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## ABSTRACT

We construct a dynamic general equilibrium model of foreign direct investment (FDI) and foreign technology adoption, incorporating adoption barriers, international technology spillover, and relative price advantages. A higher FDI conversion efficacy, a lower adoption barrier, or a stronger international technology spillover, together with a lower relative price of FDI, can propel an economy to exhibit a flying geese paradigm escaping from a middle-income trap and catching up with the world frontier. We calibrate the model to eight representative Asian economies, including Asian Tigers and less-developed countries. Growth accounting exercises show that total factor productivity, FDI conversion efficacy, and foreign technology spillover drive Asian Tigers' growth miracle, whereas a reduced adoption barrier and a favorable relative price of FDI are more crucial for the growth of less-developed Asian economies. The counterfactual analysis confirms that technology-embodied FDI serves as a flying propeller, explaining almost two-thirds of their economic growth.

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# 1 Introduction

In the modern integrated world, foreign direct investment (FDI) has been viewed as an important element for promoting economic development, especially in developing economies.[1] Of particular interest, Borensztein, De Gregorio, and Lee (1998) identify a crowding-in effect of the net inflow of FDI and find that "the main channel through which FDI contributes to economic growth is by stimulating technological progress, rather than by increasing total capital accumulation in the host economy" (p.118). Motivated by this striking finding, in the present paper, we theoretically and quantitatively examine the channels through which technology-embodied FDI from more advanced economies can promote host countries' income growth, resulting in a flying geese development paradigm (cf. Akamatsu, 1962). As an integral part of the analysis, we also investigate the key drivers for adopting foreign investment technologies and those amplifying the role of FDI.

Empirically, Alviarez, Cravino, and Ramondo (2019) find that various aspects of FDI have induced firm-embodied technologies to be transferred globally and that such transfers alone can account for a lion share of cross-country TFP differences.[2] The productivity gains from FDI are, however, heterogeneous in size across countries. In particular, such gains depend on a host country's absorptive capability of the advanced technologies (cf. Borensztein, De Gregorio, and Lee, 1998), institutional quality (Jude and Levieuge, 2017), and other costs and barriers (Alfaro, 2017). Beyond the direct productivity gains from upgrading product quality (Bajgar and Javorcik, 2020), FDI can also induce the host country to introduce more complex products, thus leading to future growth (cf. Javorcik, Turco and Maggioni, 2018). Of particular relevance, Borensztein, De Gregorio, and Lee (1998) highlight that a host country's absorptive capability for adopting advanced foreign technologies must overcome a minimum threshold, whereas Bajgar and Javorcik (2020) emphasize that FDI can play an important role for countries to escape from a middle-income trap.

Accordingly, we construct a dynamic general equilibrium model of FDI and foreign technology adoption that accounts for a host country's capability with a nonhomothetic minimum

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[1] See empirical facts established in an influential work by Borensztein, De Gregorio, and Lee (1998) using macro-level cross-country data, by Javorcik (2004) using micro-level country-study data, and by papers cited in a comprehensive survey paper, Harrison and Rodríguez-Clare (2010). See also a policy review of several Asian economies by Wang, Wong, and Yip (2018b). At the macro level, the correlation between the FDI/GDP ratio and the growth of total factor productivity (TFP) is approximately 0.26-0.27 (Alfaro and Chen, 2012). The growth effects of FDI via productivity enhancement can be found in advanced countries as well but not as strong (e.g., Barrell and Pain, 1997; Fons-Rosen, Kalemli-Ozcan, Sørensen, Villegas-Sanchez, and Volosovych, 2021).

[2] As Keller (2000) points out, such technology transfer may also be embodied in intermediate goods trade.

threshold. We allow such adoption to depend on a host country's technological distance to the technological frontier of an advanced economy, following the lead of Acemoglu, Aghion, and Zilibotti (2006) and, more recently, Peters and Zilibotti (2021). We further consider costless technology spillovers via an international diffusion process as highlighted in Buera and Oberfield (2020) and especially in Javorcik (2004) regarding micro-level spillovers from FDI. These factors help govern technology choices between domestic and foreign. When making such a decision in a general equilibrium world, of course competitive profits and hence international relative prices matter. Building FDI and endogenous technology choice into a neoclassical growth framework, we can establish under what circumstances an economy would continue to grow in the process of economic development, thus exhibiting a flying geese paradigm and escaping from a middle-income trap. That is, foreign technology adoption can serve as a flying propeller to advance an economy.

