Technology Assimilation and Aggregate Productivity

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Abstract: This paper develops a technology assimilation framework to explain how domestic firms uncover global technologies under limited technique availability and production flexibility. We construct a micro-founded measure of endogenous total factor productivity (TFP) based on the interaction of stage-dependent local knowledge of a country with advanced foreign technologies. We then perform development and growth accounting exercises to better understand the large and widening TFP gaps across countries and over time. By comparing our results with other popular models, we find that the lack of assimilation of frontier technologies can be instrumental in differentiating trapped economies from miracle economies. About half of the rapid growth experienced in miracle economies can be attributed to positive assimilation, and over 40% of the negative growth outcome in trapped economies is due to backward assimilation. This finding suggests that an adequate provision of correct incentives and institutional settings is crucial for domestic firms to assimilate relevant frontier technologies in a way that is suitable for their development stages.

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"The sixteenth-century Dutch, on the verge of becoming economic leaders of the world, borrowed heavily from the techniques of the Italians, the outgoing leaders. By then, the English were already learning not only from the Low Countries but also from other parts of the continent. The Americans borrowed heavily from the English and from other European sources, particularly from the time they achieved independence up until the middle of the nineteenth century." (Baumol et al. 1991 pp. 271-272)

1 Introduction

Why, in the past half-century, have many countries successfully taken off, catching up with world leaders, while some have experienced growth stagnation? The world income distribution has widened over the last 50 years. From 1970 to 2007, the U.S. real GDP per capita relative to that of poor nations in the bottom 10 percentile was about 5.4 times on average, with the gap rising over time. Macroeconomists attempt to account for the income differences using a neoclassical aggregate production function. They find that, even when controlling for the accumulation of physical and (education-based) human capital per worker, an unusually large total factor productivity (TFP) gap is still required to account for the income disparities (e.g., Lucas 2000). However, why would technology not flow from the rich to the poor? Are there “missing inputs” in standard aggregate production? Are there “barriers to rich” in less-developed countries? Over the past two decades, the field of development accounting has emerged; it is devoted to understanding the underlying causes of the persistent and widening world income disparities. These studies focus primarily on correcting the mismeasurements of factors inputs and identifying missing inputs in the neoclassical production framework. In this paper, we depart from neoclassical production theory to quantify endogenous TFP gaps by examining country-specific processes of technology assimilation.

To illustrate our idea of technology assimilation in a nontechnical fashion,
let us consider a product (e.g., smartphones) with different product blueprints (such as Apple iPhone, Samsung Galaxy Note, HTC One, etc.). In contrast to standard neoclassical production theory, we generalize the concept of “production techniques” developed by Houthakker (1956-57), Kortum (1997), and Jones (2005) to capture “mini-blueprints” that specify ways to organize factor inputs so that they fit a given product blueprint. In our framework, availability of such production techniques is limited due to imperfect knowledge about product orders ex ante and about the most effective mini-blueprints that are suitable for a particular firm (e.g., Foxconn Technology Group). As a result, mismatches may arise and output can fall below the potential level. In this circumstance, “production flexibility” can make firms less vulnerable to their limitations in available techniques. In a global economy, a domestic firm can “assimilate” a relevant global leader and thus expand its set of available techniques; these assimilated techniques help to re-organize factor inputs in the continually changing process of production. The endogenous choice of such techniques yields a dynamic process of technology assimilation and generates endogenous TFP; however, this process depends on “local knowledge” that summaries a country’s limitations related to the available techniques and production flexibility. Which particular leader should be assimilated can also be different across countries and over time. Assimilation under the condition of limited production techniques and restricted flexibility can prohibit the flow of technologies from developed to developing countries, leading to endogenous TFP gaps and the flying geese paradigm (FGP) of economic development documented by Akamatsu (1962) and Baumol et al. (1991).

Numerous well-documented case studies, for example Wan (2004), show that successful assimilation of technology is the common denominator in Asian economic development. Geographical proximity in technology assimilation generates the FGP, with some early birds taking off sequentially, followed by various late comers. Conversely, failure to assimilate technology has caused the backwardness seen in African economic development. In 1970, the per capita
incomes of the Sub-Saharan countries were almost comparable with those of the Asian Tigers and were even ahead of some of their ASEAN counterparts. Subsequently the Asian economies took off and continued to advance along sustained growth paths, whereas Africa’s post-independence industrialization remains isolated from world markets and frontier technologies, even in their main sectors of production, such as cash crops (e.g., cocoa and coffee in Cote d’Ivoire and Kenya).

As elaborated below, technology assimilation differs from the standard concepts of technology adoption, imitation, or spillover. In general, the ability of technology assimilation are related to entrepreneurs’ understanding of foreign techniques, their learning from experimenting, the flexibility of institutions and organizations, the human capital that is responsive to the frontier techniques, and the infrastructure and taxation schemes that enhance the adaptation. Thus, we can study how diverse growth experiences across countries can be explained by this assimilation measure over time. To investigate the relationship between technological advancement and flexible production, we need a systematic comparison between technologies with different elasticities of substitution. We therefore adopt a constant elasticity of substitution (CES) production function normalized to a particular country at a given stage of technology assimilation. We then decompose the real GDP per capita relative to the U.S. (the income ratio) into a relative technology component (the TFP ratio), a relative factor endowment component (the capital-labor ratio), and a time-varying, country-specific measure of technology assimilation with respect to an advanced foreign technology, which depends on the interaction of limited technique availability and production flexibility.

Our technology assimilation framework contributes to production theory and development economics in several significant aspects. In contrast to the neoclassical production approach, our framework disentangles the designed

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1For instance, the 1970 per capita GDP of Korea and Taiwan was 16.1% and 15.6% that of the United States, and Thailand’s and Vietnam’s were only 9.2% and 3.9%, whereas there of Cote d’Ivoire and Kenya were 12.6% and 8.4%, respectively.
usages of production factors (production techniques) for a given level of technology from the physical inputs of production factors. Because the mini-blueprints governing factor use are specific to each production input, our framework is also different from organizational capital theory. Accordingly, we are able to establish a clear-cut relationship between technological advancement and production flexibility. Moreover, by comparing local performance and global technology, we can extract more information from the data and can obtain measures of production flexibility and technology assimilation that are specific to a country over time. This allows us to generate new measures of TFP. We thus gain further insights into the role of assimilation in the dynamic process of economic advancement for various countries, and obtain new measures of aggregate productivity that are sharply different than comparable figures computed under the conventional neoclassical production framework.

As our model is related to the literature of appropriate technology, we perform income accounting exercises and systematically compare them with other popular models such as those given in Lucas (2000), Basu and Weil (1998), and Acemoglu (2009). We shall refer to the Basu-Weil-Acemoglu framework of inappropriate technology as BWA because of its high relevance. We also generalize the Cobb-Douglas benchmark of Lucas (2000) with the CES formulation, referred to this generalization as the CES model.

The main findings of this paper are as follows. Theoretically, when local information about the available techniques suitable for domestic use is limited, the technologies will not flow from more advanced to less advanced countries. Poor assimilation is the barrier to growth in our model and leaves nations in poverty traps. Using the normalized CES specification for the assimilation process, we decompose the aggregate production function into two components: a conventional Cobb-Douglas production term and a CES-type assimilation term. We show that the country-specific assimilation of a global technology can serve as an effective vehicle for development accounting and can help to reduce the unexplained component in the large TFP differences.
Quantitatively, our development accounting results suggest that our model of the assimilation of global technology, the CES and the BWA models fit the data far better than the Lucas benchmark. Moreover, our model, on average, outperforms both the CES and the BWA models in most economic and geographic groups (classified by initial stage of development, development speed, and current state of development). These advantages are particularly noticeable for countries that are either in development traps or are experiencing development miracles. Furthermore, we select a group of representative countries and separate them into the following economic/geographic clusters: OECD, Asian Miracles, late-coming miracles, trapped, and Latin economies. By conducting growth accounting exercises, we find that the Lucas benchmark performs well for OECD countries, but noticeable differences exist between our model and the CES and the BWA models for trapped and miracle countries. Specifically, more than half of the relative income growth in all of the miracle countries can be attributed to assimilation. Moreover, backward or negative assimilation accounts for over 40% of the negative growth performance of all of the trapped countries. Most of the development miracles have exhibited strongly positive assimilation over the past three decades. Many of the trapped economies are found to suffer backward (negative) assimilation. Therefore, we can conclude that the effective assimilation of frontier global technology is an important factor for explaining many of the Asian Miracle cases, and the lack of assimilation of frontier global technology is crucial for explaining why most Sub-Saharan African countries suffer the poverty trap. Moreover, we study the flexibility of production over time, finding that the two larger Asian Tigers (i.e., South Korea and Taiwan) are more flexible in (techniques-augmented) factor substitution than the two smaller Tigers and that India (software-led) is more flexible than China (assembly-based). Such flexibility has important implications for a country’s production efficiency and development success.

Finally, based on country-specific growth data, we find that the fitness
of our assimilation model significantly improves when we allow for delayed assimilation in several Latin American countries and an early stop of assimilation in Hong Kong and Singapore. Allowing Taiwan to first assimilate the techniques from Japan and then from the U.S. yields a much better fit; a similar assimilation switching does not change the results for Korea. For several ASEAN economies and China, geographical or FDI-based assimilation gives much better model fitness outcomes. In contrast, no alternative assimilation schemes improve the fitness outcomes for most of the trapped economies where technology assimilation is found lacking or backward.

**Related Literature**

Our paper is related to two strands of research: the study of appropriate technology and the study of development accounting.

To formalize the concepts of technology assimilation, we refer to the now-classic pieces by Atkinson and Stiglitz (1969) and Houthakker (1956-57) and more recent studies by Kortum (1997) and Jones (2005). Atkinson and Stiglitz specify that a country’s local production features localized learning by doing. Houthakker, Kortum, and Jones obtain a Cobb-Douglas production function as an envelope of Leontief local productions in which firms are free to choose any production techniques drawn from independent Pareto distributions. Based on the idea of local production, Basu and Weil (1998) construct a Solow-type growth model of technological progress that emphasizes that technological advances will benefit certain types of technologies, but not others. Therefore, even if all technologies are freely available and instantly transferred, a country may refrain from using a new but “inappropriate” technology. Parente and Prescott (1994) examine how barriers to technology adoption affect the process of development. With the exogenous growth of world knowledge, the amount of investment required for technological advances decreases, and this enhances long-term growth. Recent studies have focused on costly technology acquisition, including Caselli’s (1999) study of costly learning. Caselli and Coleman (2006) show that given different economic conditions and fac-
tor endowments, some countries may optimally choose not to adopt a frontier technology. Acemoglu (2009) provides a heuristic Leontief specification of the Basu-Weil appropriate technology so that the production function is Cobb-Douglas and the appropriateness can be summarized by a single parameter defined on the unit interval. Depending on the magnitude of this parameter, the latter study shows that the inappropriateness of some technologies has the potential to explain cross-country income differences. Building on the Houthakker-Kortum-Jones foundation, Wong and Yip (2014) construct a model of technology assimilation to study how adopting a frontier technology may lead to a development trap instead.

Since the pivotal works of Lucas (1990, 2000), Chari, Kehoe, and McGrattan (1996), and Prescott (1998), there has been a growing interest in development accounting. Many contributions have attempted to reduce the required TFP gap by improving the measurements of the quality of physical and human capital and the associated barriers and distortions. For example, Caselli and Wilson (2004) introduce “quality” of physical capital in the accounting exercise. Erosa, Koreshkova, and Restuccia (2010) and Schoellman (2012) improve the measurement of human capital beyond the typical Mincerian ‘years of schooling’ estimate. As capital investments depend crucially on finance, Aghion, Howitt, and Mayer-Foulkes (2005), and Buera and Shin (2012) study the role of financial markets distortions on accounting for world income disparities. Of course, many other missing inputs or frictions may account for cross-country income differences, the details of which we will not discuss for the sake of brevity.
2 The Aggregate Production Function: A Prelude

In order to understand the cross-country variation of the aggregate production function, the existing literature adopt the prototypical model

\[ y_j = \frac{Y_j}{N_j} = \frac{z_jF(K_j, N_j)}{N_j} = z_j f(k_j). \]  

(1)

According to (1), a representative firm in country \( j \) employs capital \( K \) and labor \( N \) to manufacture a final product \( Y \) using a constant-returns-to-scale technology with total factor productivity (TFP) \( z \). In per capital term, we have \( k = K/N \) and \( f(k) = F(k, 1) \). The standard practice is to allow the TFP \( (z) \) to vary across countries so that \( z \) is higher in high-income countries. Lucas (2000) focuses on the Cobb-Douglas specification of \( F \):

\[ y_j^{Lucas} = z_j^{Lucas} k_j^\alpha, \]  

(2)

where \( \alpha \in (0, 1) \) is the common output elasticity of capital for all countries. Based on (2), the common conclusion is that about 40% of the variation in world income can be attributed to differences in \( z \). However, TFP is a residual component which measures our ignorance of the production relation specified in \( f \). So recent research attempts to study extensions to the aggregate production function in order to reduce the resulting \( z \). Our model of technology assimilation follows this line of research. In the assimilation framework studied in the next section, we extend the aggregate production function by allowing a country to adopt an advanced (more capital intensive) foreign technology for its domestic production along the line proposed by Houthakker (1955-56) and Jones (2005). The assimilation between the foreign technology and the domestic factor endowment in the adoption process is shown to be captured by an elasticity of substitution to reflect the flexibility of the aggregate production

\footnote{The literature on TFP is huge and we refer the readers to Caselli (2005) for a partial survey.}
function. Specifically, we can establish the resulting micro-founded per worker aggregate production function of the form:

\[
y_j^{\text{Assim}} = \tau_j^{\text{Assim}} z_s k_s^\alpha \left[ \alpha \left( \frac{k_j}{k_s} \right)^{\sigma_j^{-1}} + (1 - \alpha) \right]^{\sigma_j},
\]

where \( \tau_j^{\text{Assim}} \) is the relative TFP of country \( j \) to the assimilation target country \( s \), and \( \sigma_j \in [0, 1] \) measures the country \( j \)'s ability of assimilating country \( s \)'s technology. The fact that the target technology being assimilated is \( k_s \), implying that the targeting choice depends on the local information of country \( j \).

Since our production function given by (3) is more general than the Lucas benchmark (2), we can expect that the resulting TFP \( z \) to be smaller.\(^3\) However, there are other alternatives that can achieve the same objective. According to (3), our assimilation approach generalizes the Lucas aggregate production function in two ways. On the one hand, production flexibility in technology substitution captured by \( \sigma_j \) matters; on the other hand, the technologically advanced source country being adopted, captured by the ratio \( k_j/k_s \), also matters. In reference to the Lucas case (2), our former generalization can alternatively be studied with a CES aggregate production:

\[
y_j^{\text{CES}} = z_j^{\text{CES}} \left[ \alpha \left( k_j \right)^{\epsilon_j^{-1}} + (1 - \alpha) \right]^{\epsilon_j},
\]

where \( \epsilon_j > 0 \) is country \( j \)'s elasticity of factor substitution in production. When \( \epsilon_j = 1 \), (4) coincides with (2). In addition, for the latter generalization, we can allow for adoption barriers following BWA where a country \( j \) adopts technology from an advanced source country \( s \) in production:

\[
y_j^{\text{BWA}} = \tau_j^{\text{BWA}} z_s \min \left[ 1, (k_j/k_s)^{\xi_j} \right] k_s^\alpha.
\]

\(^3\)The two obvious exception cases are given by either \( k_j = k_s \) (same technologies) or \( \sigma_j = 1 \) (perfect assimilation).
In (5), \( \tau_{j}^{BWA} \) measures the relative TFP of country \( j \) to country \( s \), and \( \zeta_{j} \in [0, 1] \) captures the degree of inappropriateness of the foreign technology that may be referred to as country \( j \)'s barriers to adoption. When \( \zeta_{j} = 0 \), (5) coincides with (2). It is clear that both the CES and the BWA setups are more general than the Lucas benchmark.

While our framework is more general than the Lucas benchmark, the comparison with the CES and the BWA setups is not straightforward. On the one hand, production flexibility in factor substitution matters, similar to the CES setup but in contrast to the BWA setup. On the other hand, the advanced source country matters, similar to the BWA approach but in contrast to the CES setup. Moreover, in contrast to both setups, how to assimilate the target country \( s \)'s technology captured by both the ratio \( k_{j}/k_{s_{j}} \) and \( \sigma_{j} \) is crucial. Specifically, the target country for assimilation depends on the "local" conditions of country \( j \), as highlighted by the notation \( k_{s_{j}} \) instead of \( k_{s} \), which does not necessarily have to be the world technology frontier. In order to provide a better understanding on these issues, we now turn to study the microfoundation of the underlying assimilation mechanism.

3 The Model

Consider a production environment in which a firm specializes in a particular product that has a range of product blueprints, that vary between orders. Departing from the neoclassical production framework, we introduce the concept of “production technique,” which is a mini-blueprint that specifies how to organize factor inputs to fit a given blueprint. Before a particular order specifies a blueprint, the factor inputs have already been employed by the firm. Together with imperfect knowledge about the potentially most effective component design, these ‘pre-determined’ inputs may limit the available choices of techniques. If the available techniques are limited, the firm’s optimization problem can produce an outcome that differs sharply from the neoclassical
one. In particular, not only does the set of available techniques matter, but the “flexibility” of production under limited alternatives is also crucial.

Given a limited set of available techniques, which may not be perfectly suited to the factor endowment of the firm, output can fall below the potential level. Flexibility of production is the ability to relieve the tension between limited alternatives and a pre-set factor endowment so as to reduce the output loss from its potential level. In other words, a more flexible production makes the firm less vulnerable to its limitations in available techniques. We describe the firm’s flexible organization of production inputs as “technology assimilation,” which can be understood as a process of alternating a mini-blueprint under its factor endowment. Notably, assimilation differs from Lucas’ (1978) span-of-control theory of production, which augments neoclassical production with an additional managerial input. Instead, assimilation re-organizes factor inputs in the process of production, generating flexible mini-blueprints that we refer to as “assimilated techniques.” The firm then chooses and implements the most suitable assimilated technique for production, aiming to reduce efficiency losses caused by limitations in available techniques.

Limitations in available techniques and production flexibility under assimilation are important components of a firm’s “local knowledge.” In a global economy, domestic firms are given opportunities to assimilate relevant techniques from global leaders. This advanced technique expands the set of available techniques and the local knowledge of domestic firms, initiating an assimilation process. We can then account for the output gap between a country and the global leader, the so-called TFP difference, based on the dynamic interaction of a country’s local knowledge with advanced foreign techniques. As a result, we have a theory of endogenous TFP based on technology assimilation.

Using the concepts of modified production under assimilation and cross-country variations in local knowledge, we establish a new framework for development accounting. This endeavor enables us to generate insights into the

\footnote{This captures the spirit of the local production function described in Atkinson and Stiglitz (1969).}
large and widening TFP gaps across countries and over time.

