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**CATCH-UP CYCLE: A GENERAL
EQUILIBRIUM FRAMEWORK**

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Abstract

Certain stylized facts are common among successful economic latecomers: an inverse U-shaped gross domestic product and capital per capita growth rate, high growth rates during the catch-up period, and rapid structural changes. This paper, for the first time, proposes a general equilibrium framework to document the catch-up cycle that a successful latecomer is likely to experience. We argue that technology adoption and imitation, and the diminishing marginal returns to capital are the two driving forces of the catch-up cycle. The technological gap and speed/efficiency of technological catching-up are two fundamental factors for successful catching-up. This paper concludes with a case study for the People's Republic of China and sheds light on the different policy choices in various stages of the catch-up cycle.

JEL Classification: E13, E60, O11

Contents

1. INTRODUCTION

The economic growth of latecomer economies comes in various forms. Some latecomer economies, such as Japan; the Republic of Korea; Singapore; Hong Kong, China; and Taipei,China have succeed in catching up with developed economies, while some other latecomers have not, such as the People's Republic of China (PRC), India, and Thailand. Can they finally catch up with developed economies and become successful latecomers? How can we describe the process of catching-up? Do policy choices dealing with different stages of economic catching-up differ? In this paper, we analyze the common characteristics that those successful latecomer economies share. Extracting these characteristics is important and even fundamental for us to understand the mechanism of the successful catching-up, as well as to provide policy implications for those latecomer economies which have just begun to catch-up.

Generally, there are three stylized facts accompanying the catch-up processes of those successful latecomer economies.

First, gross domestic product (GDP) and capital per capita growth depicts an inverse U-curve over time. Economies start with low growth in their low-income conditions, followed by a takeoff, a high-speed catch-up for 20–30 years, a growth rate decrease, and ending with medium or low but stable growth (see Figure 1).

Second, there is a 20- to 30-year phase during which GDP and physical capital per capita increase rapidly. Figure 1 shows that the growth rate of latecomer economies reached almost 10% and remained high during the high-speed growth phase. For instance, during 1950–1974, Japan experienced six declines and seven booms, but each recession lasted no more than 12 months. Figure 2 shows that the growth rates of physical capital per capita during the phase were also approximately 10%. The growth rates in developed economies, such as the United States (US), the United Kingdom, Germany, and France were only between 2% and 6% during the same period.

Third, rapid industrial upgrading and dramatic structural changes occur during the high-speed growth phase. The successful latecomers experienced rapid industrial upgrading in the high-speed growth phase, during which the capital stock accumulated rapidly, as did technology progress. At the same time, the structure of exports, consumption, and allocation of urban and rural populations also experienced rapid changes.

It is well known that the growth of developed economies remains at a low level. For instance, over the past 180 years, the 30-year moving average GDP annual growth rate of the US has been roughly 4%, and the 40- and 50-year moving average growth rates have been roughly 3%–4%. The long-term GDP per capita growth rate has been roughly 2%. Latecomer economies, by definition, have lower income originally. Therefore, in order to catch up, the growth rate of successful latecomers must be higher than that of advanced economies for at least several decades. As we will discuss, this is due to the large technological tap between latecomers and developed economies. After a certain period of high-speed growth, the technology difference between latecomer and developed economies decreases and the latecomers' economic growth rates begin to decrease and finally converge with advanced economies. Thus, there exists a common inverse U-shape growth pattern among the successful latecomers. This pattern is similar to a normal business cycle. We, for the first time, document it as a catch-up cycle.

Figure 1: Growth Rates of GDP Per Capita in East Asian Economies
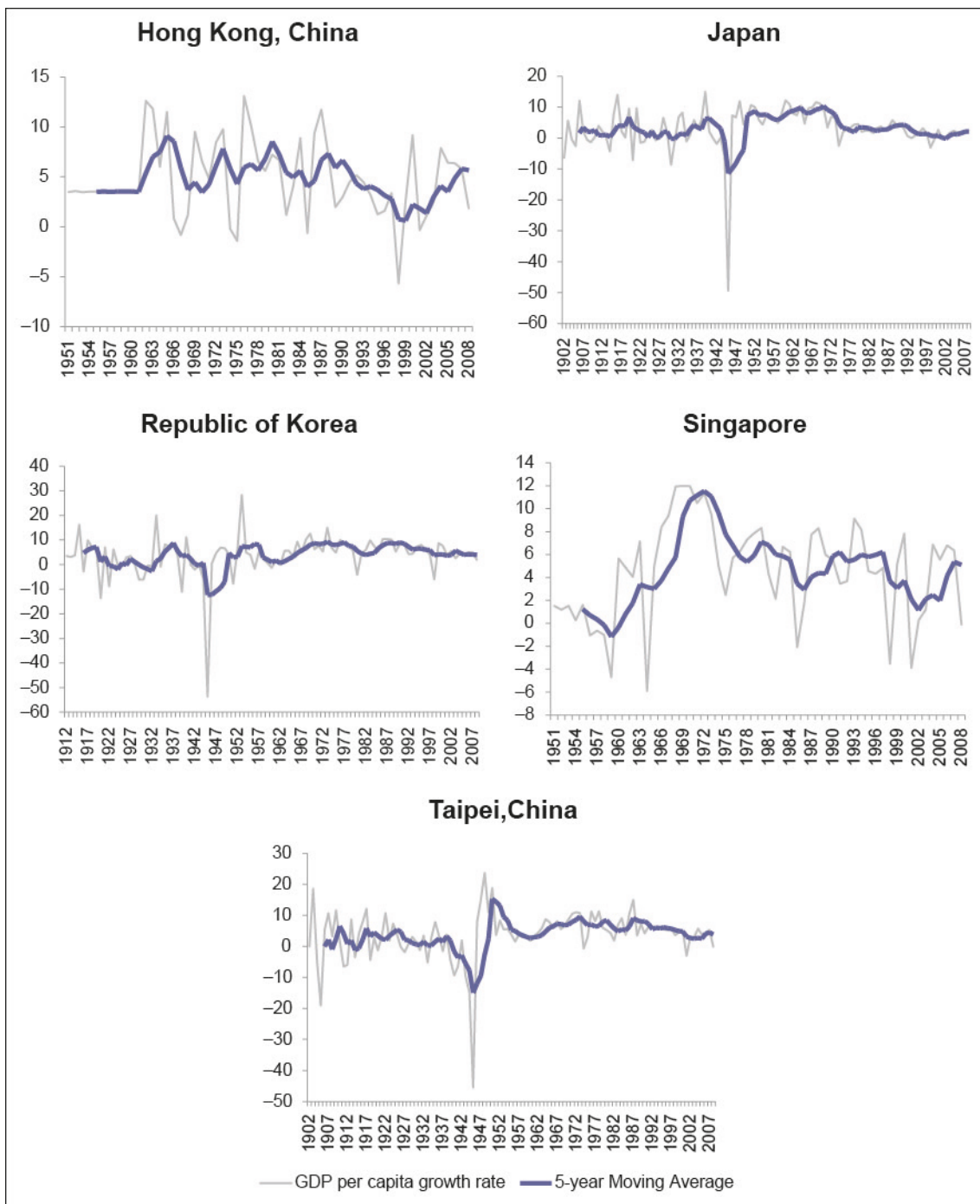
GDP = gross domestic product.

