$, and market expansion will inhibit the growth of imitation, i.e. market size has a greater effect of defusing the risk of innovation.

The effect of market size on technology progress pathway is also subject to the threshold effect. Let $Y_2=\left(\sqrt{\zeta_D(\zeta_D-\zeta_F)}+\zeta_D\right)$ be the threshold, and when $Y(t-1)\leq Y_2$, and we have $\partial\left(g_D(t)/g_F(t)\right)/\partial Y(t-1)<0$, i.e. market size will speed up imitation, shifting technology progress towards imitation. In this case, the limited market size may not scatter the huge risk of innovation and spread the cost of independent R&D. When $Y(t-1)>Y_2$, the market size is large enough to spread the cost of innovation and defuse the risk of independent R&D, $\partial\left(g_D(t)/g_F(t)\right)/\partial Y(t-1)>0$. In this case, market expansion will speed up innovation, shifting technology progress towards innovation.

On the whole, when market size $Y(t-1)\leq Y_2$, market expansion is conducive to the growth rates of both innovation and imitation, and the growth of imitation is faster and causes technology progress to be more dependent on imitation, deviating from the strategic goal of replacing imitation with innovation; when market size $Y_2<Y(t-1)\leq Y_1$, market expansion has positive effects on the growth rates of both innovation and imitation, but the growth of innovation is faster, causing the technology progress to shift towards innovation; when market size $Y(t-1)>Y_1$, further market expansion will restrain the growth of imitation, prompting innovation to speed up and replace imitation, hence accelerating the transition of the technology progress path towards innovation.

Then, we proceed to analyze the effects of market size on the technology catch-up of late-moving countries under the Innovation Instead of Imitation Strategy. The evolving path of the economy's technology gap $a(t)$ satisfies: $\dot{a}(t)/a(t)=g(t)-\bar{g}$. In relation to equation (15), it can be learned that if $g(t)>\bar{g}$, technology progress in the late-moving large country will outpace the progress of the global frontier technology, raising the country's relative level of technology, but its technology progress rate will decrease, i.e. $\dot{g}(t)<0$; if $g(t)<\bar{g}$, technology progress in the late-moving large country is below the global technology frontier, and when the country's relative level of technology declines, the technology progress rate will increase, i.e. $\dot{g}(t)>0$, and its technology progress rate will gradually converge to the global frontier technology progress rate $\bar{g}$. When $g(t)=\bar{g}$, the late-moving country maintains the same growth rate as the global frontier technology, and its relative level of technology converges at a^*:

$$a^*=\frac{\zeta_F\lambda_F(Y-\zeta_D)}{\Gamma(\bar{g})Y^2+\zeta_F\lambda_D Y+\zeta_D\zeta_F} \tag{19}$$

Where, $\Gamma(\bar{g})=\left(\exp(\bar{g})-1\right)\left(1+\lambda_D^{-1}\right)-\left(1+\lambda_D\right)$. As can be learned from equations (19), the late-moving large country's technology gap a^* along the equilibrium growth path is directly subject to market size, the degrees of technology improvement by means of innovation and imitation, as well as innovation cost.

The effect of the late-moving large country's market size on the equilibrium technology gap is also subject to the threshold effect[2]: The threshold is defined as $Y_4=\left(\zeta_D+\sqrt{\zeta_D(\zeta_D+\zeta_F(1+\lambda_D)\Gamma(\bar{g})^{-1})}\right)$, when market size has yet to reach the threshold, i.e. $Y(t-1)\leq Y_4$, $\partial a^*/\partial Y(t-1)<0$, and the domestic market size will restrain the improvement of the equilibrium technology level. On one hand, if the market size is limited, it is difficult to spread the cost of innovation and scatter the risk of independent R&D, and the enterprise will hesitate to spend on R&D. On the other hand, imitation has a limited effect on technology improvement, and whether technology improvement can be achieved still depends on the success of innovation. Market expansion cannot effectively give play to the advantage of economies of

[2] To examine the effects of market size on equilibrium technology gap a^*, let $\partial a^*/\partial Y=0$, and we have $-\Gamma(\bar{g})Y^2+2\Gamma(\bar{g})\zeta_D Y+\zeta_D\zeta_F(1+\lambda_D)=0$, the solution of which is the threshold value.

scale for R&D. When the market size of the late-moving large country crosses the threshold of scale, i.e. $Y(t-1)>Y_4$, we have $\partial a^*/\partial Y(t-1)>0$, and the late-moving large country will develop a unique large market advantage, which is conducive to narrowing the technology gap.

(2) Under the Imitation Plus Innovation Strategy, i.e. $\lambda_D \leq \lambda_F/a(t)$, the market size of the late-moving large country also has an asymmetric effect on innovation and imitation, thus influencing the technology progress path. In relation to equations (17)-(18), the effects of market size on innovation and imitation are expressed in the following equations:

$$\frac{\partial g_D(t)}{\partial Y(t-1)}=\frac{1+\lambda_D}{1+(\lambda_F/a(t-1))^{-1}}Y(t-1)^{-3}\left(2\zeta_D\zeta_F-\zeta_D Y(t-1)\right)$$

$$\frac{\partial g_F(t)}{\partial Y(t-1)}=\frac{\lambda_F}{a(t-1)}\zeta_D Y(t-1)^{-2}>0$$

First, $\partial g_F(t)/\partial Y(t-1)>0$, indicating that market expansion is always conducive to raising the growth rate of imitation $g_F(t)$. Second, the effect of market size on the growth rate of innovation $g_D(t)$ is subject to the threshold effect. Under the Imitation Plus Innovation Strategy, although market heft makes it more likely for both innovation and imitation to succeed, innovation will complement imitation and will contribute to technological advancement only when imitation fails. While market expansion makes it more likely for innovation to pull off, it may also reduce the risk of imitation. The net effect of market expansion on innovation is subject to its relative effects on innovation and imitation.

Let $Y_3=2\zeta_F$ denote the threshold, and when the market size of the late-moving large country $Y(t-1)\leq Y_3$, $\partial g_D(t)/\partial Y(t-1)>0$, and the positive effect of domestic market expansion on the success rate of innovation exceeds its risk scattering effect for imitation, which helps accelerate innovation; when the market size of the late-moving large country $Y(t-1)>Y_3$, $\partial g_D(t)/\partial Y(t-1)<0$, and further market expansion plays a stronger role in mitigating the risk of imitation, thus inhibiting the growth of innovation.