3.1 Production Technique

A production technique is a mini-blueprint that specifies the organization of factor inputs, capital ($K$), and labor ($N$), for an output level $Y_i$, defined by two parameters of factor-augmented productivity, $a_i$ and $b_i$.\(^5\) Thus,

$$Y_i = \min(a_i K, b_i N) = N b_i \min \left( \frac{k}{\kappa_i}, 1 \right),$$

where $k \equiv K/N$ and $\kappa_i \equiv b_i / a_i$. That is, technique $i$ is indexed by $(b_i, \kappa_i) \in \mathcal{P}$, where the menu $\mathcal{P}$ is the set of techniques. The capital-labor ratio $k$ is what matters to the output per capita because of constant return to scale. We want to emphasize that $\kappa_i$ is the input required by the technique $i$, and $k / \kappa_i$ measures the mismatch between the factor endowment ratio and technique requirement. This mismatch is due to the limitation in available techniques, which prevents choosing $\kappa_i = k$. When $\kappa_i > k$, capital is insufficient to achieve the potential output $\kappa_i = k$; when $\kappa_i < k$, some capital is wasted.

For choosing a technique, $k$ is given and $\kappa_i$ is the subject of selection. Given $k$, the firm would like to match the technique perfectly to the capital-labor ratio such that $\kappa_i = k$. But it may not be feasible, as the menu $\mathcal{P}$ only consists of a limited number of techniques. The concept of production techniques can be best illustrated using a two-sided matching terminology, as outlined in Chen, Mo, and Wang (2012). Technique $i'$ is called latent if $b_{i'} < b_i$ for $\kappa_{i'} = \kappa_i$ or $\kappa_{i'} > \kappa_i$ for $b_{i'} = b_i$. That is, a latent technique yields a lower output per worker given the same input requirement or requires more input to yield the same output per worker. We shall call a technique manifest if it is not latent. Then we denote the set of manifest techniques as $\mathcal{B}$, and define the manifest technique associated with $\kappa$ as $B(\kappa) \equiv \{ b_i | b_i = \max_{(b_j, \kappa) \in \mathcal{P}} b_j \} \in \mathcal{B}$, which is the best technique for a given $\kappa$ in a country. It is important to note

\(^5\)See Houthakker (1956-57), Kortum (1997), and Jones (2005) for further details of this Leontief formulation of the so-called local production.
that \( \mathcal{P} \), and hence \( \mathcal{B} \), are allowed to be different across countries and time.

### 3.2 Assimilated Technique and Production

We are now prepared to introduce the concept of technology assimilation. Recall that the menu \( \mathcal{P} \) may consist of a limited number of techniques. As a result, we may have a mismatch, and output may fall below the potential level. Technology assimilation is a means to mitigate the detrimental consequence of a mismatch by allowing for alternative ways of organizing techniques with respect to the factor endowment. To capture this, we propose the following production function under assimilation, which specifies the output with the technique \((a_i, b_i)\), given the factor endowment \((K, N)\) such that

\[
\tilde{F}(K, N; a_i, b_i) = \tau \left[ \alpha (a_iK)^{\frac{\sigma - 1}{\sigma}} + (1 - \alpha) (b_iN)^{\frac{\sigma - 1}{\sigma}} \right]^{\frac{\sigma}{\sigma - 1}}. \tag{7}
\]

It is clear that when \((a_i, b_i) = (z, z)\), \(\tilde{F}(K, N; z, z)\) becomes a standard neoclassical CES production function with TFP captured by \(\tau z\). When \((a_i, b_i) = (a, b)\), i.e., the set of techniques is a singleton, \(\tilde{F}(K, N; a, b)\) capture the production technology with factor-biased technical progress as in Acemoglu (2003).

Note that this production function under assimilation is not a simple extension of neoclassical production. As in the neoclassical framework, \(\tau\) is an efficiency measure, though it is now specific to the implementation of a particular technique for production. In sharp contrast to the neoclassical framework, we consider the endogenous choice of production technique, and introduce technology assimilation that depends crucially on the limited menu of available techniques and the flexibility parameter \(\sigma \in [0, 1]\). In particular, although limitations in available techniques can result in mismatches, assimilation under greater flexibility (higher \(\sigma\)) can help to mitigate the output loss caused by these mismatches. As analyzed below, the endogenous choice of a manifest technique under a limited menu of techniques will generate new measures of TFP, that depend jointly on technique limitation and flexibility. It is convenient to rewrite the production function in terms of an assimilated technique.
\( (b_i, \kappa_i) \in \mathcal{P} \) such that
\[
F(K, N; b_i, \kappa_i) = \tau b_i \left[ \alpha \left( \frac{K}{\kappa_i} \right)^{\frac{\alpha-1}{\sigma}} + (1 - \alpha) N^{\frac{\alpha-1}{\sigma}} \right]^\frac{\sigma}{\alpha-1}.
\]

This turns out to be the normalized CES production function proposed by Klump and de la Grandville (2000), where the normalization point is specified at the input requirement of a technique target, \( \kappa_i \). A graphical representation of the assimilation concept is given in Chart 1. Consider a menu consisting of two available techniques, \( \kappa_1 \) and \( \kappa_2 \). In the case where \( \sigma \to 1 \), we have perfect assimilation and \( F \) becomes Cobb-Douglas, and the potential output \( y_3 \) is achieved. In the case where \( \sigma \to 0 \), it is impossible to assimilate the technique and \( F \) is Leontief. The output under technique \( \kappa_1 \) is then given by \( y_1 < y_3 \). With \( \sigma \in (0, 1) \), we have partial assimilation. Under technique \( \kappa_1 \), output becomes \( y_2 \in (y_1, y_3) \); under \( \kappa_2 \), the potential output \( y_3 \) can be achieved, but some capital is wasted.

Given the capital rental rate \( r \) and the wage rate \( w \), the profit maximization problem of a representative firm can be conveniently specified in two steps. In the first step, for any manifest technique \( \kappa \), the associated output is \( F(K, N; B(\kappa) , \kappa) \) and the resulting profit is
\[
\pi(\kappa; r, w) = \max_{K,N} \{ F(K, N; B(\kappa) , \kappa) - rK - wN \},
\]
which is the standard neoclassical firm’s optimization problem. In the second step, for \( (B(\kappa) , \kappa) \in \mathcal{P} \), the optimization problem becomes
\[
\Pi(r, w) = \max_{\kappa} \{ \pi(\kappa; r, w) \}.
\]
The solution to the two-step optimization problem then gives the \textit{global} production function of Jones (2005). It can be shown that it is given by (see Appendix A)
\[
F(K, N) = z K^\alpha N^{1-\alpha},
\]
where $z$ is a positive constant. In summary, the global frontier of a country with a universe menu $\mathcal{U} \equiv \{(b, \kappa) | b \leq z\kappa^\alpha\}$ has the Cobb-Douglas functional form given in (11).

Chart 2 provides a graphical representation of $\pi(\kappa; r, w)$. It is clear that $\pi(\kappa; r, w)$ is peaked at $\kappa = k$. When factor prices are high and production efficiency is low, $\pi(\kappa; r, w)$ can be negative for a $\kappa$ far away from $k$. Consider the local and global production functions depicted in Chart 1, which consists of only two available techniques, $\kappa_1$ and $\kappa_2$, both different from $k$. As shown in Chart 2, both techniques are inferior to $k$. Although $\kappa_2$ is able to achieve the potential output $y_3$, it is not necessarily more profitable than $\kappa_1$. This is because if capital is very expensive (high $r$), the wasted capital can be costly enough to outweigh the extra output produced.

For a given production technique $\kappa$, we have $\sigma = -d\ln (k/\kappa) / d\ln (r/w)$. In the limit case $\sigma \to 0$, the mismatch $k/\kappa$ is not responsive to changes in the relative factor price, $r/w$. In the case of $\sigma \to 1$, the assimilation is so flexible that the unit cost always remains constant no matter how $r/w$ changes. A country’s local knowledge consists of a triple $\{P, \sigma, \tau\}$. If either $P$ is the universe menu $\mathcal{U}$, or $\sigma = 1$, we have the Cobb-Douglas global production function. In this case, $\tau$ is just the conventional TFP measure. In general, the other two components of local knowledge $P$ and $\sigma$ will change the TFP measure.

To apply the assimilation model for understanding world income differences, we suppose that firms can assimilate the manifest technique $(b, \kappa)$ of an advanced foreign global frontier, where $b = z\kappa^\alpha$. As a result, the menu $\mathcal{P} \subset \mathcal{U}$ is augmented by additional techniques from the global frontier aboard. Specifically, the assimilation process simply recovers one point of the foreign global production function, represented by the technique associated with $\kappa$. If the assimilation is perfect so that the domestic country recovers the whole global frontier production function, then we have $\sigma \to 1$ and $\tau = 1$. Therefore, the TFP wedge parameter $\tau$ measures the productivity difference after
the assimilation process, with a higher $\tau$ indicating less productivity loss after the assimilation.

### 3.2.1 Production Flexibility: A Remark

Just how production flexibility from assimilation may affect production efficiency? We would like to refer to a recent work by Uras and Wang (2014), who show that, given the techniques constraint $a^\psi_i b_i^{1-\psi} = z$, techniques ratio and factor inputs ratio are inversely related:

$$a_i = \left( \frac{\alpha}{1-\alpha} \right)^{\frac{1-\tau}{\tau}} \left( \frac{w}{r} \right)^{\frac{\tau}{1-\tau}} \left( \frac{K}{N} \right)^{-\frac{1-\tau}{\tau}}$$

Moreover, the unit cost of production can be solved as:

$$c(w, r) = \frac{1}{z} \left( \left( \frac{\psi}{\alpha} \right)^{\frac{\tau}{1-\tau}} \frac{r}{\psi} \right)^{\psi} \left( \left( \frac{1-\psi}{1-\alpha} \right)^{\frac{\tau}{1-\tau}} \frac{w}{1-\psi} \right)^{1-\psi}$$

In the limit cases with extreme flexibility measures, the unit cost of production converges to: (i) $\sigma \to 0$: $c(w, r) = \frac{1}{z} \left( \frac{r}{\psi} \right)^{\psi} \left( \frac{w}{1-\psi} \right)^{1-\psi}$; (ii) $\sigma \to \infty$: $c(w, r) = \frac{1}{z} \left( \frac{r}{\alpha} \right)^{\psi} \left( \frac{w}{1-\alpha} \right)^{1-\psi}$. Thus, while the factor prices are always weighted by technique usage shares ($\psi$ and $1 - \psi$), how much they affect the unit cost depend crucially on production flexibility. When flexibility is shut down ($\sigma \to 0$), the production technology (the CES aggregator) precludes technique-augmented factor inputs from substituting by each other. As a result, factor prices are deflated only by their technique usage shares. With a greater technique usage share, a factor price would not raise the unit cost of production as much. When flexibility is perfect, on the contrary, factor prices are deflated only by their income shares. In this case, an increase in the price of a factor with a greater income share would become less damaging to the unit cost of production.

Using the expressions above, one may obtain:

$$y_j^{Assim} = (1-\alpha)^{\frac{\sigma_j}{\alpha-1}} \tau_j^{Assim} b_i \left( 1 + \frac{r}{w} k_j \right)^{\frac{\sigma_j}{\alpha-1}}$$

(12)
where \( r \) and \( w \) are capital rental and labor wage, \( \tau_{j}^{\text{Assim}} \) measuring the relative TFP of country \( j \) to the assimilation target country \( s \), and \( b_{i} \) is a specific labor-augmented technique used by country \( j \). Thus, from (12), the variance of output per worker of country \( j \) \( (y_{j}^{\text{Assim}}) \) can be decomposed into three sub-components: the variance of the factor income ratio \( (rk_{j}/w) \), the variance of labor-augmented technique \( (b_{i}) \) and the variance of TFP \( (\tau_{j}^{\text{Assim}}) \).

Importantly, following the logics underlying Chart 1 and the optimization specified in \( \Pi (r, w) = \max_{\kappa} \{\pi (\kappa; r, w)\} \), assimilation of a global technology is now embedded in the parameter \( \sigma_{j} \) that entails the extent to which such an assimilation can be done effectively. More specifically, by applying Uras and Wang (2014) with \( \sigma \in (0, 1) \), production flexibility \( (\sigma_{j}) \) can be shown to monotonically reduce the unit cost of production for any given pair of factor prices \( (w, r) \). This implies a positive impact of production flexibility on production outcomes. That is, greater flexibility in a country is, other things being equal, expected to be associated with a smaller TFP gap from the frontier economy.

### 3.3 Assimilation of a Global Frontier

We define the global frontier as the country with a universe menu \( \mathcal{U} \), where the production function has the Cobb-Douglas functional form, as shown in the previous section. Suppose that firms can assimilate the manifest technique \( (b, \kappa) \) of the global frontier, where \( b = \tau\kappa^{\alpha} \). As a result, the menu \( \mathcal{P} \subset \mathcal{U} \) is augmented by additional techniques from the global frontier. Specifically, the assimilation process of global technology simply recovers one point of the global frontier production function, represented by the technique associated with \( \kappa \). If the assimilation is perfect so that the domestic country recovers the whole global frontier production function, then we have \( \sigma \to 1 \) and \( \tau = 1 \). Therefore, the TFP wedge parameter \( \tau \) measures the productivity difference after the assimilation process, with a higher \( \tau \) indicating less productivity loss after the assimilation.
According to (8), we can formulate an endogenous TFP using the global frontier technique as follows:

\[
    z \left( \frac{k}{\kappa}, \sigma, \tau \right) \equiv \frac{F_k(k, 1)}{k^\alpha} = \tau \tilde{z} \left( \frac{k}{\kappa} \right)^\sigma \left[ \alpha \left( \frac{k}{\kappa} \right)^{\frac{\sigma-1}{\sigma}} + 1 - \alpha \right]^\frac{\sigma}{\sigma-1}.
\]  

When a country assimilates the frontier technique \((b, \kappa)\), its TFP measure, \(z \left( \frac{k}{\kappa}, \sigma, \tau \right)\), becomes endogenous and contains two effects: (i) a conventional TFP effect, captured by \(\tau\); and (ii) an assimilation effect, jointly captured by the assimilation parameter \(\sigma\) and the mismatch or capital waste \(k/\kappa\) depending on the limitation on \(P\). Clearly, adopting and assimilating the frontier technique may not always lead to a higher TFP than autarky. As the assimilation ability of a country decreases (thus \(\sigma\) decreases), the endogenous TFP measured by \(z\) also decreases. Moreover, the endogenous TFP is lower when the factor endowment is further away from the input required by the advanced foreign technique (i.e., \(|k - \kappa|\) increases).\(^6\)

Interestingly, in the case of perfect assimilation, \(\sigma \to 1\) and \(z = \tau \tilde{z}\); this is the example used by Lucas (2000) for development accounting. In contrast, the extreme case of no assimilation, i.e., \(\sigma \to 0\) and \(z = \tau \tilde{z} (k/\kappa)^{1-\alpha}\), becomes a special case of BWA.

It is noteworthy that, throughout our analysis, we have used the country-specific representative-producer setup that is typically used in development accounting, including in our main reference points, in Lucas and in BWA. For completeness, however, we would like to provide a brief discussion on what happens if firms within a country are heterogeneous. Let us maintain the assumption that the share parameter \(\alpha\) is global and the elasticity parameter \(\sigma\) is country-specific but common to all domestic firms. However, firms may have different menus of techniques and different endowment ratios, that is, \(k/\kappa\) may be firm-specific. From (13), the term capturing the assimilation ef-

\(^6\)It is straightforward to show that \(\partial z/\partial \sigma > 0\) and \(\partial z/\partial (k/\kappa) > 0\) iff \(k < \kappa\).
fect is hump-shaped in $k/\kappa$, reaching the maximum of one at $k/\kappa = 1$. It is strictly concave for $k/\kappa < 1$ and turns from strictly concave to strictly convex when $k/\kappa$ becomes sufficiently larger than one. Suppose that all firms have a menu with $k/\kappa < 1$, and therefore suffer mismatch losses. Then, by Jensen’s inequality, the average of the assimilation effects associated with all of the different firms is smaller than the assimilation effect associated with the average (representative) firm. In this case, the assimilation effects become weaker when they are aggregated over heterogeneous firms. In contrast, suppose that all of the firms have values of $k/\kappa$ that far exceed one, with severe capital waste. Then the average of the assimilation effects associated with all of the firms is larger than the assimilation effect associated with the average firm, implying stronger assimilation effects in the presence of firm heterogeneity. In general, the conclusion becomes ambiguous; nonetheless, the gap between heterogeneous and representative firms tends to narrow as $\sigma$ increases. That is, the distributional effects from firm heterogeneity become smaller under greater production flexibility. When heterogeneous firms are free to choose any production techniques drawn from independent Pareto distributions, we have the Cobb-Douglas production function as in Houthakker (1956-57), Kortum (1997), and Jones (2005) and the accounting exercise reduces to Lucas (2000).

4 Development Accounting

Suppose that the reference country, the U.S., is on the frontier of technology, that is, having the collection of the highest $a$ and $b$. So the U.S. uses its own domestic technology and does not adopt any foreign technique. The US output is $y_{US,t} = z_{US,t}k_{US,t}^\alpha$. We allow the US productivity and per capita capital to change over time, as denoted by the subscript of year $t$.

In addition to the Lucas (2000) benchmark, our specification of technology assimilation is also related to the concept of localized technological changes proposed by Atkinson and Stiglitz (1969). Recently, Basu and Weil (1998)
elaborate on this idea of inappropriate technology in the Solow growth model, where appropriateness is defined in terms of capital intensity: a technology is appropriate for one and only one capital-labor ratio. The intuition is that frontier technologies are generally designed in reference to a specific capital intensity. For instance, if the technology is developed for high-capital-intensive production in advanced economies, then adopting it is not appropriate for developing countries because the production taking place in developing countries is usually high-labor intensive. We compare the assimilation model with the models of Lucas (2000) and Basu and Weil (1998). Finally, given that our production function under assimilation takes a CES specification, we also study a version of Lucas (2000) where output are produced with standard CES technologies in all countries.

The Assimilation Model. If the US technique is assimilated, the relative income $q_{j,t}$ of country $j$ to the frontier captured by the U.S. in year $t$ is

$$q_{j,t} = f_j(k_{j,t}; k_{US,t}, z_{US,t}, \tau_j^{Assim}, \sigma_j) = \tau_j^{Assim} \left[ \frac{\sigma_{j-1}}{\sigma_j} \left( \frac{k_{j,t}}{k_{US,t}} \right)^{\frac{\sigma_{j-1}}{\sigma_j}} + (1 - \alpha) \right].$$

Note that we now allow the TFP distortion parameter $\tau_j$ and the assimilation parameter $\sigma_j$ to be country specific, and they will be investigated by the development accounting exercise.