Note: Calculations are based on the Madison Project Database.

Figure 2: Capital Growth in East Asian Economies
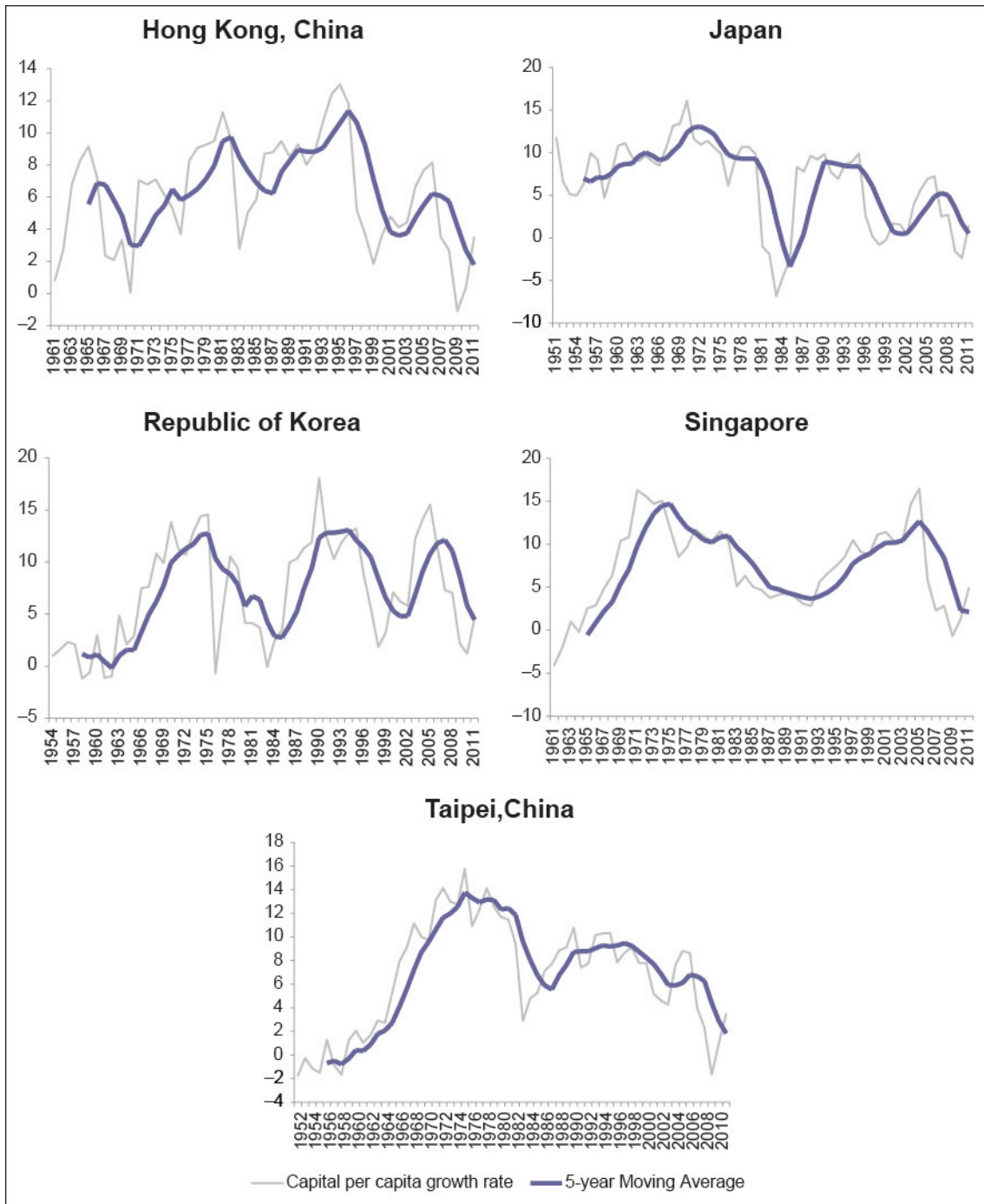
Note: Calculations are based on the Penn World Table.

In this paper, we propose a general equilibrium framework for the catch-up cycle. We argue that the catch-up cycle is driven by two forces: technology adoption and imitation, and diminishing marginal return to capital. At the early stage of catching-up, there is rapid technology adoption and imitation as the technology gap between latecomers and developed economies is large. In later stages of the catch-up cycle, as the technology gap between latecomers and advanced economies narrows, technology growth rate slows down and the law of diminishing marginal returns to capital begins to

dominate and bring down the income growth rate. Thus, the income and capital per capita growth rate both depict an inverted-U shape, or catch-up cycle.

The recognition of the catch-up cycle can deepen the understanding of short-term economic fluctuations and long-term economic growth. We also conduct a case study for the PRC, which is now the world's biggest latecomer economy, is currently in the high-speed growth phase, and has begun to switch to a medium-speed growth pattern. Based on the finding of the catch-up cycle, we are able to tell whether the PRC's slow-down is due to short-term economic fluctuation or a long-term cycle.

Among current studies, the main literature offering explanations for the latecomers' catch-up mechanism is empirical research framework provided by Barro (1991) and Barro (2012), which is inspired by the neoclassical growth theory (Solow 1956). They argue that the catch-up mechanism is the diminishing marginal return to capital. The implicit assumption of the framework is that latecomers obtain the same technology as developed economies at the beginning of the catch-up process. Therefore, the above framework ignores the technological catch-up (Lucas 2009) and, therefore, fails to explain why the successful latecomer economies can take off with economic growth rates that are much higher than developed economies. In this paper, we document the catch-up cycle as the combination of diminishing marginal returns of capital and technological catching-up. As we will demonstrate, the combination of technology imitation and diminishing marginal returns to capital can successfully explain the complete process of the catch-up cycle.