On such a basis, we will analyze the effect of market size on the technology progress pathway, $\partial\left(g_D(t)/g_F(t)\right)/\partial Y(t-1)<0$, i.e. market expansion will cause technology progress to deepen its path dependence on imitation.[3]

On the whole, when market size $Y(t-1)\leq Y_3$, market expansion has positive effects on the growth rates of both innovation and imitation, but imitation grows at a faster pace, causing the technology progress path to shift towards imitation; when market size $Y(t-1)>Y_3$, further market expansion will inhibit the growth of innovation and speed up imitation, causing technology progress to deepen its path dependence on imitation and thus deviate from the original intention for the strategy for innovation and imitation to develop in lockstep.

Then, we proceed to analyze the effect of the late-moving country's market size on its technology catch-up under the Imitation Plus Innovation Strategy. If $\tilde{a}^*$ denotes the equilibrium technology gap of the late-moving country under such an innovation strategy, the equilibrium technology gap of the late-moving country $\partial\tilde{a}^*/\partial Y(t-1)<0$ suggests that when the late-moving large country implements an Imitation Plus Innovation Strategy, market expansion will trap the country into a low-level equilibrium trap.[4]

Proposition 1: Under different innovation strategies, market size has heterogeneous effects on the shift of the late-moving large country's technology progress path: Before market size reaches the threshold $Y(t-1)\leq Y_2$, whichever innovation strategy is implemented, market expansion will deepen the reliance of technology progress path on imitation; after market size crosses the threshold $Y(t-1)>Y_2$, if the Imitation Plus Innovation Strategy is followed, technology progress will become more dependent

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[3] Let $\partial\left(g_D(t)/g_F(t)\right)/\partial Y(t-1)=0$, and we may have a quadratic equation with one unknown with respect to $Y(t)$, whose root is $Y=\left(\zeta_F\pm\sqrt{\zeta_F(\zeta_F-\zeta_D)}\right)$. When $\zeta_F<\zeta_D$, the equation has no real root, and $\partial\left(g_D(t)/g_F(t)\right)/\partial Y(t-1)<0$.

[4] Let $\partial\tilde{a}^*/\partial Y=0$, and we may solve the equation root as $Y=2\zeta_F\tilde{a}^*(1+\lambda_D)/(\tilde{a}^*\lambda_D-\lambda_F)$. Under the Indigenous Plus Imitation Strategy $\lambda_D\leq\lambda_F/a(t)$, the equation root is negative, i.e. $\partial\tilde{a}^*/\partial Y(t-1)<0$.

on imitation, thus deviating from the strategic goal; if the Innovation Instead of Imitation Strategy is followed, market expansion may cause the technology progress pathway to shift towards innovation. Following the technology progress pathway as the standard, the large country should promptly adjust its innovation strategy when its market size crosses the threshold Y_2.

Proposition 2: Under different innovation strategies, market size has heterogeneous effects on the technology catch-up of late-moving countries: Before market size crosses the threshold $Y(t-1) \leq Y_4$, whichever innovation strategy is adopted, market expansion will restrain the narrowing of the equilibrium technology gap; when market size crosses the threshold $Y(t-1) > Y_4$, if the Imitation Plus Innovation Strategy is adopted, market expansion will restrain the improvement of the country's equilibrium level of technology; if the Innovation Instead of Imitation Strategy is followed, market expansion will be conducive to the country's convergence to the global technology frontier. With technology catch-up as the standard, the threshold of market size for adjusting the innovation strategy is Y_4.

Propositions 1 and 2 reveal how a late-moving large country should identify its changing market size and promptly adjust its innovation strategy to shift its technology progress path and advance technological catch-up. The problem is that when the shift of technology progress path and technology catch-up are set as the goals, there is a non-uniformity in the threshold of market size for adjusting the innovation-driven development strategy. Table 1 lists the heterogeneous effects of market expansion on the shift of technology progress path and technology catch-up when a late-moving large country implements different innovation-driven development strategies at different levels of market size. Based on those effects, the country may enact an innovation strategy compatible with its market size: (1) When the market size of the late-moving large country increases from large to super-large but has yet to become a super-large market, whichever strategy is followed, market size has negative effects on both the shift of technology progress pathway and technological catch-up. In this case, the Imitation Plus Innovation Strategy helps achieve a higher technology progress rate, and the economy's technological advancement is primarily dependent on its late-mover advantage and competitive advantage. (2) When the late-moving large country has yet to develop into a super-strong economy, whichever strategy is adopted, market size has a negative effect on the shift of its technology progress path, but under the Innovation Instead of Imitation Strategy, market size helps the economy converge to the global technology frontier. Under the Imitation Plus Innovation Strategy, however, market expansion will restrain the improvement of the equilibrium level of technology. At this moment, although the large country still relies on its late-mover advantage for technology progress, it should shift to the Innovation Instead of Imitation Strategy to avoid the trap of low-level equilibrium. (3) After the late-moving large country completes its transition from a super-large to a super-strong economy, under the Innovation Instead of Imitation Strategy, market expansion will not only increase the equilibrium level of technology, but shift the technology progress path towards innovation.

On the whole, the effects of market expansion on the shift of technology progress path and technology catch-up are subject to dual thresholds, which correspond to market size Y_2 and Y_4. The threshold of market size for the shift of technology progress path lags behind the threshold for technology gap convergence, i.e. $Y_2 > Y_4$. The underlying reason is that a large market may scatter the risks of both types of technological innovation. When the market is large enough, it mitigates the risk of innovation more than it does the risk of imitation, prompting technology progress path to shift towards innovation.

The mathematical model provides theoretical basis for formulating an innovation strategy compatible with changing market size and conducive to the shift of technology progress path and technology catch-up for late-moving large countries. However, the stylized facts and policy practices of the shift of China's technology progress path are far more complicated than mathematical simulations.

