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ADB Working Paper Series

**TAKEOFFS, LANDING,
AND ECONOMIC GROWTH**

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and Paul Frijters

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Abstract

Economic growth in the East Asian economies was remarkable during the latter part of the 20th century, starting with Japan just after World War II, followed by the East Asian Tigers and “tiger cubs” after that and, most recently, the People’s Republic of China and India. The high, sustained economic growth of these economies during their boom period reduced the disparity between the West and these countries (in terms of standards of living). The source of such extraordinary growth has been a matter of great interest since then, but no attempt has been made so far to model the political economy of takeoffs and landings in the context of economic growth. We empirically define takeoffs and landings, and provide an overlapping generation model with technological change and skill formation to explain the relatively stable growth rates in the Asian economies for decades. The existence of a technology trap, meaning economies cannot afford available advanced technology, may explain why takeoffs are relatively rare, even when many underdeveloped economies are still waiting for their own growth miracle.

JEL Classification: O31, O43, O57

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1. INTRODUCTION

The growth takeoff in Europe during the Industrial Revolution caused massive income divergence between the present developed and underdeveloped countries. Per capita income of the Western European countries rose significantly from only 30% above those of the People's Republic of China (PRC) and India at the beginning of the Industrial Revolution to about 900% of that of the PRC and the other poor countries by 1870 (Madison 1983, Bairoch 1993). Economic growth in the East Asian economies, however, took off only in the latter part of the 20th century, starting with Japan just after World War II, followed by the East Asian Tigers in the 1960s, the “tiger cubs” after that, and most recently the PRC and India. The 6%–10% sustained economic growth rate during their boom period reduced the disparity between the West and the East (in terms of standards of living) and placed the newly industrialized economies of the past among the advanced economies of today.

The economic reforms of the 1980s have transformed the PRC from a predominantly agrarian economy to an urban-based manufacturing growth hub. The PRC is now the second-largest economy of the world, having overtaken Germany in 1982 and Japan in 1992 in purchasing power parity terms (Madison and Wu 2008) and is expected to soon overtake the United States as the largest economy of the world. Interestingly, India has also experienced high and stable output growth over the last 2 decades, surpassed only by the PRC and some of the East Asian economies.

The impressive performance of the Asian economies has been the subject of a large number and a great variety of studies, but most of them focus only on the sources of this unprecedented economic growth. This paper seeks to explain economic takeoffs, as they are much less well understood than the long-term elements of growth. Takeoffs, therefore, have remained rare in recent times, limited to a few Asian success stories while several countries still await their own takeoff miracle (Easterly 2006). The questions we address in this paper are as follows: how best to define takeoff and landing empirically? How and exactly when did the takeoff occur? Why did the takeoffs occur when they did? What are the essential features of the political economy of takeoffs? Can technological stickiness explain the relatively constant rate of growth that the Asian catch-up economies experienced in the decades following their takeoff and before their landing? We empirically define takeoffs and landing, and provide an overlapping generation model with technological change and skill formation to understand the political economy of takeoffs. To the best of our knowledge, no attempt has been made so far to study the political economy of takeoffs and to characterize the conditions that lead to their takeoff into sustained economic growth.

The political economy model formalizes the idea that takeoffs and landing are determined by forces that are internal to the economic system and are the result of a “spontaneous and discontinuous change” (Schumpeter 1911) that displaces the equilibrium state previously existing. An irreversible technology upgrade that can put an economy on a higher technology frontier is available, but at a cost that entails severe impediments to technology adoption. It is this change in the production method in the form of a “creative destruction” (Schumpeter 1942) that provides a sufficiently big push to escape the poverty trap (in the sense of a low-level equilibrium) and to take off into self-sustained growth.

Our Neoclassical–Schumpeterian hybrid growth model with overlapping generations and sticky technology is able to explain not only the high growth rates experienced by the Asian miracles for decades, but also provides insights into the political economy underlying takeoffs and landing. The growth pattern, along with the takeoffs and

landing from the simulated model economy, closely approximates those from the observed data. The predictions of the model are rather optimistic as it re-enforces the importance of

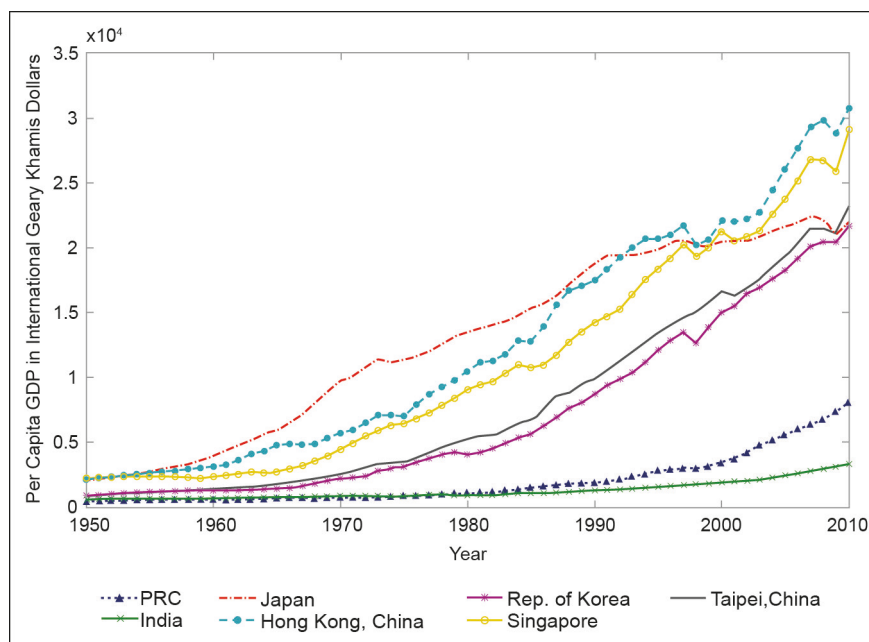
a low-level equilibrium trap (Nelson 1956) and a critical minimum effort (Leibenstein 1957) necessary to put a stagnant economy on a higher growth trajectory.

The remainder of the paper is organized as follows. Section 2 generates an empirical rule of thumb to determine when each of the Asian miracles took off and landed (in case they have already landed). In section 3, we make an attempt to model takeoffs as “radical changes in the methods of production” in an overlapping generation setup with finitely lived individuals, followed by a detailed discussion of the political economy of takeoffs in section 4. Section 5 concludes the paper.

2. TAKEOFFS AND ECONOMIC GROWTH

In the 1950s, Western Europe, the United States, and the “European satellites” (Australia, New Zealand, and Canada) produced more than 50% of the world economy, or close to 75% if the regions of Eastern Europe and the former Soviet Union are included in the definition of “the West.” The growth experience of the PRC is particularly interesting in this regard as the share of the PRC in world gross domestic product (GDP) increased from less than 5% in 1950 to 12% in 2004 and is expected to dominate the world economy soon with a 40% share (Frijters, Dulleck, and Torgler 2008). Figure 1 shows per capita GDP for selected Asian economies over time, revealing that Japan was the first to start growing, followed by the East Asian Tigers, and finally the PRC and India.

Figure 1: Per Capita Gross Domestic Product in Asian Economies over Time



GDP = gross domestic product, PRC = People's Republic of China.

Source: Historical Statistics of the World Economy on Per Capita GDP, 1-2010 A.D.

2.1 Defining Takeoff and Landing

To help us identify and understand the incidence of takeoffs among the Asian economies, we begin by empirically defining takeoff and landing using a rule of thumb in this subsection and then use it to determine exactly when these countries took off and landed. A country is said to have taken off in terms of economic growth if it has effectively applied radical changes to its available resources and has set forth on a path of sustained economic growth extending for decades (Rostow 1960).

Earlier papers in the literature on the identification of takeoffs have empirically defined “takeoff” as going from about zero growth (between -0.5% and 0.5%) to “permanent” sustained positive (above 1.5%) per capita growth (Easterly 2006). Out of the experience of the 127 countries examined in Easterly (2006), takeoffs were found in only nine of them (using both the baseline definition and the robustness checks). Both of these definitions used were not consistent and could not be used to identify all the takeoffs at a time. According to another paper by Aizenman and Spiegel (2010), a country is said to have taken off if real per capita GDP growth exceeded 3% for 5 consecutive years within 10 years of the potential takeoff from the stagnation period, while a takeoff ends when average growth falls below 3% . They found that 54.4% of the 241 stagnation episodes in their sample of 146 countries between 1950 and 2000 were followed within 10 years by takeoffs, with 46.4% of them experiencing relatively “sustained” takeoffs. This paper therefore identified too many takeoffs, with an average duration of just 9.04 years, and can be considered a very general definition of takeoffs that fails to capture the real essence of takeoffs and the possibility of sustained economic growth for decades. We believe that permanent takeoffs from poverty traps are indeed rare (Easterly 2006) and limited mostly to the Asian economies. The papers that have attempted to identify takeoffs and landing empirically so far have chosen rules of thumb that have resulted in either inconsistency (Easterly 2006) or overdetermination of takeoffs that are often not sustainable (Aizenman and Spiegel 2010). The definition that we adopt to identify takeoffs in this paper is more stringent but close to that of Aizenman and Spiegel (2010). Instead of choosing this rule a priori, we decided on an empirical rule that lacks the earlier deficiencies but could be used to correctly identify takeoffs and landing that resulted in sustained economic growth as experienced by the Asian economies.