This paper is also related to studies on economic cycles. Cycles recognized by current studies primarily cover the Kondratieff cycle, which is a 50- to 60-year long-term technology advancement cycle; the Kuznets cycle, which is a 20- to 25-year medium- to long-term building upgrade cycle; the Juglar cycle, which is an equipment upgrade cycle lasting approximately 10 years; and the Kitchin cycle, which is a commercial cycle caused primarily by inventory fluctuation lasting approximately 4 years. However, the catch-up cycle differs significantly from other cycles in several aspects, including their natures, properties of structure changes, policy implications, and durations.

The rest of the paper proceeds as follows. Section 2 sets up a general equilibrium model to illustrate the mechanism of the catch-up cycle. Section 3 discusses the determinants of successful catching-up based on the model. Section 4 concludes by conducting a case study for the PRC.

2. MECHANISM AND MODEL

The core mechanism of the catch-up cycle is the different sources of technology improvements among developed economies and latecomers. The technological progress of developed economies is primarily based on trial and error, or innovation. The costly and risky innovation results in moderate long-term growth. However, the latecomers can achieve technological progress through technology adoption and imitation, which costs much less than research and development (R&D), as there is a large technological gap between latecomers and developed economies. Therefore, in the early stage of catch-up, the technological growth rate of latecomers is much higher than that of developed economies. Only when the technology gap between latecomers and advanced economies narrows, the technology growth rate begins to slow down. The income growth rate is thus brought down.

We first provide some evidence of the technological catching-up of latecomers. Then we propose a general equilibrium framework to characterize the catch-up cycle.

2.1 Descriptive Evidence

As we have mentioned, the necessary condition for latecomers' rapid catching-up is the low cost of technology imitation. Take the PRC as an example. The most popular explanations for the PRC's economic growth are low labor costs, demographic dividends, low land costs, and low environment costs, among others. However, although developed economies, such as the US, enjoyed similar elements in their early stages of development, they never experienced a high-speed growth phase. The reason is clear: latecomers are able to adopt and imitate technology at a lower cost. This is the key condition that enabled the PRC to maintain a growth rate of nearly 10% for 30 years. Further, during the high-speed phase, the rapid accumulation of capital does not lead to a significant decrease in capital efficiency since the diminishing marginal return to capital effect is offset by the rapid catching-up of technology.

Second, after the high-speed phase, the transition from high to medium/low economic growth is due to the narrowing technology gap between latecomers and advanced economies. Consequently, latecomer advantages decrease, and the speed of technological progress is not sufficient to offset the diminishing marginal returns of capital. Therefore, the rate of economic growth begins to decrease. It is noteworthy that during the growth transition a series of changes occur: a slowdown of technology advancement, economic growth and investment growth, a change from technology imitation to R&D, and a decrease in capital returns. As the technology gap narrows, these changes continue until the latecomers complete the catch-up process and converge with developed economies.

Figure 3 shows the total factor productivity (TFP) growth rate and the relative ratio of TFP to the US of the five successful catching-up economies. We find that the following:

Catching-up economies experienced high TFP growth rates for years before economic slowdown.

At the high-speed growth phase, when latecomers' capital per capita rapidly accumulated, capital output efficiency, as measured by the incremental capital-output ratio,[1] remained at a relatively high level (see Table 1).[2]

The TFP growth slowdown of latecomers occurs when TFP is close to that of advanced economies. For instance, Japan; the Republic of Korea; and Taipei,China entered this period when their TFP reached 70%, 70%, and 100% of the US TFP, respectively.

The above stylized facts are consistent with the definition of the catch-up cycle as we propose.

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[1] The annual ratios of investment and production increase are economic indicators of investment efficiency. Generally speaking, the higher an economy's incremental capital-output ratio is, the lower its investment efficiency and production efficiency are.

[2] Bai et al. (2006) found that despite high investment, the PRC's capital return rate did not decrease significantly during the high-speed growth period.

Figure 3: Total Factor Productivity of Five East Asian Economies
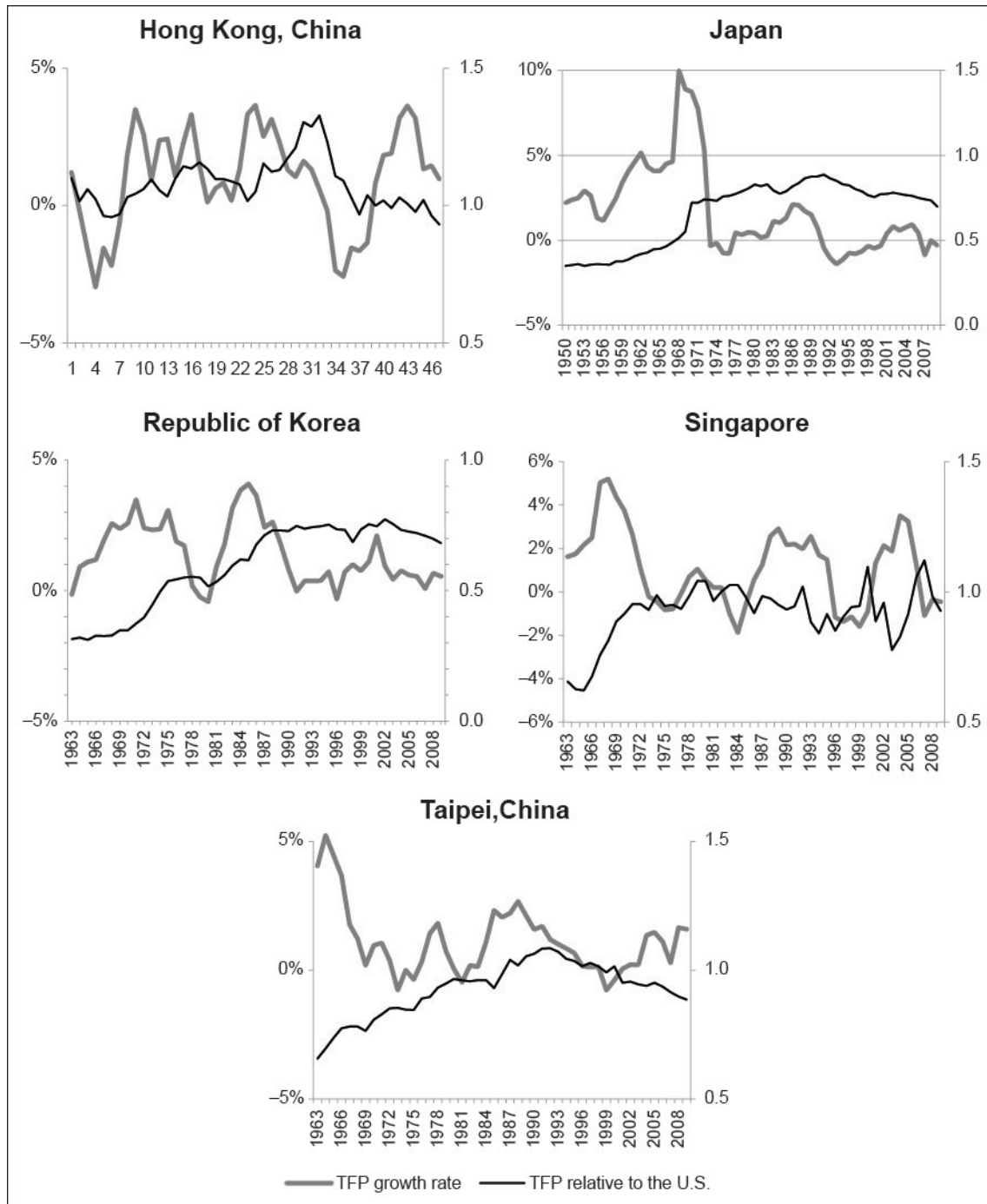
TFP = total factor productivity.