Specifically, under some regularity conditions, we show that the higher FDI conversion efficacy, the lower the foreign technology adoption barrier, or the stronger the international technology spillover is, the more likely more advanced foreign investment technology is adopted, given the relative price of FDI. We then establish that a higher FDI conversion efficacy, a lower adoption barrier, or a stronger international technology spillover, in conjunction with a lower relative price of FDI, can propel the economy to exhibit a flying geese paradigm for economic development. We further highlight the important role played by barriers to technology adoption in an echo of the emphasis by Borensztein, De Gregorio, and Lee (1998), Alfaro (2017), and Jude and Levieuge (2017). In particular, any industrial policy or institutional reform toward removing such barriers can enable a host country's absorptive capability for adopting advanced foreign technologies to overcome a minimum threshold. In this case, FDI can help developing countries escape from a middle-income trap, thus lending theoretical support to the argument by Bajgar and Javorcik (2020).

We then collate our theory with the data. Because openness and FDI are known to be critical for the development of Asian economies, we conduct our quantitative analysis using eight representative Asian economies, including four now-advanced Asian Tigers, namely, Hong Kong, Singapore, South Korea, and Taiwan, and four less-developed countries at various development stages, namely, China, Malaysia, the Philippines, and Vietnam. This list includes development miracles (Tigers), two potential future Tigers (Malaysia and Vietnam), the largest developing economy (China), and a development laggard (the Philippines). In Figure 1 below, we provide time-series plots of FDI intensity, measured by the FDI/GDP ratio over episodes of five years to remove cyclicality and divided into three groups (two smaller tigers, two greater tigers, and four less developed).[3] Figure 2 presents similar time-series plots of relative income growth to the United States (US), which is our frontier technology source country.[4] We find that FDI intensities in these Asian economies are generally rising over time, with Hong Kong and Singapore featuring the highest FDI intensities. Moreover, these economies exhibit faster growth, continuing to gain advantages against the US (albeit somewhat less robust in the early years for the case of the Philippines). These economies are, thereby, viewed as suitable candidates for our investigation of the nexus between FDI and growth in a unified framework.

We calibrate the model to these eight Asian economies, estimating key parameters related to production and foreign technology adoption, including time-varying FDI conversion efficacy, adoption barriers, and technology spillovers. We then perform capital growth and income growth accounting as well as counterfactual analyses based on the calibrated model. The main findings are as follows. First, overall, TFP plays a more crucial and robust growth-enhancing role in Tigers than in less-developed Asian countries. Second, in the two most advanced Tigers that face the highest complexity in technology advancement, the positive effect of the foreign technology spillover by and large offsets the slowdown in FDI conversion efficacy, and, hence, in addition to TFP growth, the reduced adoption barrier and the relative price of FDI contribute to their growth over the past three decades. In South Korea and Taiwan, while the reduced adoption barrier consistently contributes to their growth, the price channel plays a more important role in the first ten-year period, and the FDI conversion efficacy-technology spillover channel becomes more crucial in the last ten years. Third, in the four less-developed Asian economies, the reduced adoption barrier contributes more to growth, though at a diminishing rate. During the first ten years in China and the Philippines, the favorable price channel largely offsets the negative FDI conversion efficacy-technology spillover channel, whereas the FDI conversion efficacy-technology spillover channel and the price channel never play a substantial role in Malaysia and Vietnam. Finally, to account for the potential impact of FDI on aggregate TFP, we conduct a counterfactual analysis and find that the technology-embodied FDI generates prolonged macroeconomic effects, contributing to 70.2% and 65.6% of per capita income level and growth in Tigers and 68.1% and 64.6% in non-Tigers, respectively. These results confirm the importance of the flying-propeller role

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[3] FDI may take other forms of financial capital investment, which we ignore throughout. This is innocuous because Gourinchas and Jeannet (2006) and Prasad, Rajan, and Subramanian (2007) find that differing from the physical investment aspect of FDI, financial FDI does not contribute substantially to host countries' economic growth.

[4] For the data description to construct Figures 1 and 2, see Appendix D.