“Takeoff” in this paper is defined as a higher growth rate than that of the United States¹ consecutively for 5 years at a stretch, where the first year of this 5-year window is taken to be the takeoff period. Intensive study of the data has shown that most countries that have managed to maintain growth rates higher than the United States for 5 years at a stretch have set out on a sustained growth path lasting decades. Similarly, we define a country to have landed if it has experienced less than the United States growth for at least 3 years in a row in a 5-year window, with the first year of slower growth than that of the United States in that window period marking the year of landing for the country. In addition to the usual “takeoffs” and “landing” defined so far, we define a country to have experienced a “crisis” if it fails to sustain its growth phase for a few years post-takeoff due to an imbalance in its socioeconomic, political, and financial situations (e.g. recessions, civil wars, and Asian financial crisis) before resuming the growth again, post-crisis. We also define a country to have experienced a “failed

¹ We have used the United States as a benchmark to identify the takeoffs and landing in the Asian economies for a number of reasons. Firstly, it has grown at a constant rate of 2% on average between 1900 and 2010. Secondly, data (in International Dollars) for the United States is available for every year without a break, and lastly, it has itself not taken off during this period.

takeoff” if it has experienced a takeoff but could not sustain the growth phase beyond a few years and landed prematurely, without resuming growth again after the crisis.

2.2 Identifying Takeoff and Landing Stage

Having defined takeoffs and landing in the last subsection, we use these definitions to identify the year the country in question took off and landed, using per capita GDP data from the “Statistics on World Population, GDP, and Per Capita GDP, 1-2010 AD”² (Bolt and van Zanden 2013), measured in 1990 International Geary–Khamis dollars (also referred to as “the Maddison tables”).

Table 1: Takeoffs and Landing for Asian Economies

Economy of Interest	Year of Takeoff	Year of Landing
Afghanistan	–	–
Bangladesh	2000	–
Cambodia**	1999#	–
China, People’s Rep. of	1977	–
Hong Kong, China**	1960	1995
India	1988	–
Indonesia*	1986	–
Japan	1946	1974
Lao PDR*	1991	–
Malaysia*	1968	1998
Mongolia	–	–
Myanmar**	1992#	–
Nepal	–	–
DPRK	–	–
Pakistan	2002	–
Philippines	2001	–
Singapore*	1966	1998
Korea, Rep. of	1966	–
Sri Lanka	1990	–
Taipei, China	1963	–
Thailand	1958	–
Viet Nam	1990	–

DPRK = Democratic People’s Republic of Korea, Lao PDR = Lao People’s Democratic Republic.

* Faced economic and financial crisis. ** Faced civil wars and internal conflicts in between.

Second takeoff for Cambodia and Myanmar after first takeoff was disrupted in 1976 and 1974.

Source: Based on authors’ own calculations using Angus Maddison table.

Table 1 reports the takeoffs and landing (if any) for the South Asian and Southeast Asian economies that have taken off post-1900s, followed by a brief discussion of the takeoff, landing, and growth experience of Japan, the East Asian Tigers, the tiger cub economies, the PRC, and India. We have used the United States as a benchmark to identify the takeoffs and landings in the data, but the results of this paper are robust to the use of per capita GDP of the United Kingdom or the 12 Western European

² The Maddison table used in this paper is available from <http://www.ggdc.net/maddison/maddison-project/data.htm>

countries³ as the benchmark. We find that the “takeoff” and “landing” definitions specified in the last subsection are able to identify the incidence of takeoffs and landings from the dataset (as experienced by the Asian economies), starting with Japan as early as 1946, followed by Hong Kong, China (1960); Taipei, China (1963); Singapore and the Republic of Korea (1966); the PRC (1977); and India (1988). We are also able to identify the specific dates of takeoffs for the tiger cub economies—Thailand (1958), Malaysia (1968), Indonesia (1986), the Philippines (2001)—and the countries often referred to as Indochina—Viet Nam (1990), the Lao People’s Democratic Republic (1991), Myanmar⁴ (1992), and Cambodia (1999). Other Asian economies that took off but were not identified and have not received any attention so far include Sri Lanka (1990), Bangladesh (2000), and Pakistan (2002).

Finally, we discuss the growth experience of (i) Japan, (ii) the East Asian Tigers, and (iii) the PRC and India, widely known for their unprecedented and extraordinary growth in the latter part of the 20th century.

2.3 Japan’s Economic Takeoff Post-World War II

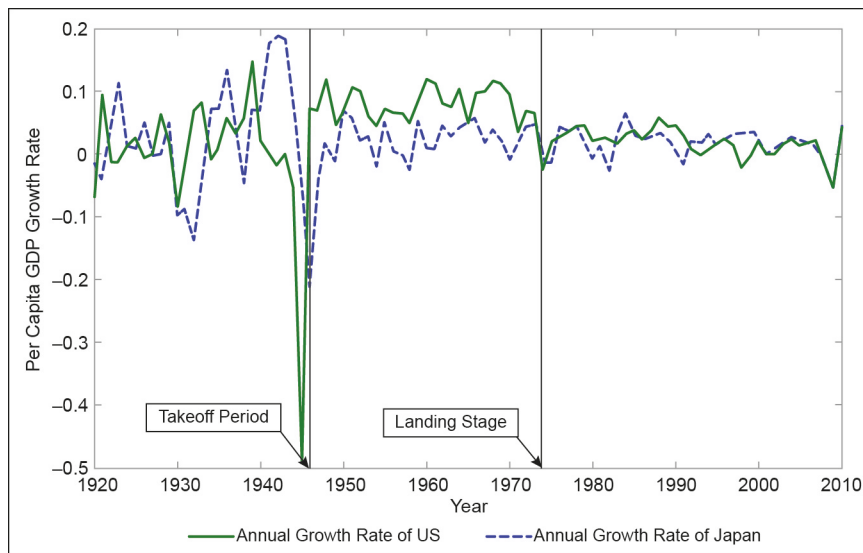
Most of the advanced economies, particularly in the West, took off well before 1900, with Japan being the only one among them to have taken off as late as the 1950s and acting as the lead goose in the “flying geese paradigm” (Akamatsu 1962), used to characterize technological development in Southeast Asia. Figure 2 presents the per capita GDP growth rates of Japan and the United States from 1920 to 2010. Japan’s takeoff in 1946 and its landing in 1974 can be clearly distinguished by comparing the GDP growth rates of these two countries.

Per capita GDP growth rates, along with the average growth rates during three different phases of economic growth—(i) pre-takeoff, (i) between takeoff and landing (also referred to as the “growth phase”), and (iii) post-landing, are presented in Figure 3 (see also Table 3). Japan experienced an average annual growth rate of about 1.88% between 1871 and 1944 (excluding 1945)⁵ and 2.02% when we only consider the period from 1900 to 1944 (excluding 1945). Japan took off in the year 1946, soon after the end of World War II and landed in 1974. During this period, Japan grew at an average annual rate of 7.97%, which increased Japan’s per capita GDP, in 1990 International Geary–Khamis dollars, from \$1,444 in 1946 to \$11,434 in 1973 (an eightfold increase). The per capita GDP growth rate increased almost fourfold between the period before the takeoff and after it, thereafter growing at about 1.80% per year between 1974 and 2010 (post-landing), which is close to the growth rate of the United States during the same period.

³ The per capita GDP of the 12 Western European countries reported in the Maddison tables has been used as a robustness check to ensure the results are not driven by the definitions used to identify takeoffs and landing. The 12 Western European countries include Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom.

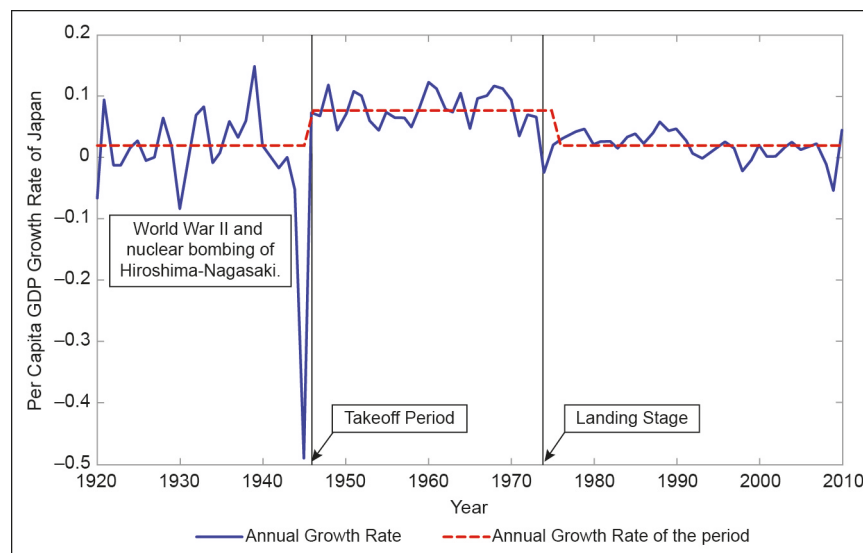
⁴ Myanmar first took off in 1974 and was disrupted by a crisis (civil war) between 1983 and 1991, but took off again in 1992. Similarly, Cambodia also landed prematurely due to internal conflicts before taking off again for the second time in 1999.

⁵ 1945 is excluded from our discussion as it is considered to be an outlier year for Japan, which experienced a tremendous blow to its economy in 1945 due to nuclear bombing of the cities of Hiroshima and Nagasaki by the United States during World War II.

Figure 2: Takeoff and Landing in Japan's Economy

GDP = gross domestic product, US = United States.

Source: Based on authors' own calculations using Angus Maddison table.