Note: Calculations are based on the Penn World Table.

Table 1: Capital Output Efficiency at the High-speed Growth Phase

Economy	Period	Growth Rate of Capital Per Capita	ICOR
Japan	1951–1970	9.3%	2.07
Republic of Korea	1966–1995	11.6%	2.64
Singapore	1965–1984	12.0%	2.53
Hong Kong, China	1963–1996	7.5%	2.46
Taipei,China	1965–1998	9.7%	1.86
United States	1951–2011	2.5%	3.55

ICOR = incremental capital output ratio.

Notes: Calculations are based on the Penn World Table. We eliminate the samples with negative ICOR.

2.2 Empirical Evidence

Next, we provide some empirical evidence. The core assumption of the catch-up cycle is that the TFP growth rate is negatively correlated with the TFP gap with developed economies. Therefore, the larger the TFP gap with developed economies, the higher the TFP growth rate.

We use country-level data from Penn World Table and regress the average TFP growth rate on TFP gap with developed economies, see Eq. (2.1):

$$g_i = \alpha + \beta * gap_i + u_i \qquad (2.1)$$

where gap_i is the TFP gap, defined by the ratio of latecomers' TFP over the TFP of the US. Here we use the average TFP gap in the early period.[3] g_i is the average growth rate of TFP in the later period.[4] u_i denotes the error term. We expect $\beta < 0$.

To simplify the model setup, we also test the following restricted regression function:

$$g_i = \gamma(1 - gap_i) + u_i \qquad (2.2)$$

γ can be seen as the speed (or efficiency) of the technology adoption and imitation. We expect γ to be positive.

Figure 4 plots the primary relationship between the TFP gap and the TFP growth rate. As expected, the larger the TFP gap with developed economies in the early period, the higher the TFP growth rate in the later period.

Table 2 presents the empirical results of equations (2.1) and (2.2). We conduct a robustness check by altering the time interval. Columns (1), (3), and (5) are the results of (2.1), and columns (2), (4), and (6) are the results of (2.2). In all regressions, we find that the TFP growth rate is negatively correlated with the TFP gap with developed economies. Specifically, according to columns (2), (4), and (6), the global average speed of catching-up ($\hat{\gamma}$) is roughly 0.01. The empirical findings provide justification and support for the catch-up cycle model, as we present below.

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[3] We report the empirical results of three time intervals: 1960–1964, 1965–1969, and 1960–1969. Altering the time intervals does not change our results significantly.

[4] For the time interval 1960–1964, we average the TFP growth rate of 1965–2011. The rest is done in the same manner.

Figure 4: TFP and TFP Growth Rates
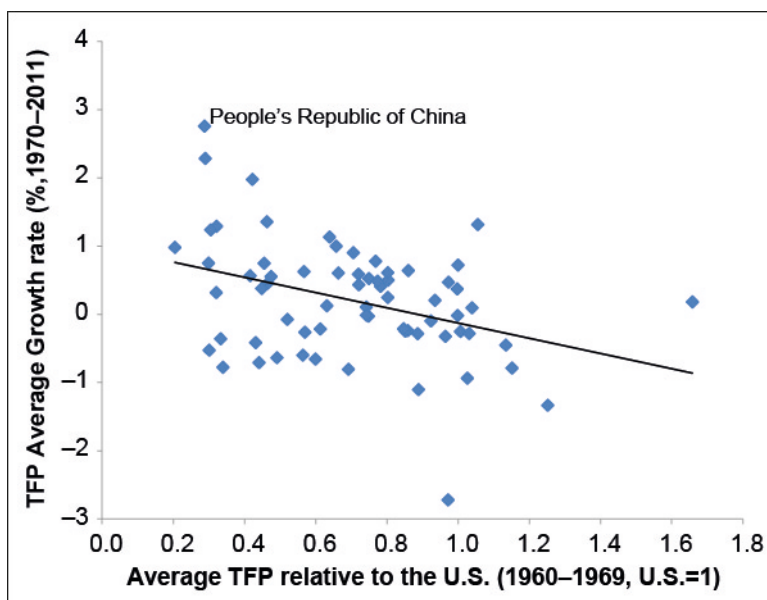
TFP = total factor productivity, US = United States.

Note: Calculations are based on the Penn World Table.

Table 2: Empirical Results: TFP Gap and TFP Growth Rate

Average TFP Growth Rate	(1)	(2)	(3)	(4)	(5)	(6)
Period (Average TFP Level to US)	**1960–1964**	**1960–1964**	**1965–1969**	**1965–1969**	**1960–1969**	**1960–1969**
Period (Average TFP Growth Rate)	**1965–2011**	**1965–2011**	**1970–2011**	**1970–2011**	**1970–2011**	**1970–2011**
TFP Level to US	−0.0121***		−0.0117***		−0.0120***	
	(0.00379)		(0.00403)		(0.00404)	
1 − TFP Level to US		0.0118***		0.00964***		0.00959***
		(0.00253)		(0.00274)		(0.00268)
Constant	0.0119***	/	0.0106***	/	0.0106***	/
	(0.00292)	/	(0.00316)	/	(0.00312)	/
N	69	69	70	70	70	70
Adj-R^2	0.190	0.318	0.152	0.194	0.160	0.199

TFP = total factor productivity, US = United States.

