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Physical Capital Accumulation in Asia-12: Past Trends and Future Projections

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Etsuro Shioji and Vu Tuan Khai

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Etsuro Shioji and Vu Tuan Khai

January 2011

Etsuro Shioji is Professor at Hitotsubashi University. Vu Tuan Khai is Assistant Professor at Seikei University. This paper was prepared under the Asian Development Bank's TA7470-REG: Long-term Projections of Asian GDP and Trade. A previous version of the paper was presented at the Finalization Workshop on Long-term Projections of Asian GDP and Trade sponsored by the Asian Development Bank and Chinese University of Hong Kong on 8–9 July 2010 in Hong Kong, China. The authors thank discussant Carsten Holz for his valuable comments. They also like thank Jong-Wha Lee, Kiseok Hong, and other workshop participants for their advice. This research would not have been possible without support and encouragement from ADB staff, especially Akiko Terada-Hagiwara and Lea R. Sumulong. The authors accept responsibility for any errors in the paper.

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Contents

Abstract	v
I. Introduction	1
II. Theoretical Background	1
A. Steady State: Simple Case with no Long-Run Growth	2
B. Steady State: Introducing Population Growth and Technological Change	3
C. Steady State under Capital–Skill Complementarity	4
D. Modeling Transition	4
E. Empirical Implications	5
III. Overview of Past Trends in the Asia-12	6
IV. Preliminary Investigation on the Investment Rate	11
A. High Serial Correlation	11
B. The Feldstein–Horioka Relationship around the Globe	12
V. Empirical Model and Estimation Results	15
A. Basics	15
B. List of Explanatory Variables in the Full Specification	16
C. Estimation Results	18
D. In-sample Decomposition for Asia-12	20
VI. Projection	22
A. Projection Methodology	22
B. Projection Results	23
C. Decomposition of Projection Differences	24

VII.	Alternative Approach	26	
	A.	Restricted Estimation Approach	26
	B.	Projection Based on the Restricted Estimation	27
VIII.	Conclusions	30	
	Appendix: Underlying Theory—Open Economy Growth Model with Adjustment Cost of Capital	31	
	References	34	

Abstract

The pace of capital accumulation in East Asia has simply been stunning. In this paper, we investigate sources of this fast accumulation and make projections for the future to see if the trend is likely to continue. East Asian economies under consideration are the People's Republic of China; Hong Kong, China; Indonesia; the Republic of Korea; Malaysia, the Philippines; Singapore; Taipei, China; Thailand; and Viet Nam, including India and Pakistan from South Asia. We estimate a "convergence" equation for physical capital per capita, which is derived from an open economy growth model, using a pooled cross-country, across-decade sample of the entire world. Based on the estimation results, we decompose past growth in physical capital per capita of the emerging Asian economies. We also conduct projections for the next two decades and study determinants of the investment rate for those economies.

I. Introduction

In this paper, we investigate sources of historical trends in physical capital accumulation for what we shall call “Asia-12”, namely, the People’s Republic of China (PRC); Hong Kong, China; India; Indonesia; the Republic of Korea; Malaysia; Pakistan; the Philippines; Singapore; Taipei,China; Thailand; and Viet Nam. We also make projections for the future. We propose a new projection approach based on estimation of a “convergence” equation for the investment rate. This equation, in turn, is based on an open economy growth model with capital mobility subject to convex adjustment costs. Using a pooled cross-country, cross-decade sample of the entire world, we identify major determinants of the growth rate of capital per capita. Based on those estimates, we decompose historical growth in the Asia-12 and make projections for the future. We will also investigate determinants of the investment rate for those countries. We study carefully the role of the saving rate.

The rest of the report is organized as follows. In Section II, we develop our empirical model based on a theoretical open economy growth model. Section III provides an overview of past trends of physical capital per capita (K/Pop) and investment rate (I/Y). In Section IV, as a preliminary step, we study data properties of the investment rate in detail. In Section V, we estimate our convergence equation for physical capital per capita, and analyze sources of past growth. Section VI uses the same model to make projections for the future. In Section VII, we propose an alternative approach that imposes more theoretical restrictions on the convergence equation estimation, and compare the results with the unrestricted case. Section VIII concludes.

II. Theoretical Background

In this section, we develop a theoretical foundation for our projection method, which is an open economy growth model (although a formal exposition of the model will be left to the appendix). The theory will help us identify key determinants of the physical capital–population ratio. We employ an open economy model primarily because most of the Asian economies are highly open economies.

Consider a small open economy. Capital is assumed to be freely mobile across countries. Capital flow is determined primarily by the country’s after-tax marginal product of capital

(MPK). Here, “tax” should be interpreted to include such elements as country risks (quality of government and institutions, openness to external transactions) and efficiency of internal capital market. Investors are assumed to have access to the world capital market in which the world real interest rate is determined exogenously. The steady state condition is thus:

$$(1-\tau)MPK = r^w, \quad (1)$$

where r^w is the world real interest rate considered to be exogenous, and τ is the tax rate broadly defined. Next, we study how this MPK is determined.

A. Steady State: Simple Case with no Long-Run Growth

We first consider a simple case without population growth or technological progress. Assume that the production function takes a Cobb-Douglas form:

$$Y = AK^\alpha L^{1-\alpha}, \quad (2)$$

where Y is output, A is a positive constant, K is physical capital, and L is labor. Also, α takes a value between 0 and 1. Then we have

$$MPK = \alpha AK^{\alpha-1} L^{1-\alpha} = \alpha A \left(\frac{K}{L} \right)^{\alpha-1} = \alpha \frac{Y}{K} \quad (3)$$

Hence, for the capital–output ratio, we obtain the following steady state condition:

$$\frac{K}{Y} = \frac{(1-\tau)\alpha}{r^w}. \quad (4)$$

Thus the tax rate becomes the primary determinant of this ratio. Note that TFP does not enter equation (4). On the other hand, for the capital–labor ratio, we get

$$\frac{K}{L} = \left[\frac{(1-\tau)\alpha A}{r^w} \right]^{1/(1-\alpha)}. \quad (5)$$

Hence, in this case, TFP does show up on the right hand side. These features will be important when we interpret our estimation results later. For the level of investment, denoted I , as the steady state requires

$$I = \delta K, \quad (6)$$

where δ is the depreciation rate, we have a one-to-one correspondence between I and K . Thus, for example, if we would like to predict the long-run investment rate, we could utilize the relationship:

$$\frac{I}{Y} = \delta \frac{K}{Y} = \delta \frac{(1-\tau)\alpha}{r^w}. \quad (7)$$

B. Steady State: Introducing Population Growth and Technological Change

Now consider introducing population growth and technological progress. We introduce a labor-augmenting technological term into the production function in the previous subsection:

$$Y = AK^\alpha (X \cdot L)^{1-\alpha} \quad (8)$$

where X is the level of technology. We assume

$$\dot{L}/L = n, \quad \dot{X}/X = x \quad (9)$$

where both n and x are constants. We can write down the “per efficiency unit” production function as:

$$\hat{y} = A\hat{k}^\alpha, \text{ where } \hat{y} \equiv Y/(XL) \text{ and } \hat{k} \equiv K/(XL) \quad (10)$$

In this case, we have

$$MPK = \alpha A\hat{k}^{\alpha-1} = \alpha \frac{\hat{y}}{\hat{k}} = \alpha \frac{Y}{K} \quad (11)$$

Note that this expression is the same as in the simpler case with no growth. Thus, again, we obtain the following steady state condition:

$$\frac{K}{Y} = \frac{(1-\tau)\alpha}{r^w}. \quad (12)$$

On the other hand, for the capital–labor ratio, we get

$$\frac{K}{L} = X \cdot \left[\frac{(1-\tau)\alpha A}{r^w} \right]^{1/(1-\alpha)} \quad (13)$$

Hence, even in the steady state, this variable will be growing at the rate x . For investment, we note

$$\dot{K} = I - \delta K \Rightarrow \frac{\dot{K}}{K} = \frac{I}{K} - \delta \quad (14)$$

Note that, in the steady state, we must have

$$\frac{\dot{K}}{K} = n + x$$

Thus, we get, in the steady state,

$$\frac{I}{K} = \delta + n + x \text{ or } \frac{I}{Y} = (\delta + n + x) \cdot \frac{(1-\tau)\alpha}{r^w} \quad (15)$$

must hold. Thus, population growth rate (or, more realistically, labor force growth rate) and the rate of technological change enter as important determinants for the steady state I/Y ratio.

C. Steady State under Capital–Skill Complementarity

Now we consider a possible role of human capital. Simply introducing “H” into the above Cobb-Douglas production function in a labor-augmenting way would not change anything fundamentally, as “H” would act just like “X” in the above analysis. Things are a little different when we consider the more interesting case of K-H complementarity.

$$Y = A(K^\rho + H^\rho)^{\alpha/\rho} (X \cdot L)^{1-\alpha} \quad (16)$$

where H is the level of human capital. Note that, in this setup, α should be considered as the share of “capital broadly defined”: its realistic value would be closer to 0.6 or 0.7 rather than 0.3 or 0.4. In this case, we have

$$MPK = \alpha \frac{Y}{K} \cdot \frac{K^\rho}{K^\rho + H^\rho} = \alpha \frac{Y}{K} \cdot \frac{(K/Y)^\rho}{(K/Y)^\rho + (H/Y)^\rho} \quad (17)$$

Hence, the long run capital–output ratio will be dependent on the country’s level of human capital (relative to gross domestic product [GDP]), unless ρ is equal to zero.

D. Modeling Transition

We assume that there is a quadratic cost of adjustment for investment. This would imply a gradual adjustment toward the steady state. The full model is developed and solved in the appendix. It is shown that the model solution exhibits a tendency toward gradual convergence to the steady state in terms of capital per efficiency unit, \hat{k} . If \hat{k} is converging, K/L is also converging. In the appendix, the following result is shown:

$$\frac{1}{T} (\ln k_T - \ln k_0) = x + \frac{1 - e^{-\beta T}}{T} \cdot \frac{1}{1 - \alpha} \cdot \ln TFP_0 - \frac{1 - e^{-\beta T}}{T} \cdot \ln k_0 + \text{constant} \quad (18)$$

where k denotes K/L , TFP_0 is the level of TFP at time 0, and β is the speed of convergence. The constant term at the end of the right hand side is negatively affected by the tax rate.

E. Empirical Implications

Our theory indicates that the following factors are at least potentially important in analyzing determinants of growth rate of K per capita:

- (i) Initial K per capita: as the economies should have a tendency toward convergence according to our model, we expect its coefficient to be negative.
- (ii) Efficiency at which investors can reap proceeds from their investment, which is represented by the parameter τ in our theoretical model. We consider institutional quality (especially protection of private property rights) and trade openness as the two most important candidates.
- (iii) Initial TFP level.
- (iv) TFP growth rates.
- (v) Human capital: our discussion in Section II-C suggests that it might also affect the steady state return to physical capital.

We also pay attention to other possible determinants of the growth rate of K per capita, though they may not directly appear in our theoretical model. We consider the following variables.