Figure 3: Per Capita Gross Domestic Product Growth Rate of Japan's Economy

GDP = gross domestic product.

Source: Based on authors' own calculations using Angus Maddison table.

2.4 The East Asian Tigers

Even though some of the East Asian Tigers who had extremely high growth rates in the 1960s are today counted as advanced or developed economies by many institutions such as the International Monetary Fund, the World Bank and the Organisation for Economic Co-operation and Development, we have grouped them separately under a different subsection as they provide an interesting case study. Their growth performance (commonly referred to as “the Asian Miracle”) has far exceeded the experiences of virtually all comparable economies in the West. The East Asian Tigers

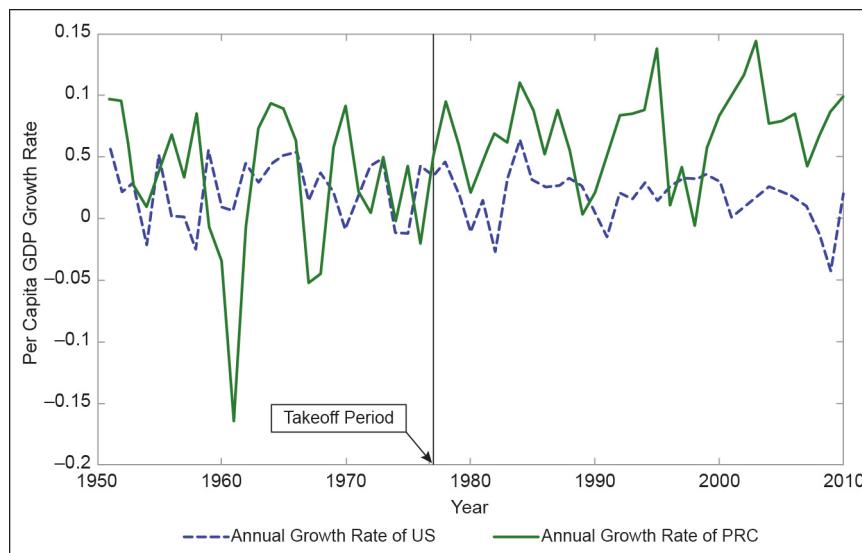
(such as Hong Kong, China; Taipei, China; the Republic of Korea; and Singapore) have transformed themselves from technologically backward and relatively poor economies into modern, affluent societies over the last 50 years, experiencing more than fourfold increases in per capita GDP. We discuss the growth experience of Hong Kong, China as an example. Hong Kong, China took off in 1960 and landed in 1995, making it the first “Asian tiger” economy to take off (due to export-oriented policies and strong development strategies). Hong Kong, China grew at an annual average rate of 2.11% from 1914 to 1959 until it took off in 1960, thereafter growing at 5.73% per year from 1960 to 1994. It finally landed in 1995, after which it has grown at an average annual rate of 2.57%.

The growth experience of the tiger cub economies (Indonesia, Malaysia, the Philippines, and Thailand) is very similar to that of the East Asian Tigers. Even though a clear takeoff can be identified from the growth path of each of these economies, their growth were relatively unstable as they were hit by crises such as the East Asian financial crisis (Indonesia) and the economic crisis (Malaysia), but they have been successful in sustaining high per capita GDP growth rates nonetheless.

2.5 The People’s Republic of China and India

The PRC and India have been at the center of many discussions over the last 2 decades. The PRC economic miracle has been a classic example for its decades of extraordinary high steady growth similar to that experienced by the East Asian Tigers between the 1960s and the 1990s. According to our definition, the PRC took off in 1977 and India in 1988, but both have not yet landed. Per capita GDP of the PRC increased from \$894 in 1977 measured in 1990 International Geary–Khamis dollars to \$8,032 in 2010. India’s per capita GDP increased from \$1,216 in 1988 to \$3,372 in 2010.

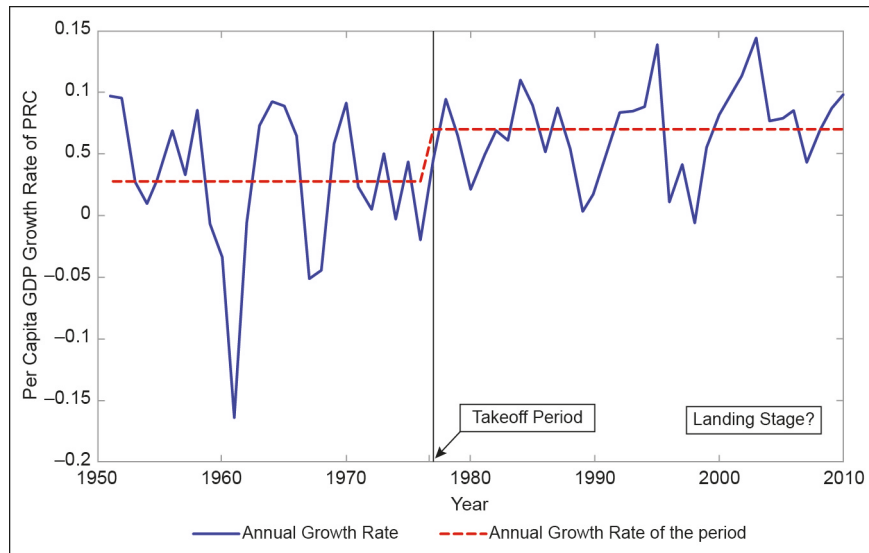
Figure 4: Takeoff and Landing in the People’s Republic of China’s Economy



GDP = gross domestic product, PRC = People’s Republic of China, US = United States.

Source: Based on authors’ own calculations using Angus Maddison table.

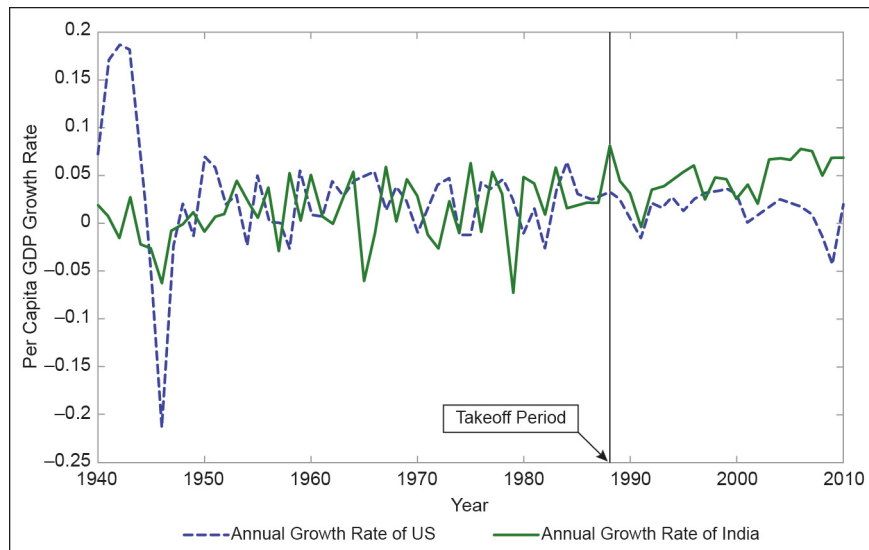
Figure 5: Per Capita Gross Domestic Product Growth Rate of the People's Republic of China's Economy



GDP = gross domestic product, PRC = People's Republic of China.

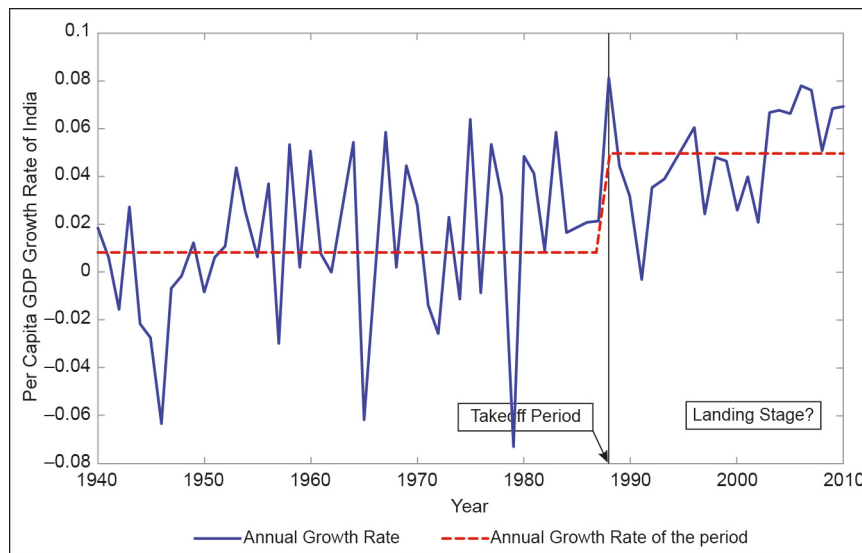
Source: Based on authors' own calculations using Angus Maddison table.

Figure 6: Takeoff and Landing in India's Economy



GDP = gross domestic product, US = United States.

Source: Based on authors' own calculations using Angus Maddison tables.