Notes: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

2.3 Model

In this section, we describe the catch-up cycle in a general equilibrium framework.

Production and Preference

The modeled economy is populated by generations of infinite-lived agents. The utility maximization problem of the representative agent is defined as:

$$\max_{c_t,k_t} \int_0^\infty lnc_t e^{-\rho t} dt$$

$$s.t. \quad \dot{k}_t = f(k_t) - c_t - nk_t \tag{2.3}$$

where c_t is the consumption per capita, k_t is capital per capita, n is the population growth rate, and ρ is a time discount factor. Moreover, the per capita production function is set to be:

$$f(k_t) = A_t k_t^\alpha \tag{2.4}$$

where A_t is the TFP, and α denotes capital share.

The solution of the utility maximization problem is given by the dynamic process of per capita consumption:

$$\frac{\dot{c}_t}{c_t} = \alpha A_t k_t^{\alpha-1} - n - \rho \tag{2.5}$$

Technology

Now we characterize the process of technological improvement.

For simplicity, we assume no technology growth in developed economies (F). In other words, the level of TFP in developed economies (A_{Ft}) is constant:

$$A_{Ft} = \overline{A_F} \tag{2.6}$$

The basic assumption of the model is that the latecomer economies (C) can directly adopt the advanced technology from developed economies and therefore catch up with them. We base Eq. (2.2) to model the technological improvement process of latecomer economies:

$$\frac{\dot{A}_{Ct}}{A_{Ct}} = f\left(\frac{A_{Ft} - A_{Ct}}{A_{Ft}}\right) = \gamma\left(1 - \frac{A_{Ct}}{A_{Ft}}\right) \tag{2.7}$$

where $\frac{\dot{A}_{Ct}}{A_{Ct}}$ denotes the TFP growth rate of latecomer economies, and γ denotes the speed (or efficiency) of technological catch-up. When $\gamma \leq 0$, there is no catch-up effect and the TFP of the latecomers remains low. When γ is positive, latecomers will begin to catch up with developed economies as long as there is a technological gap between latecomers and developed economies.

Balanced Growth Path

As latecomers catch up with developed economies, the former's technology will also be constant. In fact, assuming that there is a balanced growth path (BGP) of the technological growth (g) in latecomers, then at the BGP, we have:

$$\gamma\left(1 - \frac{A_{Ct}}{A_{Ft}}\right) \xrightarrow{BGP} g \tag{2.8}$$

Manipulating equation (2.8), we have:

$$\frac{A_{Ct}}{A_{Ft}} \xrightarrow{BGP} 1 - \frac{g}{\gamma} \tag{2.9}$$

In other words, at the BGP, the ratio of the TFP of latecomers over the TFP of developed economies is constant. Given that the TFP of developed economies is constant at $\overline{A_F}$, the TFP growth rate of latecomers should also be zero, i.e., $g \xrightarrow{BGP} 0$. Therefore, equation (2.9) becomes:

$$\frac{A_{Ct}}{A_{Ft}} \xrightarrow{BGP} 1 \tag{2.10}$$

That is, the TFP in the latecomers converges to that of the developed economies, i.e., $A_{Ct} \xrightarrow{BGP} \overline{A_F}$ and $\overline{A_C} = \overline{A_F} = \bar{A}$.

Next, we derive other variables at the BGP. It is noteworthy that the TFP levels of latecomers and developed economies are the same at the BGP. Other variables should also be the same at the BGP among latecomers and developed economies.

The growth rate of per capita consumption and capital is set to be η_c and η_k. According to equation (2.5), we have:

$$\alpha \bar{A} k_t^{\alpha-1} - n - \rho = \eta_c \tag{2.11}$$

Therefore, k_t should be constant at the BGP ($\eta_k = 0$). According to (2.3), c_t should also be constant at the BGP ($\eta_c = 0$). And

$$\bar{k} = \left(\frac{\alpha \bar{A}}{n+\rho}\right)^{\frac{1}{1-\alpha}} \tag{2.12}$$

$$\bar{c} = \bar{A} \bar{k}^\alpha - n\bar{k} \tag{2.13}$$

Catch-up Cycle

Now we formally introduce the catch-up cycle for latecomer economies.

For simplicity, we drop the time subscript. We take the growth-rate form of the production function (2.4); the growth rate of income per capita of latecomers is:

$$\frac{\dot{y}_C}{y_C} = \frac{\dot{A}_C}{A_C} + \alpha \frac{\dot{k}_C}{k_C} = \gamma \left(1 - \frac{A_C}{\bar{A}}\right) + \alpha \left(A_C k_C^{\alpha-1} - \frac{c_C}{k_C} - n\right) \tag{2.14}$$

where y_C denotes income per capita of latecomers, k_C denotes capital per capita of latecomers, and c_C denotes consumption per capital of latecomers.

As the TFP is monotonically increasing over time, we can take the first-order derivative with respect to technology:

$$\frac{\partial \left(\frac{\dot{y}_C}{y_C}\right)}{\partial A_C} = -\gamma \frac{1}{\bar{A}} + \alpha k_C^{\alpha-1} \tag{2.15}$$

We need to discuss the sign of $\frac{\partial \left(\frac{\dot{y}_C}{y_C}\right)}{\partial A_C}$ in order to determine how the growth rate of income per capita change as TFP improves.

Obviously, $\frac{\partial\left(\frac{\dot{y}_C}{y_C}\right)}{\partial A_C} \geq 0$ if and only if $\gamma k_C^{1-\alpha} \leq \alpha\bar{A}$, or $k_C \leq \left(\frac{\alpha\bar{A}}{\gamma}\right)^{\frac{1}{1-\alpha}}$. Since k_C is also increasing over time and will reach the steady-state capital per capita $\bar{k}$ in a certain period at the beginning of the catch-up, the growth rate of income per capita, that is, $\frac{\dot{y}_C}{y_C}$, will be increasing as TFP improves.