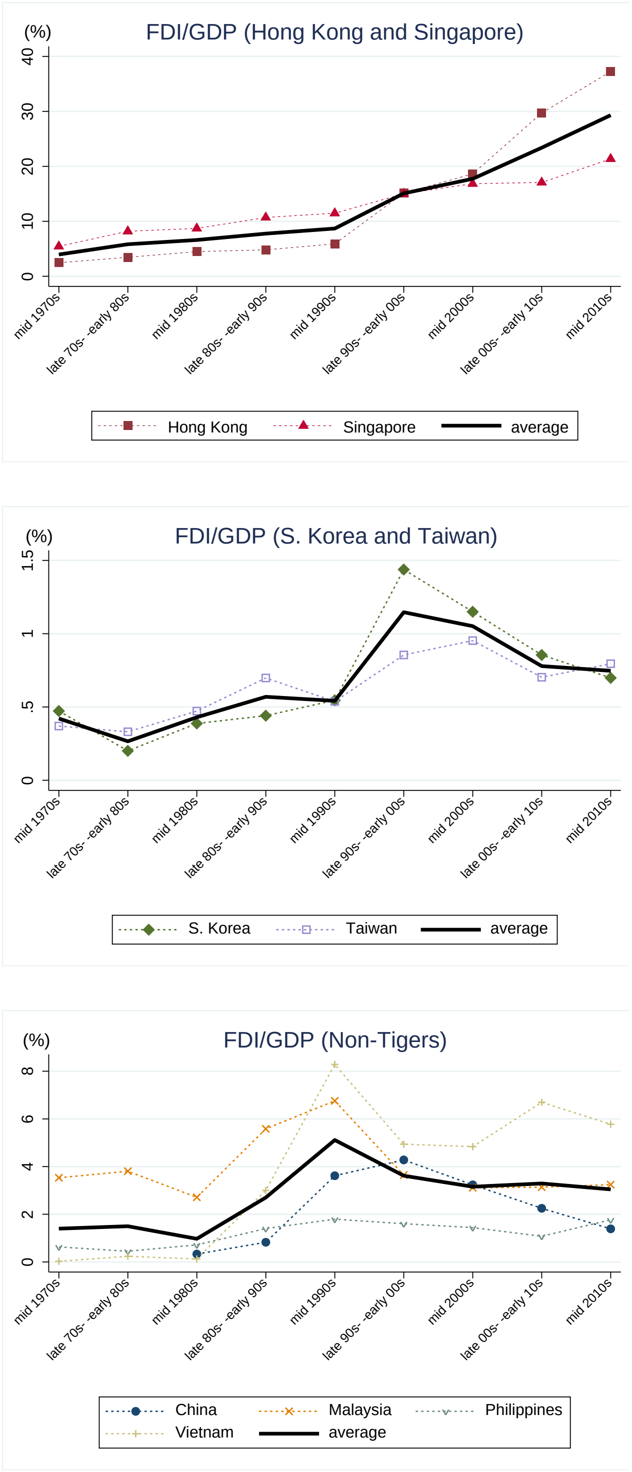

Figure 1: FDI Intensity of Asian Economies

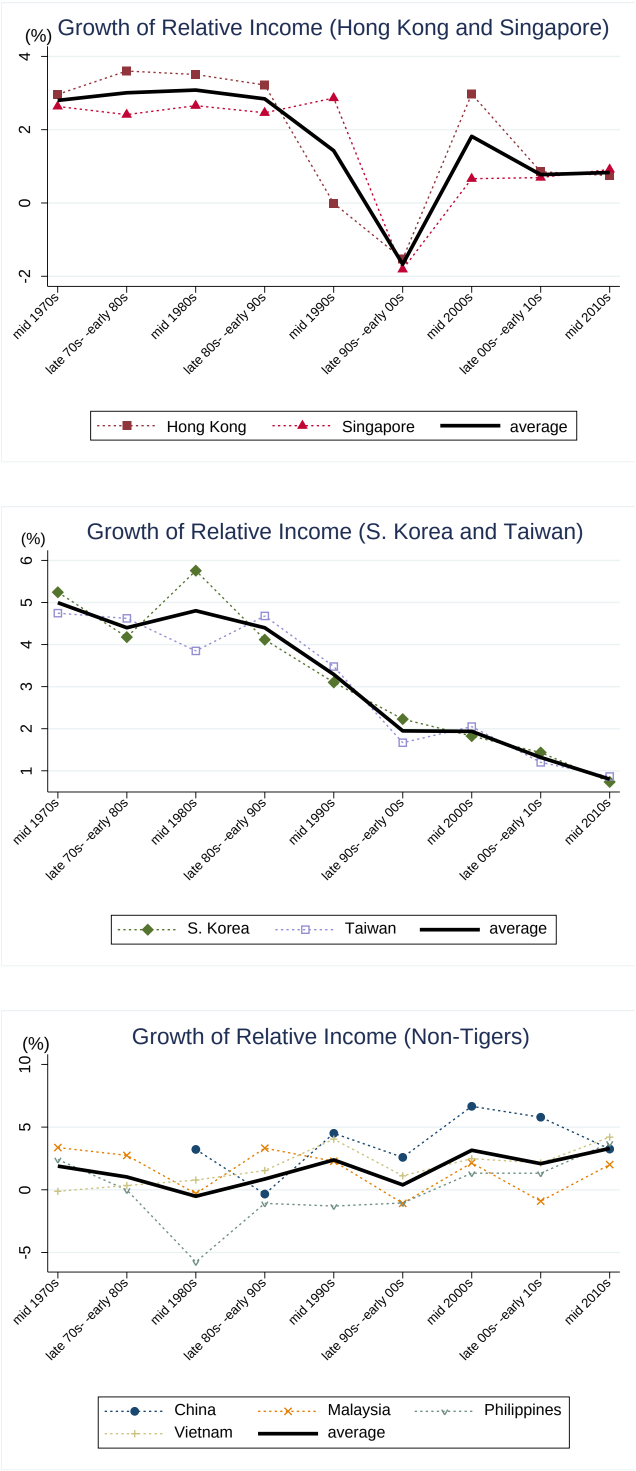

Figure 2: Growth of Relative per capita GDP to the US

of FDI.

The main takeaway is as follows: while TFP and the FDI conversion efficacy-technology spillover are the main drivers of Asian Tigers' growth miracle, the adoption barrier channel and the favorable relative price of FDI play a more significant role in promoting economic growth in less-developed Asian economies; as a whole, the technology-embodied FDI accounts for a lion share of their economic growth. The importance of mitigating the barrier to technology adoption echoes Borensztein, De Gregorio, and Lee (1998), Alfaro (2017), and Jude and Levieuge (2017) and supports the policy prescription by Bajgar and Javorcik (2020).

## 2 The Model

Consider a small open economy. Time is discrete, indexed by $t$. The economy consists of a continuum of infinitely lived identical agents. It produces a single tradable general good with two factor inputs, labor and capital. This general good can be used for consumption or investment purposes. Capital can be accumulated by domestic or foreign investments. The key feature of this model is that while foreign investments are more efficient than domestic counterparts, there are barriers to transform foreign investments into capital. It is this tradeoff relationship between efficiency and barriers, properly adjusted by the international relative price, that will pin down whether and what foreign advanced technology can be adopted.