Figure 7: Per Capita Gross Domestic Product Growth Rate of India's Economy

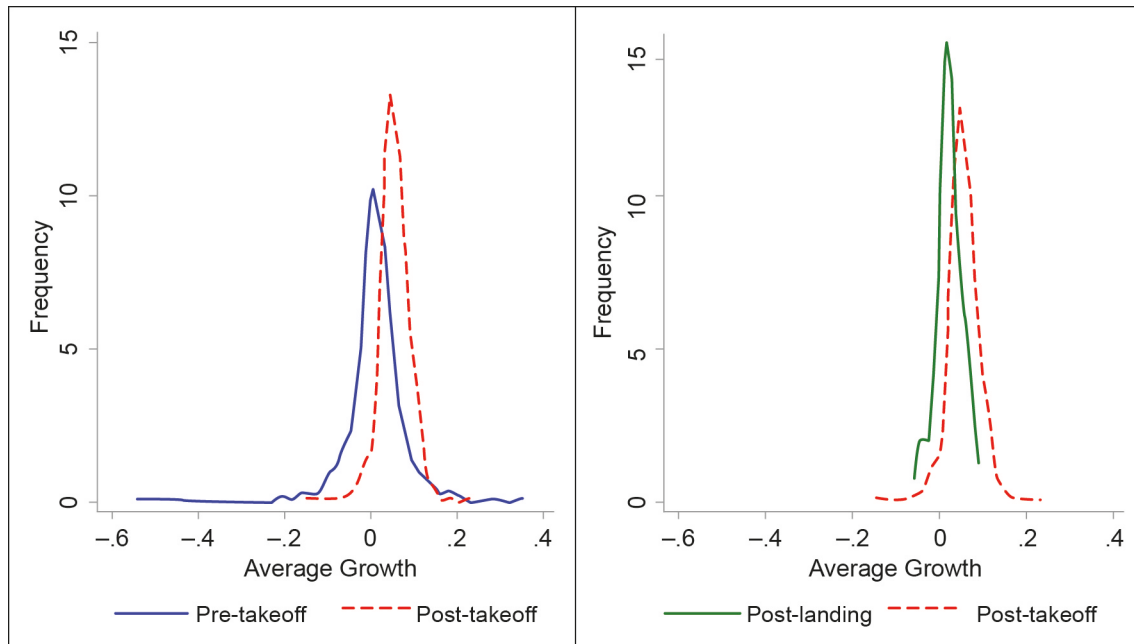
GDP = gross domestic product.

Source: Based on authors' own calculations using Angus Maddison table.

The per capita GDP growth rate of the PRC experienced a nearly threefold increase (post-economic reforms) from an average of 2.68% per year in the pre-reform period (1951–1976) to a post-reform average of 6.88% per year (1977–2010). India, however, took off only in 1988, growing at an average growth rate of 0.79% per year from 1951 to 1987, thereafter growing at 4.91% per year from 1988 to 2010 (post-economic liberalization). The per capita GDP growth rates for the PRC and India (compared with the United States' growth rate) are presented in Figures 4 and 6, while the average growth rates during the pre-takeoff and post-takeoff phases are detailed in Figures 5 and 7. They have been experiencing periods of long-sustained economic growth extending for well over 2 decades now without any sign of tapering off over the years. Their growth rates since takeoff have been not only extraordinarily high (“positive”), but also stable, and their economies seem able to better withstand unexpected shocks (decline in volatility). We provide a regression estimate in Table 2 to show that the post-takeoff and pre-landing average growth rates among the growing Asian economies have been relatively stable, sustaining “positive” growth over the years.

The distribution of the per capita GDP growth rates during the pre-takeoff and post-takeoff periods and during the post-takeoff and post-landing phases in Figure 8 suggest that there has been significant change in the growth experience of the Asian economies during the takeoff phase, with growth between the takeoff and landing phase being relatively more stable. The average growth rate during the pre-takeoff phase was 1.43%, while it was 5.71% in the growth phase, and 2.45% post-landing.

Economies in South Asia and Southeast Asia that do not seem to have taken off so far are Afghanistan, Mongolia, Nepal, and the Democratic People's Republic of Korea. The Democratic People's Republic of Korea grew at an average rate of 0.85% between 1951 and 2008 (with growth rates being mostly negative or zero after 1974)—the only nation to have shrunk, at a rate of –2.47%, between 1975 and 2008. On the other hand, between 1951 and 2008, Mongolia grew at an average rate of 1.50%, Nepal at 1.47%, and Afghanistan at 0.75%.

Figure 8: Distribution of Average Growth Rates during the Pre-takeoff, Post-takeoff, and Post-landing Phase

Source: Based on authors' own calculations using Angus Maddison table.

Table 2: Stability of Per Capita Gross Domestic Product Growth during the Growth Phase

Independent Variables	Per Capita GDP Growth Rate			
	Japan	Hong Kong, China	PRC	India
Year	0.0003 (0.0006)	-0.0005 (0.0006)	0.0015** (0.0006)	0.0021* (0.0012)
Constant	0.0755*** (0.0094)	0.0659*** (0.0147)	0.0163 (0.0129)	0.0464*** (0.0149)
Observations	28	35	32	21
R-squared	0.010	0.015	0.217	0.101
Robust standard errors in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

GDP = gross domestic product, PRC = People's Republic of China.

Source: Based on authors' own calculations using Angus Maddison table.

A striking feature of the incidence of takeoffs is that they are rare and geographically concentrated (Easterly 2006) in Asia, among countries that are now recognized to have had a range of government strategies in place, from extreme laissez-faire to extensive beneficial interventions (World Bank 1993, Stiglitz 1996). Like Japan, governments in the other Asian economies that have taken off have played a major role in maintaining law and order, expanding schooling, targeting investments in the research and development (R&D) sector, and bringing about structural changes in the economy—such as economic reforms in the PRC and trade liberalization in India—that were largely successful. The government policies were pro-growth and significantly helped the economies take off into self-sustaining economic growth.

3. THE THEORETICAL MODEL

Once we have empirically defined and identified the takeoffs, we model takeoffs as “radical changes in the methods of production” in this section. This is important as, while takeoff is important, the determinants of takeoffs are far from clear and warrant attention. An AK type production function that lacks diminishing returns could have been used to explain the stable growth experience post takeoff, but that would have implied positive long-run per capita growth without any possibilities of a landing. This is a substantial failing of the model as it does not explain “landing,” which is an empirical regularity among countries that have taken off.

In a neoclassical model, on the other hand, there are declining growth rates along the transition due to the existence of diminishing returns to capital (Solow 1956, Swan 1956) and it would have been impossible to sustain per capita growth just by accumulating capital. There may, however, be constant returns to capital when capital is broadly defined to include both physical, human, and knowledge capital similar to Lucas (1988) and Rebelo (1991), but none of these models are able to explain takeoffs into sustained growth. The model that we set up in this section is able to explain both takeoffs and the annual growth rate of 6%–10% that the Asian economies have maintained for decades. The basic features of the model are described as follows.

3.1 The Basic Assumptions of the Model

Each household in this economy is identical, and owns the inputs and assets (including the firms), which transforms the inputs—physical capital and knowledge capital—in this neoclassical growth model (Solow 1956; Mankiw, Romer, and Weil 1992) into output. The economy transforms the available inputs into output using a Cobb–Douglas-type production function of the form

$$Y(t) = K(t)^\alpha KN(t)^\beta; 0 < \alpha, \beta < 1 \quad (1)$$

that satisfies the usual properties of a neoclassical production function—increasing, concave, and twice continuously differentiable—where Y denotes the level of output or gross domestic product of the economy, produced from physical capital $K(t)$ and a composite knowledge capital component, $KN(t)$ at time t , a result of the labor augmenting technological progress undertaken in the R&D sector, financed by the government. Both sides of the production function in (1) are divided by $L(t)$, the size of the population at time t so that it does not exhibit any “scale effects.” We will henceforth use lowercase letters to denote per capita variables in this paper:

$$y(t) = k(t)^\alpha kn(t)^\beta \quad (2)$$

where k is the capital per worker and kn is the per capita knowledge capital.

A constant fraction of the output, s , $0 < s < 1$ exogenously set in this model is saved and invested (Solow 1956, Basu and Weil 1998). Each unit of the output is homogeneous, and equally productive irrespective of the time of its production and can either be consumed or invested (either in physical capital or in innovation), such that one unit of output devoted to investment yields exactly one unit of capital. While savings add to the existing stock of capital, old capital depreciates at an exogenously

fixed rate δ . The evolution of physical capital over time is exactly the same as in the neoclassical model and is given by

$$\dot{k}(t) = sy(t) - (n + \delta)k(t) \quad (3)$$

where the term $n + \delta$ is the effective depreciation rate for capital per worker.

We have a simplified version of an overlapping generation model in continuous time where agents live for a finite interval of time, which presents life cycle behavior as in models developed by Samuelson (1958), Diamond (1965), Cass and Yaari (1967), and Blanchard (1985). Time is continuous and indexed by $t \in [0, \infty)$. Individuals are identical in every respect except for their time of birth. A new cohort $B(t)$ is born at each instant $t > 0$, who lives for a finite period of time, $l > 0$, devotes a unit of labor when employed in the labor force (there is no labor–leisure choice in this model), and ultimately dies. Each individual lives through four phases (“generations” henceforth), where each generation is T years long with the oldest generation dying and exiting the model when they turn $4T$. The four generations in this model can be referred to as the (i) youngest, (ii) middle, (iii) the oldest working, and (iv) the oldest nonworking generation.