Table 1: Effects of Market Size on the Shift of Technology Progress Path and Technological Catch-Up

Development stage	Range of market size	Innovation Instead of Imitation Strategy		Imitation Plus Innovation Strategy	
		g_D/g_F	a^*	g_D/g_F	a^*
From a large to a super-large market	$Y(t-1) \leq Y_4$	–	–	–	–
From a super-large to a super-strong market	$Y_4 < Y(t-1) \leq Y_2$	–	+	–	–
Super-strong economy	$Y(t-1) > Y_2$	+	+	–	–

Source: Drafted by the authors.

The question is whether those stylized facts and policy practices are consistent with the evolving pattern of market size and logically coherent at the theoretical level? In retrospect, China vowed to enhance innovation in 2006 under the strategy of building an innovative country while encouraging enterprises to import advanced foreign technology. The 18th CPC National Congress has reaffirmed the commitment to embarking on a path of innovation with Chinese characteristics and implementing an innovation-driven development strategy. The 19th CPC National Congress further identified innovation as the primary force of economic development and a strategic pillar of building a modern economic system. Adjustment of the innovation strategy also reflects a structural change of China's R&D input. In fact, China's strategic adjustment of replacing imitation with innovation predates the adoption of the "innovation-driven development strategy." In 2010, China increased its spending on both the importation and assimilation of foreign technology, which marks the beginning of change in China's innovation strategy (Fang and Xing, 2017).[5]

However, the adjustment of innovation strategy and reallocation of R&D resources seem to have not delivered expected results. While imitation and technology spillover effects may increase total factor productivity (TFP) contribution to economic growth, scientific research and innovation did little to raise TFP in the short run (Ye and Liu, 2018). We may wonder whether the underlying reason is the failure to shift to a suitable innovation strategy according to market size at the time. With a middle-income group of some 400 million people and a land area of close to 10 million km^2, China registered a GDP aggregate of 13.6 trillion US dollars and a total retail volume of social consumer goods worth 5.8 trillion US dollars. With a large population, broad land area, market heft and market integration, China's economy is super-large, but has yet to become super-strong (Research Group of the State Council Development Research Center, 2020). According to our analysis of Table 1, China should implement an Innovation Instead of Imitation Strategy to give full play to its super-large market advantage. The Innovation Instead of Imitation Strategy is consistent with the evolving trends of China's market size. It is a realistic choice based on the goal of technology catch-up and helps avoid the premature adjustment of innovation strategy that may cause China's technology progress path to deviate from its strategic goal. Under this innovation strategy, there is a lag in the effect of market expansion on the shift of technology progress pathway, and the U-shaped trend of the contribution of innovation is also consistent with theoretical expectations. With the transition of China's economy from a super-large to a super-strong economy, market expansion will further shift China's technology progress path towards innovation.

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[5] The "turning point" mentioned by Fang and Xing (2017) in their paper is the turning point for China's technology progress mode from the perspective of R&D input, and is unlike the transition of technology progress path analyzed in this paper from the perspective of innovation output. The shift of technology progress mode in their paper is more similar to the adjustment of innovation strategy in this paper because strategic adjustment drives change in the structure of R&D input. In addition, Yu and Zhang (2015) believed that this transition could have occurred in 2002, when China's R&D input started to exceed its spending on technology importation and the gap between the two kept widening over the years.

4. Numerical Simulation

In relation to the theoretical model, this section will employ the numerical simulation method to simulate the evolving trends of the dynamic transition and technology catch-up of the late-moving large country's technology progress path amid market expansion and analyze the effects of parametric change.

4.1 Parametric Calibration

Referencing existing literature, this paper calibrates model parameters based on China's empirical data to align model specification with China's reality. Our simulation employs empirical data from the *China Statistical Yearbook*, the *China Statistical Yearbook of Science and Technology*, and the Penn World Table 10, and all indicators are actual values after deflating price volatility.

First, market size Y is measured by China's actual GDP referencing Alesina *et al*. (2000). Second, the reverse indicator of technology gap, i.e. relative technology Level a, indicates China's gap with the global technology frontier. In the iterature, this indicator is measured on such dimensions as the ratio between the capital stock per capita of Chinese and foreign-funded enterprises, technology density, as well as the total factor productivity (TFP), labor productivity and R&D spending as a share of GDP and GDP per capita of China and the US. Referencing Huang and Song (2017), this paper employs the TFP ratio between China and the United States to measure the relative level of technology. Third, the global technology frontier, i.e. the technology progress rate of early-moving countries $\bar{g}$, is specified as 0.02 following the general practice of literature (Barro and Sala-i-Martin, 2003; Acemoglu and Cao, 2015). Lastly, the degrees of technology improvement λ_D and λ_F achieved by means of innovation and imitation under different innovation strategies. The cost parameters ζ_D and ζ_F for the two types of innovation are the key to parametric calibration in this paper. Referencing Acemoglu and Cao (2015), assuming that the degree of technology improvement achieved by means of innovation is large enough to replace the results of imitation, this paper specifies technology improvement by means of innovation as 10 times that achieved by means of imitation, i.e. λ_D / λ_F=10 under the Innovation Instead of Imitation Strategy, and λ_F / λ_D=10 under the Imitation Plus Innovation Strategy.

On such a basis, referencing Fu and Wu (2013), the degrees of technology improvement by means of innovation and imitation and cost parameters are calibrated in relation to R&D input and equations (11)-(12) and (A1)-(A2) under different innovation strategies[6] using the actual data of China's technology progress rate, the relative level of technology, market size and R&D input, as well as the relative degrees of technology improvement achieved by means of the two innovation modes. With respect to the R&D input data for innovation and imitation, referencing Liu (2011), we denote the input of innovation $z_D(t)$ by R&D spending, and the input of imitation $z_F(t)$ by the sum of spending on foreign technology importation and domestic technology acquisition.

Meanwhile, the implementation status of the two innovation strategies also needs to be defined to utilize the actual data of various stages to calibrate the parametric levels of the two innovation strategies. Referencing Fang and Xing (2017), we define 2010 as the turning point of China's innovation development strategy and employ the data of 1991-2010 to calibrate the parameters for the Imitation Plus Innovation Strategy, so as to determine λ_D=0.00175, λ_F=0.0175, ζ_D=5455.69, and ζ_F=2693.78; data of 2011-2019 are for calibrating the parameters for the Innovation Instead of Imitation Strategy to be λ_D=0.0322, λ_F=0.0032, ζ_D=105879.93 and ζ_F=58599.28.