### 2.1 The environment

In the small open economy, the representative agent produces general goods $Y_t$ by applying a Cobb-Douglas production technology $Y_t := AZ_{t-1}^{\beta}L_t^{1-\beta}$ $(0 < \beta < 1)$, the inputs of which are labor $L_t$ and capital $Z_{t-1} := K_{t-1}+K_{t-1}^{*}$, where $K_{t-1}$ and $K_{t-1}^{*}$ are the capital accumulated by means of domestic and foreign investments, respectively. Note that, for period $t$ production, the capital input $Z_{t-1}$ takes one period to set up, that is, capital needs "time-to-build." Labor grows at a rate $n_{t+1} := L_{t+1}/L_t$. $A$ is the total factor productivity (TFP). The general goods are consumed or saved for investment. The aggregate constraint is given by

$$Y_t := AZ_{t-1}^{\beta}L_t^{1-\beta} = I_t + p_t^{*}I_t^{*} + C_t, \tag{1}$$

where $C_t$ is aggregate consumption, $I_t$ and $I_t^*$ are domestic and foreign investments, respectively, and $p_t^*$ is the world price of foreign investments. Note that the trade balance is assumed to be periodically and $I_t^*$ is foreign direct investment (FDI) from the perspective of the rest of the world. Rearrange the above relation with per worker variables to obtain $y_t := Az_{t-1}^{\beta} = i_t + p_t^* i_t^* + c_t$ where $z_{t-1} := Z_{t-1}/L_t = k_{t-1} + k_{t-1}^*$, $k_{t-1} := K_{t-1}/L_t$, $k_{t-1}^* := K_{t-1}^*/L_t$, $i_t := I_t/L_t$, $i_t^* := I_t^*/L_t$, and $c_t := C_t/L_t$.