- (i) Period dummies, certain regional dummies (such as Sub-Saharan Africa dummy), and possibly their interaction terms.
- (ii) Industrial structure: some industries are more capital-intensive than others, and thus economies with different industrial compositions might require different amounts of capital. We could also try including interaction terms between shares of different industries in output and period dummies.
- (iii) Share of government expenditure in GDP: Our theory completely ignored the presence of government: however, in reality, a large government could crowd out private investment activities.
- (iv) Population growth rate: it is an important determinant of the growth rate of capital per capita in the Solow type growth model.
- (v) Savings rate: if the world is truly characterized with free capital mobility, we expect no strong relationship between savings and investment. However, the Feldstein-Horioka puzzle (Feldstein and Horioka 1980) suggests that,

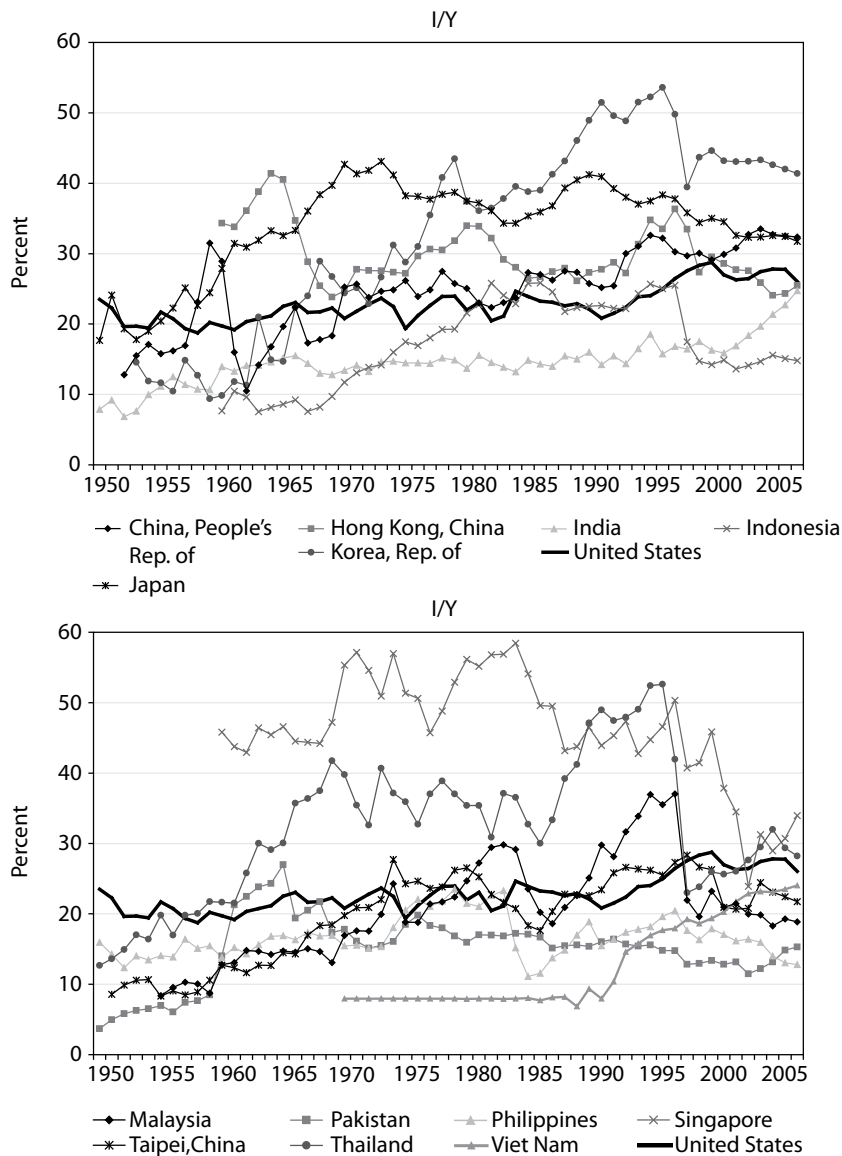
in reality, those two might be closely related. We intend to control for this possibility by including the saving rate for the same period as the investment rate on the left hand side.

- (vi) Relative price of investment goods: an underlying assumption behind our model was that the price of consumption and investment goods are the same: however, in reality, several past studies have found that the relative price between the two types of goods is an important determinant of growth.
- (vii) Lagged growth rate of K per capita: we shall comment more on this variable after we present an overview of trends in the data in Section IV.

III. Overview of Past Trends in the Asia-12

In this section, we overview historical evolution of investment and physical capital in the Asia-12 plus Japan. We also show data for the United States (US), for the sake of comparison.

As estimates for physical capital stock are normally constructed from data on investment, we shall first review past trends in the investment rate. In Figure 1, we report historical evolution of the investment rate or the investment–GDP ratio (I/Y). The data is taken directly from the Penn World Table Version 6.3 (Heston et al. 2009). As is well known, some Asian economies have very high investment rates: at the end of our sample, they are over 30% for the PRC; Japan; the Republic of Korea; and Singapore, though the sample ends in 2007 and thus does not reflect changes during the global financial crisis for the years 2008–2009. Another notable feature, which turns out to be important in the estimation stage, is that the investment rate exhibits a very high degree of serial correlation. For example, since the early 1980s, the investment rates for Japan and the Republic of Korea were never below that of the US. For the PRC and Singapore, their investment rates were above that of the US for most of the time since the early 1980s, with the exception of a few years. On the other hand, for Pakistan, the Philippines, and Viet Nam, their I/Y were always below the US level at least since the mid-1980s. India is another country that has had a persistently low investment output ratio, though it started increasing rapidly during the 2000s, and, by the end of our sample period, it had caught up with the US level. On the other hand, the I/Y ratio sometimes exhibits large within-economy swings. Most notably, Malaysia and Thailand experienced sudden declines in their investment rates toward the end of the 1990s, during the Asian crisis period.

Figure 1: Historical Evolution of the I/Y Ratios in Asia-12, Japan, and the US

I/Y = investment-GDP ratio.
Sources: Penn World Table 6.3.

On the stock of physical capital, we use the data set used in Lee and Hong (2010). Their approach, like the one employed by King and Levine (1994), assumes that each economy is initially in the steady state in which K grows at the same constant rate as Y ¹. Denote the growth rate of Y in the steady state as g and the depreciation rate of K as δ . Then we can write

¹ Our exposition here is based on a note sent from ADB on Lee and Hong (2010).

$$(K_t - K_{t-1}) / K_{t-1} = (I_t / K_{t-1}) - \delta \quad (19)$$

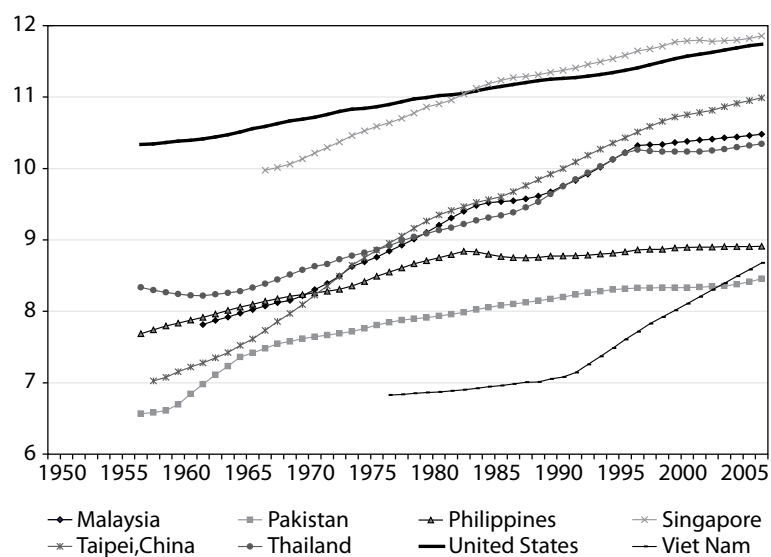
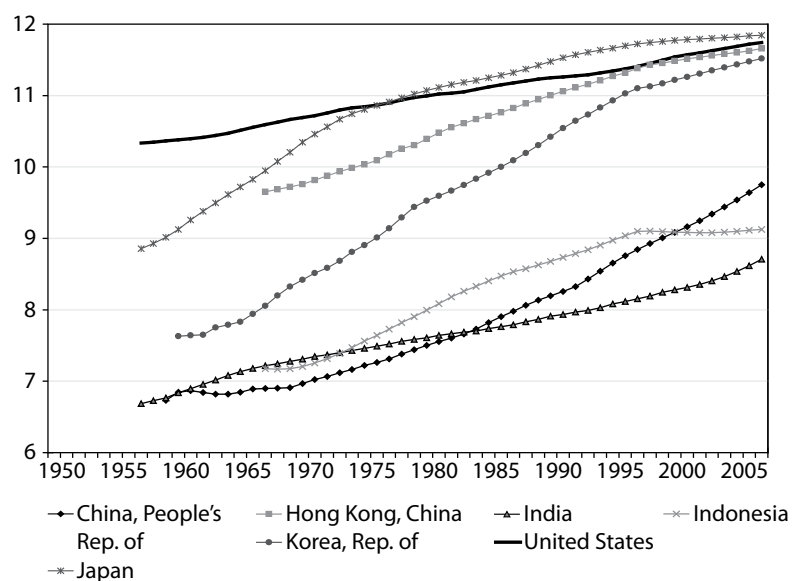
and thus, in the steady state, we have

$$(I_t / K_{t-1}) - \delta = g \Rightarrow K_{t-1} = I_t / (g + \delta). \quad (20)$$

Lee and Hong (2010) use the value of 0.06 for δ (annual). Much of the differences between different methods come from how they estimate the steady state growth rate. King and Levine (1994) use a weighted average of economy i 's output growth rate and the world growth rate over a 30-year period to produce economy i 's estimated steady state growth rate. Lee and Hong used 5-year average growth rate of output around the initial year. Once initial values are obtained, both approaches use the perpetual inventory method to construct long run capital stock series. We compared the K-Y ratio derived from our update of King and Levine (1994) estimates with that of Lee and Hong (2010) and confirmed that the two series are strongly correlated with each other for each economy. We also find that, by the year 1975, the two series are almost perfectly converged: as our empirical analysis uses data from 1977 onward only, we can reasonably assume that our results will be robust to use of alternative data on physical capital. From here on, we will limit our attention to the physical capital series from the Barro and Lee (2010) data set.