In the later period, as capital per capita converges to the steady state and exceeds the threshold value, the sign of equation (2.15) turns to negative. That is, when $k_C > \left(\frac{\alpha\bar{A}}{\gamma}\right)^{\frac{1}{1-\alpha}}$, we have $\frac{\partial\left(\frac{\dot{y}_C}{y_C}\right)}{\partial A_C} < 0$.

To sum up, as latecomer economies catch up with developed economies, the growth rate of income per capita depicts an inverted-U shape: at the beginning of the catch-up, when capital stock is sufficiently small, the effect of technological catching-up dominates, and the income per capita growth rate increases; when the capital stock exceeds the threshold value, the growth rate of income per capita begins to decrease. Therefore, the growth rate of income per capita depicts an inverse U-shape. This is the definition of the catch-up cycle.

Simulation

To illustrate the catch-up cycle, we simulate the model using different parameter values. Table 3 reports the three scenarios of representative parameter values for simulation. From Scenario 1 to Scenario 3, the speed of the catch-up process increases gradually. It is also noteworthy that changing the parameter values does not alter our results significantly. The time interval is set as 100 years.

Table 3: Parameter Values for Numerical Simulation

Variable	Parameter	Scenario 1	Scenario 2	Scenario 3
Capital share in production	α	0.5	0.5	0.5
Population growth rate	n	0.01	0.02	0.02
Subjective discount rate	ρ	0.01	0.01	0.01
Speed/efficiency of technological catching-up	γ	0.03	0.035	0.05

Figure 5 shows the simulated results for six key variables of latecomers, namely the TFP relative to developed economies $\left(\frac{A_{Ct}}{A_{Ft}}\right)$, growth rate of TFP, capital per capita, income per capita, growth rate of income per capita, and capital return.

We find that TFP relative to developed economies continues to increase and converges to 1, while its growth rate decreases gradually. For the scenario with the highest value of catching-up speed, TFP improves most rapidly. This is consistent with the empirical results in Table 2 and the model setup (2.7).

Next, we illustrate the catch-up cycle. This is mainly characterized by three indicators: the growth rate of capital per capita, growth rate of income per capita, and capital return. As can be seen from Figure 5, they all depict an inverse U-shape, which is consistent with the stylized facts and the definition of the catch-up cycle. The simulated values of the three indicators are also in reasonable intervals: the highest growth rates of income and capital per capita are about 8.0%–9.0%, while they gradually decrease to 2.0%–3.0%. The capital return reaches 6.5% in the high growth phase and gradually returns to 3.0% in the long run.

Figure 5: Simulation Results
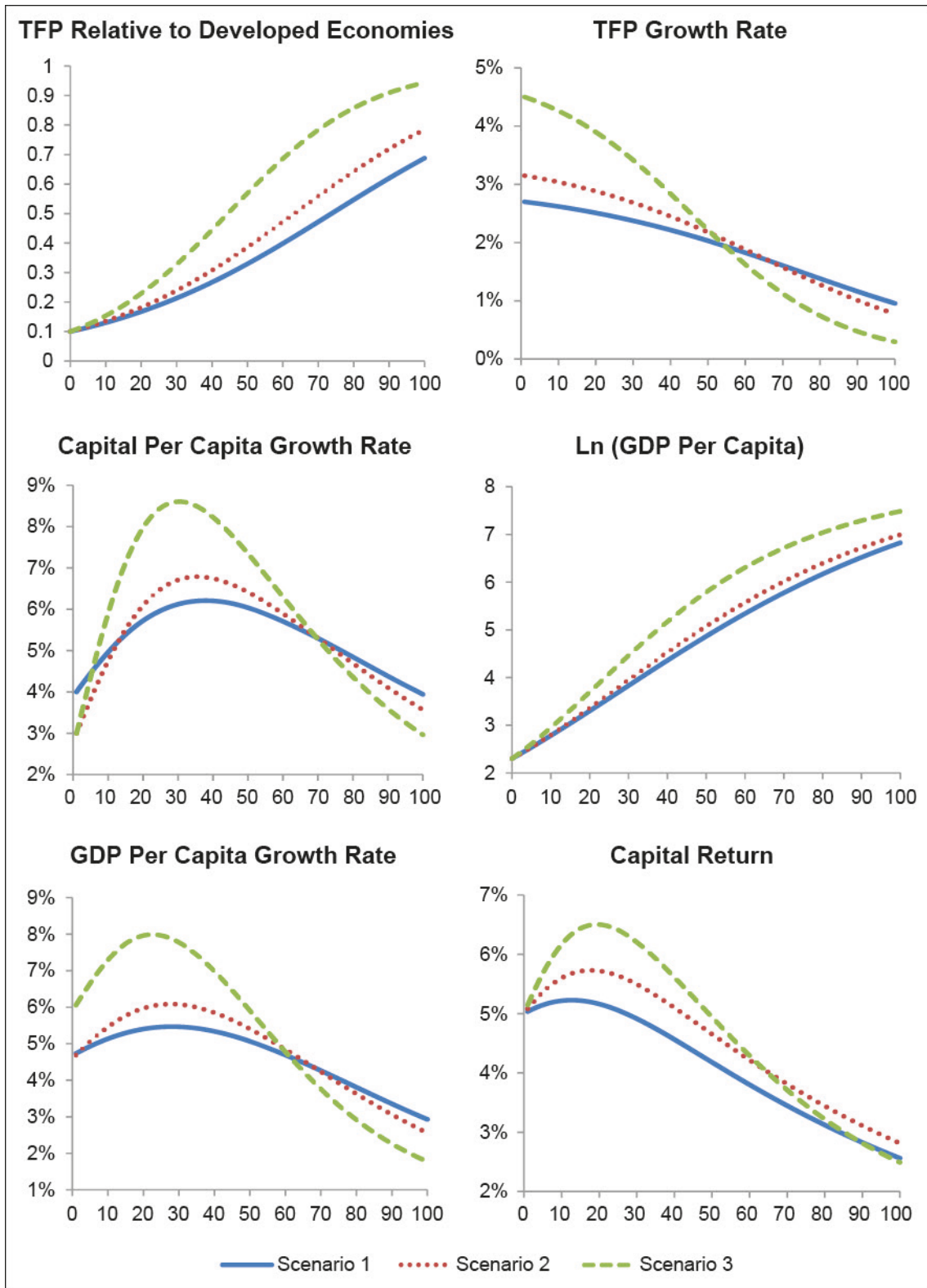
GDP = gross domestic product, TFP = total factor productivity.