## 2.2 Optimization

The representative agent solves the following maximization problem for her lifetime utility subject to the three constraints in addition to the typical nonnegativity constraints on investments:

$$\max \sum_{s=t}^{\infty} \delta^{s-t} \ln c_s$$

subject to

$$y_s := Az_{s-1}^{\beta} = c_s + i_s + p_s^* i_s^*, \tag{2}$$

$$n_{s+1} k_s = h(i_s), \tag{3}$$

and

$$n_{s+1} k_s^* = g(i_s^*; \bar{z}_{s-1}, \bar{z}_{s-1}^*, \bar{y}_s) \tag{4}$$

for $s \geq t$, where $\delta \in (0,1)$ is the subjective discount factor. In Eqs. (2)-(4), capital depreciates entirely in one period.

In the small open economy, the representative agent faces two types of investment choices: one is to use domestic investment goods embodied with domestic investment technologies and the other is to use imported foreign investment goods embodied with foreign investment technologies. Whereas the capital formed by domestic and foreign investment goods are perfect substitutes, the two investment choices generate different evolution processes over time. In the first choice, capital production with domestic investment goods is involved in a linear technology form. More concretely, since capital will depreciate away after one period, the production function with respect to domestic investment, $h(i_s)$, is given by

$$n_{s+1} k_s = \Omega \cdot i_s, \tag{5}$$

where $\Omega$ is the productivity of this technology.

Moreover, the center of economic activity in this paper is described by Eq. (4), where $g(\cdot)$

is a capital production function that summarizes the conversion from FDI, $i_s^*$, to productive capital, $n_{s+1}k_s^*$. Specifically, $g(\cdot)$ is expressed as follows:

$$g(i_s^*; \bar{z}_{s-1}, \bar{z}_{s-1}^*, \bar{y}_s) = \underbrace{\chi_s\left(\bar{z}_{s-1}; \theta, \eta\right) \cdot \left(\bar{z}_{s-1}^*\right)^{\varsigma} \cdot \left(\frac{\bar{z}_{s-1}^* - \eta^*}{\bar{z}_{s-1} - \eta}\right)^{\varepsilon}}_{\substack{\Gamma(\bar{z}_{s-1}, \bar{z}_{s-1}^*; \theta, \eta) \\ \text{(capital conversion multiplier)}}} \cdot \frac{i_s^*}{\bar{y}_s}, \tag{6}$$

where $0 \leq \varsigma < 1$ and $\varepsilon > 0$. In Eq. (6), $\bar{z}_{s-1}$ is the (average) past domestic capital accumulation that includes all tangible and intangible domestic capital inclusive of knowledge/experience, $\bar{z}_{s-1}^*$ is the (average) past capital accumulation of the frontier foreign country that owns the world cutting-edge technology, and $\bar{y}_s$ is average domestic output. That is, the conversion from FDI to productive capital is equal to a capital conversion multiplier times a scale adjustment factor. The capital conversion multiplier consists of three components: (i) a direct foreign technology adoption component, $\chi_s\left(\bar{z}_{s-1}; \theta, \eta\right)$, (ii) an international technological spillover component, $\left(\bar{z}_{s-1}^*\right)^{\varsigma}$, and (iii) a technology gap component, $\left[(\bar{z}_{s-1}^* - \eta^*)/(\bar{z}_{s-1} - \eta)\right]^{\varepsilon}$. The scale adjustment factor is given by $i_s^*/\bar{y}_s$. While we remove the scale effect (cf. Jones 1995) by rescaling FDI ($i_s^*$) by average domestic output ($\bar{y}_s$) such that only the ratio $i_s^*/\bar{y}_s$ matters for capital conversion, the setting for the conversion multiplier is designed to incorporate the key aspects of international technology adoption in the literature as well as our unique technology choice aspect. The three components of the multiplier are further elaborated below.

The second component measures the strength of international technology spillover as hypothesized in Eaton and Kortum (1999), Buera and Oberfield (2020), and Perla, Tonetti, and Waugh (2019), where a higher elasticity $\varsigma$ indicates a stronger spillover effect.[5] Large spillovers enhance FDI conversion.