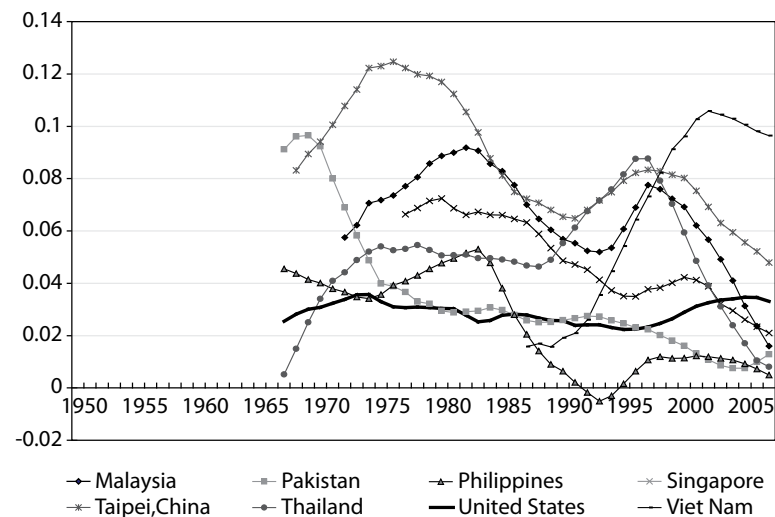
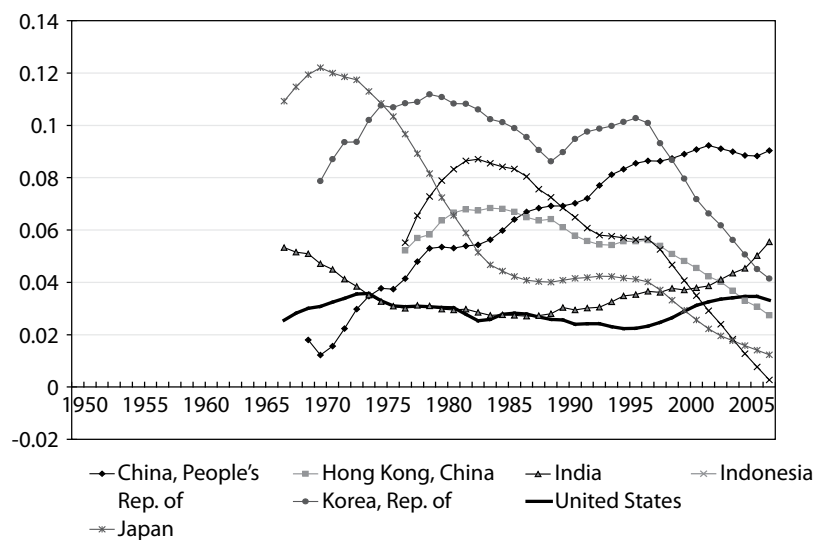
In Figure 2, we report historical evolution of physical capital stock from the Barro and Lee (2010) data divided by population, in logarithms. The population data is taken from the Penn World Table 6.3. We also add data for Japan and the US. We note that only two countries, Japan and Singapore, have accumulated capital per capita higher than that of the US. Hong Kong, China and the Republic of Korea are at comparable, though at lower levels. We also compute the growth rate of K per capita, shown in Figure 4. Growth rates are again defined as log differences from 10 years ago. In the figure, we report our estimates for each year. We realize that growth in capital per capita is decelerating in much of Asia, even for the economies with a much lower K per capita than the US, with the exception of the PRC, India, and Viet Nam. Deceleration is particularly notable for Malaysia and Thailand, starting from the period of the Asian financial crisis. As this growth rate appears to be highly persistent (although less so than the I/Y ratio shown in Figure 1), it is likely that this growth slowdown will continue for most of the economies, while the PRC and Viet Nam (and perhaps India) are expected to enjoy some period of relatively high growth.

Figure 2: Cross Country Comparison of the Historical Evolution of the K/Pop Ratio in the Asia-12 (and the US), in Logs



$\frac{K}{Pop}$ = growth rate of physical capital stock per capita, Pop = population.
 Sources: Lee and Hong (2010) data set (K) and Penn World Table 6.3 (Pop).

Figure 3: Cross country Comparison of the Historical Evolution of the Growth Rate of the K/Pop Ratio: Log Difference from 10 Years Ago, Annualized



K/Pop = growth rate of physical capital stock per capita, Pop = population.
 Sources: Authors' calculation based on Penn World Table 6.3 and Lee and Hong (2010) data set.

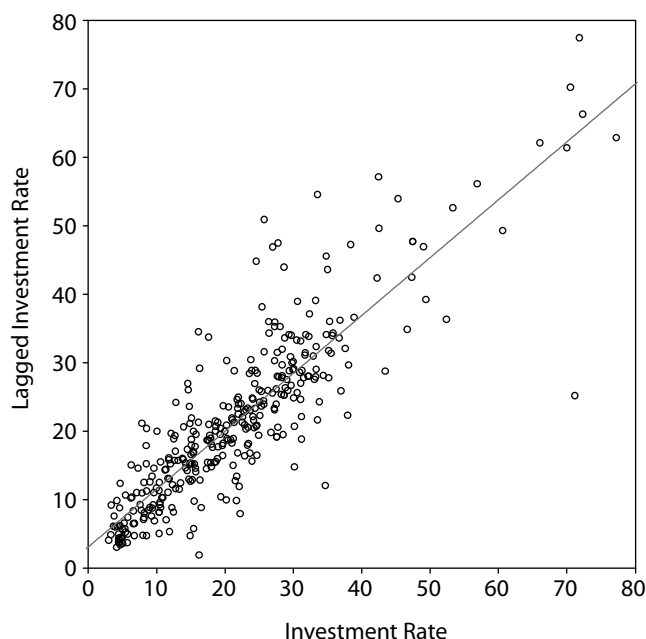
IV. Preliminary Investigation on the Investment Rate

Before turning to our main estimation stage, in this section, we make some preliminary investigation on the data on investment rate. As we have seen, our estimated series on capital stock is constructed from the investment rate series. For that reason, we believe it is worth investigating the empirical properties in detail.

A. High Serial Correlation

The investment rate is highly serially correlated. In Figure 4, we plot the average investment rate for the 10-year periods of 1987–1997 and 1997–2007, against the same variable from the previous 10-year periods, i.e., 1977–1987 and 1987–1997. The data source is the Penn World Table 6.3 and we include all the countries with available data into our sample. There is evidently a very strong positive correlation (with perhaps the exception of a single observation in the southeast of the box, which turns out to be Suriname for the period 1997–2007). This suggests that, in our empirical analysis on the determinant of the growth rate of physical capital stock per capita, it is better to include its own lag as an explanatory variable, though our theory does not predict its relevance.²

Figure 4: Decadal Investment Rate versus Its Own Lag



Note: Sample period: 1978–2007.

Sources: Authors' calculation based on Penn World Table 6.3.

² In recent business cycle studies, it is often assumed that the investment adjustment cost is derived from changing the flow of investment, rather than changing the stock of physical capital. We believe such a specification could render justification to the inclusion of the past capital growth as an explanatory variable.

B. The Feldstein–Horioka Relationship around the Globe

Feldstein and Horioka (1980) demonstrate that there is a very tight relationship between the saving rate and the investment rate among countries of the Organisation for Economic Co-operation and Development (OECD), contrary to what is expected from an open economy model with free capital mobility (including the one we presented in Section II). We check if such a relationship is present in a data set that includes not only advanced countries but also many developing countries. Specifically, we again take data from the Penn World Table and include all the countries for which both the investment rate and the saving rate are available. The saving rate is computed as 1 minus the shares of private consumption (kc in the data set) and government consumption (kg). Note that those are in real terms. Figure 5(a) simply plots the investment rate against the saving rate for the entire sample, which includes three 10-year periods, i.e., 1977–1987, 1987–1997, and 1997–2007. Both are defined as averages over the 10-year period. In the figure, we do observe a positive correlation but not a very strong one. In Table 1 column (1), we run a simple ordinary least squares (OLS) with the investment rate on the left-hand side and the saving rate on the right-hand side. The coefficient is positive and very significant, but its size is just 0.15. This might be due to some outliers. In Figure 5(b), we mechanically exclude observations with the saving rate below -30% and above 60% , as well as those with the investment rate over 60% . The positive correlation is now stronger. In column (2) of Table 1, we run the same regression as in column (1), but excluding those outliers. The coefficient is now about 0.31.

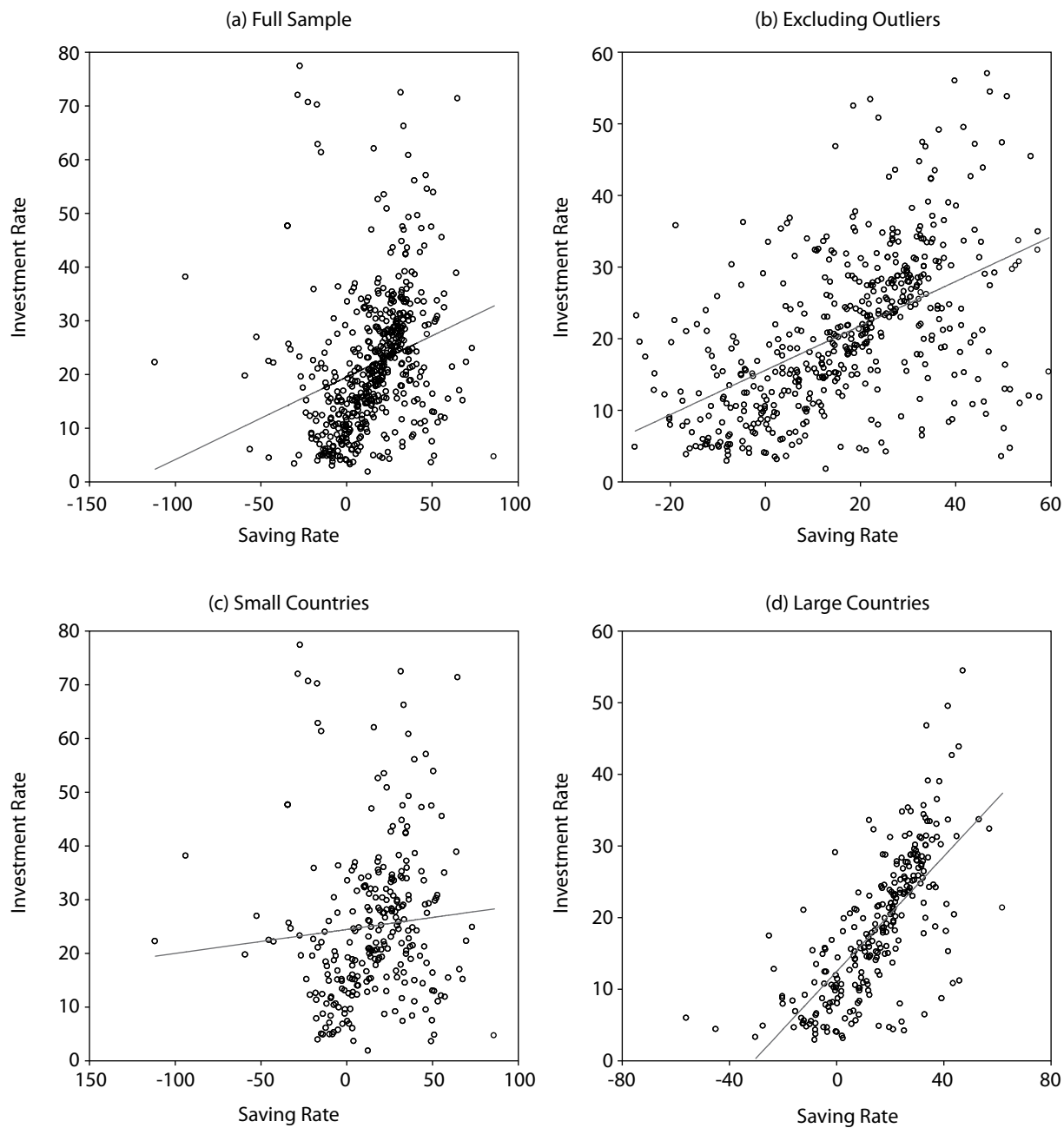
Ho (2003) argues that the strength of the saving–investment correlation depends on the country’s size in terms of its gross national product (GNP) share. Bahmani-Oskooee and Chakrabarti (2005) argue that the degree of openness of a country is also important, though they use a very different econometric technique than the one used here. We now investigate these possibilities. We divide the entire sample into four 25% quantiles, based on population size, GDP, GDP per capita, or openness (defined as exports plus imports divided by GDP). Those variables are all taken from the Penn World Table. In the regression, we allow both the intercepts and the slope coefficient to vary across the four quantiles. Table 1 column (3) shows the results in which the sample is divided based on the population size. In columns (4), (5), and (6) the quantiles are based on GDP, GDP per capita, and openness. We can see that when we use either population or GDP to divide the sample, there is a clear tendency for the coefficient on the saving rate to increase with size. That is, the Feldstein–Horioka relationship is more applicable to economies with larger sizes, either in terms of population or GDP. In panels (c) and (d) in Figure 5, we again plot investment rate against saving rate, but this time splitting the sample between observations with population lower than the median or panel (c), which is titled “smaller countries”, and those above the median or panel (d), titled “larger countries”. On the contrary, we do not observe any clear tendency for the coefficient to go either up or down in columns (5) and (6). The R squares are also low.