Therefore, the complete catch-up process can be described as follows: latecomer economies absorb the advanced technology from developed economies and begin their economic take-off, with continuous accumulation of physical capital per capita and an increase of output per capita. This is the specific phase of the catch-up cycle when the effects of continuous and rapid technological progress are sufficient to offset the effects of diminishing marginal returns to capital. With the gradual reduction of latecomer advantages, technology progress slows down and the law of diminishing marginal return to capital dominates, resulting in a reduction of the economic growth rate. Therefore, without precluding the law of diminishing marginal returns to capital, the catch-up cycle hypothesis successfully explains the stylized facts of catching-up economies.

The catch-up cycle model is also of great help in explaining what stimulates high investment during the period of fast economic growth. It is often concluded that high-speed growth is driven by investment. However, according to the catch-up cycle model, high investment is itself endogenous to the rapid growth of TFP. The effects of continuous and rapid technological progress provided by technology adoption and imitation are sufficient to offset the diminishing marginal returns to capital. As supplementary evidence, Kehoe and Prescott (2002) and Zhu (2012) provide detailed growth accounting work, breaking down the growth rate of output per capita into the labor participation rate, capital-output ratio, human capital, and TFP. Their results show a less-than-unity weight of the capital-output ratio while a more-than-unity weight of TFP.

3. DETERMINANTS OF SUCCESSFUL CATCHING-UP

Contrary to successful catching-up economies, most developing economies, which have lower incomes and larger technological gaps, still have not attained high-speed growth. Many other countries that had once had fast economic growth experienced growth slowdowns before they completed the catch-up cycle. These facts indicate that the completion of the catch-up cycle requires a series of conditions. In this section, we discuss the determinants of successful catching-up.

3.1 Factors of Successful Catching-up

According to the catch-up cycle model, especially equation (2.7), factors of successful economic catching-up can be decomposed into two parts:

Technology Gap

The technology gap is characterized by $\left(1 - \frac{A_{Ct}}{A_{Ft}}\right)$. Obviously, the larger the TFP gap with developed economies, the higher the TFP growth rate latecomers can achieve through technological imitation and adoption, and the faster the latecomers can catch up with developed economies. However, the technology gap cannot be altered by latecomers themselves and therefore is objective.

Speed/Efficiency of Technological Catching-up

The speed/efficiency of technological catching-up is characterized by parameter γ. As long as $\gamma > 0$, the economy can catch up sooner or later. In the case of $\gamma \leq 0$, the economy experiences no growth in technology and cannot catch up.

In fact, γ can be seen as the efficiency of technology's practical applications and the reallocation of elements of the entire production system based on the requirements of the new technology and thus proxies the institution of the economy in terms of technology adoption and imitation. For latecomers, the difficulties in catching up lie not only in obtaining new technologies (determined by the technology gap) but also in providing incentives for the broad application of new technologies. We raise some factors that will affect an economy's γ, and therefore technological and economic catching-up. We also conduct empirical analysis to verify the relation between the speed of catching-up and those factors.

1) Competition

Technology upgrading is costly. Only by competition and allowing flexible industry entry and exit can enterprises have an incentive to invest continuously in new technologies (Aghion and Griffith 2005).

2) A financial system that is beneficial to resource reallocation

The technology upgrading is a process during which various types of resources flow to efficient sectors and enterprises, and in which capital is the most important medium. If capital cannot lead to the efficient flow of elements, new technology cannot be widely applied (Midrigan and Xu 2014).

3) Openness

On the one hand, technology adoption is achieved through foreign investment and international trade. On the other hand, an increase in openness confronts domestic manufacturers with fierce competition and further increases the likelihood of learning and adopting new technology (Alesina et al. 2005).

3.2 Empirics of γ

Based on the discussion above, it is interesting to see whether γ is the fundamental factor for economic catching-up empirically. In other words, we can investigate whether γ well proxies those factors that result in successful catching-up.

First, we calculate the country-specific γ_i using equation (3.1)

$$\gamma_i = g_i / (1 - gap_i) \qquad (3.1)$$

Table 4 compares the values of γ_i among economies. We find that economies vary significantly in the values of γ_i. The values of γ_i for the five successful latecomers are larger than the average value as indicated by the empirical results in Table 2, except for Japan for which γ_i is still positive. The PRC, as we will discuss later, is also in the club of top γ_i. India's speed is also beyond average, indicating that India will finally catch up, as long as the speed/efficiency of catching-up remains, but the time to catch up may be longer than the PRC. Brazil and the Philippines have negative γ_i, indicating that in order to catch up, the two economies should take reforms to improve the technological catch-up speed. It is also noteworthy that, Thailand and Malaysia have moderate catching-up speeds. These two economies have experienced fast growth but fell into the middle income trap before they could catch up with developed economies, indicating that there must be systematic change in the value of γ_i, or the institution of economy in terms of technological adoption and imitation, during the catching-up period.

Table 4: Comparison of Speed/Efficiency of Technological Catching-up (γ)

Value of γ	Economies
$(0.03, \infty)$	Hong Kong, China; Austria; Taipei,China; France; Iceland; People's Republic of China; Malta; Sri Lanka; United Kingdom; Sweden; Finland
$[0.02, 0.03]$	Tunisia, Cyprus, Denmark, Belgium, Ireland, Singapore, Netherlands
$[0.01, 0.02]$	Republic of Korea, Romania, Israel, Panama, Australia, Thailand, Norway, Ecuador, Mozambique, India, Malaysia
$[0, 0.01]$	Indonesia, Argentina, Dominican Republic, Senegal, Japan, Tanzania, Italy, Germany
$[-0.01, 0]$	Portugal, New Zealand, Brazil, Uruguay, Cameroon, Colombia, Greece, Bolivia, Kenya
$[-0.02, -0.01]$	Philippines, Zimbabwe, Niger, Côte d'Ivoire, Turkey, Peru, Spain
$(-\infty, -0.02)$	Morocco, Egypt, Jamaica, Guatemala, Costa Rica, Chile, Iran

Notes: The calculation of γ is based on equation (3.1). Since the technological gap is based on the United States level, we are not able to calculate the value of γ of the United States.