The third component measures the impact of the technology gap that captures the easiness of the technology adoption. Following the distance-to-frontier framework developed by Acemoglu, Aghion, and Zilibotti (2006), Vandenbussche, Aghion, and Meghir (2006), and Peters and Zilibotti (2021), we assume that the larger the technology gap, the easier the technology adoption effort is, where the elasticity $\varepsilon$ measures the strength of the positive impact of the technology gap.[6]

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[5] By counterfactual analysis comparing models with and without technological diffusion effects, Buera and Oberfield (2020) find that their results of technological diffusion on trade gains and TFP growth are twice as large. In a benchmark case, they calibrate the strength parameter of diffusion as $\varsigma = 0.6$.

[6] By calibrating to US and Indian data, Peters and Zilibotti (2021) find the elasticity can reach a level of

Turning now to the first component, we assume that this direct foreign technology adoption component takes the following nonhomothetic form:

$$\chi_s\left(\bar{z}_{s-1};\theta,\eta\right) := \theta(\bar{z}_{s-1}-\eta)^{\sigma} \tag{7}$$

for all $\bar{z}_{s-1} \geq \eta$, where $\theta > 0$ measures the efficacy of FDI conversion and $\eta > 0$ is the barrier to foreign technology adoption. As noted from Eq.(7), $\chi_s(\cdot)$ is subject to past capital accumulation, $\bar{z}_{s-1}$, that enhances domestic capability in knowledge/experience to adopt foreign technologies. More concretely, given the world cutting-edge technology as in Caselli and Coleman (2006), we allow the higher domestic capability to depend on past capital accumulation, where, for the capital conversion multiplier to be effective, the domestic capability must pass over the barrier. This thereby captures the minimum skill requirements highlighted by Borensztein, De Gregorio, and Lee (1998) and institutional quality stressed by Jude and Levieuge (2017). In a broader sense, it also captures the scale barrier emphasized in the endogenous growth literature led by Romer (1986) and the threshold externality in the big push literature following Azariadis and Drazen (1990). Because we regard the adoption barrier as a relative measure, such a barrier in the frontier country is thereby normalized to zero, i.e., $\eta^* = 0$. Then, from Eqs. (6) and (7), the capital conversion multiplier becomes

$$\Gamma(\bar{z}_{s-1},\bar{z}^*_{s-1};\theta,\eta) := \theta(\bar{z}_{s-1}-\eta)^{\sigma-\varepsilon}\cdot\left(\bar{z}^*_{s-1}\right)^{\varsigma+\varepsilon}. \tag{8}$$

We impose a regularity condition:

**Assumption 1.** $\beta+\varepsilon<\sigma<1+\varepsilon$.

The first inequality in Assumption 1 restricts the curvature of the domestic technology to ensure that adoption increases the domestic capability, and the second inequality rules out social increasing returns in production. The framework of capital formation with the use of FDI is viewed as natural because it satisfies the following regularity properties: (i) $\partial g/\partial i^*_s > 0$, (ii) $\partial^2 g/\partial \bar{z}_{s-1}\partial i^*_s > 0$, and (iii) $\partial^3 g/\partial^2 \bar{z}_{s-1}\partial i^*_s < 0$. Intuitively, (i) indicates the positive marginal product of FDI, $i^*_s$, and (ii) and (iii) together ensure that past capital accumulation, by enhancing domestic capability, yields a positive effect on the marginal product in adopting FDI, $i^*_s$, at a diminishing rate.

Whereas $\tilde{\imath}_s := i_s + p^*_s i^*_s$ is the total investment, the representative agent chooses the domestic or foreign investment technology depending upon their productivity. From Eqs.

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$\varepsilon = 0.42$.

(2)-(6), it follows that when the capital conversion multiplier scaled by domestic average output, $\Gamma(\bar{z}_{s-1}, \bar{z}^*_{s-1}; \theta, \eta)/\bar{y}_s$, exceeds $p^*_s\Omega$, the foreign investment technology provides more efficiency units of capital than the domestic investment technology. In this case, the foreign investment technology is adopted. Conversely, if $\Gamma(\bar{z}_{s-1}, \bar{z}^*_{s-1}; \theta, \eta)/\bar{y}_s < p^*_s\Omega$ (inclusive of the degenerate case with $\bar{z}_{s-1} < \eta$), the foreign investment technology is never adopted. Therefore, the capital stock is formed according to Lemma 1 below.