Table 1: Investigation of the Saving–Investment Relationship (dependent variable: investment rate)

Quantile Based on	(1)		(2)		(3)		(4)		(5)		(6)	
	Estimate	Std.	Estimate	Std.	Estimate	Std.	Estimate	Std.	Estimate	Std.	Estimate	Std.
Intercept	19.48	0.65	15.56	0.56								
Saving rate	0.15	0.02	0.31	0.02								
Quantile 0–25% intercept					29.27	1.10	27.57	1.02	14.95	1.08	19.49	1.26
Quantile 25–50% intercept					19.47	1.11	13.69	1.14	20.72	1.24	16.05	1.41
Quantile 50–75% intercept					12.58	1.11	14.51	1.42	22.71	1.56	17.78	1.33
Quantile 75–100% intercept					12.06	1.52	13.63	2.47	30.56	3.14	24.00	1.21
Quantile 0–25% coefficient					-0.02	0.04	0.12	0.04	0.08	0.05	0.12	0.05
Quantile 25–50% coefficient					0.11	0.04	0.24	0.05	0.08	0.06	0.22	0.05
Quantile 50–75% coefficient					0.38	0.05	0.22	0.05	0.11	0.06	0.25	0.05
Quantile 75–100% coefficient					0.42	0.06	0.38	0.08	-0.12	0.08	0.08	0.04
R-squared	0.073		0.271		0.275		0.239		0.135		0.112	
Adjusted R-squared	0.071		0.269		0.266		0.228		0.123		0.099	
Sample size	533		501		533		509		509		525	

Note: Definition of the quantiles assumes that the observations are ordered “from low to high”. For example, in column (3), the quantile contains the ones with the largest population. Source: Authors’ calculation.

Figure 5: Saving–Investment Relationship



Note: Sample period: 1978–2007.
Source: Authors' calculation based on Penn World Table 6.3.

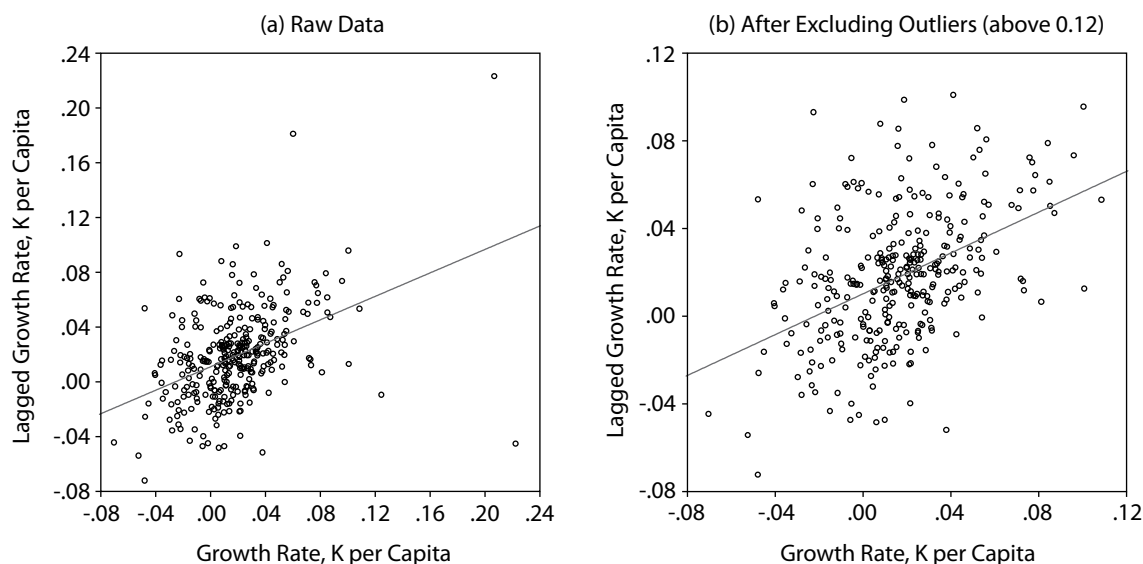
In consideration of the above evidence, in our main estimation stage, we shall split the entire sample based on a size variable. To secure sufficient sample sizes, we split the entire sample into two, rather than four, at the median. We decided to split the sample based on GDP size: a major advantage is that all the economies in Asia-12 are classified as “large” with this criterion, thus we do not need to use two models. For this reason, in what follows, we shall focus mostly on the sample that consists of larger economies.

V. Empirical Model and Estimation Results

A. Basics

Now we turn to our main estimation stage. Our data set for the empirical analysis consists of all the economies in the world for which the data is available (though we split the sample into two based on GDP, as just stated above), rather than focusing exclusively on the data on the Asia-12. There are two primary reasons for this choice. First, we would like to have as large a data set as possible for the analysis. Second, we believe it is not enough to examine past data on the Asia-12 carefully to make future projections for those economies. As we suspect many of them are in a long transition from poor to rich economies, it is more informative to look into a data set that includes many poorer and wealthier economies, to gain perspective on where they might have come from and where they might be headed to. As virtually all of our data set ended in 2007, we have decided to split the sample, along the time series dimension, into the following three 10-year periods: 1977–1987, 1987–1997, and 1997–2007 (data for the 1967–1977 period was not available for some of the economies in the sample; also, as we discussed in Section III, data on physical capital stock appears to be somewhat sensitive to the choice of the initial values toward the beginning of the sample).

We use the growth rate of physical capital stock per capita (the K/Pop ratio) as the dependent variable to be denoted “KPG”. This, like all the growth rates in this report, KPG is defined as annualized log differences, in this case between the initial year of the next 10-year period and the initial year of the current 10-year period. Data on physical capital stock (K) is taken from the Barro and Lee (2010) data set and the population data is from the Penn World Table 6.3. This KPG variable is plotted against its lagged value (i.e., KPG from the previous 10-year period) in Figure 6(a). The positive correlation is preserved when we exclude outliers that record the value of KPG (or its lag) of over 0.12, as shown in Figure 6(b). We observe a positive serial correlation, just as in the case of the investment rate (refer to Figure 4), though the correlation is weaker. This has strengthened our conviction that we should include the lagged dependent variable in our estimation. This means that we lose the 1977–1987 period to be used as the initial condition, hence our estimation sample consists of just two 10-year periods, 1987–1997 and 1997–2007.

Figure 6: Decadal Growth Rate of K Per Capita versus Its Own Lag

Note: Sample period: 1978–2007.

Source: Authors' calculation based on Penn World Table 6.3 and Lee and Hong (2010) data set.

B. List of Explanatory Variables in the Full Specification

We employ a pooled cross-economy, cross-decade OLS approach, splitting the entire sample into “large” and “small” based on GDP. For both “large” and “small” samples, we started with a “full” specification in which we include practically all the variables in our data set that might affect the investment rate as explanatory variables. But we found that many of those variables were insignificant. To improve accuracy of projection, we started excluding variables that were apparently irrelevant for the determination of KPG. We arrive at the “final” specification, in which we are left with only variables that have significant coefficients. Below, we will briefly explain our full specification but will present results only for the final specification.

In our full specification, the following explanatory variables, besides the constant term (denoted “CONST”) are used. Those variables that are given abbreviations are the ones that survive in the final specification for either “large” or “small”.

- (1) We include physical capital stock per capita, in logarithms, called “LKP0”.
- (2) For indices of institutional quality, we tried the rule of law index from the World Governance Indicators (World Bank 2010b), denoted as “RULE”, as well as the political stability index and others. We also tried including some indicators from the Heritage Foundation’s (2010) Index of Economic

Freedom 2010, such as their overall scores and the property rights index. As an indicator for openness, we included the openness indicator from the Penn World Table 6.3, denoted “OPEN”, defined as the sum of exports and imports as percentages of GDP. We also tried including the ratio of bank credit to GDP (from the World Development Indicators) and the ratio of M3 to GDP, as proxies for the degree of financial development.

- (3) TFP growth rate and population growth rate: TFP growth rate, defined as 10-year log difference, is based on Park (2010) and is called “TFPG”. Population growth data is taken from the Penn World Table 6.3 and called “POPG”. Also, we add “POP_15_64”, the population share of people aged between 15 and 64, to control for the effects of the labor force participation rate. This variable is taken from the World Development Indicators and is the average over each of the 10-year periods.
- (4) Human capital: Data on average year of schooling is taken from the Barro and Lee (2010) data set and is denoted “HUMAN”.
- (5) The period dummy for 1997–2007 (note that we have already included the constant term). We also include dummy variables for groups of economies. That is, we include typical dummy variables such as the OECD country dummy, the Sub-Saharan Africa country dummy, and the fuel-exporting country dummy. Another interesting dummy variable we constructed is the “small island dummy”. Small islands often need to rely on external sources of investment and their I/Y ratio tends to be large. We define this variable so that it is equal to 1 for the economies defined as “small island developing states” by United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and the Small Island Developing States. We also tried including interaction terms between those dummies and the 1997–2007 period dummy.
- (6) Industrial structure: Share of agriculture in GDP, taken from the World Development Indicators (World Bank 2010a) and called “AGRS”. We also tried using the share of industry in GDP taken from the same data source. We also tried including the interaction term between each of them and the 1997–2007 period dummy.
- (7) Initial TFP level: initial value of TFP, in logarithm, called “TFP0” and based on Park (2010).
- (8) Share of government consumption in GDP, called “GOVS”, taken from the World Development Indicators.

- (9) Savings rate, called “SAVE”, from the Penn World Table 6.3, expressed in percentage.
- (10) Relative price of investment goods: We took the investment deflator and the consumption deflator from the Penn World Table 6.3, took the ratio between them and averaged over each 10-year period, and took its logarithm. This is called “RELP”.
- (11) Lagged dependent variables: The lagged growth rate in K per capita, namely the growth rate from the previous 10-year period, will be called “KPG_LAG”.