The size of an individual cohort at any point in time is denoted by $B(t)$ and is assumed to grow at an exogenous rate of n

$$B(t + \tau) = B(t)e^{n\tau} \quad (4)$$

Only a part of the population from the first generation that had finished their compulsory level of education θ chosen by the government at time t enter the labor force at $t + \theta$. Let ζ be the schoolgoing age of the individual, which could also be chosen by the government, but is assumed to be 0 in this model for simplicity. It is interesting to note here that we have represented the time-dependent variables in such a way that we can see the effect of the government’s choice of education today on the outcomes in the future, i.e., a decision made today at time t will affect the outcomes only when the agents in question finish schooling and enter the labor force at $t + \theta$. So, there is a lag between the time of the decision regarding the state of the technology, the associated level of education (to be discussed in much detail next), and the time it affects the outcome variables.

The total population at any point in time includes the preexisting individuals plus the new born kids but not the people who die and leave the model economy. This can be represented as

$$L(t + \theta) = \int_{\tau=0}^{4T} B(t + \theta - \tau) d\tau \quad (5)$$

where the population at $t + \theta$ includes anyone born between $t + \theta$ and $t + \theta - 4T$ (to be read backwards in the timeline). The total population also grows at the rate of n , which is the same as the cohort growth rate because of the net influences of fertility and mortality (migration is not included here). Even though four generations coexist at any point in time, the labor force will include only a part of the first generation and generations two and three (the middle and the oldest working generation in this model). The oldest generation (also referred to as the fourth generation), include individuals

who have turned $3T$, are retired and therefore do not form a part of the labor force. Similarly, the part of the first generation (the youngest group of individuals) who are still in school are also not included in the labor force. Labor force participation at time $t + \theta$ can then be denoted by

$$LF(t + \theta) = \int_{\tau=\theta}^{3T} B(t + \theta - \tau) d\tau \quad (6)$$

including anyone born between t and $t + \theta - 3T$. Next, we discuss the structural change that explains the takeoffs and landing in the context of this neoclassical growth model.

3.2 Structuring the “Technological Change”

Growth is believed to have been faster among latecomers,⁶ especially the East Asian economies, as they had access to the advanced technology of the developed economies (Collins and Bosworth 1996), which they imitated or borrowed from the early starters (Gerschenkron 1962). Other papers that have modeled barriers to growth and traps are Basu and Weil (1998), Parente and Prescott (2005), and Benhabib and Spiegel (2005). Murphy, Shleifer, and Vishny (1989) and Banerjee and Newmann (1994) also set out a model of poverty trap, while Azariadis and Stachurski (2004) provided a survey of a number of theoretical models on poverty traps. In this paper, we model it as a “technology trap” similar to Azariadis and Drazen (1990) and Basu and Weil (1998), where every country has access to a traditional technology to begin with, and has the option to upgrade to a modern, more productive technology in line with those used in the advanced economies.

$$\mu \in \{\underline{\mu}, \bar{\mu}\}$$

where $\mu(t) > 0$, $\bar{\mu} > \underline{\mu}$ and $\underline{\mu} \neq 0$

$$\mu = \begin{cases} \underline{\mu} & \text{the traditional technology} \\ \bar{\mu} & \text{the modern technology} \end{cases}$$

This irreversible change to the production method in this theoretical model takes the form of “creative destruction” (Schumpeter 1942), which, if and when undertaken, provides a push sufficiently big to escape the poverty trap and to take off into self-sustained economic growth. Technological changes broadly defined in this model can refer to (i) direct changes—structural or institutional changes, stability in law and order, reforms (social, economic, political or legal); or (ii) indirect technological changes—trade liberalization: leading to increased trade and foreign direct investment, etc. While direct technological changes improve the productivity of every dollar spent in the R&D sector, indirect changes facilitate imitation from new markets.

⁶ Due to “catching up,” a process also referred to as “leapfrogging.”

$$\dot{c}[\mu(t), t] = \begin{cases} c(t) [\bar{\mu} - \underline{\mu}] & \text{if } \dot{\mu}(t) > 0 \\ 0 & \text{if } \dot{\mu}(t) = 0 \end{cases}$$

However, the takeoff into self-sustained growth comes at a cost—to adopt the new advanced technology, the country has to incur a one-time initial setup cost, which is assumed to be sufficiently large to make the incidence of takeoffs so “rare” in the literature. This setup cost can include psychological, political, and financial costs. The country, however, has the option to continue with the use of the primitive technology without having to pay the setup cost, unless it is prepared to make the shift toward that new advanced technology. The per capita setup cost $c(\cdot)$ therefore depends on both the size of the “radical change” $\mu(t)$ and the time t .

3.3 The Role of the Government

Throughout the 1960s, development economists often defined underdevelopment as a state that arose when the economy failed to achieve the necessary coordination or push needed to land on that higher balanced growth path. This provided a theoretical justification for the role of government, and several developing countries opted for a more centrally planned mode of development (Nelson 1956, Leibenstein 1957, Rosenstein–Rodan 1961). Even in East Asia, governments have played a major role by initiating and promoting significant pro-growth policy changes that led to persistent growth, economic reforms, and liberalization (Collins and Bosworth 1996).

Even though economists today tend to favor free markets or the “invisible hand” as a better economic system, we emphasize an important role for the government sector to plan strategies in the region as targeted interventions are required for the efficient functioning of the economy (more in a complementary role rather than as a substitute for the market economy). This can lead to a more coordinated approach (as required for takeoffs), when individual economic agents are unable to make the change themselves. The importance of technology adoption was emphasized by Schumpeter (1961), and Nelson and Phelps (1966), who connected technology lags to the growth performance of the developing countries, while Benhabib and Spiegel (1994), Parente and Prescott (1994), and Segerstrom (1999) linked human capital formation and technology adoption to economic growth.

Endogenous technical progress through purposeful activities carried out in the R&D sector (particularly in universities or government research institutes) may also provide opportunities to escape the diminishing returns associated with investments in physical capital. Takeoffs and sustained “positive” economic growth in this model are driven by technological change in the R&D sector and so government policies can influence takeoffs into economic growth (Romer 1990, Grossman and Helpman 1991, Aghion and Howitt 1992). The R&D sector in this model has an AK type production function similar to the one used by Jones (1995) and Aghion and Howitt (2007):

$$i(t) = \mu(t)rd(t). \tag{7}$$

Thus, the intermediate good $i(t)$ (new innovations or inventions—new patents, trademarks, and blueprints) crucial in the formation of human capital is produced using the available technology $\mu(t)$, and the resources $rd(t)$ devoted to the R&D sector. A constant fraction η of the income $y(t)$, exogenously set in this model, is invested in the R&D sector, i.e., $rd(t) = \eta y(t)$. We can rewrite equation (7) as

$$i(t) = \eta\mu(t)y(t) \quad (8)$$

New innovations are, therefore, a by-product of (i) the R&D expenditure (referred to as the “R&D effect”) and (ii) the technology used in the R&D sector (the “Mu-effect”), both of which ultimately lead to more inventions or greater innovation. However, as R&D is exogenously set in this model, the only interesting effect on the R&D sector arises from the “Mu-effect.” The R&D technology is, therefore, key to ensuring long-term development of the economy.

3.4 Dynamics of Skill Formation and Human Capital

The government in our model can affect the human capital and the growth rates in the economy by investing in a new technology, and choosing the level of (formal) schooling to be imparted to the youngest generation through the education system, also referred to as the “compulsory level of education.” The government does not only invest in the accumulation of knowledge through technology adoption, but also provides for its absorption—through channels like formal education gained while attending school, on-the-job training, etc. Accumulation and absorption seems to play a complementary role in this regard.

Human capital of a typical worker is a result of the skills absorbed through schooling provided by the education system. The quality-adjusted human capital of an individual, represented by $h(t)$ is therefore the product of the cohort (referring to individuals born in a particular period) specific discoveries in the R&D sector $i(t)$ (affected by the state of the art technology) and the absorption capacity of the cohort $a(t)$:

$$h(t) = a(t)i(t) \quad (9)$$

Education increases the absorption capacity and can be represented by a strictly increasing function of the level of schooling attained:

$$a(t) = \psi(\theta(t)) = \phi\theta(t); \quad \psi' > 0 \quad (10)$$

where $\phi > 0$ captures the conversion rate of education to cohort-specific absorption capacity in the economy. The cohort-specific human capital (adjusted for education and skills) at time t will then be

$$H(t) = h(t)B(t) \quad (11)$$

where $B(t)$ is the number of individuals born at time t and $h(t)$ is the human capital of a representative worker.

The human capital of the first generation as of period $t + \theta$ will include the human capital of all individuals born between t and $t + \theta - T$ (individuals who have finished the level of education θ chosen by the government at period t).

$$G_1(t + \theta) = \int_{\tau=\theta}^T h(t + \theta - \tau)B(t + \theta - \tau)d\tau \quad (12)$$

By definition, the human capital of the second generation will then be

$$G_2(t + \theta) = \int_{\tau=T}^{2T} h(t + \theta - \tau) B(t + \theta - \tau) d\tau \quad (13)$$

while the human capital of the third generation or the oldest working population in the labor force will be represented by

$$G_3(t + \theta) = \int_{\tau=2T}^{3T} h(t + \theta - \tau) B(t + \theta - \tau) d\tau \quad (14)$$

3.5 Sticky Technology and Takeoffs

New knowledge is continuously being created by the government through the infusion of funds into the R&D sector, but obsolete technology is extremely sticky (often due to rigid institutions or the high cost of changes) even after the adoption of a new technology, taking a few generations to die out, particularly in developing countries. In a developing country, new innovations or inventions are mostly spread through the formal education system as the economy lacks the resources needed to regularly upgrade the skills of the population (with current information) once students graduate and enter the labor force. There is an intergenerational knowledge effect in developing countries, which is nonexistent in developed countries, where new technology quickly replaces outdated technology (through on-the-job training to update skills). In other words, the learning of skills and knowledge through formal education only makes complete replacement of the old technology by advanced technology a slow and gradual process, rather than rapid or instantaneous as in developed countries.