The relative capital-labor ratio $k_{j,t}/k_{US,t}$ in the relative income expression above must be recognized as a techniques-augmented factor proportion: the effective factor of the country $j$ in terms of the input required by the US technique. Here, the decisions on assimilated foreign techniques and optimized factor demands are made jointly. This techniques-augmented factor proportion and the elasticity of substitution between the two techniques-augmented factor inputs capture the process of technology assimilation. One should not view our techniques-augmented factor proportion as one that simply measures the capital accumulation effect relative to the reference country because of its
different meaning from the conventional literature.

**The Lucas Model.** In this case, countries produce output according to their domestic production functions so that the income ratio becomes

\[ q_{j,t} \equiv \frac{f_j(k_{j,t}; k_{US,t}, z_{US,t}, \tau_{j}^{Lucas})}{y_{US,t}} = \tau_{j}^{Lucas} \left( \frac{k_{j,t}}{k_{US,t}} \right)^{\alpha}. \]  

(15)

Note that the calibration exercise based on (14) has Lucas (2000) as a special case of \( \sigma = 1 \). We denote \( \tau_{j}^{Lucas} \) as the corresponding TFP distortion parameter in the Lucas model.

**The CES Model.** To allow for more flexibility into the Lucas benchmark, suppose that all countries’ output are given by the standard CES production functions:

\[ y_{j,t} = z_{j,t} \left[ \alpha \left( \frac{k_{j,t}}{k_{US,t}} \right)^{\frac{\epsilon_{j}-1}{\epsilon_{j}}} + 1 - \alpha \right]^{\frac{\epsilon_{j}}{\epsilon_{j}-1}}. \]

In order to compare with the BWA and assimilation models, we apply the idea of normalized CES technique to the US economy so that \( \epsilon_{US} = 1 \) and hence \( y_{US} = z_{US} (k_{US})^{\alpha} \).

Since normalization per se does not have any implications on technology adoption, we do not impose any restriction on the parameterization of \( \epsilon_{j} \). Thus, the resulting \( \epsilon_{j} \) can take on values that are either greater or less than unity. The relative income is given by

\[ q_{j,t} \equiv \frac{f_j(k_{j,t}; k_{US,t}, z_{US,t}, \tau_{j}^{CES}, \epsilon_{j})}{y_{US,t}} = \tau_{j}^{CES} \left( \frac{k_{US,t}}{k_{US,t}} \right)^{-\alpha} \left[ \alpha \left( \frac{k_{j,t}}{k_{US,t}} \right)^{\frac{\epsilon_{j}-1}{\epsilon_{j}}} + 1 - \alpha \right]^{\frac{\epsilon_{j}}{\epsilon_{j}-1}}. \]

(16)

Again, note that the Lucas case is a special case of the CES model, where \( \epsilon_{j} = 0 \).

**The BWA Model.** To compare the concept of inappropriate technology with our assimilated technology, we follow the specification of Acemoglu (2009) to have the following intensive production function of country \( j \):

\[ f(k_j, k_s) = \tau_{j}^{BWA} z_{s} \min \left[ 1, \left( \frac{k_j}{k_s} \right)^{\epsilon_{j}} \right] \left( \frac{k_j}{k_s} \right)^{\alpha}, \]

(17)

where \( k_s \) is the level of foreign capital designed for the technology with TFP \( z_{s} \).
in the source country $s$, and $\zeta_j \in [0, 1]$ captures the degree of inappropriateness of the foreign technology. As $\zeta_j$ increases, the inappropriateness increases so that the productivity of the adopted technology and thus the domestic production is reduced. Again the TFP wedge parameter $T_j^{BWA}$ captures the net efficiency in overall production after the adoption of the inappropriate technology. Setting the U.S. as the source country implies that the per capita income ratio of country $j$ relative to that of the U.S. is

$$q_{j,t} = \frac{f_j(k_{j,t}, k_{US,t}, z_{US,t}, T_j^{BWA}, \zeta_j)}{y_{US,t}} = T_j^{BWA} \left( \frac{k_{j,t}}{k_{US,t}} \right)^{\alpha + \zeta_j}. \quad (18)$$

We will compare the calibration and development accounting results between the BWA model and our assimilation model. Again, note that the Lucas case is a special case of the BWA model, where $\zeta_j = 0$.

4.1 Data, Parameterization, and Methodology

We use the Penn World Table 8.0 (PWT) over the period of 1970 to 2011. The first 10 years of the data (1960 to 1969) are discarded to calculate the initial level of capital as in standard real business cycle exercises. We exclude former USSR countries (data do not start in 1970) and all OPEC countries (due to nonstandard economic responses similar to the concern with the financial tsunami). For China, we use the Version 2 data. In the end, we have a panel of 151 countries over a time span of 38 years.

Following Hall and Jones (1999), we set $\alpha = 1/3$ and 6% as the depreciation rate of capital to calculate the level of capital from the investment data in PWT. Bearing in mind the potential endogeneity problem when recovering parameters from the data of output and capital, we calibrate the TFP wedge parameter $T_j$ and the assimilation parameter $\sigma_j$ to match the average level of log ($q_{i,t}$) and the average lag difference of log $q_{i,t}$ (thus matching the long-run income gap with respect to the US and the long-run growth rate of the income
Similarly, we calibrate the productivity ratio $\tau_i$ and the inappropriateness parameter $\zeta_i$ of the BWA model to match the average level of $\log(q_{i,t})$ and the average lag difference of $\log q_{i,t}$. The Lucas model only has one free parameter, and we calibrate the productivity ratio $\tau_i$ to match the average level of $\log(q_{i,t})$. (See Appendix B for detailed calibration steps)

Conventionally, in the development accounting literature, fitness is measured by the success rate:

$$S = \frac{\text{var(explained component of log(income ratio))}}{\text{var(log(income ratio))}}.$$  

Note that this measure crucially depends on the magnitude of the variance of the explained component of log(income ratio), which cannot reflect any bias in the explained component. For example, consider $\log \hat{y} = \beta + \log y$, where $\beta \neq 0$. Then, we have $S(\hat{y}) = 1 = S(y)$; i.e., $\hat{y}$ and $y$ are equivalently good fit to $y$. To rectify this problem, we propose a mean squared error ($MSE$) measure over the period of interest $t = 1, \ldots, T$:

$$MSE \equiv \sqrt{\frac{1}{T} \sum_{t=1}^{T} \text{[error]}_t^2}. \quad (19)$$

Specifically, $MSE$ captures the income ratio that cannot be captured by the explained component. Although $MSE$ is not a normalized measure and can be greater than one, it is a measure that will not suffer the bias problem mentioned above. Therefore, whenever bias may be present, we shall use the $MSE$ measure as the criterion to judge the fitness of the model. In the Appendix, we compare

### 4.2 Results

The average of our calibrated values of the productivity ratio $\tau_j$ and the assimilation parameter $\sigma_j$ are reported in Table 1. The average values are based on various groupings of countries: (i) initial stage of development measured
by the income ratio (real GDP per capita relative to that of the U.S.) in 1970 (< 10%, 10% – 20%, 20% – 50%, and > 50%); (ii) speed of development measured by the average growth rate from 1970 to 2011 (< 0%, 0% – 1%, 1% – 2%, 2% – 4%, and > 4%); (iii) current state of development measured by the income ratio in 2011 (< 20%, 20% – 40%, 40% – 60%, 60% – 80%, and > 80%). As an illustration, Figure 1a (1b) plots the MSEs of the BWA (CES) model and our assimilation model based on different country groupings of their average growth rates. We have adjusted the number of categories from five to four by combining the first two groupings (< 0% and 0% – 1%) for better graphical display.\footnote{Similar plots that based on groupings of income levels, either initially (1970) or currently (2011), are demonstrated in the Appendix.}

The results suggest that the fitness of our assimilation model based on our constructed $MSE$ measure is very good: the averaged value of our $MSE$ measure in all different groups ranges from 0.09 to 0.21. Interestingly, the best fitness is obtained for countries experiencing moderate to fastest growth ($MSE = 0.09$ for those growing at a rate between 2% and 4% annually) or for those in the upper-middle income group ($MSE = 0.09$ and 0.08, respectively, for those reaching more than 50% of the US real GDP per capita in 1970 and 60% to 80% in 2011). For the countries experiencing non-positive growth, the performance of our model is the least ($MSE = 0.21$), although the other approaches behave the same.

Next, we examine the assimilation parameter $\sigma_j$ that measures the flexibility of production in (techniques-augmented) factor substitution. Three observations are noticeable. First, the best-fitting countries in income levels (those with the least $MSE$), either initially (1970) or currently (2011), have the highest assimilation measures (with average $\sigma_j$ of 0.78 and 0.73 respectively). Our finding suggests that these economies enjoy high per capita income levels due to their successful assimilation. Second, the average speed of growth (1% to 2%) have the highest assimilation measures (average value of $\sigma_j$ is 0.85). This finding is intuitive: overall, the development success of
these countries hinges heavily on whether or not they can assimilate and move toward the world frontier. Third, the growth miracles (countries growing more than 4% annually) have the lowest measure in assimilation (average values of $\sigma_j$ is only about 0.38). At the first glance, the result is puzzling and thus deserves further country-by-country studies.

Let us look at our calibrated TFP ratio. Note that the calibrated $\tau_j$ is a good measure of relative technology only if the fit is good; otherwise, a significant part of this measure captures information contained in unexplained error terms. Many of such cases with poor fit generates extreme values of $\tau_j$. Keeping in mind this measurement issue, we must neglect the groups with large standard deviations (particularly those with standard deviations exceeding 1). We can then draw two inferences. First, not surprisingly, countries with higher income ratios either initially or currently have higher TFP ratios. Second, the slowest growing ($< 0\%$, and $0\%$ to $1\%$) economies exhibit the highest TFP ratios.

### 4.2.1 A Comparison

By comparing the $MSE$ measures across the four models in Table 1, we can see that although it is not surprising that both our assimilation model and the BWA model fit far better than the Lucas benchmark, our model, on average, outperforms the BWA model in essentially all economic and geographic groups (i.e., initial stage of development, development speed, and current state of development). The advantage of using our assimilation model is the greatest for two groups of countries in terms of the average growth rate. Figure 1a highlights the fact that trapped countries with average growth below $1\%$ (or even negative growth) as well as those experiencing development miracles, with an average growth that exceeds $4\%$, work very well with our model. Specifically, as shown in the upper left and lower right panels, almost all the data lie above the $45^\circ$ line.\(^9\)

\(^9\)For the group of different initial income levels, as shown in the upper left panel of Figure A1a, our assimilation model provides the best fit for countries falling in development traps
Next, for the CES model, the results suggest that the overall fitness of our assimilation model based on our constructed $MSE$ measure, on average, outperforms it in essentially all economic groups (i.e., initial stage of development, development speed, and current state of development).\textsuperscript{10} For instance, for the groups of countries based on different growth rates, the averaged value of our $MSE$ measure in all different growth-rate groups ranges from 0.09 to 0.21, compared with the CES case of 0.10 to 0.31. In particular, for trapped countries, the performance of our model is the least ($MSE = 0.21$), but still out-performed the Lucas case of 0.31. The same comparative result applies to the case of fastest-growing countries: we have $MSE = 0.12$ whereas the Lucas case yields $MSE = 0.24$. Finally, for the moderate growing economies, i.e., with growth rates averaging $1\% - 2\%$ and $2\% - 4\%$, the fitness results of $MSE$ in the CES case improve a lot: the $MSE$ are 0.12 and 0.10 respectively. Our $MSE$ for these groups are given by 0.13 and 0.09 respectively. It seems that assimilation may not be the main story for growth of these countries.\textsuperscript{11}

In terms of different stages of development, the advantage of using our assimilation model is the greatest for the low income country groups, both in terms of the initial level of income and the current level of income. For the former group, our assimilation model provides the best fit for countries falling in development traps with less than 10\% of the US real GDP per capita in 1970 ($MSE = 0.14$ compare to $0.18 - 0.21$ in the other three cases). Similarly, for the latter group, trapped countries with at least 40\% of the US real GDP per capita in 2011 work very well with our model ($MSE = 0.14$ compare to $0.17 - 0.19$ in the other three cases for countries with relative income of 20\% and less in 2011, and 0.11 compare to 0.16 for countries with relative

\ \textsuperscript{10}There are two exceptions. The first one is the group of initial income (in 1970) that are above 50\% of the US income. The second group is those countries whose average growth rates are between 1\% and 2\%.

\ \textsuperscript{11}But BWA performs worse for these countries where the $MSE$ are 0.15 and 0.12 respectively.
income between 20% and 40%). As a matter of fact, our assimilation model also fits at least as good as the other three models for countries in other stages of development, except for those initially rich countries whose real GDP per capita in 1970 were above 50% of the US (our \(MSE = 0.09\) compare to 0.08 in the CES case).

4.2.2 Assimilation Dynamics: A Preview

Let us take a first look at assimilation dynamics along economic development. Recall the income of country \(j\) relative to the US frontier in year \(t\):

\[
q_{j,t} = \tau_{j,t} \left[ \alpha \left( \frac{k_{j,t}}{k_{US,t}} \right)^{\frac{\sigma_{j} - 1}{\sigma_{j}}} + (1 - \alpha) \right]^{\frac{\sigma_{j}}{\sigma_{j} - 1}}.
\]

By defining \(k_{j,US,t} \equiv k_{j,t}/k_{US,t}\), log-linearization then produces

\[
\dot{q}_{j,t} = \dot{\tau}_{j,t} + \pi_{j,US,t-1} \dot{k}_{j,US,t},
\]

(20)

where \(\pi_{j,US,t} \equiv \alpha \left( k_{j,US,t} \right)^{\frac{\sigma_{j} - 1}{\sigma_{j}}} / \left[ \alpha \left( k_{j,US,t} \right)^{\frac{\sigma_{j} - 1}{\sigma_{j}}} + (1 - \alpha) \right]\) is the relative capital share of country \(j\) under CES assimilated technology. As \(\pi_{j,US,t-1}\) is time varying, we define \(\log \left( k_{j,US,t} \right) \cdot \Delta \pi_{j,US,t-1}\) as the measures the assimilation dynamics of country \(j\), where \(\Delta \pi_{j,US,t-1} \equiv \pi_{j,US,t} - \pi_{j,US,t-1}\).

A Remark on the CES Specification. The growth accounting decomposition of the CES case based on (16) is given by

\[
\dot{q}_{j,t} \cong \dot{\tau}_{j,t} + \ddot{\pi}_{j,t} \dot{k}_{j,t} - \alpha \dot{k}_{US,t}
\]

\[
= \dot{\tau}_{j,t} + \alpha \dot{k}_{j,US,t} + (\ddot{\pi}_{j,t} - \alpha) \dot{k}_{j,t}.
\]

(21)

where

\[
\ddot{\pi}_{j,t} \equiv \frac{\alpha \left( k_{j,t} \right)^{\frac{\sigma_{j} - 1}{\sigma_{j}}}}{\alpha \left( k_{j,t} \right)^{\frac{\sigma_{j} - 1}{\sigma_{j}}} + 1 - \alpha}.
\]

It is noted that the assimilation dynamics between the two CES specifications, captured by the RHS terms of (20) and (21), are very different.
5 Assimilation Dynamics

In this section, we conduct growth accounting and country-specific studies and examine the assimilation dynamics facing each country over its development process. Upon studying each country’s development experiences and institutions, we then modify the assimilating target most relevant to each country. We also provide country-by-country case studies for understanding why in some occasions a country’s relative performance is difficult to explain based on our development and growth accounting exercise in the Appendix.

To elaborate on this without overkill using the entire sample, we select several representative countries from each of the following geographic clusters:

(i) OECD countries: the three leading players, namely, France, Germany, and the U.K., and three less dominant ones, Greece, Portugal, and Spain;

(ii) Development miracle countries - Early Birds (all countries from Asia that are relatively more advanced than others): Japan and the newly industrial economies (NIEs) that are known as the four Asian Tigers, namely, Hong Kong, Singapore, South Korea, and Taiwan;

(iii) Development miracle countries - Late Comers (two from Africa and five from Asia; all relatively less advanced compared with miracle countries Set 1): two African miracles, namely, Botswana and Mauritius, three ASEAN miracles, namely, Malaysia, Thailand, and Vietnam, and two Asian giants, namely, China and India;

(iv) Trapped countries (five from sub-Saharan Africa and one from South Asia): Comoros, Cote d’Ivoire, Ghana, Kenya, and Uganda;

(v) Latin American economies: the major four economies, namely, Argentina, Brazil, Chile, and Mexico, plus two relatively unsettled countries, namely, Colombia and Nicaragua.
Table 2 summarizes the results. By comparing the calibrated TFP ratios, we can see that for OECD countries (especially for the leading ones), the Lucas model performs relatively well. In general, no significant differences exist between our assimilation model and the Lucas-CES and BWA models. This finding is intuitive: these countries are arguably on or close to the frontier with few barriers or distortions; the same explanation applies to Japan under miracle Early Birds). In particular, the assimilation dynamics for the leading OECD countries are all zero, indicating further that these countries are producing using global technology. Therefore, neither assimilation nor appropriate technology could change the calibrated TFP much from the Lucas benchmark. For Latin economies, the findings are mixed, some with large differences (e.g., Argentina, Brazil, and Nicaragua) and others with small differences. In terms of the big four countries in this region, again, all three models perform the same in MSE, and their calibrated assimilation dynamics are also zero. However, this group is a very different case compared with the OECD group as it is hardly convincing to argue that the Latin American countries are on the technology frontier. This finding explains why we have to study the assimilation dynamics associated with country-specific growing experience (e.g., the inflationary environment and the external problem for the Latin American group). For all other groups, our model has significant improvements over the two alternatives for most countries.

5.1 Development Stage and Assimilation Dynamics

By studying various groups of countries at different development stages, we can further investigate their assimilation dynamics over the past three decades. We report this “assimilation dynamics” pattern in Table 2, where assimilation dynamics is *strong* if its absolute value is above 0.2 and *weak* if its absolute value falls in the range of 0.03 to 0.1.

It is not surprising that all OECD countries except Portugal have either no change in assimilation or exhibit only weakly positive assimilation dynam-
ics. The same applies to the most advanced early bird, that is, Japan. In these countries, their industries are mature and the growth of their producers depends much less on the improvement in assimilating the global technology.

On the contrary, many development miracles, whether early birds or late comers, exhibit either positive or strongly positive assimilation over the past three decades. Of particular interest are the two small-sized economies in the “Tale of Two Cities” (i.e., Hong Kong and Singapore) and one large-sized economy in the “Emerging Giant” (i.e., China) show little or weakly positive assimilation. This finding is understandable because Hong Kong is service industry-based, Singapore’s TFP is difficult to detect for whatever the reason (e.g., see the stimulating debates between Young (1995) and Hsieh (2002)), and China is the “World Factory” that accepts orders using the given foreign technologies. Whereas India exhibits weakly positive assimilation because its fast growth only began in the mid-1990s with most industries simply taking orders as China, Mauritius is a tour-based economy with little assimilation similar to Hong Kong. Among these development miracles, the two larger-sized Asian Tigers, namely, Korea and Taiwan, and the three “Emerging Tigers,” namely, Malaysia, Thailand and Vietnam, all exhibit strongly positive assimilation.