Finally, as we have noted above, in Figure 6(a), we observe three outliers that report either KPG or KPG_LAG (or both) greater than 0.12 (those are two observations from Equatorial Guinea and one observation from the Sudan). In our estimation, we simply eliminate those three observations from the sample.

C. Estimation Results

In our full specification estimation, we found that many of the dummy variables, such as period dummies, OECD dummies, and Sub-Sahara Africa dummies, were insignificant. The Heritage Foundation indices were either insignificant or significant with wrong signs. The financial depth variables were also insignificant. After eliminating those from the right hand side, we arrive at our final specification. Table 2 presents estimation results from this specification for “larger” countries, and also serves as a list of variables that survived the elimination stage. In the table, the lagged dependent variable is very significant and its coefficient is a respectable 0.27, which indicates a high serial correlation in the growth rate of K per capita. Initial value of K per capita is highly significantly negative, which gives strong support to the convergence hypothesis. The speed of this convergence turns out to be very slow, around 4% per year. TFP0 appears significant: again, this is consistent with the prediction of the theoretical model. The coefficient on TFPG is positive, while that on POPG is negative, and both are significant, as expected. The result that RULE is positive and significant is consistent with our prior expectation from the theoretical model, which we find encouraging. SAVE (saving rate) has a positive sign. This was fully expected from our preliminary investigation in the previous section, but nevertheless is contrary to the prediction of our open economy model with perfect capital mobility, in which the domestic saving rate does not play any particular role. We interpret this as an indication that world capital mobility is probably not completely perfect, and that there are some elements of home bias in international investment. The magnitude of the coefficient, however, is small at 0.00040. This means that a 10 percentage point increase in the saving rate increases KPG by 0.4% (annually) in the short run. POP15_64 has a positive effect as it implies a greater labor force participation rate. RELP and AGRS are again significantly negative.

Table 2: Estimation Results for Growth Rate of K per capita (KPG), Large Countries

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CONST	0.199	0.057	3.519	0.001
KPG_LAG	0.270	0.057	4.779	0.000
LKP0	-0.041	0.004	-10.501	0.000
TFP0	0.026	0.008	3.428	0.001
TFPG	0.259	0.103	2.505	0.014
POPG	-0.709	0.171	-4.158	0.000
RULE	0.011	0.002	4.556	0.000
SAVE	0.00040	0.000	2.487	0.014
POP15_64	0.002	0.000	3.558	0.001
RELP	-0.038	0.006	-6.122	0.000
AGRS	-0.001	0.000	-2.655	0.009
R-squared	0.692			
Adjusted R-squared	0.663			

CONST = constant term.

Note: Refer to Section VB for the definitions of the explanatory variables.

Dependent variable: KPG; method: least squares; outliers with either $KPG > 0.12$ or $KPG_LAG > 0.12$ are eliminated. Included observations: 116.

Regression results with KPG, growth rate of capital per capita (K/Pop ratio) as the dependent variable. World cross country data, sample period = 1987–1997 and 1997–2007. Large countries = observations with GDP above the median.

Source: Authors' calculation.

Table 3 presents corresponding results for the “small” sample. Very briefly, the results are qualitatively similar to the case of the “large” sample, except that SAVE is now insignificant³ (as expected from the analysis of the previous section) and that OPEN, GOVS, and HUMAN now enter with significant coefficients.

³ We did not drop this variable from the right hand side despite its insignificance simply to make this point.

Table 3: Estimation Results for Growth Rate of K Per Capita (KPG), Small Countries

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CONST	0.219	0.048	4.561	0.000
KPG_LAG	0.236	0.066	3.570	0.001
LKP0	-0.038	0.004	-10.304	0.000
TFP0	0.024	0.006	4.240	0.000
TFPG	0.055	0.033	1.688	0.095
POPG	-0.920	0.225	-4.095	0.000
RULE	0.019	0.003	5.812	0.000
OPEN	0.023	0.005	4.795	0.000
SAVE	0.000	0.000	0.646	0.520
GOVS	-0.025	0.006	-3.934	0.000
POP15_64	-0.037	0.005	-7.619	0.000
RELP	-0.001	0.000	-3.323	0.001
AGRS	0.003	0.001	2.446	0.016
HUMAN	0.219	0.048	4.561	0.000
R-squared	0.717			
Adj. R-squared	0.680			

CONST = constant term.

Note: Refer to Section VB for the definitions of the explanatory variables.

Dependent variable: KPG; method: least squares; outliers with either $KPG > 0.12$ or $KPG_LAG > 0.12$ are eliminated. Included observations: 116.

Regression results with KPG, growth rate of capital per capita (K/Pop ratio) as the dependent variable. World cross country data, sample period = 1987–1997 and 1997–2007. Small countries = observations with GDP below the median.

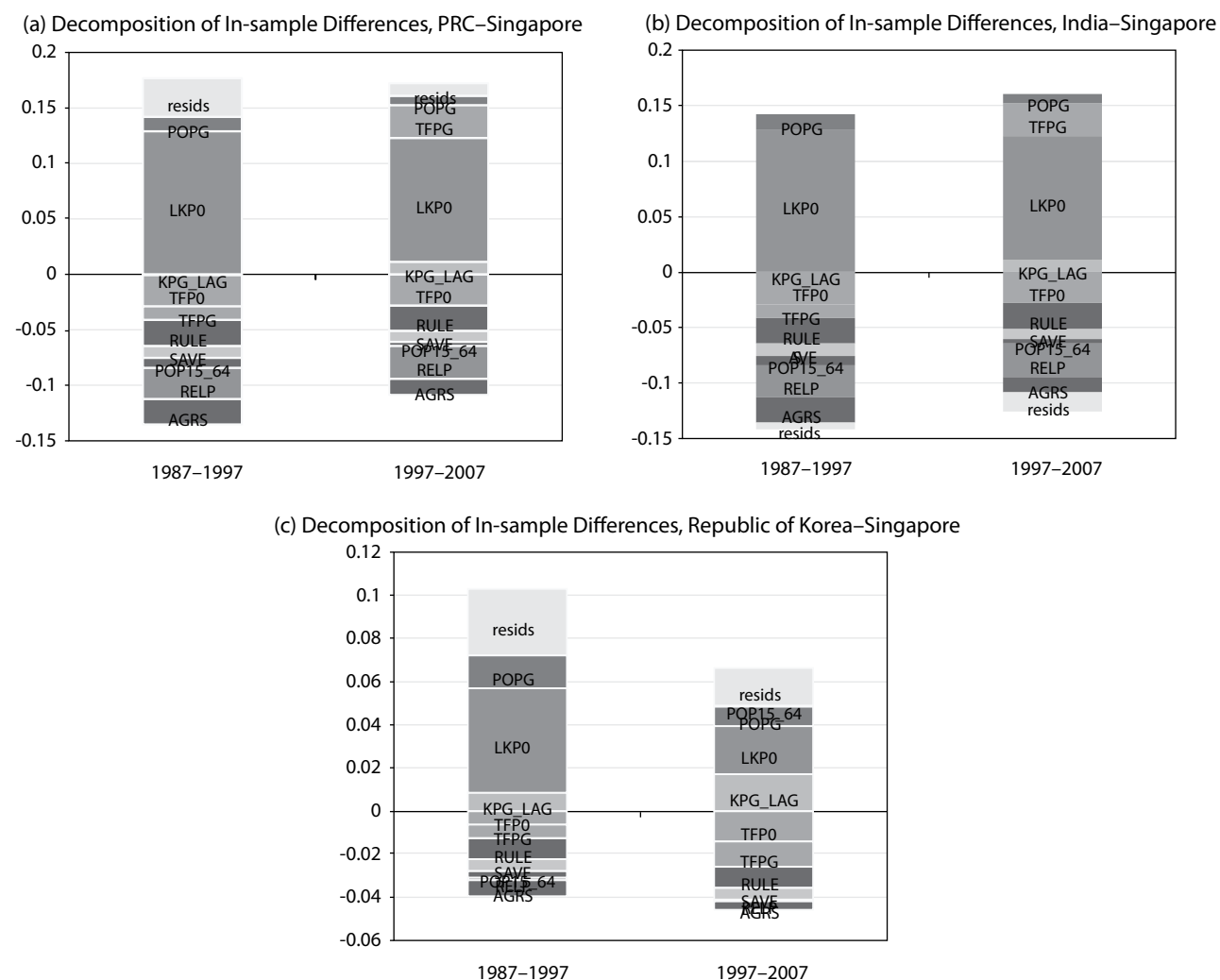
Source: Authors' calculation.

D. In-sample Decomposition for Asia-12

What does the above estimation result tell us about the sources of physical capital accumulation in Asia-12? Except for Taipei, China, for which we do not have sufficient data, we can plug in observed values of the explanatory variables for those countries to derive predicted in-sample contribution of each component to growth in physical capital per capita. Then we sum up contributions of all the factors and compare the result with observed growth in K per capita in Asia-12. We ask which factor (including the residual term) contributed to differing performance between an Asian economy and the US. This type of decomposition would not be very informative without setting some benchmark. Here, we will take Singapore as the benchmark and ask which factor contributed to differing performance of each Asian economy with this country. Figure 7 presents results for the PRC, India, and the Republic of Korea. In panel (a), we see that the PRC, simply by the fact that it started from a lower level of K per capita than Singapore, had a tremendous advantage. This fact alone would have given it an almost 13% advantage in annual K per capita growth. This advantage was offset, though not completely, by lower TFP level, lower rule of law score, lower saving rate, higher relative price of investment

goods, and higher share of agriculture. The positive and sizable residual indicates that the PRC's strong performance was still a surprise. Panel (b) is for the India–Singapore decomposition. A broad picture is similar to the case of the PRC. The main difference is that the residual differences are small, even for the period 1997–2007 when India's capital accumulation accelerated. Panel (c) reports the Korea–Singapore decomposition results. For the period 1987–1997, the Republic of Korea's K per capita was still at a low level, which gave it an advantage to grow faster. The Republic of Korea also has a lower population growth rate compared to Singapore. Most of the other factors are working in favor of Singapore. But the true “winner” is the residual term. The estimated model predicts that the Republic of Korea would have grown 3.4% faster, annually, than Singapore for the period 1987–1997. In reality, the Republic of Korea's KPG was 6.3% larger. Thus, the model says that much of growth in capital per capita in the Republic of Korea was still a sort of “miracle”. This tendency is still observed for the period 1997–2007, but to a lesser extent.

Figure 7: In-sample Decomposition of Growth of K Per Capita



Note: Refer to Section VB for the definitions of the explanatory variables.

Source: Authors' calculation.

VI. Projection

A. Projection Methodology

We turn to the projection stage. We will make projections for K per capita for Asia-12 for the years 2020 and 2030, taking 2010 as the starting year. As our sample ends in 2007, we have to make a certain assumption to derive our starting value of the projection, namely, the 2010 value. We simply assume that during those 3 years, KPG remained the same as the average over the 1997–2007 period. This gives us K per capita in 2010.