To test the validity of the theoretical model, this paper performs a numerical simulation of the above theoretical model based on empirical data calibration parameters for a comparative analysis of the simulated technology progress rate and the actual technology progress rate. The mean values and

[6] The R&D input and allocation equations under the Indigenous Plus Imitation Strategy will be provided upon request from the authors.

variation trends of the simulated and estimated values of the technology progress rate are generally consistent, thus verifying the validity of the mathematical model.[7]

4.2 Different Types of Innovation Strategy

This paper specifies 2019 as the base period to simulate the dynamic evolving trends of the technology progress path $g_D(t)/g_F(t)$ and relative technology Level $a(t)$ amid market expansion under the two types of innovation strategies after multiple iterations, as shown in Figure 1 and Figure 2. Figure 1 is the dynamic shift of the technology progress path under different innovation strategies, which shows that under the Imitation Plus Innovation Strategy, innovation contributes a diminishing share to imitation amid the large country's continuous market expansion. As a result, the late-moving large country's technology progress path becomes increasingly dependent on imitation, deviating from the strategic goal of combining innovation with imitation. Under the Innovation Instead of Imitation Strategy, market expansion will give rise to a dynamic U-shaped trend of innovation relative to imitation.

From Phase 1 to Phase 11, innovation continuously slows relative to imitation, and with the turning point of Phase 12, the technology progress path starts to shift towards innovation. This shift stems from the positive effect of the late-moving country's market expansion on the growth rate of innovation. Despite slowing innovation, the effect on the growth rate of imitation demonstrates an inverted U-shaped threshold. This result also implies that when the strategy of imitation is replaced with innovation at the macro level, the continuous shift of R&D resources towards innovation is not accompanied by equal changes in the relative contribution rates of the two types of innovation at the level of R&D output. Indeed, there is a certain lag in the effect of market expansion on the shift of the technology progress path. The market size threshold for the transition of technology progress path is 18,795.79 billion yuan, i.e. after China's actual GDP exceeds this level, market expansion may induce a transition of the technology progress path towards innovation.

Figure 2 shows the dynamic evolving trends of technology catch-up for the late-moving country.

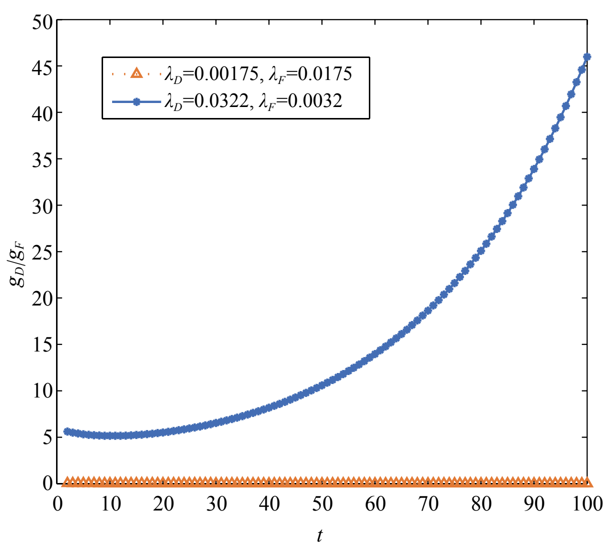


Figure 1: Technology Progress Path of the Late-Moving Large Countries under Different Innovation Strategies

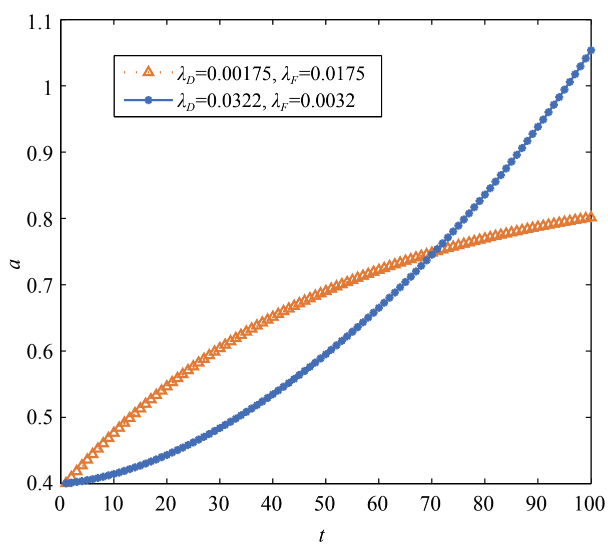


Figure 2: Technological Catch-Up Trend of the Late-Moving Large Countries under Different Innovation Strategies

Source: Drafted by authors.

[7] The model validity test will be provided upon request from the authors.

Data suggest that whichever innovation strategy is adopted by the late-moving large country, its technology gap with early-moving countries will narrow amid its domestic market expansion. In comparison of the dynamic evolving trajectories of technology catch-up for the late-moving country under the two innovation strategies, if the Imitation Plus Innovation Strategy is adopted, the late-moving country's relative level of technology will increase logarithmically, and while the economy's relative level of technology increases fast in the early stage, its domestic market expansion will cause its growth to slow; if the Innovation Instead of Imitation Strategy is adopted, however, the country's relative level of technology will increase exponentially, and while its relative level of technology increases slowly in the initial stage, the growth of local market demand in the late stage may bring about exponential economies of scale, causing the relative level of technology to improve at a faster pace.

Throughout Phases 1-70, technology catch-up under the Innovation Instead of Imitation Strategy lags behind that under the Imitation Plus Innovation Strategy, but since Phase 71, the catch-up trend starts to reverse, i.e. under the Innovation Instead of Imitation Strategy, the relative level of technology starts to catch up and overtake that under the other strategy. In the long run, if the Innovation Instead of Imitation Strategy is followed, market expansion will increase the relative equilibrium level of technology; if the Imitation Plus Innovation Strategy is followed, market expansion will inhibit improvement in the relative equilibrium level of technology.