Several trapped economies, including Comoros, Cote d’Ivoire, and Kenya, suffer backward (negative) assimilation: the lack of improvement in the assimilation of frontier technology. Moreover, even though their industries are not as productive as the OECD’s, Latin American countries have had little improvement in technology assimilation. This finding may explain why many of them are lagged compared with East Asian fast-growing economies.

Remark: We can further examine $\sigma_i$ to obtain better insight on assimilation dynamics, which depends on the substitutability of production inputs in a complicated manner (refer to the definition of $\pi_{i/US,t}$ in Section 4.2.2). Table 2 does not exhibit any stable pattern over economic/geographic clusters. According to Table 2, production flexibility and assimilation dynamics need not go hand in hand. However, of particular interest are the patterns of
production flexibility among miracle countries. All miracle countries exhibiting strongly positive assimilation dynamics are associated with a relatively flexible production. On the contrary, those exhibiting little assimilation have calibrated elasticities of the factor substitution close to zero (i.e., Hong Kong, Singapore, China, and Mauritius). So the two larger Asian Tigers (i.e., Korea and Taiwan) are more flexible in (techniques-augmented) factor substitution than the two smaller Tigers (i.e., Hong Kong and Singapore), whereas that the software-led Indian industry is more flexible than the assembly-based Chinese economy.

5.2 Growth Accounting

To gain insight into the role played by assimilation, we decompose relative income growth into three underlying driving forces, namely, neoclassical capital accumulation, technology assimilation, and residual TFP. We again use expression (20) derived in Section 4.2.2. From a growth accounting perspective, we take the annual variation and average the contributions of each component to obtain the growth accounting results. For the purpose of comparison, we conduct similar exercises, decomposing the relative income growth rate based on the BWA into neoclassical capital accumulation, adoption inappropriateness, and residual TFP. The results are reported in Table 3.

Overall, technology assimilation plays an important role by contributing to growth in many countries. In all countries that have experienced faster growth (over 4%), the contribution of assimilation is substantial. In countries that have experienced negative growth, the contribution of backward assimilation is also very large. Specifically, in miracle countries, approximately half of income growth relative to the U.S. can be attributed to technology assimilation. In trapped economies, negative assimilation accounts for more than 40% of their negative growth outcomes.

Relative to the BWA model, our assimilation framework reduces the contribution of the unexplained residual TFP component to relative income growth,
especially for the miracle and the trapped countries; compared to the CES
model, the reduction in the unexplained residual TFP is substantial. More-
over, in the Appendix, we document that our positive and negative assimilation
clearly fit the development experiences of countries in various categories.\textsuperscript{12}

5.3 Country-Specific Assimilation Dynamics

We now examine assimilation dynamics linked to country-specific environment
and development process. Rather than simply assimilating the world frontier
technology (the U.S.), we study how a country can move up according to a
growth ladder. Moving up is done by adopting the technology of the country
in the next upper-tier in geographical proximity and with strong international
interrelationships. Such an assimilation is a result of learning by observing
the success of earlier adopters at similar innovation stages in the region (see
Rogers (1983)) and/or of spatially dependent costs of adoption (see Comin,
Dimitriev and Rossi-Hansberg (2012)).

The modification of the basic assimilation scheme consists of three alter-
natives, depending on the experiences facing different developing countries:

(i) While maintaining the same assimilation-targeted country (the U.S.), we
may allow a country to start assimilating late (the laggards) or to stop
assimilating at a given point in time (the fast advancers);

(ii) We may allow a country to assimilate a foreign technology leader in
geographical proximity;

(iii) We may allow a country to assimilate one or more targeted countries at
different stages based on the strength of its international ties with these
targeted countries.

\textsuperscript{12}To determine the importance of technology assimilation in driving the variation of rel-
ative income growth, we also decompose the variance of the relative income growth rate
into the same three underlying driving forces: neoclassical capital accumulation, technology
assimilation, and residual TFP. To save space, all the details are presented in the Appendix
C.
We restrict our attention to the episodes of the miracle countries and the trapped economies. For the OECD countries, as explained earlier, our assimilation model does not provide any significant value added to the calibrated TFP of the Lucas model (Figure A8 in the Appendix). For the Latin American countries, many of them have experienced, at some stages, high or hyper-inflation over the past half century. Although both the BWA and our benchmark assimilation models significantly outperform the Lucas model, the fitness is not applicable to miracle and trapped economies. We omit the detailed analysis on these two groups of countries.

In what follows, we document key economic conditions and institutions relevant to our study for each individual country and focus on two miracle groups. We present the details in Appendix D and E. Then, by considering geographical proximity and international interrelationships, we propose an alternative assimilation (to an alternative country) to replace the US frontier technology in the benchmark case. Based on our MSE criterion, we explore whether the proposed assimilation can perform better than the benchmark one in terms of accounting for the upturns and downturns in the growth dynamics. We then summarize the results in each of the three clusters.

5.3.1 Miracle Countries: Early Birds

Japan led the group of rapidly growing economies, creating an interesting class of “Asian Economic Miracles” that have been intensively studied in development economics. In terms of $MSE$, the assimilation model provides the best fit, although the corresponding calibrated TFP is not significantly different from the alternatives. The calibrated assimilation parameter $\sigma$ is 0.49, which implies that factor accumulation may matter more in growth performance. This finding is caused by the lost decade of the country since 1990s, as technology adoption was no longer the main contributor to growth.

As thoroughly documented by Uchida (1991) and Wan (2007), Japan assimilated the U.S. to advance its technologies in many of its major industries
(e.g. electronics) since the late 19th century. In the 1960s and the 1970s, Japanese FDI went to Taiwan first and then to South Korea and Hong Kong for “efficiency seeking” and “market seeking.” In the late 1970s, Japanese firms have expanded production facilities to Singapore, where American semiconductors operated at that time and suppliers were concentrated. Learning from the success of neighboring economic giant, Japan, the Asian Tigers followed Japanese footsteps, realizing that export expansion is the main momentum to growth. Particularly, Weiss (2005) notes a wave of Asian countries after Japan that illustrates the successful application of ELG: (i) first tier of Asian Miracle countries, namely, Taiwan, South Korea, Hong Kong, and Singapore, whose takeoff began in the 1960s, (ii) second tier, namely, Thailand, Malaysia, Philippines, and Indonesia, whose takeoff began in the 1980s, and (iii) the 1990s wave, featuring China and, to a lesser extent, Vietnam. These Asian growth experiences exhibit the “Flying Geese” Pattern (FGP) of economic development, as documented by Akamatsu (1962). Therefore, we shall refer to Japan and Asian Tigers as the “Early Birds” of development miracles.

As shown in Table 2, the assimilation story best fits the growth experience of Asian Tigers according to $MSE$ measures. In terms of calibrated $\sigma$, South Korea and Taiwan have a higher assimilation ability than Hong Kong and Singapore, which is consistent with the fact that the former group is manufacturing based and the latter is service oriented.

Figure 2 reports the assimilation dynamics based on the world technology frontier (the U.S.). Our model fits well for each country’s development process. In the case of Japan, the Lucas benchmark, the CES and BWA model fit well already ($MSE = 0.15$). Our model is even better on the margin ($MSE = 0.09$). In the case of Hong Kong, the performance of the Lucas benchmark and the CES model are almost the same ($MSE = 0.17$); the BWA model fits better ($MSE = 0.14$); our model is even better ($MSE = 0.12$). The structural transformation can account for the downward bias of the assimilation model since the 1980s as well as the low calibrated $\sigma$. As shown
in Figure 2, Hong Kong has suffered three noticeable downturns. The first is the Sino-British Joint Declaration in 1984 of the return of Hong Kong to China that triggered sizable capital flights and skilled labor emigration. The second is the Asian financial crisis that hit Hong Kong in the summer of 1998, causing both currency and housing market crises. Third is the severe epidemic (i.e., SARS) that broke out in 2003, damaging the operation of Hong Kong businesses across the board and specifically hurting the tourism industry. In the cases of Singapore, South Korea, and Taiwan, the BWA framework fails to improve on the baseline Lucas model. For Singapore, the assimilation model perform well in terms of the dynamics until the 1985 recession. Since the new millennium, the development of the high-tech industries has pushed out the technology frontier of the country far enough so that it may even be ahead of those of the U.S. As a result, assuming the U.S. as the frontier economy can become a misspecification for the sample period since the first half of the 2000s. The dynamics of the assimilation model has outperformed the alternatives for the sampling period for both Korea and Taiwan. The only drawback of Korea is the 1997 crisis. However, the strong influence of Japan on its initial economic development until the 1980s may be worth taking into consideration in optimizing the assimilation model for its application to the Korean and Taiwan experience.

Modified Assimilation Schemes Based on the above documentation, we can draw the following conclusions on technology assimilation by geographical proximity and by international interrelationships: (i) Hong Kong assimilated the U.S. until 1992, when its joint operation with China became the dominant force; (ii) South Korea assimilated Japan until 1980 and then assimilated the U.S.; (iii) Singapore assimilated the U.S. until 2002, when the country caught up with the technology frontier; (iv) Taiwan assimilated Japan until 1980 and then assimilated the U.S.

In the Appendix D, we calibrate the assimilation dynamics of the Asian
Tigers according to geographical proximity and international interrelationships. For all countries but South Korea, the alternative assimilation results fit better than their benchmark. The alternative assimilation is particularly better performed in the case of Hong Kong. Specifically, our benchmark assimilation setup under-predicts the relative performance of Hong Kong to the U.S. since the late 1970s when China adopted its open policy. This downward bias is corrected when we stop the close tie between the U.S. and Hong Kong after the 1992 reform by China. However, for the other members of the Asian Tigers, the benchmark assimilations already perform well so that the alternative assimilations do not lead to a significant improvement: for Singapore, the \( \text{MSE} \) improves slightly from 0.11 to 0.08; for Taiwan, the \( \text{MSE} \) remains about the same as 0.08; for South Korea, the \( \text{MSE} \) actually gets worse from 0.06 to 0.1.

### 5.3.2 Miracle Countries: Latecomers

Aside from geographical proximity, international interrelationships are essential in determining the technology assimilation pattern of LDCs. FDI from more advanced countries is a good indicator to measure how enterprises of developing countries can benefit from more advanced source countries, not only in the financial but also in the technological aspects.

For the ASEAN countries, Singapore was the largest FDI source country. Within the ASEAN, 63.7% of source FDI is from Singapore and more than 34% of outward FDI from Singapore was directed to Malaysia. However, as these ASEAN countries further developed, especially over the past decade or two, they became more globalized and less dependent on its regional leader. For China, the introduction of the open door policy led to a huge relocation of Hong Kong’s labor-intensive industries to Guangdong province in the late 1970s. An overwhelming 90% of FDI in Guangdong was invested by entrepreneurs from Hong Kong. Under the export-oriented growth strategy of China, other East Asian early-starters, especially Taiwan, also began to relocate and diversify
their costly production bases. As regards India, between 1950 and 1990, the government implemented restrictive trade, financial, and industrial policies and took control of major heavy industries. However, the well-known 1991 balance-of-payment crisis finally ended the protectionist policies and started the liberalization of the economy that resulted in its takeoff in the mid-1990s.

So far, the assimilation story seems to be all about Asian growth miracles. However, we believe that this should not be the case as the international interrelationships involved in the assimilation model, such as FDI and ELG, are universal.\textsuperscript{13} To address this issue, we apply our assimilation analysis to two African miracle countries, Botswana and Mauritius. Interestingly, to a large extent, our assimilation model also fits better because of its growing experience than the two alternatives.

As shown in Table 2, our assimilation model has the lowest MSE compared with the alternatives. It also provides reasonable improvement over the Lucas model in calibrated TFPs. In terms of the calibrated $\sigma$, only China and Mauritius yield extremely low values. The latter is a very small open economy that survives mainly on tourism. For China, the low calibrated $\sigma$ suggests that its growth performance depends heavily on factor accumulation, which we will study in more detail below.

In Figure 3, we report the benchmark assimilation dynamics of these latecomers, based on the world technology frontier (the U.S.). Our model fits best for the development processes of all six countries over the period of 1960 to 2007, compared with the BWA and Lucas alternatives. In the cases of the ASEAN countries Thailand, Malaysia, and Vietnam, our outperforming is obvious in terms of both $MSE$ and the calibrated $\tau$. For Malaysia, the assimilation model misses two episodes: 1) the scale-back adjustment and the economic transformation from agriculture and resource to manufacturing in

\textsuperscript{13}Nevertheless, the fact that the Asian miracle growth can be well accounted by the assimilation model supports the conclusion of Nelson and Pack (1999) that “the absorption or assimilation of increasingly modern technology and the change in industrial structure has been the critical component of this (miracle) process” (p.416).
the 1980s after the triple-digit growth in the 1970s, and 2) the Asian Financial Crisis era. In the case of Thailand, we are also unable to capture the dynamics associated with the Asian Financial Crisis. For China and Botswana, the performances of the BWA model and ours are close, and both are far better than the Lucas benchmark. For the Orient giant that is China, our assimilation model captures the dynamics well except for initial period of the 1960s. This finding may be due to the events of the Great Leap Forward and the Cultural Revolution. Nonetheless, our model still outperforms the alternatives in terms of \textit{MSE}. We interpret our low calibrated $\sigma$ to be consistent with the conventional view that the China growth is not technology based but investment based. The calibrated $\tau$, which is larger than unity, may indicate that, as the “World Factory,” China is subsidizing its technology adoption in production. For the African miracle that is Botswana, the assimilation model shows a downward bias in the 1990s because of the economic transformation caused by the diversification of the economy. Then, the overshoot of the assimilation dynamics followed is mainly caused by the major recession of the industrial sector that took place afterwards. Finally, in the case of India, the Lucas benchmark and the BWA model are similar, and both dominated by ours. Before the 1990s, all three models overshoot the assimilation dynamics. However, the assimilation model begins to have an increasing trend in 1990, outperforming the alternatives in terms of \textit{MSE} and calibrated $\tau$.

\textbf{Modified Assimilation Schemes} We report the assimilation dynamics, again based on the world frontier, geographical proximity, and international interrelationships inspired by the FGP of economic development: (i) Malaysia assimilated Singapore in 1985; (ii) Thailand assimilated Japan until 1991, and then it assimilated the U.S.; (iii) Vietnam assimilated either Japan or the Asian Tigers beginning 1996; (iv) China assimilated Hong Kong from 1978 and Taiwan after 1992; (v) India assimilated the U.S. beginning 1995; (vi) Botswana assimilated the U.K. (colonial origin).
The improvement of the assimilation dynamics calibrated based on geographical proximity and international interrelationships can be highlighted by the cases of Malaysia and Vietnam. Our alternative assimilation (i) for Malaysia reduces $MSE$ from 0.09 to 0.05, whereas alternative assimilation (iii) for Vietnam reduces $MSE$ from 0.07 to 0.02 (for the Japan case). This finding reflects the close economic interrelationship between these two adjacent economies. The alternative assimilation (ii) for Thailand because of the booming decade 1987 to 1996 of the Japan FDI also improves assimilation the dynamics, with $MSE$ increasing from 0.07 to 0.11. From (v), performing only the US assimilation since the economic takeoff of India improves the fitness is expected, reducing $MSE$ from 0.03 to 0.02. Nevertheless, for China and Botswana, the alternative assimilations do not yield much better outcomes.\(^{14}\)

### 5.3.3 Trapped Countries

Even with many emerging economies advancing their development statuses, many countries remain in the poverty trap, including many Sub-Saharan economies, which are our focus. In the Appendix D, we report the details of the assimilation dynamics based on either the world frontier or geographical proximity/international interrelationships. The results in Table 2 suggest that our assimilation model always yields better fitness outcomes than the BWA and Lucas models. In general, the growth performance of almost all countries can be understood as negative assimilation in our model (see Table 2). We further conduct an alternative calibration for each country by assimilating the country of their colonial origin in Figure A11b A5b in the Appendix, which can be compared with the benchmark in Figure A11a. Except for Comoros and Uganda, the alternative calibrations do not yield better fit.

\(^{14}\)See the Appendix D for further details of our modified assimilation analysis.
5.4 Summary

After examining the country-specific assimilation dynamics, we can conclude that most of the development miracles generally exhibit strongly positive assimilation over the past three decades (see Table 2). On the contrary, many of the trapped economies suffer backward (negative) assimilation; that is, the lack of assimilation of frontier technology is at least partly responsible for these countries to remain in poverty traps.

Based on growth rate decomposition exercises, we conclude that countries that experiencing faster growth have more substantial assimilation contributions; for miracle countries, about half can be attributed to assimilation. For trapped countries, except Ghana, negative assimilation accounts for about 40% of the negative growth performance.

Moreover, we characterize the calibrated elasticities of factor substitution (technique-augmented). Our main findings are summarized as follows: (i) no clear pattern of the magnitude of factor substitution over economic/geographic clusters exist; (ii) Korea and Taiwan are more flexible in techniques-augmented factor substitution than Hong Kong and Singapore; and (iii) India is more flexible than China.

In terms of assimilation dynamics, we further conclude the following: (i) for developing economies (especially those in Asia) where assimilation dynamics is either positive or strongly positive, the $\sigma$’s are reasonably high and the fitting is much better than the other two alternative models in terms of $MSE$; (ii) for zero or no assimilation, $\sigma$ is either insignificantly small (close to zero like Hong Kong and Singapore) or large (close to one like Germany and Chile); and (iii) for negative assimilation, then deciding on a relation is difficult because the calibrated $\sigma$ can go in either direction in terms of magnitude with good fitting (i.e., lowest $MSE$ like the trapped African countries).

Furthermore, by conducting alternative assimilation schemes, we find that (i) for development laggards, especially those experiencing development reversal from rich to poor, or those experiencing domestic unsettledness (including
several Latin American countries), allowing for delayed assimilation can improve the fitness of the model; (ii) for fast advancers, especially those moving up to peer with the world-leading developed countries (i.e., Hong Kong and Singapore), allowing for the early stop of assimilation can result in better fit; (iii) for the case of Taiwan, switching assimilation from targeting Japan to the U.S. yields significantly better fit, but such alternative scheme does not work for the case of Korea; (iv) for many countries in the latecomer group of development miracles (including several ASEAN economies and China), geographical or FDI-based assimilation can lead to much better model fitness outcomes, as advocated by the FGP; and (v) for most of the trapped economies, none of these alternative assimilations can improve the fit.