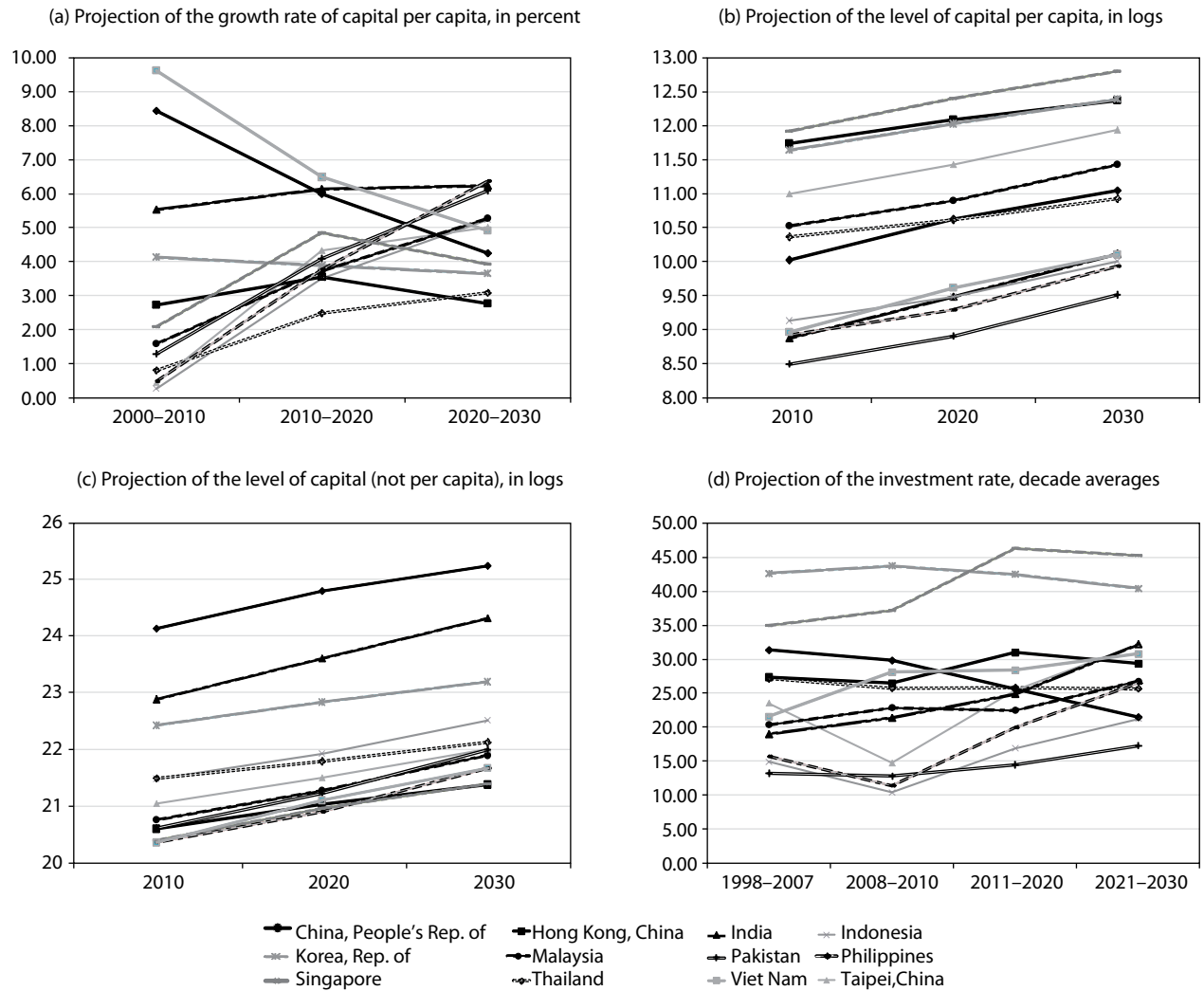
Our approach is to make projections for the explanatory variables in the empirical models in the previous section, and plug them into the estimated model to arrive at our projections for the growth rate of K per capita. It is straightforward to go from the growth rate projection to the levels projection for K per capita. We shall assume that the explanatory variables RULE, RELP, and AGRS will take the same values as in the period 1997–2007. For TFP growth and the TFP level, we use projections provided by Park 2010.⁴ For the saving rate, we employ projections by Horioka and Hagiwara (2010). For the human capital variable, we use projections by Lee and Hong (2010). For the population variables, we utilize the United Nations projections. Using 2010 as the starting year, we first make projections for 2020. We then use 2020 as the starting year, and the projected K per capita in 2020 as the initial value, to make projections for 2030. As for Taipei,China, there is no data on its rule of law index: we simply assume that its value is the same as that of the Republic of Korea.

Figure 8(a) presents prediction results for the growth rate of K per capita. The basic pattern that emerges from the figure is that of convergence in growth rates. Economies that record fast growth in the past period, such as the PRC, India, the Republic of Korea, and Viet Nam are projected to grow slowly. Economies with low previous growth, such as Indonesia; Malaysia; the Philippines; and Taipei,China are projected to experience growth acceleration. However, if we look more closely, we notice sizable heterogeneity in that general pattern. For example, among the group with currently high growth, the PRC, the Republic of Korea, and Viet Nam are projected to experience drastic deceleration, while India is projected to maintain relatively high growth. Among the group with low current growth, growth will remain strong for the period 2020–2030 for Indonesia, Malaysia, Pakistan, and the Philippines, while it will decelerate again for Singapore; Thailand; and Taipei,China. Finally, the growth rate for Hong Kong, China is predicted to go down each decade. It is also noteworthy that most economies, other than Indonesia, Malaysia, Pakistan, and the Philippines, are predicted to experience growth slowdown between the period 2010–2020 and the period 2020–2030. In the next subsection, we investigate sources of the cross-economy heterogeneity as well as the changes across the periods.

⁴ The data contains TFP level estimates up to 2007 and projected growth rates after 2010. We assumed that, between 2007 and 2010, TFP growth rate was the same as the period 2000–2007.

B. Projection Results

Figure 8: Projection Results



Note: For Figure 8a, numbers for 2000–2010 are equal to historical observations for 1997–2007. For Figure 8d, numbers for 1998–2007 are historical observations.

Source: Authors' calculation.

In Figure 8(b), we present projected levels of K per capita, in logarithms. Here, we do not see a clear tendency for convergence in levels, despite that the estimated model clearly has a property of (conditional) convergence.

In Figure 8(c), projected levels of aggregate K , in logarithms, are shown. We used the United Nations population projection to derive those numbers from K per capita. Despite the projected decline in the growth rate of K per capita, the PRC is projected to remain

solidly at the top in terms of aggregate K . India is expected to narrow the gap with the top to some extent. The Republic of Korea is predicted to lose ground against those two.

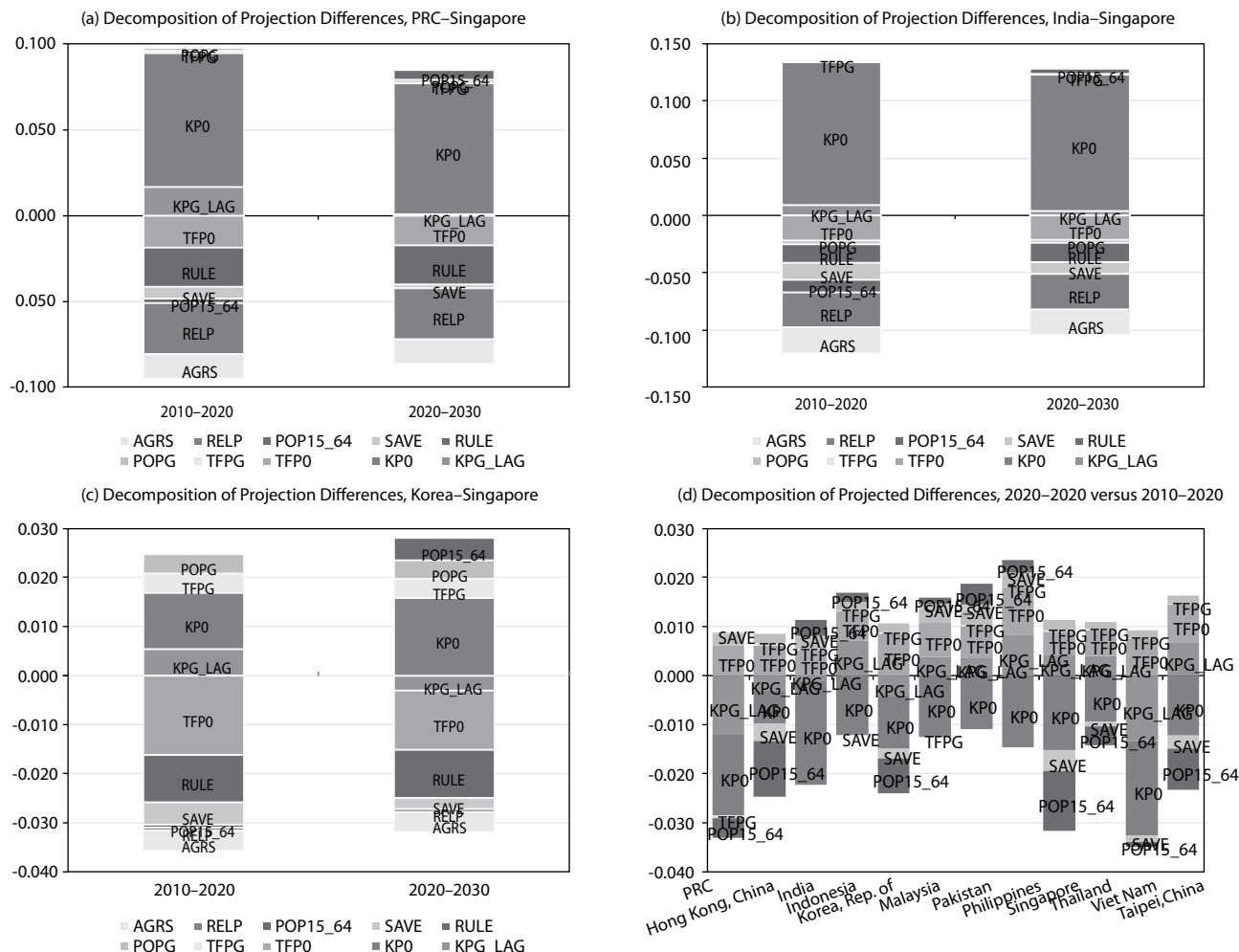
In Figure 8(d), we show our projections for the investment rate. From the predicted K in Figure 8(c), we can apply the perpetual inventory method “backward” to arrive at projected investment for each year. In that calculation, we assumed that, during each decade, the investment rate (i.e., its ratio against GDP) remained constant. Then we divide the projected investment by projected GDP to obtain our projected investment rate. In this calculation, we utilize GDP projection by Lee and Hong (2010). In the figure, we demonstrate decade averages of those projected investment rate. The current top two, namely the Republic of Korea and Singapore, are to experience declines in their investment rates by the 2020s. However, one could argue that the declines are relatively gradual, as their investment rates are projected to be around 25% even in the 2020s. On the other hand, the PRC is projected to experience a large decline: its investment rate is predicted to go down from the current level of over 30% to below 15%.