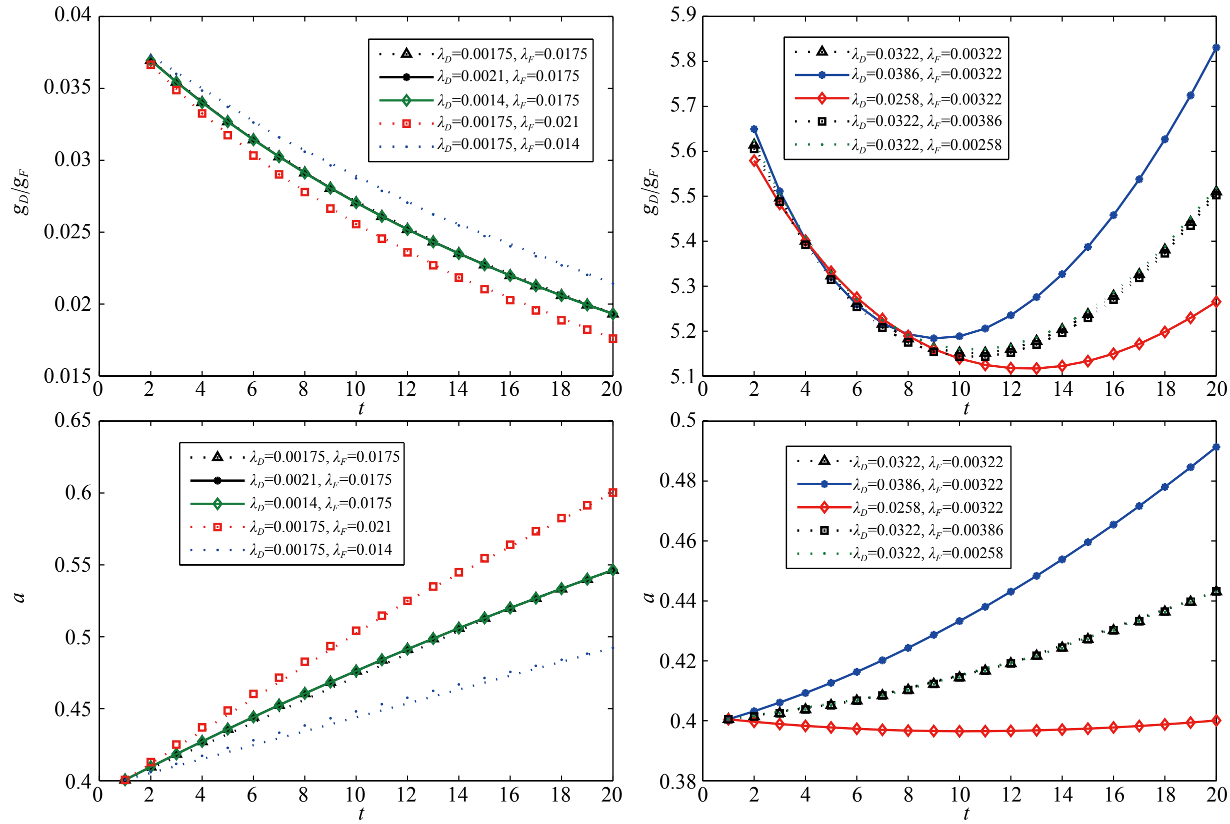
Based on China's large and expanding market and in relation to the numerical simulation results of Figure 1 and Figure 2, we find that China's economy is transitioning from super-large to super-strong. To avoid the low-level equilibrium trap, the Innovation Instead of Imitation Strategy with the goal of technology catch-up may raise the relative equilibrium level of technology. In this sense, China's innovation-driven development strategy is compatible with its current domestic market size. In terms of the shift of technology progress path, since China's economy has yet to reach a super-strong level, market expansion will reduce the contribution of innovation to technology progress in the short term. As China completes its transition from a super-large to a super-strong economy in the long run, however, market expansion will not only increase the equilibrium level of technology, but will scatter the risks of innovation and the cost of independent R&D to support the transition of technology innovation mode and shift its technology progress path towards innovation.

4.3 Adjustment in the Intensity of Innovation Strategies

On such a basis, this paper further analyzes the effect of adjustment in the intensity of innovation strategy on the shift of technology progress path and technology catch-up for the late-moving large country, i.e. the degree of technology improvement achieved by means of innovation and imitation to move λ_D and λ_F upwards and downwards by 20%, respectively, to denote the adjustment in the intensity of the two innovation strategies and the intensity of inclination towards innovation or imitation, as shown in Figure 3:

Under the Innovation Plus Imitation Strategy (see Figure 3a), the degree of technology improvement is more significant by adjusting imitation while the effect of innovation is insignificant. Under this innovation strategy, the late-moving large country may raise its relative level of technology by means of imitation. Meanwhile, the shift of the innovation strategy to imitation will cause the technology progress path to be more dependent on imitation, deviating from the strategic goal of reinforcing innovation through imitation.

Under the Innovation Instead of Imitation Strategy (see Figure 3b), compared with imitation, technological improvement by means of innovation has a more significant effect, indicating that a further shift towards innovation under this strategy allows market expansion to better serve the late-moving large country's shift of technology progress path and technological catch-up. Increasing intensity in the Innovation Instead of Imitation Strategy will enhance the positive effect of a large market on the shift of technology progress path, allowing the turning point for the late-moving large country's technology



a. Innovation Plus Imitation Strategy b. Imitation to Innovation Strategy

Figure 3: Effects of Intensity of Innovation Strategies on the Late-Moving Countries' Technology Progress Path and Technology Catch-Up

Source: Drafted by the authors.