6 Concluding Remarks

In this paper, we have developed a technology assimilation framework in which technological advancement needs be accompanied by flexibility in production. By applying this technology assimilation approach to studying global technology and development accounting, we have shown that our assimilation model performs very well. It is not only much better than the Lucas benchmark but significantly dominates the BWA model especially, for trapped countries with consistently low income ratios throughout the sample period and for miracle countries with fast economic growth. Thus, we have identified the lack of assimilation of frontier technology as key to differentiating between poverty-trapped and fast-growing miracle economies. The main implication is clear: to pull a poor country out of the trap, we need an adequate provision of correct incentives and institutional settings that is crucial for domestic firms to assimilate relevant frontier technologies in a way that is suitable for their development stages. In particular, the establishment of science parks can be rewarding. This is because that with high tech firms clustering, local learning to the specific need can greatly enhance the effectiveness of technology assimilation. Additionally, the establishment of incentives to encourage know-how
and tacit knowledge that are essential for technology assimilation can further ensure technology advancement and sustained economic growth.

Along these lines are several interesting avenues for future studies, but for brevity we shall discuss only two. The first is to evaluate various human capital, industrial, and trade policies for their effectiveness to promote growth through the channel of technology assimilation. Specifically, our framework of techniques and technology assimilation may be incorporated with Jovanovic (2009) to explain the interdependence of vintage technology and human capital distribution. As a consequence, directional human capital policies may possibly affect cross-industry human distribution as well as manifest techniques, industry-specific assimilation, and vintage technology. Moreover, the promotion of key industries in some developing countries may possibly be harmful for growth because of the lack of proper and efficient assimilation. Furthermore, the reluctance to a further reduce in tariffs associated with imported technology may have differential effects on the development processes, depending on the flexibility in production and ability to assimilate world technologies. The second is to apply our framework to country-by-country analysis across sub-industries. As firms in different industries can be foreseen to have different frontier technologies and different assimilation process, the results obtained can be readily compared with those in the misallocation literature pioneered by Hsieh and Klenow (2009) and Restuccia and Rogerson (2008).

References


### Table 1: Comparison between Lucas, BWA and Our Assimilation Models (by various groups)

<table>
<thead>
<tr>
<th>Country Group</th>
<th>Assimilation Model</th>
<th>Lucas Model</th>
<th>BWA Model</th>
<th>Lucas-CES Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>sigma</td>
<td>sd(sigma)</td>
<td>tau</td>
<td>sd(tau)</td>
</tr>
<tr>
<td>1. By 1970 income</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;10%</td>
<td>0.56</td>
<td>0.40</td>
<td>0.55</td>
<td>0.59</td>
</tr>
<tr>
<td>10% - 20%</td>
<td>0.66</td>
<td>0.35</td>
<td>0.54</td>
<td>0.28</td>
</tr>
<tr>
<td>20% - 50%</td>
<td>0.44</td>
<td>0.43</td>
<td>0.84</td>
<td>0.40</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>0.78</td>
<td>0.36</td>
<td>0.94</td>
<td>0.25</td>
</tr>
<tr>
<td>2. By average growth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1%</td>
<td>0.41</td>
<td>0.40</td>
<td>0.82</td>
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<tr>
<td>1-2%</td>
<td>0.85</td>
<td>0.32</td>
<td>0.49</td>
<td>0.50</td>
</tr>
<tr>
<td>2-4%</td>
<td>0.67</td>
<td>0.36</td>
<td>0.69</td>
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<tr>
<td>&gt;4%</td>
<td>0.38</td>
<td>0.34</td>
<td>0.68</td>
<td>0.35</td>
</tr>
<tr>
<td>3. By 2007 income</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;20%</td>
<td>0.58</td>
<td>0.41</td>
<td>0.55</td>
<td>0.55</td>
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<tr>
<td>20-40%</td>
<td>0.64</td>
<td>0.41</td>
<td>0.63</td>
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<tr>
<td>40-60%</td>
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<td>0.44</td>
<td>0.83</td>
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<tr>
<td>60-80%</td>
<td>0.73</td>
<td>0.30</td>
<td>0.86</td>
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<tr>
<td>&gt;80%</td>
<td>0.60</td>
<td>0.44</td>
<td>1.08</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Table 2: Comparison between Lucas, BWA and Our Assimilation Models (by selected countries)

<table>
<thead>
<tr>
<th>Assimilation Model</th>
<th>Fitness</th>
<th>Lucas and BWA Models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BWA</td>
<td>CD</td>
</tr>
<tr>
<td>1. OECD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>0.69</td>
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</tr>
<tr>
<td>Germany</td>
<td>0.72</td>
<td>1.02</td>
</tr>
<tr>
<td>Greece</td>
<td>0.56</td>
<td>1.02</td>
</tr>
<tr>
<td>Portugal</td>
<td>0.35</td>
<td>1.03</td>
</tr>
<tr>
<td>Spain</td>
<td>0.54</td>
<td>1.03</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.68</td>
<td>1.02</td>
</tr>
<tr>
<td>2. Miracles: Early Birds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hong Kong</td>
<td>0.39</td>
<td>1.05</td>
</tr>
<tr>
<td>Japan</td>
<td>0.64</td>
<td>1.02</td>
</tr>
<tr>
<td>Korea, Republic of</td>
<td>0.16</td>
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</tr>
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<td>Singapore</td>
<td>0.29</td>
<td>1.05</td>
</tr>
<tr>
<td>Taiwan</td>
<td>0.16</td>
<td>1.06</td>
</tr>
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<td>3. Miracles: Late Comers</td>
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<td></td>
</tr>
<tr>
<td>Botswana</td>
<td>0.05</td>
<td>1.06</td>
</tr>
<tr>
<td>China</td>
<td>0.04</td>
<td>1.06</td>
</tr>
<tr>
<td>India</td>
<td>0.06</td>
<td>1.03</td>
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<tr>
<td>Malaysia</td>
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<td>1.05</td>
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<td>Mauritius</td>
<td>0.21</td>
<td>1.04</td>
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<tr>
<td>Vietnam</td>
<td>0.04</td>
<td>1.04</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.09</td>
<td>1.04</td>
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<tr>
<td>4. Trapped Countries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comoros</td>
<td>0.09</td>
<td>1.00</td>
</tr>
<tr>
<td>Cote d’Ivoire</td>
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<td>1.00</td>
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<td>Ghana</td>
<td>0.07</td>
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<td>Kenya</td>
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<tr>
<td>Uganda</td>
<td>0.05</td>
<td>1.00</td>
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<td>5. Latin America</td>
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<tr>
<td>Argentina</td>
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<td>Brazil</td>
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<td>Colombia</td>
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</tr>
<tr>
<td>Mexico</td>
<td>0.29</td>
<td>1.02</td>
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</tbody>
</table>
Table 3: Contribution to Growth according to Lucas, BWA and Our Assimilation Models

<table>
<thead>
<tr>
<th>1970 income income growth rate</th>
<th>average relative income growth rate</th>
<th>capital</th>
<th>assimilation</th>
<th>Lucas residual</th>
<th>inappropriately absorbed technology</th>
<th>BWA residual</th>
<th>Lucas-CES factor share</th>
<th>Lucas-CES residual</th>
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Table 3: Contribution to Growth according to Lucas, BWA and Our Assimilation Models

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<th>assimilation</th>
<th>Lucas residual</th>
<th>inappropriately absorbed technology</th>
<th>BWA residual</th>
<th>Lucas-CES factor share</th>
<th>Lucas-CES residual</th>
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Appendix
(Not Intended for Publication)

Appendix A: Mathematical Details

In this appendix, we provide the mathematical details of our analytical model. In particular, we cast the analysis in a deterministic environment and derive the following:

1. the assimilated technique given by (8) using the normalization procedure of Klump and de La Grandville (2000) for the CES function;
2. the production function before and after assimilating a foreign technique;
3. the assimilation parameter $\sigma$ given by (8) and showing that $\sigma \in [0, 1]$.

Recall a production technique, defined by two parameters of factor-augmented productivity, $a_i$ and $b_i$, which specify the quantity of capital ($K$) and labor ($N$) for producing output $Y$ after assimilation:

$$Y = \tilde{F}(a_i K, b_i N) = b_i N \tilde{F}(\frac{k}{\kappa_i}, 1),$$

where $\tilde{F}$ exhibits constant return to scales, $\kappa_i \equiv b_i/a_i$ and $k \equiv K/N$. Therefore, the technique $i$ is fully indexed by $(b_i, \kappa_i) \in \mathcal{P}$, where $\mathcal{P}$ is a compact set of techniques. For analytical convenience, we assume that the techniques are completely localized (Atkinson and Stiglitz 1969) so that they can be represented by a Leontief function as in Chart 1 (Houthakker 1956-57; Jones 2005). That is, we have $Y = b_i N \min(k/\kappa_i, 1)$ as given in (6).

Under technology assimilation, firms can modify $(b_i, \kappa_i)$ for a more profitable utilization of factor endowment $k$. Through this capability, the output per capita of an assimilated technique $(b_i, \kappa_i)$ associated with $k$ is specified by a standard CES function:

$$y = H_i(k) = A_i \left[ \pi_i k^{\frac{\sigma-1}{\sigma}} + 1 - \pi_i \right]^{\frac{\sigma}{\sigma-1}},$$

where $A_i$ and $\pi_i$ are respectively the scaling and share parameters under technique $i$, and the substitution parameter $\sigma > 0$ is assumed to be invariant to $\kappa$. Also, $\sigma$ captures how well firms can modify technique $i$ in response to changes in factor prices, i.e., the degree of assimilation. As we need to compare results with different degrees of assimilation (i.e., different $\sigma$), we need to normalize the CES function at an arbitrary baseline point following the normalization procedure proposed by Klump and de La Grandville (2000) to avoid arbitrary and inconsistent results. Given that we need to compare our model with the no-assimilation case (i.e., localized technique), the Leontief-kink, where $k = \kappa_i$, seems to be a natural choice for the baseline point of the
normalized CES (NCES) technique.\textsuperscript{15} To apply normalization at \( k = \kappa_i \), we have to choose the per capita income (denoted by \( H_i(k) \)) and the marginal rate of technical substitution (MRTS, which equals \( [H_i(k) - H'_i(k)]/H'_i(k) \)) at this baseline point. They are given by\textsuperscript{16}

\[
\begin{align*}
    b_i &= H_i(\kappa_i), \\
    h_{i\kappa_i} &= \frac{H_i(\kappa_i) - \kappa_i H'_i(\kappa_i)}{H'_i(\kappa_i)}.
\end{align*}
\]

Using the formulation of \( H_i(k) \), the scaling and share parameters are reduced to

\[
\begin{align*}
    \pi_i &= \frac{1}{h_{i\kappa_i} + 1}, \\
    A_i &= \frac{b_i}{\kappa_i} \left[ \frac{h_{i\kappa_i} + 1}{1 + h} \right]^{\frac{\sigma - 1}{\sigma}}.
\end{align*}
\]

Substituting the above into \( H_i(k) \) so that it now only depends on the normalization parameters:

\[
\begin{align*}
    H_i(k) &= A_i \left[ \pi_i k^{\frac{\sigma - 1}{\sigma}} + 1 - \pi_i \right]^{\frac{\sigma}{\sigma - 1}}, \\
    &= b_i \left[ \frac{h_{i\kappa_i} + 1}{1 + h} \right]^{\frac{\sigma - 1}{\sigma}} \left[ \frac{k^{\frac{\sigma - 1}{\sigma}}}{h_{i\kappa_i} + 1} + \frac{h_{i\kappa_i} + 1}{h_{i\kappa_i} + 1} \right]^{\frac{\sigma}{\sigma - 1}}, \\
    &= b_i \left[ \frac{h_{i\kappa_i} + 1}{1 + h} \right]^{\frac{\sigma - 1}{\sigma}} \left[ \frac{k^{\frac{\sigma - 1}{\sigma}}}{h_{i\kappa_i} + 1} + \frac{h_{i\kappa_i} + 1}{h_{i\kappa_i} + 1} \right]^{\frac{\sigma}{\sigma - 1}}, \\
    &= b_i \left[ \frac{1}{1 + h} \left( \frac{k}{\kappa_i} \right)^{\frac{\sigma - 1}{\sigma}} + \frac{h}{1 + h} \right]^{\frac{\sigma}{\sigma - 1}}.
\end{align*}
\]

\textsuperscript{15}This is equivalent to normalizing the CES function \( y = b_i F(k/\kappa_i, 1) \) at the baseline point, where \( k/\kappa_i = 1 \). As discussed by Klump et al. (2012), this NCES function has been widely used in the literature.

\textsuperscript{16}We use the following notation: \( H'(k) \equiv \partial H/\partial k \).
Define \( \alpha \equiv (1 + h)^{-1} \). Matching \( H_i(k) \) with the definition of \( \tilde{F} \), we have

\[
\tilde{F} \left( \frac{k}{\kappa_i}, 1 \right) = \left[ \alpha \left( \frac{k}{\kappa_i} \right)^{\frac{\sigma-1}{\sigma}} + 1 - \alpha \right]^{\frac{\sigma}{\sigma-1}}.
\]

Then, the output of the assimilated technique \((b_i, \kappa_i)\) is given by

\[
Y = b_i N \tilde{F} \left( \frac{k}{\kappa_i}, 1 \right) = b_i N \left[ \alpha \left( \frac{k}{\kappa_i} \right)^{\frac{\sigma-1}{\sigma}} + 1 - \alpha \right]^{\frac{\sigma}{\sigma-1}}, \tag{A1}
\]

which is (8) in the text. Showing that \( \tilde{F}_1 > 0 \) and \( \partial \tilde{F} / \partial \sigma > 0 \) is straightforward.

Given capital rental \( r \) and labor wage \( w \), the typical firm chooses factor demand \( K \) and \( N \) as well as technique \( i \) to maximize the profit:

\[
\Pi (r, w) = \max_{K \geq 0, N \geq 0} \left\{ b_i N \tilde{F} \left( \frac{k}{\kappa_i}, 1 \right) - rK - wN \right\}.
\]

Denote \( B(\kappa) \equiv \{ b_i \mid b_i = \max_{(b_j, \kappa_j) \in P} b_j \} \) as the set of frontier \( b \) (i.e., the set of manifest techniques) for any given \( \kappa \) out of all the available techniques in a country. (Note that it can be different across countries). Then, the profit maximization problem is reduced to

\[
\Pi (r, w) = \max_{\kappa} \{ \pi (\kappa; r, w) \}, \tag{A2}
\]

where

\[
\pi (\kappa; r, w) = \max_{K, N} \left\{ B(\kappa) \tilde{F} \left( \frac{K}{\kappa}, N \right) - rK - wN \right\}.
\]

Fixing \( K \) and \( N \), the global production function is defined as

\[
F(K, N) \equiv B(\kappa) \tilde{F} \left( \frac{K}{\kappa}, N \right) \text{ s.t. } \exists (r, w) \text{ s.t. } (K, N, \kappa) \text{ solves (A2)}. \tag{A3}
\]

Before proceeding further, we introduce the following axioms on \( B \):

**Axiom 1** \( B(\kappa) \) is differentiable for any interior \( \kappa \).

Axiom 1 is a standard assumption such that the set of techniques is rich enough to guarantee that the technique choice of the problem (A2) is “smooth,” as in Jones (2005).

**Axiom 2** If \((K, N, \kappa)\) is the solution to (A2), then \( \kappa = K/N \).
Axiom 2 is simply to reiterate the fact that we have normalized the Leontief-kink of the technique, where $\kappa = k$. For any given $\sigma$, we alter the choice of parameters such that choosing the technique whose input requirement $\kappa$ is equal to the factor endowment $k$ is optimal. This practice is common in the business cycles analysis of the NCES technology in which the normalization point is taken at the steady state (e.g., Klump and Saam 2008, Guo and Lansing 2009). See also Wong and Yip (2014) for an alternative stochastic treatment and a richer microfoundation on deriving the formulation of technology assimilation.

Suppose a solution to the problem (A2) exists and is interior. Given Axiom 1, the first-order condition with respect to $\kappa$ is well-defined and is given by

$$\frac{\partial}{\partial \kappa} B(\kappa) N \tilde{F}(\frac{k}{\kappa}, 1) - \frac{k}{\kappa^2} B(\kappa) N \tilde{F}_1(\frac{k}{\kappa}, 1) = 0.$$  \hspace{1cm} (A4)

Given Axiom 2, the first-order condition with respect to $\kappa$ implies a first-order ordinary differential equation (ODE) as follows:

$$\frac{\partial}{\partial \kappa} B(\kappa) = \alpha \frac{B(\kappa)}{\kappa}.$$  

Clearly, the solution to the above ODE has the following closed-form function

$$B(\kappa) = z \kappa^\alpha,$$  \hspace{1cm} (A5)

where $z$ is a positive constant. Recall that by fixing any technique $i$, the first-order conditions of (A2) with respect to $K$ and $N$ imply that the MRTS equals the factor price ratio:

$$G \left( \frac{k}{\kappa} \right) \equiv \frac{\tilde{F}_1(\frac{k}{\kappa}, 1)}{\kappa \tilde{F}_2(\frac{k}{\kappa}, 1)} = \frac{r}{w}.$$  \hspace{1cm} (A6)

Therefore, fixing any $(K, N, \kappa)$ and then $(K, N, \kappa)$ also solves (A2) when the supporting factor prices $r$ and $w$ satisfy (A6). We note that (A6) can be interpreted as a factor demand curve in the $(k, r/w)$ space. Substituting $\kappa = k$ and $B(\kappa)$ given by (A5) into the definition of the global production function, we have the following:

**Lemma A1** Given the maintained assumptions, the global production function is given by

$$F(K, N) = z K^\alpha N^{1-\alpha},$$

where $z$ is a positive constant.

Therefore, we establish that the global production function must be Cobb-Douglas as in Section 3.2. Showing that $a_i = z \kappa_i^{\alpha-1}$ and $b_i = z \kappa_i^{\alpha}$ is straightforward.
By substituting (A1) and (A5), then the output per capita after having assimilated the US technique with input requirement $\kappa = k_{US}$ is given by

$$\frac{Y}{N} = b_{US} F \left( \frac{k}{k_{US}}, 1 \right) = z_{US} \left( k_{US} \right)^{\alpha} \left[ \alpha \left( \frac{1}{k_{US}} \right)^{\frac{\sigma - 1}{\sigma}} + 1 - \alpha \right]^{\frac{\sigma}{\sigma - 1}}, \quad \text{(A7)}$$

which is the reduced form given by (8) in the paper.

Finally, the second-order necessary condition for $\kappa = k$ optimal to (A2) is

$$\frac{\partial^{2}}{\partial \kappa^{2}} B(\kappa) N \tilde{F}(\frac{k}{\kappa}, 1) - \frac{k}{\kappa^{2}} \frac{\partial}{\partial \kappa} B(\kappa) N \tilde{F}_{1}(\frac{k}{\kappa}, 1)$$

$$+ \frac{2k}{\kappa^{3}} B(\kappa) N \tilde{F}_{1}(\frac{k}{\kappa}, 1) - \frac{2k}{\kappa^{2}} \frac{\partial}{\partial \kappa} B(\kappa) N \tilde{F}_{1}(\frac{k}{\kappa}, 1) + \frac{k^{2}}{\kappa^{4}} B(\kappa) N \tilde{F}_{11}(\frac{k}{\kappa}, 1) \leq 0,$$

which, evaluated at $\kappa = k$, can be simplified to

$$\alpha (1 - \alpha) N \left[ 1 - \sigma^{-1} \right] \leq 0.$$

We then establish the following lemma:

**Lemma A2** Given the maintained assumptions, the solution to (A2) is interior only if

$$\sigma \leq 1.$$

Therefore, to obtain an interior solution to the profit maximization problem (A2) based on (A5) and (A7), as otherwise the optimal $\kappa$ will be a bang-bang solution and Axiom 2 will fail, we have to restrict $\sigma \in [0, 1]$.