We model the intergenerational effect in our neoclassical growth model by disaggregating human capital by generations such that the generation-specific human capital differs in skills owing mainly to their access to different levels of technology. A number of other papers have also used disaggregated inputs: Romer (1990) used disaggregated capital, and Jorgenson and Griliches (1967) and Jorgenson, Gollop, and Fraumeni (1987) used input quality.

The firms combine the human capital of all three generations of individuals in the labor force to produce an economy-wide knowledge capital, which is then used as an input for the aggregate production function:

$$KN(t + \theta) = G_1(t + \theta)^\varphi G_2(t + \theta)^\gamma G_3(t + \theta)^{1-\varphi-\gamma} \quad (15)$$

with the additional assumption that $\varphi = \gamma = 1 - \varphi - \gamma$ and $0 < \varphi < 1$. The knowledge capital of the economy at $t + \theta$ can then be rewritten as a complex function of the choices made at time t , the level of technology, μ and θ , the level of education.

$$KN(t + \theta) = \prod_{x=1}^3 G_x(t + \theta) = \Omega(\mu, \theta) \quad (16)$$

4. THE POLITICAL ECONOMY OF TAKEOFF

The government in this model maximizes the net present discounted value of all future per capita income of the population. The government chooses the level of education and the state of the technology to maximize the objective function of the government—which is maximizing the net (expected) present discounted value of all future income, represented by

$$\underset{\theta}{\underset{\mu}{\text{Max}}} \omega(t) = v(t) - F\{\theta(t)\} - c\left[\dot{\mu}, t\right] \quad (17)$$

$$v(t) = \int_{\tau=0}^{\infty} e^{-\rho\tau} y^e(t+\tau) \partial\tau = \int_{\tau=0}^{\theta} e^{-\rho\tau} y(t+\tau) \partial\tau + \int_{\tau=\theta}^{\infty} e^{-\rho\tau} y^e(t+\tau) \partial\tau \quad (18)$$

The present discounted value of future income $v(t)$ in (18) can be rewritten as two separate parts using the “Additivity property” of the integration for any choice of education $\theta \in [0, T]$, where T (which is also the length of a generation in this model) is a finite number, $T < \infty$. Future (expected) per capita income is discounted using the discount factor $e^{-\rho\tau}$, where ρ is the rate of time preference or the discount rate: $0 < \rho < 1$.

$c(\cdot)$ is the setup cost associated with the adoption of the superior technology and $F\{\theta(t)\}$ the cost of providing education, which includes infrastructure cost, cost of hiring teachers in the international market, expenses incurred by the government to provide incentives, and regulations to ensure that the compulsory level of education is actually properly enforced.

The decision makers in this model are assumed to be characterized by myopic behavior defined as “short-sighted expectations.” Thus, the formation of expectations about the future is based entirely on the current observed market and economic situations, which assumes that the present circumstances will also continue in the future. In other words, the best guesses about future circumstances will be based on the situations that exist today and can be represented as

$$y^e(1+\tau) = y(t+\theta); \tau > \theta \quad (19)$$

After substituting (19) in equation (17) and maximizing the objective function of the government (using the Leibniz Integration rule) for the optimal level of education, we get

$$\int_{\tau=\theta}^{\infty} e^{-\rho\tau} \frac{\partial}{\partial\theta} \{y(t+\theta)\} \partial\tau = F'(\theta) + e^{-\rho\theta} y(t+\theta) \quad (20)$$

The first term (on the left-hand side) is the present discounted value of the increase in future income from a marginal increase in schooling, the second term denotes the (direct cost) marginal increase in cost associated with an increase in the compulsory level of education, while the third term is the (indirect cost) marginal increase in forgone income (the opportunity cost of education) from a marginal increase in schooling (both on the right-hand side).

There is a trade-off that the government faces when choosing the level of education, θ —a compulsory level of schooling that every individual born at time t should finish before they can enter the labor force. A higher level of θ implies a larger direct effect on the absorption capacity of the economy and the cost of providing more education, but an indirect negative effect is also involved: a higher level of education also means that students will be compelled to attend school for longer, resulting in forgone income. So, there is a clear trade-off between higher benefits tomorrow versus losses today. The equilibrium level of education in this model is specific to a particular choice of the level of technology, i.e., $\theta^* = \theta(\mu^*)$, where $\theta'(\mu) > 0$ i.e., μ and θ are complements in this model.

The government will install⁷ the new advanced technology if and only if

$$\text{Max}_{\theta} \omega(t) \Big|_{\mu=\bar{\mu}} \geq \text{Max}_{\theta} \omega(t) \Big|_{\mu=\underline{\mu}} \quad (21)$$

i.e., the net present discounted value from $\{\bar{\mu}, \theta^*(\bar{\mu})\}$ is greater than or equal to that associated with $\{\underline{\mu}, \theta^*(\underline{\mu})\}$. The government therefore pays for this new technology (and incur the setup cost) if and only if the increase in per capita output from this new advanced technology is sufficient to offset the setup cost and the cost associated with the complementary level of education.

Proposition 1: A country takes off into sustained “positive” stable growth if and only if it crosses a certain threshold level $y(t) \geq y^*$, where the threshold level is

$$y^* = \frac{F\{\theta^*(\bar{\mu}) - \theta^*(\underline{\mu})\} + c(t)[\bar{\mu} - \underline{\mu}]}{\int_{\tau=0}^{\infty} e^{-\rho\tau} \chi \partial \tau} \quad (22)$$

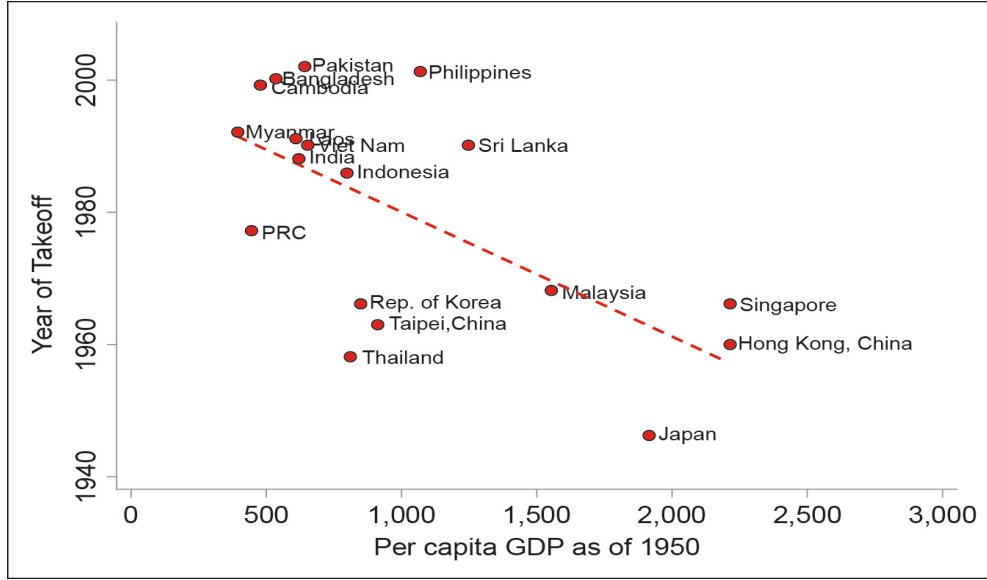
Proof: See Appendix for a detailed discussion.

The high cost associated with the so-called “radical change” constrains the adoption of the new technology and their takeoff into sustained growth, even though the countries are willing to undergo the change. This condition (22) is, in fact, reflective of a “technology trap” that exists in underdeveloped countries, and impedes their transition out of poverty. This is somewhat similar to Basu and Weil (1998), where the follower is only able to use the technology of the leading country if they have a sufficiently high level of development, and to Azariadis and Drazen (1990), which discussed threshold levels in terms of a similar “technological jump.”

The incidence of a takeoff thus depends on the costs associated with the adoption of the new technology and the level of development of the country in question. Thus, if we define takeoff (Φ) as a dichotomous variable, which takes a value of 1 if the country takes off and 0 otherwise, we can rephrase the takeoff condition as

$$\Phi = \Phi\{y, c(\cdot)\}; \Phi'(y) > 0; \Phi'(c) < 0.$$

⁷ Technology shift cost is a onetime fixed cost, and there are only two alternative modes of production (R&D technology) available to the countries. There is no cost if there is no installation at all, while the cost includes both psychological and financial cost associated with this new installation.

Figure 9: Initial Conditions and Their Year of Takeoff

GDP = gross domestic product, PRC = People's Republic of China.

Source: Based on authors' own calculations using Angus Maddison table.

The takeoff condition therefore suggests that countries that start off with higher levels of per capita income, other things being equal, are more likely to take off early, but are less likely to take off early if the cost of takeoff is extremely high. Figure 9 shows that economies at higher initial level of development as of 1950 took off earlier than those at comparatively lower levels (measured in per capita GDP at purchasing power parity). If we expect a linear relation to exist between the year of takeoff and per capita GDP, we can assume that economies that faced comparatively higher takeoff costs, other things being equal, lie above the straight line (taking relatively longer) while those with lower impediments took off earlier than expected (below the straight line).

Corollary 1: Countries with a relatively lower rate of time preference take off earlier and choose higher levels of education in equilibrium.