C. Decomposition of Projection Differences

Why does our estimated model predict differing speeds of capital accumulation? Why does it predict practically no convergence within the Asia-12, despite that the model itself predicts a tendency toward (conditional) convergence? In this subsection, we decompose projected growth in K per capita into contributions of different explanatory variables. We use Singapore as the benchmark, and investigate how the differences in projected growth rates of K per capita between this country and selected countries can be attributed to each element. In short, we ask why they are projected to fail to catch up with Singapore. Figures 9a, 9b, and 9c demonstrate results for the PRC, India, and the Republic of Korea. Looking at Figure 9a for the PRC, we realize that the PRC indeed enjoys a substantial advantage, just from the fact that its initial K per capita is lower than that of Singapore (refer to the section of the bar graphs labeled “ KP_0 ”). The figure shows that the benefit of convergence amounts to 7.8% (annual). Also, the fact that the PRC’s growth rate for 1997–2007 was high gives it a small advantage initially (+1.7% for the 2010–2020 period). Its high TFP growth gives it only a negligible advantage, because its estimated coefficient is very small. Other factors go in the opposite direction. The model predicts that the low TFP level, a lower score in “rule of law”; the higher relative price of investment goods; and the higher share of agriculture will discourage physical capital investment in the PRC, at least in relative terms. Figure 9b is for the India–Singapore decomposition. The story is quite similar to the case of the PRC. One important quantitative difference, though is that India enjoys a bigger advantage of starting from a low level. The fact that its current K per capita is low alone gives India an advantage of over 12% throughout the projection period. This is the main reason why, in Figure 8(a), India is projected to maintain relatively high growth, at least in comparison with the PRC. Figure 9c shows the decomposition results for the Republic of Korea and Singapore. We can see that the differences between the two economies are quantitatively

small compared to Figures 9a and 9b. It is noteworthy that TFP emerges as an important determinant between the two.

Figure 9: Decomposition of Out-of-sample Projection



Note: Refer to Section VB for the definitions of the explanatory variables.
 Source: Authors' calculation.

Finally, in Figure 9d, we undertake projection decomposition from a different angle. We ask what explains the changes in predicted *K* per capita growth from the 2010–2020 period to the 2020–2030 period. We have seen from Figure 8a that for most economies, the projected growth rate declines between the two periods. Those differences are decomposed into contributions of various factors.⁵ We can see that the main reason behind the projected growth slowdown is the convergence effect: as those economies accumulate physical capital, its speed toward further accumulation slows down. This

⁵ Note that, as we assume that values of RULE, RELP, and AGRS will remain the same throughout the projection periods, they have zero contribution to those changes, by construction.

effect is partially offset by the growing levels of TFP, but not entirely. For Hong Kong, China and Singapore (and, to a lesser extent, the Republic of Korea and Taipei,China), the projected aging of the population also contributes.

VII. Alternative Approach

The last result in the previous section indicates that our estimated model does not satisfy the usual “balanced growth path” condition. That is, despite that TFP is projected to continue growing at rates over 2% for most of those economies (and over 3% for the Republic of Korea; the Philippines; and Taipei,China), its estimated effect on KPG is not strong enough for capital per capita to keep growing at the rate of the Harrod-neutral technological progress.⁶ In this section, we start by reestimating the convergence equation imposing an additional restriction that is derived from theory. Then we redo the projection exercise based on this restricted estimation results.

A. Restricted Estimation Approach

We consider imposing a restriction on our estimated equation based on the model in Section II. An implication of equation (18) to our estimated equation is as follows:

$$(\text{coefficient on TFP0}) = -(\text{coefficient on LKP0})/(1-(\text{capital share})) \quad (21)$$

Assuming that the capital share is 0.4, the above condition is obviously not satisfied in our results in Table 2: in that table, the coefficient on TFP0 is 0.026 while that on LKP0 is -0.041 . Given the latter number, according to equation (21), the coefficient on TFP0 should be around 0.068.

We reestimate the model in Table 2 imposing the restriction in equation (21). The results are shown in Table 4. The coefficient on LKP0 is now -0.031 , which implies that the coefficient on TFP0 is now 0.052, which happens to be exactly double the original number. Unfortunately, SAVE, RULE, and AGRS turn insignificant in this specification. We nevertheless retain those variables in the estimation for the sake of comparison with the unrestricted case.

⁶ As our model in Section II reveals (refer also to the appendix), if the growth rate of TFP is $g\%$, the corresponding rate of Harrod neutral technological progress is $x=g/(1-\alpha)\%$, where α is the share of capital. Hence, assuming that $\alpha =0.4$, if $g=3\%$, x is equal to 5%: this means that, in the steady state, capital per capita should be growing at 5%, theoretically speaking.

Table 4: Restricted Regression Results for Growth Rate of K Per Capita (KPG), Large Countries

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CONST	-0.062	0.030	-2.031	0.045
KPG_LAG	0.354	0.061	5.846	0.000
LKP0	-0.031	0.004	-8.126	0.000
TFP0	0.052			
TFPG	0.451	0.108	4.167	0.000
POPG	-0.916	0.186	-4.935	0.000
RULE	0.003	0.002	1.559	0.122
SAVE	0.00022	0.000	1.229	0.222
POP15_64	0.002	0.000	3.742	0.000
RELP	-0.036	0.007	-5.265	0.000
AGRS	0.00035	0.000	1.085	0.281
R-squared	0.611			
Adj. R-squared	0.578			

CONST = constant term.

Note: Refer to Section VB for the definitions of the explanatory variables.

Dependent variable: KPG; method: least squares; outliers with either $KPG > 0.12$ or $KPG_LAG > 0.12$ are eliminated. Included observations: 116.

Restricted regression results with KPG, growth rate of capital per capita (K/Pop ratio) as the dependent variable. World cross country data, sample period = 1987–1997 and 1997–2007. Large countries = observations with GDP above the median.

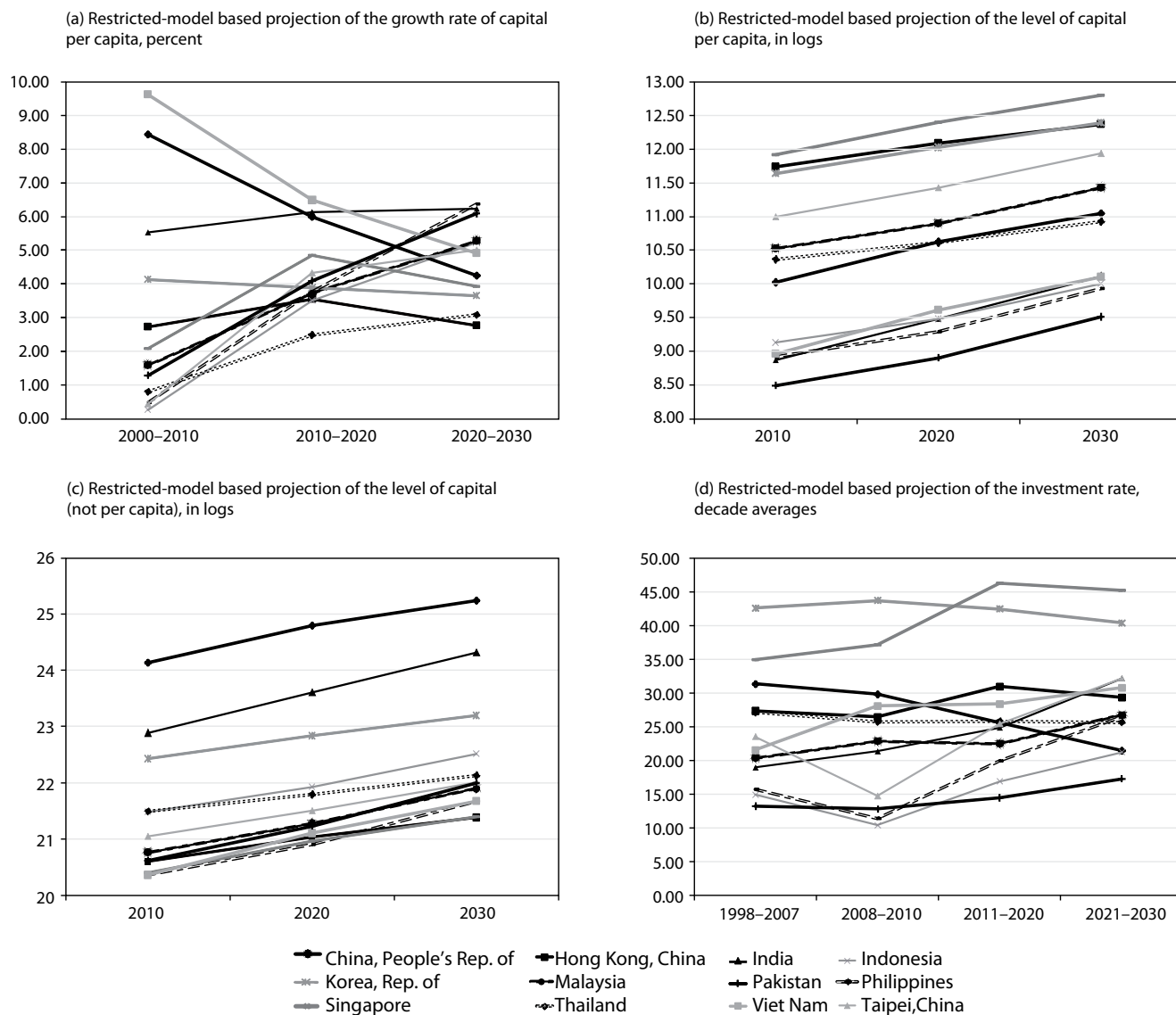
The restriction is: $(\text{coefficient on TFP0}) = -(\text{coefficient on LKP0})/0.6$.

Source: Authors' calculation.

B. Projection Based on the Restricted Estimation

Figure 10 presents projection results based on the restricted estimation, in the same way as in Figure 8, which corresponds to the case of the unrestricted estimation. In panel (a), we see that much less countries are projected to experience slowdowns in KPG. Even for the PRC and Viet Nam, which are projected to experience largest declines in KPG, the extent of the declines is much less severe. Those features are translated into upward shifts in projected paths of K per capita (panel (b)) and aggregate K (panel (c)). In panel (d), we see that most countries lose tendencies for long-run declines in the investment rate that we observed in the corresponding panel in Figure 8. The PRC's investment rate still goes down, but by only about 10%: it goes from about 30% to about 20%.