**Appendix B: Calibration Details**

Let $\bar{q}_{i}$ and $\Delta \bar{q}_{i}$ denote the average log relative income and the average log relative income growth from the data, which are given respectively by

$$\bar{q}_{i} \equiv \frac{1}{42} \sum_{t=1970}^{2011} \log \left( \frac{y_{i,t}}{y_{US,t}} \right),$$

$$\Delta \bar{q}_{i} \equiv \frac{1}{41} \sum_{t=1971}^{2011} \log \left( \frac{y_{i,t}}{y_{i,t-1}} \frac{y_{US,t}}{y_{US,t-1}} \right) = \frac{1}{41} \left\{ \log \frac{y_{i,2011}}{y_{US,2011}} - \log \frac{y_{i,1970}}{y_{US,1970}} \right\}.$$
According to the assimilation model, the log relative income and the log relative income growth are given respectively by

\[
\log q_{i,t} = \log \tau_i + \frac{\sigma_i}{\sigma_i - 1} \log \left[ \alpha \left( \frac{k_{i,t}}{k_{US,t}} \right)^{\frac{\sigma_i-1}{\sigma_i}} + (1 - \alpha) \right],
\]

\[
\log \left( \frac{q_{i,t}}{q_{i,t-1}} \right) = \frac{\sigma_i}{\sigma_i - 1} \left\{ \log \left[ \alpha \left( \frac{k_{i,t}}{k_{US,t}} \right)^{\frac{\sigma_i-1}{\sigma_i}} + (1 - \alpha) \right] \right\} - \log \left[ \alpha \left( \frac{k_{i,t-1}}{k_{US,t-1}} \right)^{\frac{\sigma_i-1}{\sigma_i}} + (1 - \alpha) \right],
\]

where \( \sigma_i \in [0, 1] \) and \( \alpha = 1/3 \). Note that the block-recursive structure: \( \log \left( \frac{q_{i,t}}{q_{i,t-1}} \right) \) depends only on \( \sigma_i \) but not on \( \tau_i \), and \( \log q_{i,t} \) depends on both \( \sigma_i \) and \( \tau_i \). Therefore, we can first calibrate \( \sigma_i \) with matching \( \Delta \bar{q}_i \) and then calibrate \( \tau_i \) with matching \( \bar{q}_i \). To match \( \Delta \bar{q}_i \), the parameter \( \sigma_i \) is calibrated as the solution to

\[
\frac{1}{41} \sum_{t=1971}^{2011} \log \left( \frac{q_{i,t}}{q_{i,t-1}} \right) = \Delta \bar{q}_i,
\]

\[
\Leftrightarrow 0 = \log \frac{y_{i,2011}}{y_{US,2011}} - \log \frac{y_{i,1970}}{y_{US,1970}} - \frac{\sigma_i}{\sigma_i - 1} \left\{ \log \left[ \alpha \left( \frac{k_{i,2011}}{k_{US,2011}} \right)^{\frac{\sigma_i-1}{\sigma_i}} + (1 - \alpha) \right] \right\} - \log \left[ \alpha \left( \frac{k_{i,1970}}{k_{US,1970}} \right)^{\frac{\sigma_i-1}{\sigma_i}} + (1 - \alpha) \right] \}
\]

If there is no solution \( \sigma_i \) between zero and one, we set \( \sigma_i \) as the solution minimizing the square of the right hand side. To match \( \bar{q}_i \), the parameter \( \tau_i \) is calibrated as the solution to

\[
\frac{1}{42} \sum_{t=1970}^{2011} \log q_{i,t} = \bar{q}_i,
\]

\[
\Leftrightarrow \log \tau_i = \frac{1}{42} \left\{ \sum_{t=1970}^{2011} \log \frac{y_{i,t}}{y_{US,t}} - \frac{\sigma_i}{\sigma_i - 1} \sum_{t=1970}^{2011} \log \left[ \alpha \left( \frac{k_{i,t}}{k_{US,t}} \right)^{\frac{\sigma_i-1}{\sigma_i}} + (1 - \alpha) \right] \right\}.
\]

According to the BWA model, the log relative income and the log relative income growth are given respectively by

\[
\log q_{i,t} = \log \tau_i^{\text{BWA}} + (\alpha + \zeta_i) \log \left( \frac{k_{i,t}}{k_{US,t}} \right),
\]
\[
\log \left( \frac{q_{i,t}}{q_{i,t-1}} \right) = (\alpha + \zeta_i) \left\{ \log \left( \frac{k_{i,t}}{k_{US,t}} \right) - \log \left( \frac{k_{i,t-1}}{k_{US,t-1}} \right) \right\},
\]

where \( \zeta_i \in [0, 1 - \alpha] \) and \( \alpha = 1/3 \). Note that the block-recursive structure \( \log \left( \frac{q_{i,t}}{q_{i,t-1}} \right) \) depends only on \( \zeta_i \) but not on \( \tau_i^{BW,A} \), and \( \log q_{i,t} \) depends on both \( \zeta_i \) and \( \tau_i^{BW,A} \). Therefore, we can first calibrate \( \zeta_i \) with matching \( \Delta \bar{q}_i \) and then calibrate \( \tau_i \) with matching \( \bar{q}_i \). To match \( \Delta \bar{q}_i \), the parameter \( \zeta_i \) is calibrated as the solution to

\[
\frac{1}{41} \sum_{t=1971}^{2011} \log \left( \frac{q_{i,t}}{q_{i,t-1}} \right) = \Delta \bar{q}_i,
\]

\[
\Leftrightarrow 0 = \log \frac{y_{i,2011}}{y_{US,2011}} - \log \frac{y_{i,1970}}{y_{US,1970}} - (\alpha + \zeta_i) \left[ \log \left( \frac{k_{i,2011}}{k_{US,2011}} \right) - \log \left( \frac{k_{i,1970}}{k_{US,1970}} \right) \right].
\]

If there is no solution \( \zeta_i \) between zero and \( 1 - \alpha \), we set \( \zeta_i \) as the solution minimizing the square of the right hand side. To match \( \bar{q}_i \), the parameter \( \tau_i^{BW,A} \) is calibrated as the solution to:

\[
\frac{1}{42} \sum_{t=1970}^{2011} \log q_{i,t} = \bar{q}_i,
\]

\[
\Leftrightarrow \log \tau_i^{BW,A} = \frac{1}{42} \left\{ \sum_{t=1970}^{2011} \log \frac{y_{i,t}}{y_{US,t}} - (\alpha + \zeta_i) \sum_{t=1970}^{2011} \log \left( \frac{k_{i,t}}{k_{US,t}} \right) \right\}.
\]

According to the Lucas model, the log relative income is given by

\[
\log q_{i,t} = \log \tau_i^{Lucas} + \alpha \log \left( \frac{k_{i,t}}{k_{US,t}} \right),
\]

where \( \alpha = 1/3 \). To match \( \bar{q}_i \), the parameter \( \tau_i^{Lucas} \) is calibrated as the solution to:

\[
\frac{1}{42} \sum_{t=1970}^{2011} \log q_{i,t} = \bar{q}_i,
\]

\[
\Leftrightarrow \log \tau_i^{Lucas} = \frac{1}{42} \left\{ \sum_{t=1970}^{2011} \log \frac{y_{i,t}}{y_{US,t}} - \alpha \sum_{t=1970}^{2011} \log \left( \frac{k_{i,t}}{k_{US,t}} \right) \right\}.
\]

Finally, from the CES model, the log relative income and log relative income growth are given by

\[
\log q_{j,t} = \log \tau_j^{CES} - \alpha \log k_{US,t} + \left( \frac{\epsilon_j}{\epsilon_j - 1} \right) \log \left[ \alpha \left( k_{j,t} \right)^{\epsilon_j-1} + 1 - \alpha \right], \quad (22)
\]
and
\[
\log \left( \frac{q_{j,t}}{q_{j,t-1}} \right) = -\alpha \log \left( \frac{k_{US,t}}{k_{US,t-1}} \right) + \left( \frac{\epsilon_j}{\epsilon_j - 1} \right) \log \left[ \frac{\alpha (k_{j,t})^{\epsilon_j-1} + 1 - \alpha}{\alpha (k_{j,t-1})^{\epsilon_j-1} + 1 - \alpha} \right],
\]
respectively. Note that, as in the assimilation model, the block-recursive structure allows us to first calibrate \( \epsilon_j \) with matching \( \Delta \bar{q}_j \) and then calibrate \( \tau_j \) with matching \( \bar{q}_j \). To match \( \Delta \bar{q}_j \), the parameter \( \epsilon_j \) is calibrated as the solution to
\[
\frac{1}{41} \sum_{t=1971}^{2011} \log \left( \frac{q_{i,t}}{q_{i,t-1}} \right) = \Delta \bar{q}_j,
\]
\[
\Leftrightarrow 0 = \log \frac{y_{j,2011}}{y_{US,2011}} - \log \frac{y_{j,1970}}{y_{US,1970}} + \alpha \log \left( \frac{k_{US,2011}}{k_{US,1970}} \right) - \frac{\epsilon_j}{\epsilon_j - 1} \left\{ \log \left[ \frac{\alpha (k_{j,2011})^{\epsilon_j-1} + (1 - \alpha)}{\alpha (k_{j,1970})^{\epsilon_j-1} + (1 - \alpha)} \right] \right\}. \]
If there is no solution \( \epsilon_j > 0 \), we set \( \epsilon_j \) as the solution minimizing the square of the right hand side. To match \( \bar{q}_j \), the parameter \( \tau_j \) is calibrated as the solution to
\[
\frac{1}{42} \sum_{t=1970}^{2011} \log q_{j,t} = \bar{q}_j,
\]
\[
\Leftrightarrow \log \tau_j = \frac{1}{42} \left\{ \frac{\sum_{t=1970}^{2011} \log \frac{y_{j,t}}{y_{US,t}} + \alpha \sum_{t=1970}^{2011} \log k_{US,t}}{\sum_{t=1970}^{2011} \log \left[ \frac{\alpha (k_{j,t})^{\epsilon_j-1} + (1 - \alpha)}{\alpha (k_{j,t-1})^{\epsilon_j-1} + (1 - \alpha)} \right]} \right\}. \]

**An Alternative Fitness Measure: The Q Ratio**  For the convenience of visually detecting the fitness of calibrated models, we introduce the following ratio for each country:
\[
Q_i = \frac{\log(\text{explained component of log(income ratio) in country } i)}{\log(\text{country } i\text{'s income ratio})}
\]
Particularly, the closer the scatter points are to the 45 line, the better the fit is. The cross-country plot of this ratio in 1970 is presented in Figure A3 for Lucas’ model and BWA model, and Figure A4 for our model. The results show that the overall fitness of our assimilation model is very good.

Our conclusion on the comparison of the three models can be further con-
firmed using the $Q_t$ ratio. Based on Figures A3 and A4, both our assimilation model and the BWA model outperform the simple benchmark of Lucas across the board. Moreover, our model of technology assimilation is, on average, significantly a better fit than the BWA model of inappropriate technology.

**A Preview on Assimilation Dynamics** Let us divide the full sample of 38 years into two sub-periods of equal length (1970 to 1988 and 1989 to 2007; 19 years for each period). Denote the average relative per capita capital as $\bar{k}_{i/US}$. We can then study the patterns of assimilation dynamics measured by $\Delta \pi_{i/US,t-1} \log (\bar{k}_{i/US})$. We are particularly interested in understanding the relationships between the assimilation dynamics coefficients and economic development measures, such as the initial 1970 relative incomes, current 2007 relative incomes, and their growth rates. No clear relationship exists between assimilation dynamics and initial relative income, and a positive relationship exists between assimilation dynamics and current relative income. One can perform the same analysis for changes in inappropriateness of technology in the BWA model. The changes in the coefficients of assimilation and in the coefficients of inappropriateness ($\zeta$) versus growth rates for the entire sample of 152 countries are plotted in Figures A5 and A6, respectively. As expected, although a positive relationship exists between assimilation dynamics and growth, the relationship between inappropriateness changes and growth is negative.

As noted in the main context of Section 3, technology assimilation for economic development need not fit with every single country's development process. To better understand the role played by assimilation, we eliminate 37 countries with little assimilation (the coefficient is between -0.03 and 0.03). As shown in Figure A5, although no clear relationship exists between assimilation dynamics and initial relative income, the relationship between assimilation dynamics and either current relative income or growth rate is strongly positive. Therefore, we can conclude with confidence that the initial state of a country is not essential: countries with poor initial levels of income can still achieve high growth and higher relative income through the assimilation of global technologies. Moreover, countries achieving high growth and high relative income exhibit positive assimilation, whereas those performing poorly over a prolonged period of time have backward (negative) assimilation.

**Can Assimilation Promote TFP Growth?** To gain further insight into the implication of technology assimilation with flexible production for the advancement of overall productivity, we calibrate $(\sigma_i, \tau_i)$ for each country over the two sub-periods, as defined above, and conduct variance decomposition of the (averaged) income ratio over each sub-period to study whether the relative importance of TFP and capital accumulation of each country in the five economic/geographic clusters (see Section 4 in text) change over the two sub-periods.

Figure A7 shows how TFP growth over the two sub-periods is related to production flexibility measured by $\sigma_i$ before 1989. The result suggests a positive relationship between assimilation and the subsequent growth of TFP. Note
that our calibrated $\tau_i$ will be a good measure of relative technology only if the
fit is good; otherwise, it will capture information contained in unexplained
error terms. Moreover, by using normalized CES, our calibrated $\sigma_i$ may be-
come imprecise when its value is too close to one (perfect substitution). As a
result, this positive relationship is weaker than one would expect ex ante. This
cross-country shortcoming is mitigated when we perform country-by-country
studies in Section 4.

**Appendix C: Variance Decomposition**

In this appendix, we document the detailed findings of the variance de-
composition of the relative income growth rate. Table A1 summarizes the
statistics of the contribution of different components of the different models.\(^{17}\)

Overall, the result suggests that, in each stage of development, technology
assimilation plays a greater role in contributing to growth fluctuation than
technology inappropriateness. For the first generation of fast-growing countries
except Hong Kong, assimilation accounts for about 9% to 36% of the relative
income growth variance, which is much more than the inappropriateness of
technology captured by BWA (0% to 3%). For Hong Kong, both assimilation
and inappropriateness are as important as each other at about 15%. For the
second generation of fast-growing countries, assimilation accounts for about
12% to 46% variance of relative income growth, except for India and Thailand.
Inappropriateness of technology of the BWA contributes significantly about
90% and 53% for Vietnam and Botswana, respectively (the residual TFP also
accounts for about 200% in both countries), but contributes little for India and
Malaysia. Even for the trapped countries, assimilation accounts for 10% to 16%
variance of relative income growth for half of the countries; inappropriateness
of technology of BWA mostly accounts for 19% but only to one country (i.e.,
Kenya); it is insignificant for the rest of the countries. Finally, for the group
of Latin American countries, neither assimilation nor inappropriateness seems
to have a significant role in relative income fluctuation. Most of the variations
in growth rates come from the unexplained residual TFP component $\tau$. For
Latin American countries, neither approach can account for over 10%, except
Argentina and Brazil, which are 11% and 22% by assimilation, compared with
11% and 12% by inappropriateness, respectively. In sum, in each group of
countries different in different development stage, the result is consistent with
the idea that technology assimilation is important in driving the fluctuation
of the income growth disparity from the frontier country.

**Appendix D: Country-specific Analysis for Selected
Groups**

In this appendix, we report the detailed results for different selected groups
of countries.

\(^{17}\)Note that the variance terms do not sum up to 100% because of the presence of covari-
ance terms.
Low Calibrated TFP for Mildly Growing Countries  We return to the issue about the relatively low TFP ratios experienced by countries growing at 2% to 4% annually, compared with those of countries rapidly growing (exceeding 4%) and stably growing (1% to 2%) economies. To understand this issue, we further study the countries in this category with TFP ratios lower than the average of the group (0.63 from Table 1), as reported in Table A2.

All countries except for Portugal are emerging growing Asian, European, Middle Eastern, and Latin American countries (including Egypt, which is economically and geographically closer to Europe and Middle East than sub-Saharan African countries). These countries are significantly behind the advanced OECD countries (most of them are in the stably growing group) and have grown much slower than the rapidly growing miracle countries. As a result, their TFP ratios are not as high as those of countries in the other two groups. These emerging growing countries can be concluded to be responsible for the relatively low average TFP ratio of the 2% to 4% annual growth category.

Miracle Countries  Figure A9 depicts the assimilation dynamics of the Asian Tigers which are calibrated based on geographical proximity and international interrelationships. For all countries but South Korea, the alternative assimilation results fit better than their benchmark. For the sake of fair comparison, we obtain the benchmark cases by applying the full-sample calibrated parameters to simulate the predictions in the sub-samples of the modified assimilation schemes. The alternative assimilation is particularly better performed in the case of Hong Kong ($MSE = 0.06$ vs. the benchmark case of 0.08). Specifically, our benchmark assimilation setup under-predicts the relative performance of Hong Kong to the United States since the late 1970s when China adopted its open policy. This downward bias is corrected when we stop the close tie between the United States and Hong Kong after the 1992 reform by China. In the case of Singapore, the alternative assimilation is slightly better performed ($MSE = 0.11$ vs. the benchmark case of 0.12). However, our assimilation model over-predicts during the second half of the 1980s and under-predicts during the second half of the 1990s. The over-prediction is due to that fact that the 1985 recession in Singapore is a result of a foreign exchange crisis which is unrelated to technological factors. The under-prediction is due to the establishment of the world leading biotech industry, which boosts Singapore’s relative performance and yields larger development accounting residuals and measured TFP. For South Korea, the alternative assimilation is slightly worse than the benchmark assimilation ($MSE = 0.075$ vs. the benchmark case of 0.073). First, both assimilations are well performed, making any fitness differential insignificant. Second, the performance of the alternative assimilation is again dampened because of the sudden switch of the assimilation regimes. A gradual transition from assimilating Japan to the United States would give a nearly perfect fit except for the 1997 to 1998 period, when the regional Asian Financial Crises hit South Korea hard. Finally, in the case of Taiwan, our benchmark assimilation setup already fits the data well so the additional improvement from a more realistic assimilation process...
is small ($MSE = 0.081$ vs. the benchmark case of $0.084$). Nonetheless, under this alternative assimilation process, the fitness prior to 1982 and after 1992 is clearly better. Therefore, we can conclude that the fitness will be nearly perfect if we allow “gradual transition” in assimilation from targeting Japan to the United States in the period of 1982 to 1992.