The costs associated with (i) R&D expenditure, (ii) providing the compulsory level of education to the first generation, and (iii) installing the new technology (if actually installed) endogenously determine the total expenditure of the government, and are financed by levying a constant tax rate of λ per unit of output so as to maintain the balanced budget condition of the government:

$$\lambda y(t) = \eta y(t) + F\{\theta(t)\} + c \left[\dot{\mu}(t), t \right] \quad (23)$$

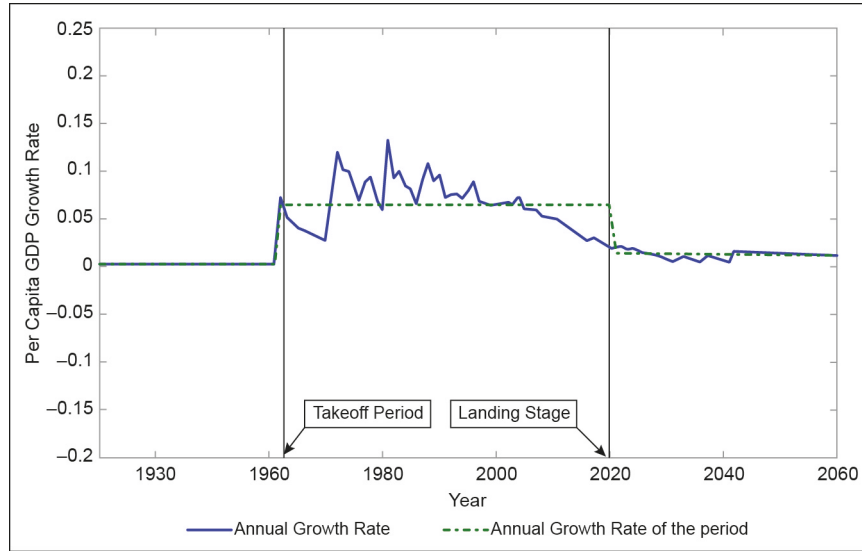
Once s_y is invested for the accumulation of capital and the government recovers the costs incurred by levying a tax at the rate of λ , the rest is consumed. Per capita consumption ξ can then be denoted as $\xi(t) = (1 - s - \lambda)y(t)$. Therefore, all output produced by the firms in this economy is either consumed, saved by individuals, or taxed by the government (to fund public expenditure).

Corollary 2: Countries without minimum age laws choose comparatively lower levels of education in equilibrium.

4.1 A Numerical Example

The empirical evidence presented in the previous sections suggest that countries are able to sustain high economic growth rates after their takeoffs. In our model, we want to capture, or at least accommodate, the main views on takeoffs that are evident from the data and that make it relatively “rare.” The theoretical model that we set up in section 3 therefore tries to capture the basic idea, using the concept of a “technology trap” in the context of an overlapping generation model with “sticky technology.”

Figure 10: Per Capita Gross Domestic Product Growth Rate from Simulated Data



GDP = gross domestic product.

Source: Based on authors' own calculations using Angus Maddison table.

To test if the model that we have set up so far can actually produce a growth path similar to that experienced by the South Asian economies, we calibrate the key parameters of the model. We specify values for the parameters $\alpha, \beta, \varphi, \gamma, s, \rho, \eta, \delta$. Since there is no direct estimation model for the political economy model of takeoffs, we assign some parameter values for this model from the literature. Capital is more scarce and labor cheap in emerging and developing economies compared with advanced countries, so we assume a capital share (α) of 0.5. We set the sum of the depreciation rate δ and population growth n at 0.1 (Kraay and Raddatz 2007) and the rate of intertemporal preference ρ at 0.01 (Fehr, Jokisch, and Kotlikoff 2007). We specify $\varphi = \gamma = 0.33$, i.e., each of the generations is set to have an equal share in the knowledge capital.

As a region, East Asia has high savings rates, which have helped finance high rates of capital accumulation and growth. Japan, the PRC, and other East Asian economies have had savings rates that exceeded 30% (Adams and Ichimura 1998). As East Asian economies exhibited savings rates in the range of 30%–40%, we set $s = 0.30$. Further, we assume $\eta = 0.01$, $\underline{\mu} = 0.01$, and $\bar{\mu} = 0.06$. An average R&D intensity (defined as R&D spending as a percentage of GDP) of 1% seems to be a relatively sensible parameter value as many countries tend to have a target of 1%, where they aim to invest about 1% of their GDP in R&D; with some of the East Asian economies setting their target at 3% or even higher. Finally, T , the size of a generation, is set at 10.

The political economy model is able to generate predictions somewhat similar to those observed in the data. Based on the simulations from the calibrated model, we find that adoption of the advanced technology helps the country take off onto a self-sustained positive growth path. The model economy seems to experience a relatively stable growth rate of 6.47% for a few decades after takeoff, before it lands and grows at a rate of 1.2% per year thereafter. The political economy model of takeoffs provides support in favor of the existence of a technology trap in poor economies and calls for coordinated government interventions in terms of pro-growth policies.

5. CONCLUSION

After relatively stable stagnant growth rates for many years, a number of Asian economies have started taking off into periods of sustained “positive” economic growth, reducing the gap between the West (developed countries) and the East (underdeveloped countries). While takeoffs are important, they are relatively rare, with the determinants of takeoffs being far from clear. Thus, this is a matter that warrants attention as a number of countries are still waiting for an economic miracle.

We empirically define takeoffs and landing, and develop an overlapping generation model with sticky technology to understand the political economy of takeoffs in the context of economic growth. This definition allows us to successfully and consistently identify takeoffs, landing, and periods of stable economic growth. The simple theoretical model with technology adoption, and human capital accumulation is able to explain the experience of the East Asian economies, which have managed to take off and sustain relatively stable rates of growth for decades. Our model suggests that mechanisms that could trigger such a growth takeoff may include structural changes and technological adoption that comes only at a relatively high cost, and hence there is a possibility that there exists a “technology trap” that seems to affect the timing and the possibility of an economic takeoff. An economy may therefore be stuck in a “low technology” equilibrium even when “better technology” is available for adoption.

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APPENDIX: PROPOSITIONS AND PROOFS

In this section, we provide the proofs for all the propositions and corollaries presented in the main text of the paper:

1. Proof of Proposition 1

A country takes off into self-sustaining growth if and only if

$$\text{Max}_{\theta} \omega(t) \Big|_{\mu=\bar{\mu}} \geq \text{Max}_{\theta} \omega(t) \Big|_{\mu=\underline{\mu}}$$

i.e., it is optimal for a country (using a traditional technology) to install the new and advanced technology if the net present discounted value from installing the advanced technology is higher than the net present discounted value from the use of the conventional technology. We can rewrite the takeoff condition in (21) after substituting for (17) and (18) as

$$\int_{\tau=0}^{\infty} e^{-\rho\tau} y^e(t+\tau) \partial\tau \Big|_{\mu=\bar{\mu}} - \int_{\tau=0}^{\infty} e^{-\rho\tau} y^e(t+\tau) \partial\tau \Big|_{\mu=\underline{\mu}} \geq F \{ \theta^*(\bar{\mu}) - \theta^*(\underline{\mu}) \} + c(t) [\bar{\mu} - \underline{\mu}] \quad (24)$$

As the per capita income is a function of the past per capita income and growth rates, $y(t+\tau)$ can be expressed as a product of $y(t)$ and a complex function Ψ of the growth rates between t and $t+\tau$:

$$y(t+\tau) = y(t) \prod_{z=0}^{\tau} [1 + g(t+z)]^{\partial z} = y(t) \Psi$$

where \prod is called the “geometric integral” and is a multiplicative operator. This can be used to rewrite the left-hand side of the takeoff condition in (24) as

$$y(t) \int_{\tau=0}^{\infty} e^{-\rho\tau} \left\{ \Psi^e \Big|_{\mu=\bar{\mu}} - \Psi^e \Big|_{\mu=\underline{\mu}} \right\} \partial\tau = y(t) \int_{\tau=0}^{\infty} e^{-\rho\tau} \chi \partial\tau$$

Rearranging the takeoff condition in (24) after substituting for the left-hand side we derive the condition under which the government or the social planner will install the new technology. The technology will be adopted if

$$y(t) \geq y^*$$

where the threshold level is

$$\frac{F \{ \theta^*(\bar{\mu}) - \theta^*(\underline{\mu}) \} + c(t) [\bar{\mu} - \underline{\mu}]}{\int_{\tau=0}^{\infty} e^{-\rho\tau} \chi \partial\tau}$$

This condition ensures that the social planner will incur the setup cost $c(t)[\mu]$ and move to a higher technology frontier only when the per capita output has reached a certain threshold level. Therefore, it may be possible for an economy to remain stuck in a “low-level equilibrium trap” (also referred to as a “technology trap”) even when the “better technology” is available for adoption, as the country may not have sufficient resources for the “big push.”

2. Proof of Corollary 1

The proof for this corollary follows directly from the equilibrium education and the takeoff condition: where countries are caught up in a “technology trap,” which can only be escaped when the country is able to cross a certain threshold level, $y(t) \geq y^*$ where the threshold level of per capita income is a function of the costs and a present discounted value of the growth prospects from a better technology presented in (22).

$$y(t) \geq \frac{F\{\theta^*(\bar{\mu}) - \theta^*(\underline{\mu})\} + c(t)[\bar{\mu} - \underline{\mu}]}{\int_{\tau=0}^{\infty} e^{-\rho\tau} \chi \partial\tau}$$

A decline in the rate of time preference or discount rate, $\rho \rightarrow 0$ will mean that countries are relatively more patient and value future more, thereby leading to an increase in the discounting and $\int_{\tau=0}^{\infty} e^{-\rho\tau} \partial\tau = \frac{1}{\rho} \rightarrow \infty$. Thereby, leading to a decline in the critical threshold level y^* and the country will take off earlier as they are more patient now and will value the future more.