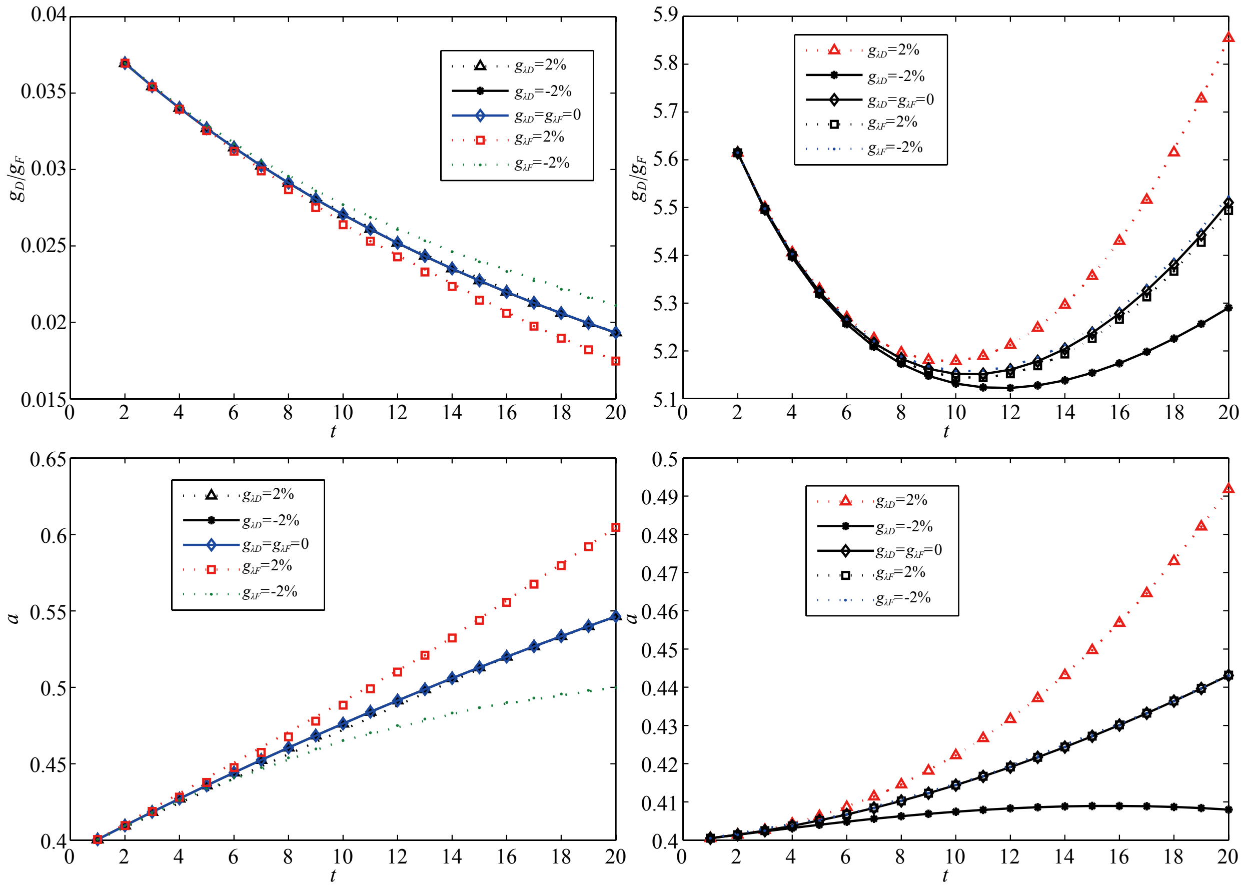
progress path to shift from imitation to innovation, so as to raise the country's relative equilibrium level of technology and give play to the scale advantage of market heft at the level of innovation.[8]

4.4 Dynamic Adjustment of Innovation Strategy

The above section has verified the exponential effect of the increase in the intensity of innovation strategy. Considering that the late-moving large country's innovation strategy is not constant and keeps deepening, this paper further evaluates the evolving trends of the late-moving large country's technology progress path and technology catch-up amid market expansion when the time-varying innovation strategy is adopted, as shown in Figure 4. To reflect the dynamic adjustment of innovation strategy, it is assumed that technology improvement under the two modes of innovation will change with time, i.e. $\lambda_D(t+1)=\lambda_D(t)\times(1+g_{\lambda D})$, $\lambda_F(t+1)=\lambda_F(t)\times(1+g_{\lambda F})$, and $g_{\lambda D}$ and $g_{\lambda F}$ are specified as 2%, -2% and 0, respectively.

Under the Innovation Plus Imitation Strategy (see Figure 4a), the benchmark scenario is specified as: $g_{\lambda D}=g_{\lambda F}=0$. First, the benchmark scenario $g_{\lambda D}=0$ is replaced with $g_{\lambda D}$=2% or $g_{\lambda D}$=-2%, which has a minimal effect on the late-moving large country's technology progress path and technological catch-

[8] Since the adjustment of the innovation cost parameter will also influence the allocation of R&D resources, this paper further considers the evolving trajectories of the late-moving large country's technology progress path and relative technology level with the adjustment of the innovation cost parameters. The results of comparative analysis will be provided upon request from the authors.



a. Innovation Plus Imitation Strategy

b. Imitation to Innovation Strategy

Figure 4: Effects of Time-Varying Innovation Strategy on the Late-Moving Large Countries' Technology Progress Path and Technological Catch-Up

Source: Drafted by the authors.

up, indicating that the adjustment of λ_D to weaken (deepen) the innovation strategy has a limited impact on the strategy's policy effect. But if the innovation strategy is increasingly deepened by adjusting λ_F to shift the innovation strategy towards imitation, i.e. when $g_{\lambda F}$=0 is replaced with $g_{\lambda F}$=2%, the technology progress path will increasingly shift towards imitation amid rapid market expansion, the technology gap will converge at a faster pace in sync, and its evolving trend will lead the benchmark by an increasing margin; if specified as $g_{\lambda F}$=-2%, the imitation strategy will become less intense, and the evolving trends of the late-moving country's technology progress path and technology catch-up will lag behind in comparison.