For the latecomers, Figure A10 delineates the assimilation dynamics that are calibrated based on geographical proximity and international interrelationships. We first discuss the ASEAN countries. For Malaysia, our alternative assimilation (i) provides a perfect example that highlights the importance of geographical proximity. By switching our targeted assimilation from the United States to Singapore, our fitness improves drastically (with $MSE$ decreasing from $0.1194$ to $0.0464$). This finding reflects the close economic interrelationship between these two adjacent economies. We perform the alternative assimilation (ii) for Thailand because of the booming decade 1987 to 1996 of the Japan FDI, but the result does not improve as much (with $MSE$ decreasing from $0.1467$ to $0.0938$); the main improvement is during the 1980s. The over-estimation of the 1970s may be due to the oil crises and high inflation, whereas the under-estimation of the 1990s can be due to the combination of the downturn of the Japanese economy and the soaring of the Thai economy. For Vietnam, the alternative assimilation calibrations of (iii) that focus on the takeoff period generate much better fitness than the US benchmark. In this regard, geographical proximity does provide significant additional explanatory power. The FGP of economic development is implied to be an important explanation for the fast-growing experience of Asian countries in the last century. For China, the US benchmark assimilation beats all the alternatives in (iv). However, as shown in Table 2, China has a very low value of the assimilation parameter. We reckon that this may be due to the fact that factor accumulation is more important for China growth, as suggested by Young (1992), for the cases of Hong Kong and Singapore. The case of India is simpler. Performing only the US assimilation since the economic takeoff of the country improves the fitness, and such outcome is expected and very intuitive. The underestimation of the growth surge of India is likely due to the inability of capturing the non-fundamental factor. To understand the African miracle, we simply study an assimilation of its colonial origin, that is, the United Kingdom. Our results show that it does not yield a better outcome (with $MSE = 0.1059$ for the United Kingdom vs. $0.1053$ for the United States).

**Trapped Countries** Even with many emerging economies advancing their development status, many countries remain in the poverty trap, such as many Sub-Saharan economies, which are our focus. The African post-independence leaders—like those in many developing countries in the 1960s and the 1970s—looked to state-led, import-substituting industrialization as the key to rapid economic growth. On average, the average manufacturing–agricultural labor productivity ratio for low-income Africa is 2.5 to 1. According to the World Bank’s *Long Term Perspective Study* (1989) on industrialization of African countries: (i) Africa’s post-independence industrialization concentrated on creating physical capacity; (ii) import substitution policies attracted foreign
investment through protected markets; (iii) agricultural taxation and foreign borrowing helped finance public investment in heavy industry, which served a narrow market at high cost; (iv) modern manufacturing remains mostly small, stagnating at around 10% of the GDP and 9% of employment between 1965 and 1987; and, (v) most industries remain isolated from world markets and frontier technologies, and protectionism has stimulated investment but not innovation to increase productivity.

Over the period of 1970 to 2009, real GDP per capita in Africa only grew from USD530 to USD620. In contrast, China’s real GDP per capita in 1970 was less than a quarter of that of Africa; by 1990, it increased to three-quarters; and in 2010, it was nearly five times the African average. In Africa, agricultural value-added represented 22% of GDP in 1965, services 47%, and industry 31% (of which manufacturing contributed 17.5%). More than 40 years later, agricultural value-added still contributed 15% of the GDP, and services contributed 52% and industry 33%, of which manufacturing represented less than 15%. The industrial share of employment did not change in half a century, whereas export diversification either stagnated or declined. According to the new structuralist literature (e.g., Lin 2011), Africa’s lack of diversity and sophistication in its production and exports of the manufacturing sector leads to the slowdown in economy-wide productivity change and growth.

Aside from the five trapped countries in Africa, we also consider a South Asian poor economy, that is Papa New Guinea, which “had long, protracted armed insurgencies that disrupted development” (Parente and Prescott 2002, p.29). The economy is supported mainly by agriculture, natural resource, and foreign aid. As expected, technological assimilation may not be able to account for much of these non-economic effects. Explaining its development experience is beyond the ability of the assimilation models so that the three models yield more or less the same outcome of fitness. Therefore, we do not include in our discussion below.

In Figure A11a, we report assimilation dynamics based on either the world frontier or geographical proximity/international interrelationships. The results in Table 2 suggest that our assimilation model always yields better fitness outcomes than the BWA and Lucas models. In general, growth performance of almost all of these countries can be understood as a negative assimilation in our model (see Table 2). For Comoros, Kenya, and Uganda, our model outperforms the alternatives in terms of $MSE$ as it can effectively determine the turning points in the assimilation dynamics. Uganda can be understood as an inverse case of China as its calibrated assimilation parameter is also very small. The extremely high calibrated $\tau$ indicates that heavy subsidy to technology adoption exists. One possible interpretation is that Uganda relies heavily on foreign aid. We believe that the poor growth performance may be caused by factor decumulation, such as capital outflows and/or insufficient education. For instance, its literacy rate is around 66.8% according to the 2002 census. For Comoros and Kenya, the one-sided downturns are well fitted by our assimilation framework. The BWA and Lucas models seriously underestimate the growth performance of the former for the initial period before the mid-1980s, whereas their estimation bias is in the opposite direction for the latter for the same period. For Ghana, all three models miss the surge of the economy.
before the early 1970s, with the BWA model having the highest over-estimation bias. Lall (1990) points out that Ghana finds absorbing technology difficult because of insufficient R&D effort. Therefore, our assimilation model performs almost identical to the Lucas model, although both are better than the BWA model. As a result, the calibrated \( \sigma \) is close to unity, which is the special case of Lucas (2000). Ghana is one of the few countries that has no value added in the Lucas model in assimilation dynamics. Conversely, our assimilation model can better capture the strong growth of Côte d’Ivoire for the first 20 years, but it has a strong upward bias for performance in the 1980s. Since the 1990s, both the BWA and Lucas models have upward bias in the fitness, whereas ours produces downward bias. This mixed outcome may be due to the presence of both foreign aid and domestic corruption. Therefore, the growth dynamics caused by these problems can only be satisfactorily calibrated with a combination of the three models for this period.

To better understand the experience of trapped countries within the assimilation framework, we conduct an alternative calibration for each country by assimilating the country of their colonial origin in Figure A11b. Except for Comoros and Uganda, the alternative calibrations do not yield better fit for the growth dynamics. The reason for Comoros is that it is still not completely independent from France since its declaration of independence in 1975. Therefore, the influence of France on Comoros remains strong compared with the other countries. For Uganda, the suggested explanations include: being a member of the Commonwealth (but both Kenya and Ghana are also members) and a large diaspora resides in the U.K. (also in the U.S.) that contributes to the growth of Uganda through remittances. Nevertheless, we regard it as an open question to be explored further in future studies.

Latin American Countries Many Latin American countries have experienced, at some stages, high or hyper-inflation over the past half-century. Our main focus is on the most representative “Southern Cone” ABC countries, namely, Argentina, Brazil, and Chile – plus the only developing economy under NAFTA, namely, Mexico.

Starting from the 1940s, most Latin American nations followed an economic strategy based on protectionism, government-led industrialization, and a broad involvement of the state in economic activities. The practice of these import substitution industrialization (ISI) strategies were popular between the 1960s and 1970s. Unfortunately, when the oil price shocks of 1973 and 1979 deteriorated the terms of trade, many Latin American countries started accumulating external debt at a pace that became unsustainable. For example, Mexico experienced a debt crisis in 1982, a crisis that rapidly spread through the region and resulted in stagnation and economic suffering for almost a decade (the so-called “lost decade” of Latin America). Hyperinflation attacked the region: the rate of inflation exceeded 3,000% in Argentina in 1989 and in Brazil in 1990. Heterodox plans (e.g., price controls) in the mid-1980s worsened the situation (e.g., Austral Plan in Argentina and Cruzado Plan in Brazil). This event then led to the launch of the market-oriented reforms of the “Washington Consensus” in 1989 to 1990, which became increasingly unpopular in
the region during the last 20 years because of the successive currency crises, including the Mexican crisis of 1994 to 1995, the Brazilian crises of 1999 and 2002, and the Argentine crisis of 2001 to 2002. As it turns out, Chile is one of the few countries in the region that has succeeded in economic reform shortly after its 1982 crisis. Overall, the central theme to discuss in this group of countries is their high inflation episodes that have led to severe unsettledness and instability, thus damaging the performance of these economies.

We also take a look into Colombia and Nicaragua, but refrain from going much into detail. Despite the serious internal armed conflicts, Colombia’s GDP increased at an average rate of over 4% per year between 1970 and 1998. This increase may be due to austere government budgets, focused efforts to reduce public debt levels, an export-oriented growth strategy, an improved security situation in the country, and high commodity prices (especially oil). Similar to Papa New Guinea, Nicaragua is another country that “had long, protracted armed insurgencies that disrupted development” (cf. Parente and Prescott 2002, p.29). Arguably, one can easily classify Nicaragua into the group of trapped countries. Indeed, the assimilation dynamics between Papa New Guinea and Nicaragua is similar. We obtain both calibrated low $\sigma$ and high $\tau$ for these two countries.

We report assimilation dynamics based on the full sample in Figure A12a. For the cases of Chile, Colombia, Mexico, and Nicaragua, neither the BWA model nor our benchmark assimilation framework can improve the baseline Lucas model. As all three models have the same $MSE$, both technology assimilation and inappropriate technology do not offer additional explanation to the growth performance of the country over the simple Lucas model. Moreover, all three models have subpar fitness with the data, especially in the case of Nicaragua. On the contrary, in the cases of Argentina and Brazil, both the BWA and our benchmark assimilation models fit well and significantly outperform the Lucas model. Specifically, in terms of our assimilation model, the low calibrated $\sigma$ implies that growth is not technology based, and the high calibrated TFP indicates subsidized technology adoption. Nonetheless, the fitness is not applicable to miracle and trapped economies.

Based on the above documentation, it is reasonable to postulate that for all ABC countries and Mexico, high inflation episodes have led to severe unsettledness and instability, not only damaging their macroeconomic performance but also their businessmen’s incentives to invest in technological advancement. Therefore, as an alternative, we uniformly set assimilation to start from 1992 onwards. For Colombia and Nicaragua, whose economic development was disrupted by armed insurgencies, we will not consider alternative assimilation schemes.

In the alternative assimilation scheme that starts from 1992 onwards (Figure A12b; red lines), our modified model fits well with Brazil, Chile, and Mexico. Even in the case of Argentina, the fitness also improves significantly, although the Argentine currency crisis of 2001 to 2002 is too severe for our technology-based assimilation model to capture (and to a lesser degree, we also miss the downturn during the Mexican currency crisis of 1994 to 1995). We can conclude that, for these Latin American countries, chronic inflation is the main detrimental factor to the performance of our assimilation model.
Appendix E: Documentation Details on the Selected Countries

In this appendix, we provide some supplementary notes on countries to account for the results presented in Section 5.3.

**Hong Kong** In the 1960s to the 1970s, Hong Kong’s wider manufacturing industry successfully developed a reputation as a low-cost, labor-intensive original equipment manufacturing (OEM) center by producing goods for export to Western countries. Morawetz (1981) argues that the mass production of Hong Kong’s garment and more general textile industry started with the American production lines built for producing supplies to the Korean War. Wan (2007) also provides cases for electronics, but they are not that significant. Ever-increasing wages and land prices in the late 1970s seriously threatened the OEM manufacturing strategy adopted by most manufacturing firms in Hong Kong. Since China’s opening-up policy in 1979, many firms in Hong Kong have transformed themselves into service providers, from manufacturing to trading. A rapid transition to a service-based economy then took place in the 1980s, and Hong Kong further grew to become a financial center in the 1990s.

**Singapore** By the turn of the century, the manufacturing and financial sectors contributed to almost half of the country’s GDP. The government set high priority for high-tech industries, such as electronics, chemicals, and biotechnology. Although similar to all ELG countries, Singapore was unique in pursuing a high wage policy from 1979 to 1985 with a view to inducing a shift in production away from labor-intensive to capital-intensive and high-tech activities. During this period, labor costs increased at an annual average rate of 15% as nominal wages increased rapidly. During the first half of the 1980s, Singapore’s external competitiveness, measured in relative unit labor costs adjusted for the exchange rate, deteriorated by more than 60%, contributing to the slowdown in economic activity and to the severe, but short-lived, recession in 1985. Over the same period, increases in foreign reserves were moderate, and the effective exchange rate of the Singapore dollar appreciated substantially. Since early 1985, however, the level of reserves increased sharply, and the effective exchange rate depreciated markedly, reversing most of the appreciation that had taken place earlier. Concerned with the loss of external competitiveness, the authorities implemented several measures to reduce labor costs, including imposing limits on nominal wage increase, which contributed to economic recovery. Toward the end of the 1990s, Singapore became world technology leader, particularly in its main electronic and biotech industries (cf. Lim and Lloyd 1986).

**Korea** South Korea pursued an export-oriented growth strategy led by the government and shifted from import-substitution to export-oriented industrialization in the early 1960s. The Five Year Economic Development Plan of
1967 to 1971 focused on shifting from primary exports to labor intensive manufacturing sectors. Starting in 1970, the country shifted to promote heavy industries through the supply of cheap credit. In the 1980s, although the country had to deal with over-investment, excess capacity negative growth, it stuck to its strategy of long-term investment in the high-tech exports, which contributed to the great take-off in the next decade.

During its industry transformation, South Korea benefitted greatly from Japan, as documented by Kim (1997) and Wan (2004). Note that South Korean high school students were required to take Japanese language courses. Moreover, its business structures, inclusive of both large conglomerates (Chae-bols) and organized international trading companies (General Trading Corporation), resemble those of Japan, not to mention its significant technology transfers in electronics industry (Sony to Samsung and Hitachi to LG) and automotive industry (Honda to Hyundai).

With the onset of the Asian Financial Crisis in 1997, the financial sector liberalized, and the proactive industrial policy to promote exports almost came to an end. However, with international lending and economic restructuring, South Korea recovered after only 18 months since the start of the crisis. Globalization of Korea’s industries since then reached a milestone in the nation’s history, and South Korea joined the high-income group shortly after, becoming only the second in Asia to do so following the lead of Japan.

**Taiwan** During the 1960s and the 1970s, the Taiwan economy became industrialized and technology oriented. It was the second fastest growing state in Asia after Japan. Starting in 1974, Chiang Ching-kuo implemented the Ten Major Construction Projects, the beginning foundations that helped Taiwan transform into an export-led growing economy. Exports provided the primary impetus for industrialization. Trade surplus was substantial, and foreign reserves were the world’s fifth largest. Over the past 20 years, Taiwan’s IT industry has played an important role in the worldwide IT market.

Note that the Japanese rule prior to and during World War II brought changes in the public and private sectors, including rapid communications, good transportation system throughout much of the island, and compulsory primary education. As documented by Kuo (1983) and Li (1988), Taiwan has benefitted from Japan, particularly in agricultural and textile technology. Moreover, Tatung was established in 1918, and it later became Taiwan’s consumer electronic giant. The Sanyo to Sampo technology transfer also played an important role in broadening the range of electronic products.

However, the development of Taiwan’s modern IT industry was mostly influenced by the U.S. As documented by Tung (2001), Wan (2004), and Lee and Wang (2011), a series of key stepping stones helped Taiwan to grow into an IT giant. In 1966, General Instrument built the largest foreign headquarter in Taipei Hsien, and it was crucial to the development of machineries and tools. In 1970, RCA started its technology transfer to Taiwan. Robert Tsao was trained at RCA and later returned to Taiwan to establish the country’s first major IT firm, the United Microelectronics Corporation (UMC), in 1982. Similarly, Texas Instrument started its technology transfer to Taiwan in 1970. Its senior
VP Morris Chang returned to Taiwan to establish the Taiwan Semiconductor Manufacturing Company (TSMC) in 1987. The semiconductor industry forms a major part of Taiwan's IT industry. It overtook that of the U.S., which was second only to Japan, in 2007. TSMC and UMC are the two largest contract chipmakers in the world, and MediaTek is the fourth-largest fabless supplier globally. Despite their success, small- and medium-sized businesses still make up a significant proportion of the businesses in Taiwan (i.e., they account for 85% of the industrial output), unlike in Japan and South Korea. The small and medium-sized enterprises rely on the importation of key components and advanced technology from the U.S. and Japan.

Malaysia Since it became independent in 1957, Malaysia's economic record has been one of Asia's best. It is the third largest economy among the ASEAN countries. Its GDP grew by an average of 6.5% per year from 1957 to 2005. Performance peaked in the early 1980s until the mid-1990s, as the economy experienced sustained rapid growth that averaged almost 8% annually. The major economic activities of the country are international trade and manufacturing. Malaysia is an exporter of natural and agricultural resources, and is also the largest Islamic banking center of the world.

By the end of the 1960s, the controversial New Economic Policy was launched by Prime Minister Tun Abdul Razak. The predominantly mining and agricultural-based economy began a transition towards a more multi-sector economy in the 1970s. Under Prime Minister Mahathir Mohamad, a period of rapid economic growth and urbanization occurred beginning in the 1980s. The economy shifted from being agriculturally based to one based on manufacturing and industry. Many mega-projects were completed, such as the Petronas Towers, the North-South Expressway, the Multimedia Super Corridor, and the new federal administrative capital of Putrajaya. In the late 1990s, the Asian Financial Crisis almost caused the collapse of its currency and its stock and property markets. Its GDP suffered a sharp 7.5% contraction in 1998. However, Malaysia rebounded to grow by 5.6% in 1999. The post Y2K slump of 2001 did not affect Malaysia as much as other countries.

Thailand Similar to the Asian Tigers, Thailand is a heavily export-dependent country, with exports accounting for more than two-thirds of its GDP. Thailand is the second largest economy in Southeast Asia. It has completed industrial transformation two decades ago despite its relatively slow urbanization process.

The Srisdi regime, in power from 1957 to 1973, introduced the market-oriented ISI that led to a period of rapid growth in 1958, with an averaged growth rate of 7% a year since then. From the 1970s to 1984, Thailand suffered from many economic problems, including reduced American investments, sizable current account deficits, high inflation due to the two oil crises, and unstable domestic and unfriendly international politics. To deal with these economic problems, from 1981 and 1984, the Thai government decided to devalue the national currency, the Thai baht (THB), three times. After the baht devaluation in 1984 and the Plaza Accord in 1985, the Thai private sector
began to soar. Improved foreign trade situations, together with an influx of foreign direct investment, mainly from Japan, caused the booming decade of the Thai economy from 1987 to 1996. Nevertheless, many economic problems persisted: along with a huge current account deficit (averaged at 5.4% of the GDP per year), domestic capital shortage and rising external debt also occurred. All these led to the currency attack in 1997 that started the regional Asian Financial Crisis: the baht was forced to float starting July 2, 1997. The economy began to recover in 1999. It increased to over 4% in 2000, largely because of strong exports. However, its growth dampened (to 2.2%) by the softening of the global economy in 2001, but it picked up in the subsequent years because of the strong growth in Asia. A relatively weak baht encouraged exports and increased domestic spending as a result of the several mega projects of Prime Minister Thaksin Shinawatra.