Next, we analyze the effect of a fall in ρ on the optimal choice of education in the economy. We know that the optimal level of education from the first order condition of the government’s maximization problem in (20) is

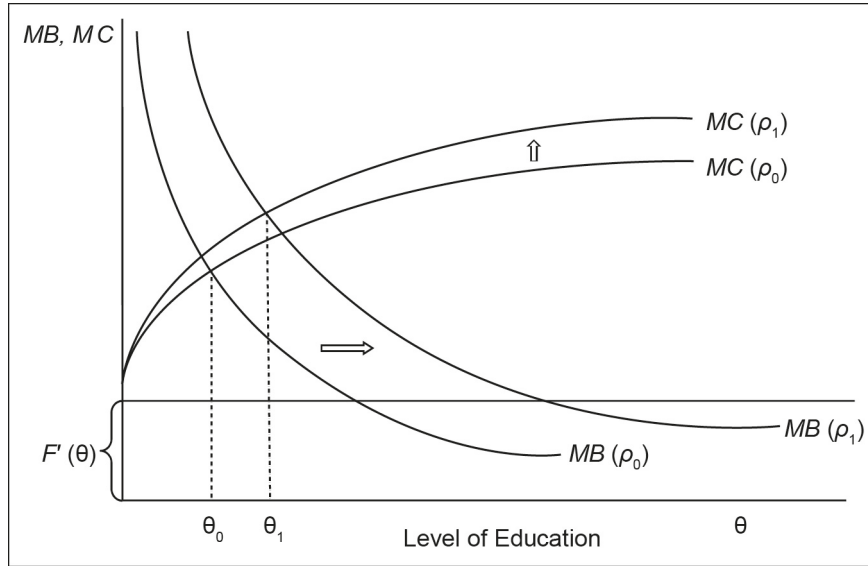
$$\int_{\tau=\theta}^{\infty} e^{-\rho\tau} \frac{\partial}{\partial\theta} \{y(t+\theta)\} \partial\tau = F'(\theta) + e^{-\rho\theta} y(t+\theta)$$

which can be rewritten in the form of a present discounted value of future income from a marginal increase in schooling, as

$$MR_{\theta} \frac{e^{-\rho\theta}}{\rho} = F'(\theta) + e^{-\rho\theta} y(t+\theta)$$

where the left-hand side of the equilibrium condition in (20) is

$$\int_{\tau=\theta}^{\infty} e^{-\rho\tau} \frac{\partial}{\partial\theta} \{y(t+\theta)\} \partial\tau = \int_{\tau=\theta}^{\infty} e^{-\rho\tau} MR_{\theta} = MR_{\theta} \frac{e^{-\rho\theta}}{\rho}$$

Figure A.1: Time Preference and Level of Education

MB = marginal benefit, MC = marginal cost.

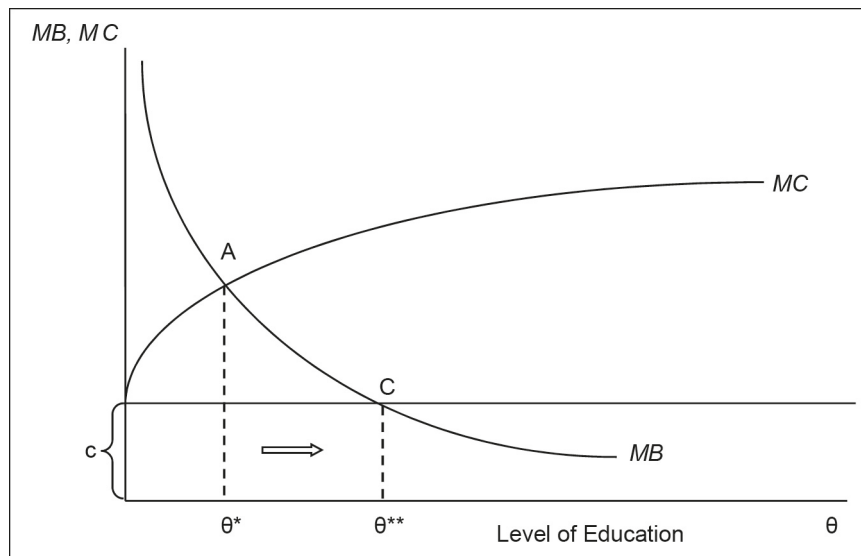
MB and MC in Figure A.1 denote the marginal benefit and marginal cost from education—with direct cost $F'(\theta)$ and the indirect cost of education (forgone income). The changes associated with a decrease in ρ from ρ_0 to ρ_1 changes the (MB, MC) schedules from $\{MB(\rho_0), MC(\rho_0)\}$ to $\{MB(\rho_1), MC(\rho_1)\}$. The equilibrium level of education therefore increases from $\theta_0(\rho_0)$ to $\theta_1(\rho_1)$ where $\theta' < 0$. A decline in the discount rate will lead to an increase in the marginal benefit at every level of education (sufficiently large), making it optimal for the government to choose higher levels of education in equilibrium.

3. Proof of Corollary 2

Given that the optimal level of education in the economy is determined from the first-order condition of the government's maximization problem in (17) and (18), we can prove the corollary directly from the equilibrium condition in (20). The total marginal cost for every level of education is the vertical summation of both marginal costs (direct and indirect costs)—marginal cost of education (direct) and forgone lost income (indirect).

The equilibrium level of education with and without the minimum age laws is presented in Figure A.2. The left-hand side of condition (20) is presented as MB in the figure, while the right-hand side is the MC of schooling — $F'(\theta)$ and $e^{-\rho\theta} y(t+\theta)$, the (present discounted) opportunity cost of an addition year of schooling.

$$\int_{\tau=\theta}^{\infty} e^{-\rho\tau} \frac{\partial}{\partial \theta} \{y(t+\theta)\} \partial \tau = F'(\theta) + e^{-\rho\theta} y(t+\theta)$$

Figure A.2: Minimum Employment Age Laws and Level of Education

MB = marginal benefit, MC = marginal cost.

When minimum age laws are nonexistent or established but not properly enforced (which is very common in many developing countries), the opportunity cost of higher education (forgone income) to the society constitute an important component of the cost of higher compulsory education, over and above the direct cost of education and countries choose comparatively lower levels of education in equilibrium. The equilibrium level of schooling with minimum age laws θ^{**} at C is therefore higher than the equilibrium without minimum age laws⁸ θ^* at A.

⁸ Minimum age laws limit children from joining the labor force before they reach a certain age, thereby reducing the opportunity cost of being at school.

Average Per Capita Gross Domestic Product Growth Rates of the Asian Economies during Different Phases

Economy of Interest	Pre-takeoff Phase	Pre-takeoff Growth (%)	Takeoff-landing Phase	Takeoff-landing Growth (%)	Post-landing Phase	Post-landing Growth (%)
Afghanistan	1951–2008	0.75	–	–	–	–
Bangladesh	1951–1999	0.95	2000–2010	4.08	–	–
Cambodia	1951–1998	2.04	1999–2010	6.75	–	–
PRC	1951–1976	2.68	1977–2010	6.88	–	–
Hong Kong, China	1914–1959	2.11	1960–1994	5.73	1995–2010	2.57
India	1885–1987	0.79	1988–2010	4.91	–	–
Indonesia	1885–1985	1.67	1986–2010	3.62	–	–
Japan	1900–1945	2.02	1946–1973	7.97	1974–2010	1.80
Lao PDR	1951–1990	1.05	1991–2008	3.33	–	–
Malaysia	1951–1967	1.01	1968–1997	5.06	1998–2010	1.94
Mongolia	1951–2008	1.50	–	–	–	–
Myanmar	1951–1991	1.75	1992–2010	8.69	–	–
Nepal	1951–2008	1.47	–	–	–	–
DPRK	1951–2008	0.85	–	–	–	–
Pakistan	1951–2001	2.17	2002–2010	3.17	–	–
Philippines	1951–2000	1.62	2001–2010	2.63	–	–
Singapore	1951–1965	1.30	1966–1997	6.24	1998–2010	2.93
Korea, Rep. of	1920–1965	2.40	1966–2010	6.29	–	–
Sri Lanka	1871–1989	0.94	1990–2010	3.97	–	–
Taipei, China	1920–1962	2.31	1963–2010	6.00	–	–
Thailand	1951–1957	1.63	1958–2010	4.55	–	–
Viet Nam	1951–1989	1.19	1990–2010	5.75	–	–

DPRK = Democratic People's Republic of Korea, Lao PDR = Lao People's Democratic Republic, PRC = People's Republic of China.

Notes:

1) The United States, the benchmark country of this model, grew at an average rate of exactly 2% between 1900 and 2010.

2) Premature takeoffs (Cambodia and Myanmar) and failed takeoffs (DPRK and Pakistan) were not considered while calculating average growth rates.

3) 1945 is excluded from our discussion as it is considered to be an outlier year for Japan because of the World War II nuclear bombings of Hiroshima and Nagasaki.

Source: Historical Statistics of the World Economy on Per Capita GDP, 1–2010 A.D from Angus Maddison. Based on authors' own calculations.