Next, as we have argued, the speed/efficiency of the catch-up process, γ, represents the institution of the economy to allow technological adoption and imitation. Therefore, we regress a series of measures (G_i) that can represent the extent to which a country allows technology adoption and imitation on the country-specific γ_i:

$$G_i = \alpha + \beta * \gamma_i + u_i \qquad (3.2)$$

The results are reported in Table 5. We base the discussion on the determinants of successful catching-up to select the measures of G_i. In column (1), we measure competition using the cost of business start-up procedures. The larger is the cost to start a business, the less the degree of competition will be. The results of column (1) confirm that the speed/efficiency of catching-up is negatively correlated with the cost of business start-up.

Table 5: Empirics of γ

Dependent Variables	(1) Cost of Business Start-up Procedures (% of gross national income per capita)	(2) Ln (Fixed telephone subscriptions per 100 people)	(3) Ln (Internet users per 100 people)	(4) Ln (Documents to export, number)	(5) Ln (Documents to import, number)	(6) Ln (Time to export, days)	(7) Ln (Time to import, days)
γ	−0.0662**	0.00334***	0.00267***	−0.00123***	−0.00797***	−0.00142***	−0.0239**
	(0.0257)	(0.000839)	(0.000663)	(0.000217)	(0.00210)	(0.000412)	(0.0113)
Constant	33.39***	2.405***	2.548***	1.607***	6.370***	2.683***	19.32***
	(7.731)	(0.179)	(0.141)	(0.0421)	(0.310)	(0.0612)	(1.736)
N	61	67	67	67	67	67	67
Adj-R^2	0.006	0.022	0.023	0.052	0.041	0.033	0.012

Notes: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Next, we find variables that are beneficial to resource reallocation. Infrastructure, by connecting factors of production, like capital, labor, and information, helps resource reallocation. In columns (2) and (3), we include two types of infrastructure penetration, fixed telephone subscription and internet users, and find a positive correlation with the speed/efficiency of catching-up (see columns 2 and 3).

Finally, we measure openness using the number of documents to import and export, and the time to import and export. These measures represent the difficulty of trade. For instance, the greater the number of documents to import and export, the more difficult trade will be, and thus the less open an economy will be. We expect that the speed/efficiency of catching-up will be negatively correlated with these four variables. Columns (4)–(7) confirm the hypothesis.

Above all, through empirical analysis, we confirm that γ well proxies the institution of the economy in terms of technology adoption and imitation, and therefore is fundamental for successful catching-up.

4. CONCLUDING REMARKS: A CASE STUDY OF THE PEOPLE'S REPUBLIC OF CHINA

To sum up, we propose a general equilibrium framework to analyze latecomers' catching-up with developed economies. We find that technological adoption and imitation and diminishing marginal returns to capital are the two driving forces of the catch-up cycle. The technological gap and speed/efficiency of technological catching-up are two fundamental factors for successful catching-up.

It is noteworthy that unlike business cycles, the catch-up cycle itself cannot and should not be flattened. In a certain sense, it is a cycle that the latecomer economies should experience. Therefore, in terms of policy response, during the period of rapid growth, governments should not adopt deflation policies, but on the contrary, should support growth through macro policies. As the growth rate slows down due to a decrease in the technological gap, governments should not cope with the slow-down by expanding policies (Liu 2011; Liu 2012). Rather, the switch from technological imitation and adoption towards technological advance through R&D should be encouraged.

At the end of this paper, we conduct a case study for the PRC, which is now the world's biggest latecomer economy, is currently in the high-speed growth phase, and has begun to switch to a medium-speed growth pattern. The discussion of the catch-up cycle has certain implications for the PRC's long-term economic growth.

First, the PRC's past rapid growth since the Reform and Opening can be seen as being on the left side of the catch-up cycle. During 1978–2009, the PRC's annual TFP growth rate reached 3.16%. TFP growth became the primary source of the PRC's economic growth as its average contribution rate to GDP per capita growth reached 77.89%. Compared with the TFP growth and contribution rates of other successful catching-up economies, such as Japan; Hong Kong, China; and the Republic of Korea, the contribution of technology to the PRC's economic growth is much higher. This does not support the view that the PRC's past growth was "extensive growth."

Second, the PRC's future catch-up potential remains promising, as its technological gap with developed economies remains large. The PRC's TFP in 2009 was close to 40% of that of the US (see Figure 4), while the rates of catching-up economies that once experienced continuous high-speed growth were significantly higher when their growth was down. For instance, the TFP of Japan; the Republic of Korea; and

Taipei,China basically reached 70% of the TFP of the US or even higher before they entered a slowdown period. The comparison clearly indicates that the PRC's future catching-up potential remains promising.

Third, the PRC still needs reform to continue its economic growth. Especially, the PRC should increase its speed/efficiency of technological catching-up. Since the adoption of the Reform and Opening, the PRC's economic growth has mainly been driven by the two agricultural reforms of the 1970s and 1980s (the enforcement of the family contract responsibility system, the agricultural product price reform, and reform of the agricultural input market), the non-agricultural reforms in the early 1980s (the dual-track price system and decentralization of economic decision-making), the marketization implemented in 1997, and being a member of the World Trade Organization from 2001. Obviously, these reforms have helped increase the PRC's market competition and openness, and also contribute to the financial system and are beneficial to resource reallocation. Therefore, these reforms are important in improving the speed/efficiency of technological catching-up.

However, recent empirical analysis indicates that the PRC is still facing systematic distortion in technology upgrading and productivity improvement, including structural labor misallocation, low efficiency allocation of agricultural land and capital, and low efficiency allocation of non-agricultural capital (Zhu 2012). Although these distortions bring a certain level of artificially high competitiveness (Zhang and Hou 2010), they restrict more sustainable growth potential with high quality. Therefore, future growth still requires a timely new round of significant reform to provide new incentives for firms to adopt more advanced technology.

Finally, regarding resource allocation, Japan's experience is particularly worth examining for the PRC. After 50 years of rapid growth, Japan experienced a severe recession in the 1990s, which academia refers to as the "lost decade." Japan's recession has been attributed to the decrease in productivity growth (e.g., Hayashi and Prescott [2002]). However, a deeper reason for the decrease in the productivity growth rate was misallocation, particularly credit rationing. Japan's credit department allocated most credit resources to enterprises with relatively low productivity, without viability, and on the verge of bankruptcy when the crisis came so that they could "safely" survive. The misallocation, in turn, resulted in the failure of enterprises with high productivity to obtain sufficient credit resources, and their development was accordingly limited. This led to a large decrease in the growth rate of Japan's productivity (Caballero et al. 2004; Peek and Roentgen 2005).

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