Vietnam After the national reunification in 1975, Vietnam followed the centrally planned model of the Soviet Union until the late 1980s. The economy was stagnant throughout most of the 1970s and 1980s, forcing Vietnam to undertake economic reforms, including the first serious reform known as Doi Moi in 1986 and the even more radical market-oriented reform of 1989. It has implemented preferential trade agreement with the European Union beginning 1992. It became a member of the ASEAN in June 1995 and joined the Asia Pacific Economic Cooperation (APEC) in 1998. In 2000, Vietnam signed a historic comprehensive trade agreement with the U.S. to normalize trade relations between the two countries. A few years later in 2007, it became a member of the World Trade Organization. In the period 1990 to 2008, Vietnam's GDP growth rate averaged at over 7% per year, second only to China in the region.

Initially, Vietnam's exports focused on the early birds of miracle countries, namely, Japan, Singapore, Taiwan, Hong Kong, and South Korea. A few years after the Bilateral Trade Agreement with the U.S., Western markets such as the U.S., Australia, Germany and the U.K., including Japan, became the main destinations for Vietnam's exports. Although Western markets still account for the largest share of Vietnam exports, the emergence of China and ASEAN countries, such as Malaysia and the Philippines, is beginning to change the pattern of trade. For example, exports from Vietnam to China increased about 11 times in the 10-year period of 1997 to 2008. In terms of imports, a shift from imports from first-tier countries to imports from other countries occurred. In 2008, China, Taiwan and Hong Kong together exported about USD26 billion worth of goods to Vietnam, exceeding imports from any G-7 country.

China China pursued an export-oriented growth strategy in the context of late industrialization toward the end of 1970s when the East Asian early-starters were beginning to feel the need to relocate and diversify their costly production bases. Among the late industrializing nations, China has adopted a comprehensive ELG strategy, particularly since the 1992 “Southern Trip” announcement by Deng Xiao-Ping. It provided the correct incentives from all
government policies, including industry and trade policies, regulations (new laws and rules in all aspects of Chinese economic and trade reforms), administrative guidance and support (establishment of economic and technological development zones (ETDZs) and directive measures to lead finance and investment to the key sectors), and FDI policy.

China’s policies concurrently affect all sectors of exports, including primary goods, intermediate goods, and finished products. Its processing trade policy exempts imports for production to exports from tariff and VAT, and it is a major support to exporters. Its exports through export and special economic zones have been encouraged, and its imports for R&D center establishment and operation are also exempt from tariff and VAT. China’s broad support for exports represents a departure from the promotion of selective sectors or products approach of its neighbors in the 1970s. China took only two decades to make herself the number-one exporter of the world. The FDI share in China’s exports increased from 1.94% in 1986 to 54.8% in 2003.

On average, from 1990 to 2004, China’s annual real GDP growth rate was 10%, which is the highest in the world. International trade makes up a major portion of China’s GDP, and it exceeded USD2.4 trillion at the end of 2008. However, aside from the external factors of trade and FDI, the Chinese economy experienced a series of internal structural transformations since the opening-up economic reform in 1978. These transformations include rural industrialization, reform of state-owned enterprises (i.e., SOEs), modernization of the banking sector, and the recent proposal of fighting corruption.

India From 1950 to 1990, India’s per capita income grew at an average annual rate of only about 2%, a result due to the Indian government’s implementation of restrictive trade, financial, and industrial policies. The Indian state took control of major heavy industries, including additional licensing requirements, capacity restrictions, and limits on the regulatory framework. Following the foreign exchange crisis in the mid 1950s, trade policies oriented towards self-sufficiency and the government gradually tightened control by increasing statutory liquidity and cash reserve requirements.

Despite all these regulations, the Indian government promoted R&D by fostering commercialization of research undertaken by government-funded bodies after the country’s independence. Moreover, several training schools for engineers and scientists were established. The average R&D expenditure was 0.4% of the GDP from 1950 to 1990, but it surged to an average of 0.8% of the GDP in the period of 1991 to 2005, twice as much as the pre-reform period. The restrictions on trade and production were gradually lifted, and capital markets were liberalized in a series of reforms that started in the late 1970s and gained strong momentum in the early 1990s. As argued by Rodrik and Subramanian (2005), the trigger for India’s economic growth was an attitudinal shift on the part of the national government in 1980 in favor of private business. Specifically, this shift is the pro-business attitude of Indira Gandhi, who returned to power in 1980, to garner political support from existing business groups. Such suspension of the national government’s hostility to the private sector then had an important impact on the investors’ animal spirit.
The final trigger of the major economic reform of Manmohan Singh in the 1990s was due to the well-known 1991 balance-of-payment crisis. The economic reform that helped India’s recovery was the condition of the emergency loan imposed by the IMF on the Narasimha Rao government. This reform ended the protectionist policies followed by previous Indian governments and started the liberalization of the economy toward a free-market system. This event led to an average annual growth rate that exceeded 6% in per capita terms in the period of 1990 to 2005.

**Botswana** From 1966 to 1988, Botswana’s GDP grew at an annual rate of 14.5%. Its strong performance branded Botswana as the African Miracle. Rapid export growth followed the discovery of diamonds, with mining contributing 13% to the GDP in 1975 to more than 50% by the end of the 1980s. Then, the government sought to diversify the economy by encouraging foreign investment. According to Sachs and Warner (1997), reform took place in 1979 that led to the country being open to international markets.

In the period of 1997-1998 to 2001-2002, its average GDP growth rate decreased to 5.9%. Moreover, AIDS has been a serious problem for Botswana: according to a United Nations report on AIDS in 2009, HIV prevalence in Botswana is 24.8%, one of the highest in the world, similar to the countries of Swaziland (26%) and Lesotho (23.2%).

**Mauritius** Another miraculous performer in Africa is Mauritius, whose success is due to its early reform that took place in 1968. The reform institutionalized a spectacular transformation into tourism and out of sugar production. Consequently, agriculture in GDP composition dropped from 24% in 1970 to 5% in 2007, and services increased from 56% to 74% in the same period. From 1970 to 1999, the annual growth of export volumes was 5%. It began at with only 1% in the 1970s, increased in the 1980s (about 10%) and became moderate (5%) in the 1990s. Given its economic focus on tourism, the technological assimilation of Mauritius is not expected to be important, as is confirmed by its low value of the assimilation parameter at 0.0037.

**Comoros** Comoros was colonized by France in 1912, and it was transformed into a plantation-based economy. It declared independence in 1975. However, it experienced political interruptions since then, with its on and off independence from France.

Agriculture dominates the production activity of Comoros, and it features three main cash crops: ylang-ylang (for perfume), vanilla, and coconut. Its high total fertility rates created serious population pressure because of the people’s fear of hunger. Not surprisingly, its education level was low as well. Moreover, the government deficits were large because the country lacked stable tax revenues. In the past few decades, the economy of Comoros mainly relied on foreign financial and technical assistance.
Cote d’Ivoire  Different from that of Comoros, the real GDP per capita of Cote d’Ivoire was strong from 1960 to 1979. However, since then, it declined for a long span of 25 years. Its real GDP per capita in 2003 was about the same as that in early 1960s. Underpinning the per capita output decline since the late 1970s are: rapid population growth (3.95% for the first period of 1960 to 1979 and 3.26% for the second period) and decrease in capital investment (the growth rate of the gross capital formation per capita was 5.61% for the first period and -2.90% for the second period).

Cote’ d’Ivoire has become dependent on one raw commodity, that is, its single cash crop: cocoa. Over the last 40 years, cocoa output has grown to dominate Cote’ d’Ivoire’s economy and world production. Its cocoa output was 1.4 million tons in 2001, equivalent to about 40% of the world’s output. The nominal and real cocoa prices in the world market increased until they hit an all-time high in 1976. Then, the prices collapsed and never fully recovered. Cocoa exports dominate Cote d’Ivoire’s trade and economy. By 2000, raw cocoa represented 80% of the country’s commodity exports, over 50% of all exported goods and services, and 21% of the GDP. The decline of commodity price since 1977 has undermined the benefits of growth in Cote d’Ivoire’s physical cocoa output. A related long-term trend reinforcing the negative terms of trade impact is the depreciation of the US dollar vis-à-vis the French franc since the 1985 Plaza Accord. In 1994, the year of CFA devaluation, the output per worker began to climb and then increased over the trend. It crossed trend in 2001 and was well under the trend in 2002. The terms of trade seriously deteriorated as did the growth performance of the country. The decision to have cocoa specialization is somehow irreversible: Cocoa takes seven years to become commercially productive after initial planting, and it has a useful life of only three to four decades. The investment in productive cocoa acreage represents sunk costs, and it may not pay to uproot and replant with another crop. In short, the gamble of Cote d’Ivoire on cocoa to finance development efforts failed.

The support of foreign aid (from IMF and World Bank) is crucial to the economy. Note that Côte d’Ivoire is one of the most corrupt countries in the world (cf. Easterly 2001).

Kenya  Following Kenya’s emergence as an independent nation in 1963, the years were marked by rapid growth of domestic products, strong fiscal performance, low rates of inflation, and manageable, external accounts. Since the early 1970s, growth has slowed because of the two oil crises, as Kenya is heavily dependent on imported petroleum. Other international economic events occurred, such as the collapse of the East African Community, the major market for Kenyan manufactured goods. International recession and high international interest rates resulted in a steady tightening of the foreign exchange constraint on growth. Dramatic swings in the prices of Kenya’s key exports, coffee and tea, compounded the already difficult problems of economic management. Real prices for raw cocoa, cotton, and coffee increased in world commodity markets in 1960 until they hit all-time highs in 1977. After 1977, real prices crashed, and on average, they have declined steadily ever
since. From 1977 to 2003, coffee production did not increase, and real prices declined.

Other factors that contribute to the poor growth performance of Kenya include rapid population growth, AIDS outbreak, poor infrastructure, and the extended and recurrent banking crisis since the mid-1980s.

**Uganda**  Uganda became independent from the U.K. in 1962. At that time, over 80% of households lived in rural area, with the majority earning a living from quasi-subsistence agriculture. Unfortunately, this independent nation suffered a sharp economic downturn in the 1970s and the 1980s. The prolonged recession was due to the expulsion of South Asians in 1972, the administration of Idi Amin (the so-called “the state of blood”), the breakout of the Uganda-Tanzania War in 1978 to 1979, and the “bush war” by the National Resistance Army (NRA) in 1981 to 1986.

In 1986, the government (with the support of foreign countries and international agencies) attempted to rehabilitate the economy devastated during the regime of Idi Amin and the subsequent civil war. However, the economy was still in very poor conditions. Its agriculture sector accounted for 56% of the real GDP, with coffee as its main export (its price fell sharply in the late 1970s). The reform in 1988 helped the agriculture-based export expansion, causing an annual growth rate of 14%. Inflation was at 240% in 1987 and 42% in June 1992.

**Ghana**  Attaining its political independence in 1957, the Ghana government adopted a “fast track” strategy by launching state-owned import substitution industries in the 1960s. In 1970, Ghana had one of the most diverse and dynamic manufacturing sectors in sub-Saharan Africa. To understand the surge until the early 1970s, we can plot the G/Y ratio over time and ignore the outlier of 1968. A clear negative correlation exists between the G/Y ratio and per capita GDP. This finding can be understood by Prescott’s suggestion that, for developing countries, the government size can be used as a measure of distortions. However, as Ghana pursued non-selective industrialization policies behind high barriers of protection, its industry failed to develop adequate industrial capabilities and infrastructure. The Ghanaian industrial structure is typical of a low-level industrialization, showing a natural evolution from traditional to simple processing and assembly activities. Consequently, growth rates slowed down and, with declining revenues from the primary exports that had financed industry, even turned negative. Thus, structural reform policies were undertaken in the 1980s. Growth resumed by the end of the 1990s.

Unlike the formal technological effort in Ghanaian manufacturing, practically all industrial R&D in Ghana was conducted by public institutions rather than by enterprises. The R&D effort declined sharply in the 1980s, and it was well below the critical mass needed to make a significant contribution to the absorption, adaptation, or creation of technology [Lall (1990)].

**Argentina**  Argentina is the third-largest economy in Latin America and was one of the richest countries in the world back in the early 20th century. How-
ever, after the Great Depression, the government pursued a strategy of import substitution to achieve industrialization. The cost-push effect of high wages on inflation started the country’s nightmare. From 1975 to 1990, growing government spending, large wage increases, and inefficient production created a chronic inflation that increased until the 1980s, and real per capita income fell by more than 20%. The annual rate of inflation never fell below 100% over this period. Starting with the Rodrigazo (the group of economic policies announced in Argentina on June 4, 1975), inflation accelerated sharply, reaching an average of more than 300% per year during the 1975 to 1991 period, and prices increased by a factor of 20 billion. Moreover, it brought in a huge foreign debt by the late 1980s; this debt was equal to three-fourths of the GNP. Record foreign debt interest payments, tax evasion, and capital flight resulted in a balance of payments crisis that plagued Argentina with severe stagflation for this period. In the early 1990s, the government reigned in inflation by making the peso equal in value to the US dollar and privatized many state-run companies, and it used part of the proceeds to reduce the national debt. Nevertheless, the economy continued to crumble slowly from 1995 and eventually collapsed in 2001. A year later, Argentina defaulted on its debt, its GDP declined by nearly 20% in four years, unemployment reached 25%, and the peso depreciated by 70% after being devalued and floated. Since then, the economy has started to recover.

**Brazil** Brazil is the largest national economy in Latin America and is famous for its corruption (ranking 69th among 178 countries in 2012 in the Transparency International’s Corruption Perceptions Index). Corruption costs Brazil an estimated USD41 billion a year alone.

In the middle of the 19th century, coffee was the main economic activity of the Brazilian economy, and it accounted for more than 50% of the country’s export in the beginning of the 20th century. However, as the coffee demand in the world shrank together with the Great Depression, Brazil faced a serious external crisis and started its import substitution industrialization process in the 1930s. The period of after the Second World War to the early 1960s was a phase of intense import substitution. Brazil achieved an average annual rate of growth of GDP that exceeded 7% from 1950 to 1961. The engine of growth was the structural transformation from agriculture to industry. However, the import substitution industrialization also resulted in a substantial increase in imports, notably of inputs and machinery. The foreign exchange policies of the period meant inadequate export growth. Moreover, a large influx of foreign capital in the 1950s resulted in a large foreign debt so that the balance of payments problems of the country increased dramatically. Nevertheless, the 1968 to 1973 period was still one of very rapid industrial expansion and modernization of Brazil, despite the stagnation of the industrial sector due to adverse macroeconomic conditions from 1962 to 1967. In this five-year period, the average annual rate of growth of the GDP jumped to 11.1%, and Brazil’s industrial exports increased from USD1.4 billion in 1963 to USD6.2 billion in 1973.

Brazil suffered drastic reductions in its terms of trade as a result of the
1973 oil shock. Brazil continued its high-growth policy by running up the foreign debt because of increasing import requirements of industrialization. Another feature of the post-1973 period is the acceleration of inflation. In the period of 1973 to 1991, Brazil experienced high inflation; its annual rate was in 30% to 40% in the 1970s and accelerated in the 1980s. Its government deficit (corrected for inflation) fell from an average of 13% of the GDP in the early 1980s (peaked at 22.1% in 1983) to 3.3% in 1987. Capital continued to flow out of the country for more than a decade from 1982 to 1991, estimated at over USD10000 billion per year for the second half of the 1980s (Edwards 1998). Its inflation peaked as follows: 1986:2 (20%), 1987:6 (24%), 1989:1 (33%), and 1990:3 (59%). The 1986 Cruzado Plan and the 1990 Collor I Plan helped only temporarily. Only after the 1991 Collor II Plan did the economy stabilize. Nonetheless, similar to its neighboring country, Argentina, Brazil continued to suffer crises afterward, including the crises of 1999 and 2002, although these crises were considerably less severe than the Argentine crisis in 2001 to 2002.

Chile From the Second World War to 1970, the real GDP per capita of Chile increased at an average annual rate of 1.6%, and its economic performance was behind those of Latin America’s large and medium-sized countries. Chile pursued an import-substitution strategy, and it resulted in an acute overvaluation of its currency that intensified inflation. During the 1950s and the 1960s, three major stabilization programs, one in each administration, were launched, but all were futile. The programs only focused on tackling the various consequences of inflationary pressures, such as prices, wages, and exchange-rate increases, rather than the fundamental cause of money growth due to the monetization of the fiscal deficit. Inflation continued to be a serious problem of Chile in the 1970s and the 1980s. However, since its adoption of its inflation target in 1991, the Chilean economy has stabilized.

During the second half of the 1970s, and while most of Latin America moved further and further into the direction of protectionism and government control, free market reforms were being implemented at a rapid pace in Chile. A group of Chicago economists – the so-called “Chicago boys” – were brought in for the formulation and implementation of Chile’s reforms. The outcomes are as follows: exports grew rapidly, per capita income took off, inflation declined to single digit, wages increased substantially, and the incidence of poverty plummeted (cf. Edwards and Edwards 1991). During the early 1990s, the democratic government of Patricio Aylwin, who took over from the military in 1990, deepened the economic reform initiated by the military government. This occurrence made Chile the brightest star in the Latin American firmament for the next two decades.

Mexico Similar to most Latin American countries, Mexico pursued an inward-looking development strategy of import-substitution industrialization since the Great Depression. The economic performance of Mexico remained strong in the 1960s, when per capita GDP growth and CPI inflation both averaged about 3% annually. Manufacturing remained the country’s dominant growth sector, expanding to 7% annually and attracting considerable foreign investment.
From the 1940s to the 1970s, the structural transformation from agriculture to industry (with services remaining constant) produced sustained economic growth and this 30-year period, which is known as the Mexican miracle.

Although the Mexican economy continued its rapid growth during most of the 1970s, it was progressively undermined by fiscal mismanagement of the government and by a poor export industrial sector. The major oil discovery in 1977 provided important support for both foreign borrowing and destructive fiscal expansion. Eventually, the boom was ended by the infamous Mexican debt crisis of 1982. Over the subsequent years from 1982 to 1991, Mexico experienced high inflation, large government deficit, and large capital outflows, although at a lesser degree compared with the Southern Cone ABC countries. The economy stabilized only after 1991 when inflation targeting was adopted. However, there was still a severe currency crisis from 1994 to 1995. Nevertheless, since then, the Mexican economy has been on the upward trajectory again in less than one-and-a-half years, maintaining an average annual growth rate at 5.1% between 1995 and 2000.

Note that Mexico is known to have a large informal sector where drug trafficking is the major activity. Crime has always been a main concern of Mexico, as it is the center of cocaine, heroin, and marijuana transiting between Latin America and the U.S.

References cited only in the Appendix