Under the Innovation Instead of Imitation Strategy (see Figure 4b), the benchmark status is specified as $g_{\lambda D}$=$g_{\lambda F}$=0, and if the innovation strategy is gradually shifted in favor of innovation by adjusting λ_D, i.e. when $g_{\lambda D}$=0 is replaced with $g_{\lambda D}$=2%, there will be earlier changes in the evolving trajectories of the large country's technology progress path and relative level of technology compared with the benchmark status. Specifically, continuous market expansion will be accompanied by a shift of technology progress path towards innovation and a faster increase in the country's relative level of technology; if technology improvement by means of imitation is adjusted to reduce the intensity of innovation strategy, i.e. when $g_{\lambda D}$=0 is replaced with $g_{\lambda D}$=-2%, the evolving trends of the late-moving large country's technology progress path and technology catch-up will lag behind the benchmark status with widening gaps. Under the condition of continuous market expansion, if the shift of technology progress path towards innovation weakens, the convergence of technology gaps will slow. If the benchmark status $g_{\lambda F}$=0 is replaced with $g_{\lambda F}$=2% or $g_{\lambda F}$=-2%, the effect on the late-moving large country's technology progress path and technology catch-up is insignificant, indicating the ineffectiveness of strategic adjustment by weakening or deepening the innovation strategy through the dynamic change of λ_F. On the whole, there is a certain lag effect in the continuous adjustment of the innovation strategy's intensity compared with the direct adjustment of the innovation strategies intensity, but it may still further unleash the exponential effect of the large market advantage.

4.5 Robustness Test

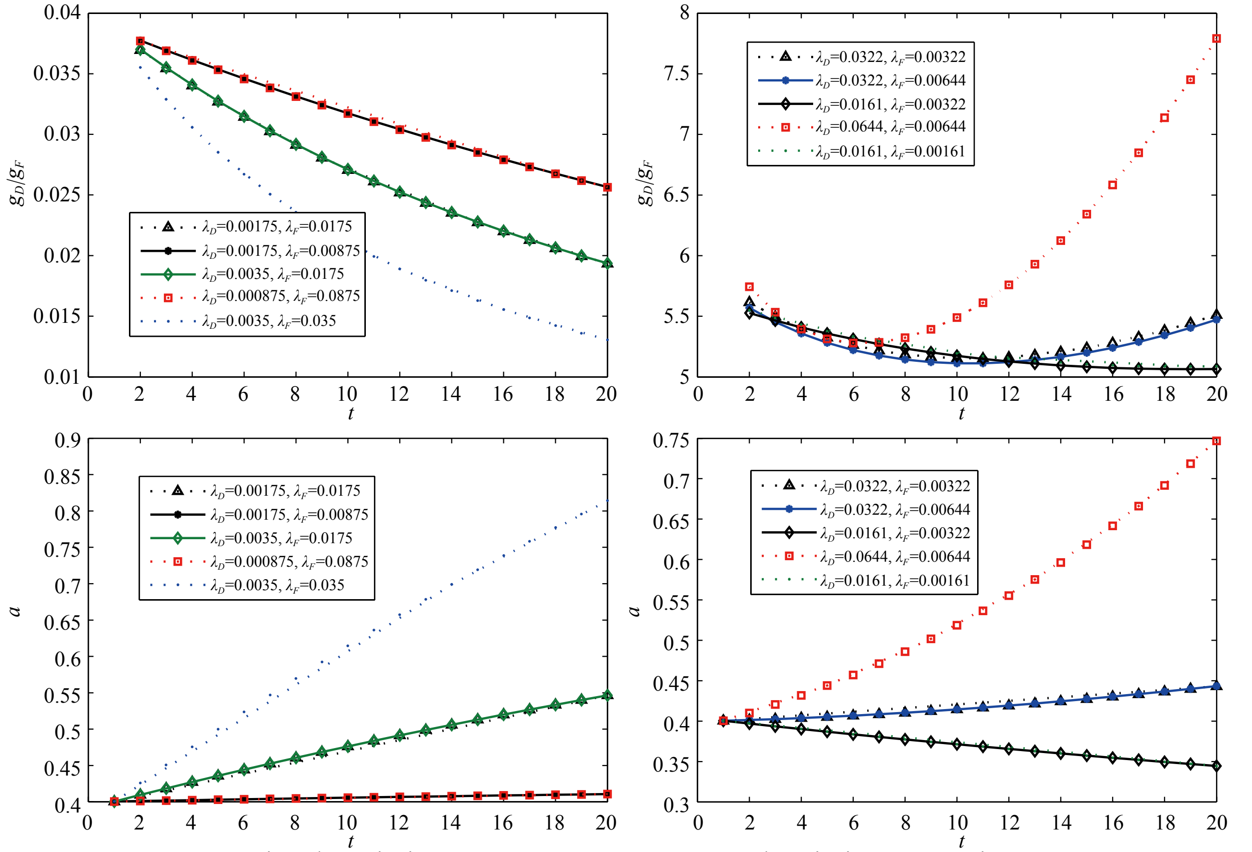
In calibrating parameters, this paper specifies the relative magnitudes of technological improvement by means of innovation and imitation based on Acemoglu and Cao (2015). Yet literature based on the empirical facts of developed countries is inconsistent with the reality of China's technological catch-up. For this reason, this paper has adjusted the ratio between technology improvements by means of innovation and imitation to examine whether changes in the relative magnitudes of technological improvement have an effect on the path of technology progress and technology catch-up to test the robustness of simulated -the results, as shown in Figure 5.

Under the Innovation Plus Imitation Strategy (see Figure 5a), the ratio between technology improvements under the two modes of innovation is adjusted under different scenarios. The benchmark scenario is λ_D=0.00175, λ_F=0.0175, and λ_F/λ_D=10. Scenario 1 maintains the same degree of technological improvement λ_D=0.00175 by means of innovation, specifies λ_F=0.00875, and adjusts λ_F/λ_D from 10 to 5. With the increasing market size, the late-moving large country's path of technology progress becomes less dependent on imitation, but its relative level of technology also decreases.

Scenario 2 considers λ_F=0.0175 to be constant, and adjusts the level of technological improvement by means of innovation λ_D to 0.0035, making λ_F/λ_D=5, and the late-moving large country's technology progress path and technology catch-up barely change. Compared with Scenario 2, parametric adjustment in Scenario 1 has a more significant impact on the simulated results, but further research is needed to unravel whether such an impact stems from technological improvement by means of innovation or the adjustment of ratio between technological improvements under the two types of innovation. Hence, both Scenario 3 and Scenario 4 specify λ_F/λ_D=10, but the former specifies λ_F=0.00875, which is consistent with Scenario 1, and the latter specifies λ_D=0.0035, which is consistent with Scenario 2.