Figure 10: Projection Based on the Restricted Regression Results

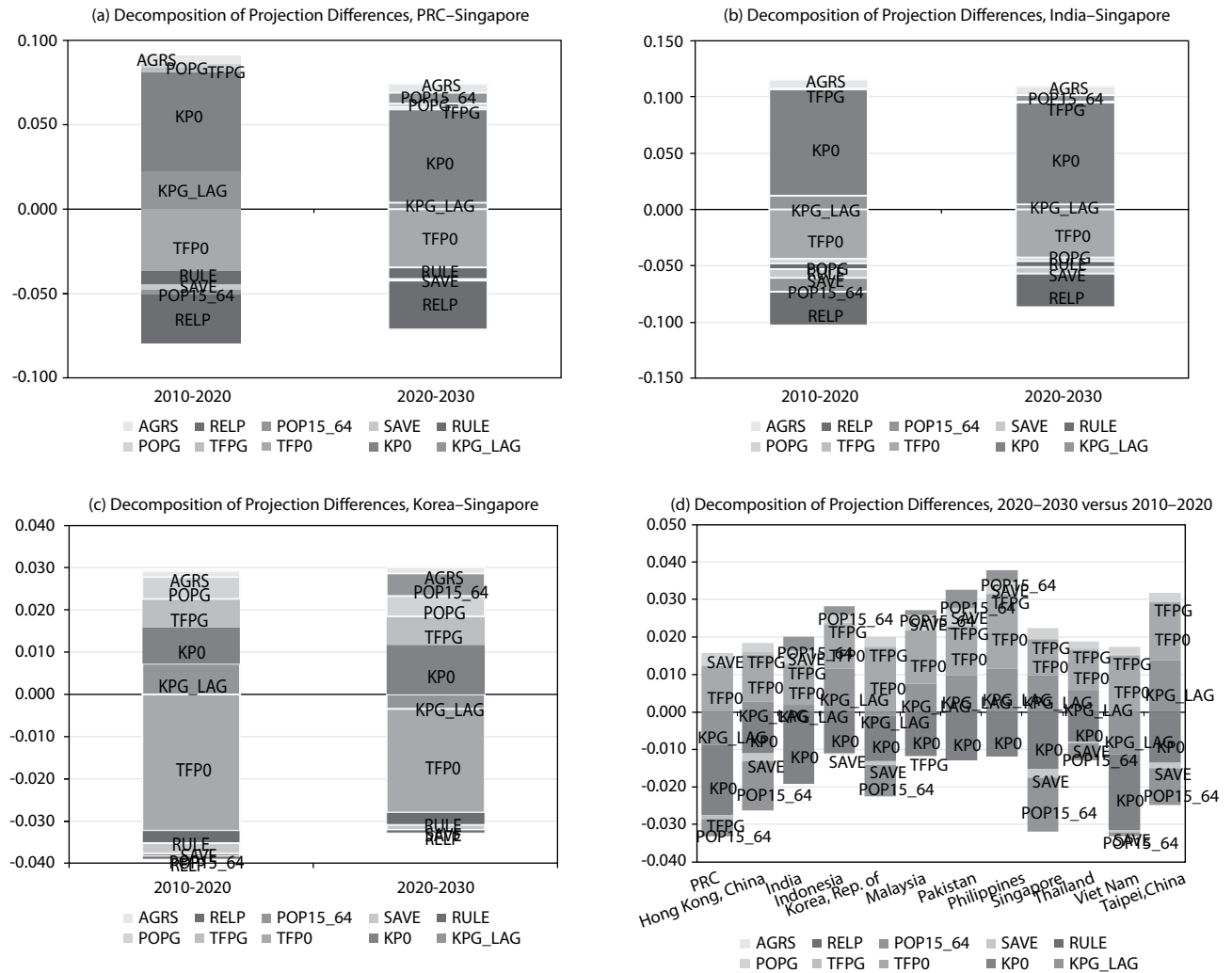


Note: In Figure 10a, numbers for 2000–2010 are equal to historical observations for the period 1997–2007. In Figure 10d, numbers for 1998–2007 are historical observations.

Source: Authors' calculation.

Figure 11 presents examples of some decomposition exercises based on the restricted model. It corresponds to Figure 9 in the unrestricted case. We see that, compared with the unrestricted case, the role of TFP0 has become much more important, as expected. And this contributes to upward revisions in the projected growth rates. In panel (d), we see that the convergence effect, which sets in more strongly as an economy accumulates capital, is often more than offset by the positive effect of TFP improvements.

Figure 11: Restricted-model Based Decomposition of Out-of-sample Projection



Note: Refer to Section VB for the definitions of the explanatory variables.
 Source: Authors' calculation.

VIII. Conclusions

In this paper, we examined historical trends in physical capital per capita in the Asia-12 and produced projections for the future, with the help of a cross-country empirical approach based on an open economy growth model. Our in-sample decomposition shows that many of initially capital-poor Asian economies did have the benefit of the convergence effect. However, they often suffered from other forces working in the opposite direction, such as a low rule of law score and high investment goods prices. Likewise, our projection based on the unrestricted model shows that, if those economies wish to maintain their current pace of fast capital accumulation, the keys would be to reduce distortion in the domestic market (reflected in the relative price of investment goods), and to improve the quality of institutions (as reflected in the rule of law index). Note that the values of those variables were assumed to be fixed at their current values in our projection based on the unrestricted model. With conscious efforts by those economies along those dimensions mentioned above, the future could look very different from the picture drawn in this work.

The projection based on the restricted model provides a slightly brighter picture for the future. It however needs to be emphasized that the restricted model gives a crucial role to TFP, and that TFP might well be endogenous in reality. Such factors as institutional quality and minimizing distortions in the market could still be fundamental for the Asia-12 to achieve the paths projected here (and hopefully to surpass them), as we believe that those factors are important long-run determinants of an economy's productivity level.

Appendix: Underlying Theory—Open Economy Growth Model with Adjustment Cost of Capital

Our model is an open economy growth model with adjustment cost of installing capital. Similar models can be found in textbooks of Blanchard and Fischer (1989) and David Romer (2006). Capital is assumed to be freely mobile across countries. Capital flow is determined by the country's after-tax MPK. Here, "tax" should be interpreted to include country risk (quality of government and institutions, openness to external transactions) and efficiency of internal capital market. Investors have access to the world capital market in which the world real interest rate, r^w , is assumed to be constant over time. The domestic interest rate, r , is given by

$$r = r^w / (1 - \tau) \quad (\text{A1})$$

where τ is the tax rate broadly defined.

The aggregate production function is given by

$$Y_t = A \cdot K_t^\alpha (X_t \cdot L_t)^{1-\alpha} \quad (\text{A2})$$

where Y_t is output, A is a country specific productivity term (constant), K_t is physical capital, L_t is labor and X_t is the technology term. Labor is assumed to grow at a constant rate over time:

$$\dot{L}_t / L_t = n, \quad \dot{X}_t / X_t = x \quad (\text{A3})$$

where n denotes the labor growth rate, and x is the rate of technological progress. Denote capital per labor and capital per effective labor as:

$$k_t \equiv K_t / L_t, \quad \hat{k}_t \equiv K_t / (X_t L_t), \quad (\text{A4})$$

respectively. Then we have

$$MPK_t = \alpha A \hat{k}_t^{-(1-\alpha)} = \alpha A (k_t / X_t)^{-(1-\alpha)} \quad (\text{A5})$$

For simplicity, the price of a unit of capital is assumed to equal 1. Firms, when installing new capital, have to incur adjustment cost of the following nature. It is assumed that the adjustment cost *per effective labor* is quadratic with respect to *net* increases in capital per effective labor:

$$\frac{\Psi}{2} \cdot \left(\hat{k}_t \right)^2 / \hat{k}_t \quad (\text{A6})$$

Hence total adjustment cost is given by

$$\Psi_t = \frac{\Psi}{2} \cdot X_t L_t \cdot \left(\hat{k}_t \right)^2 / \hat{k}_t \quad (\text{A7})$$

Hence the representative firm's objective function is

$$V_t = \int_0^{\infty} e^{-rt} \left[A \cdot K_t^\alpha (X_t \cdot L_t)^{1-\alpha} - \dot{K}_t - \Psi_t \right] dt \quad (\text{A8})$$

This can be rewritten as

$$V_t = \int_0^{\infty} e^{-(r+n+x)t} \left[A \cdot \hat{k}_t^\alpha - (n+x) \cdot \hat{k}_t - \hat{k}_t - \frac{\psi}{2} \cdot \left(\frac{\hat{k}_t}{\hat{k}_t} \right)^2 / \hat{k}_t \right] dt \quad (\text{A9})$$

Solving this problem using the Hamiltonian method yields the following set of two differential equations:

$$\dot{\hat{k}}_t / \hat{k}_t = \frac{1}{\psi} \cdot (q_t - 1) \quad (\text{A10})$$

$$\dot{q}_t = -\alpha \cdot A \cdot \hat{k}_t^{-(1-\alpha)} - (n+x) + \frac{1}{\psi} \cdot (q_t - 1)^2 - (r+n+x) \cdot (q_t - 1)$$

where Tobin's q is defined as

$$q_t \equiv \mu_t e^{(r+n+x)t} \quad (\text{A11})$$

where μ_1 is the costate variable (the Lagrange multiplier) associated with the capital transition equation in the optimization problem.

Steady State (Balanced Growth Path)

The steady state condition is thus:

$$MPK^* = \alpha \cdot A \cdot \hat{k}^{*(1-\alpha)} = r \quad (\text{A12})$$

Also, Tobin's q has to equal 1. Thus,

$$\hat{k}^* = \left[\frac{\alpha A}{r} \right]^{1/(1-\alpha)} \quad (\text{A13})$$

Capital stock per labor will be growing at the rate of technological progress in this state:

$$k^*_t = X_t \cdot \left[\frac{\alpha A}{r} \right]^{1/(1-\alpha)} \quad (\text{A14})$$

Transition

We next log-linearize the system with respect to capital per effective labor, while take a simple linearization around Tobin's q . After some algebra, we arrive at:

$$\begin{bmatrix} \ln \hat{k}_t \\ \dot{q}_t \end{bmatrix} = \begin{bmatrix} 0 & 1/\psi \\ (1-\alpha)r & r+n+x \end{bmatrix} \cdot \begin{bmatrix} \ln \hat{k}_t - \ln \hat{k}^* \\ q_t - 1 \end{bmatrix} \quad (A15)$$

Solving this and imposing saddle path stability yields:

$$\ln \hat{k}_t = -\beta \cdot (\ln \hat{k}_t - \ln \hat{k}^*) \quad (A16)$$

where β is the absolute value of the negative eigenvalue of the above coefficient matrix:

$$\beta = (1/2) \cdot \left[r+n+x - \sqrt{(r+n+x)^2 + (4/\psi)(1-\alpha)r} \right] \quad (A17)$$

Deriving an Empirically Relevant Equation

Solving the above differential equation gives:

$$\ln \hat{k}_T - \ln \hat{k}_0 = -(1 - e^{-\beta T}) \cdot (\ln \hat{k}_0 - \ln \hat{k}^*) \quad (A18)$$

Now we wish to express this relationship in terms of capital per labor, rather than capital per effective labor. We get:

$$\begin{aligned} \frac{1}{T} (\ln k_T - \ln k_0) &= x + \frac{1 - e^{-\beta T}}{T} \cdot \frac{1}{1-\alpha} \cdot \ln TFP_0 \\ &- \frac{1 - e^{-\beta T}}{T} \cdot \ln k_0 + \frac{1 - e^{-\beta T}}{T} \cdot \frac{1}{1-\alpha} \cdot (\ln \alpha - \ln r) \end{aligned} \quad (A19)$$

where

$$TFP_0 = A \cdot X_0^{1-\alpha} \quad (A20)$$

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About the Paper

Etsuro Shioji and Vu Tuan Khai investigate sources of the fast accumulation of capital for 12 East and South Asian countries over the last decades. They also conduct projections for the next 2 decades and study determinants of the investment rate for those economies. They find evidence of convergence in terms of capital per capita in Asia. They also find that, among others, factors such as the degree of distortion in domestic markets and the quality of domestic institutions appear to be key in determining capital accumulation in Asia in both the past and the future.

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