Under Scenario 1 and Scenario 3, technology improvement by means of imitation are the same,. technological improvement by means of innovation and the ratio of technological improvements under the two types of innovation are different. Results suggest that the path of technology progress and the trend of technology catch-up are almost identical. Meanwhile, innovation leads to the same degree of technology improvement under both Scenario 2 and Scenario 4. Although the ratio of technology improvement by means of imitation and the ratio of technological improvements under the two types of innovation are different,, there is no change in the path of technology progress and the trend of technological catch-up.

As can be learned from a comparative analysis of the above four scenarios against the benchmark scenario, under Innovation Plus Imitation Strategy, the degree of technology improvement achieved by means of imitation - rather than the ratio of technology improvements achieved by means of the two innovation modes - has a key impact on the late-moving large country's technology progress path and technology catch-up trend. Under the Innovation Instead of Imitation Strategy (see Figure 5b), the result of adjusting parameters is similar, i.e. the degree of technology improvement achieved by means of innovation - rather than the ratio of technology improvements achieved under the two innovation modes - holds the key to the late-moving large country's technology progress path and technology catch-up



a. Innovation Plus Imitation Strategy b. Imitation to Innovation Strategy

Figure 5: Robustness Test for the Late-Moving Large Countries' Technology Progress Path and Technology Catch-up Trends

Source: Drafted by the authors.

trend. This result is consistent with that for the intensity of the innovation strategy in the above section. Under the Imitation Plus Innovation Strategy, adjustment in the technology improvement achieved by means of imitation has a major impact on the late-moving large country's technology progress path and technology catch-up trend; under the Innovation Instead of Imitation Strategy, technology improvement achieved by means of innovation has a major effect, and the degree of technology improvement by means of both types of innovation are calibrated using China's actual data. Specification of the technology improvement ratio for the two types of innovation referencing the literature does not affect the technology progress path and the technology catch-up trend, thus verifying the robustness of simulated results.

5. Conclusions and Policy Recommendations

This paper creates an endogenous technology progress model for late-moving large countries to simulate the heterogeneous effects of market size on indigenous and imitation under various innovation strategies, as well as the mechanism of its effects on the shift of technology progress path and technology catch-up. Based on China's empirical data, a numerical simulation is performed for the evolving trajectories of shifting technology progress path and technology catch-up under various types and intensities of innovation strategies amid domestic market expansion. Our research suggests that first, the scale advantage for R&D innovation is reflected in the large market being able to motivate enterprises to innovate, spread the high innovation cost, reduce R&D risk, and increase the success rate of innovation Second, under the Imitation Plus Innovation Strategy, market expansion will inhibit the convergence of the economy to the technology frontier, making its technology progress more dependent on imitation. Under the Innovation Instead of Imitation Strategy, the effects of market size on the technology progress path and technology catch-up are subject to a non-uniform U-shaped threshold effect, and the threshold of market size for the shift of technology progress path lags behind that for technology catch-up. The reason is that a large market may mitigate the risks of both indigenous and imitation, and that market size should be large enough to defuse the risk of innovation more than it does the risk of imitation to induce the transition of technology progress to innovation. Third, China should pursue a benchmark goal of technology catch-up, and advance and reinforce the strategy of replacing imitation with innovation to avoid the low-level convergence trap and further unleash the exponential effect of large market advantage. Lastly, China's innovation-driven development strategy is a realistic choice for its current market size. However, since China's economy remains in the stage of transition from a super-large to a super-strong economy, market expansion will cause the contribution of innovation to technology progress to decrease at first before increasing. The seemingly ineffective adjustment of innovation strategy stems from the choice of different strategic goals and the lagged policy effect. Of course, real-world innovation strategies are far more complex than theoretical simulations, and Chinese enterprises remain weak and inefficient when it comes to innovation.

In creating a new development pattern of domestic and international circulations, China should not only use its large market to induce endogenous firm innovation, but implement an innovation strategy at the national level to wean its dependence on critical foreign technologies. Based on the conclusions, we put forth the following policy recommendations:

First, we should further explore and give play to our super-large market advantage based on domestic demand. We should break through market segmentation and increase market integration by enhancing transportation, telecom, policy and institutional assurances and form a unified domestic large market by consolidating commodity market demand, deepening factor market reforms, removing barriers to factor flow and reallocation, and improving the factor demand system Various measures should be taken to improve inequalities in primary income distribution and redistribution to broaden domestic demand, smoothen domestic economic circulation, and derive profits from the super-large market to incentivize firms to innovate.

Second, we should create demand with high-quality supply for domestic demand to drive innovation and create a virtuous cycle between innovation and market demand. Institutional market environment should be improved to strengthen the agglomeration effect of the super-large market and foster a strong domestic market. In this manner, China should transition from a super-large economy to a super-strong one and scatter the risk in corporate R&D innovation with its huge market demand and ramp up the input of innovation resources. Efforts should be made to increase market competition, encourage R&D entities to learn from consumers, and improve the trial and error mechanism for innovation to bear fruit. Technology innovation driven by domestic demand should shift from imitative to innovation. On one hand, new demand for high-quality supply should be created to improve supply quality amid demand growth, create a dynamic demand-supply equilibrium, and smoothen domestic economic circulation by matching supply with demand on a dynamic basis. On the other, the shift from imitation to innovation has also become a new strength for China to take part in international technology cooperation, reshape the international innovation alliance, and form the basis for participation in the international circulation.

Lastly, the innovation-driven development strategy should be followed to remove institutional barriers preventing the large market demand from inducing innovation. The large domestic market should be leveraged to induce critical technologies. Under the dual circulations, we should rely on our domestic market demand as a driver of original firm innovation but not technology progress in early-moving countries and international market demand. In this process, we should also give play to the institutional strengths of Chinese socialism and government top-down design, identify changing market size, promptly shift our innovation strategy, and adjust the intensity of innovation strategy for specific industries. After the adjustment of innovation strategy, market expansion will induce the contribution of innovation to decrease before increasing. To reduce the gap between the dual thresholds for the shift of technology progress path and technology catch-up and reduce the downward cycle of contribution from innovation, it is necessary to break through institutional barriers to the transition of innovation modes by means of institutional innovation, and improve the property system conducive to the protection of innovation results and the performance management and profit-sharing systems for R&D personnel to spur the innovation dynamism and potentials of R&D entities.

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