**Lemma 1.** *The (per worker) capital stock prepared for the production in period $s+1$ is given by the following equation:*

$$n_{s+1}z_s = \max\left\{\Omega, \frac{\Gamma(\bar{z}_{s-1}, \bar{z}^*_{s-1}; \theta, \eta)}{p^*_s\bar{y}_s}\right\}\tilde{\imath}_s. \tag{9}$$

*Proof.* See Appendix A.

Eq. (9) enables us to rewrite the budget constraint (2) as

$$Az^{\beta}_{s-1} = c_s + M_s n_{s+1} z_s, \tag{10}$$

where $M_s := \min\left\{1/\Omega, p^*_s\bar{y}_s/\Gamma(\bar{z}_{s-1}, \bar{z}^*_{s-1}; \theta, \eta)\right\}$. Hence, the Lagrangian for the representative agent's utility maximization problem is

$$\mathcal{L}_t := \sum_{s=t}^{\infty} \delta^{s-t} \ln c_s + \sum_{s=t}^{\infty} \delta^{s-t}\lambda_s \left(Az^{\beta}_{s-1} - c_s - M_s n_{s+1} z_s\right), \tag{11}$$

where $\lambda_s$ is the shadow price of general goods in period $s$. The first-order conditions are

$$\frac{\partial \mathcal{L}_t}{\partial c_t} = 0 \iff \lambda_t = \frac{1}{c_t} \tag{12}$$

$$\frac{\partial \mathcal{L}_t}{\partial z_t} = 0 \iff \lambda_t M_t n_{t+1} = \lambda_{t+1}\delta\beta A z^{\beta-1}_t \tag{13}$$

$$\frac{\partial \mathcal{L}_t}{\partial \lambda_t} = 0 \iff Az^{\beta}_{t-1} = c_t + M_t n_{t+1} z_t. \tag{14}$$

The necessary and sufficient conditions for the optimality of the maximization problem consist of the first-order conditions (12)-(14) together with the transversality condition:

$$\lim_{t\to\infty} \delta^t \lambda_t M_t n_{t+1} z_t = 0. \tag{15}$$

# 3 Equilibrium

In this section, we establish the dynamics of capital evolution and determine optimal technology choice given the relative price of FDI.

## 3.1 Capital evolution and technology choice

Under the log-linear utility function and the Cobb-Douglas production function, we can establish a single dynamic equation for the capital stock in equilibrium below.

**Proposition 1.** *(Capital Evolution) The dynamic equation for capital stock in equilibrium is given by*

$$z_t = \frac{A\Omega\delta\beta}{\min\left\{1, \frac{p_t^* \Omega y_t}{\Gamma(z_{t-1}, z_{t-1}^*; \theta, \eta)}\right\} n_{t+1}} z_{t-1}^{\beta}. \tag{16}$$

*Proof.* See Appendix B.

Note that we have used equilibrium conditions such that $z_{t-1} = \bar{z}_{t-1}$, $z_{t-1}^* = \bar{z}_{t-1}^*$, and $y_t = \bar{y}_t$ in Eq. (16). By using Eq. (8), we unpack the right-hand side of Eq. (16) and establish the following:

**Proposition 2.** *(Technology Choice) The technology choice is determined by*

$$z_t = \begin{cases} \frac{\delta\beta\Omega}{n_{t+1}} A z_{t-1}^{\beta} =: h^D(z_{t-1}) \textit{ (domestic tech curve)} & \textit{if } p_t^* \geq \frac{\theta(z_{t-1}-\eta)^{\sigma-\varepsilon} \cdot \left(z_{t-1}^*\right)^{\varsigma+\varepsilon}}{\Omega A z_{t-1}^{\beta}} \\ \frac{\delta\beta\left(z_{t-1}^*\right)^{\varsigma+\varepsilon}}{n_{t+1} p_t^*} \theta(z_{t-1}-\eta)^{\sigma-\varepsilon} =: h^F(z_{t-1}) \textit{ (foreign tech curve)} & \textit{if } p_t^* < \frac{\theta(z_{t-1}-\eta)^{\sigma-\varepsilon} \cdot \left(z_{t-1}^*\right)^{\varsigma+\varepsilon}}{\Omega A z_{t-1}^{\beta}} \end{cases}. \tag{17}$$

*Under Assumption 1 and given the relative price of FDI, the higher the FDI conversion efficacy ($\theta$), the lower the FDI barrier ($\eta$), or the stronger the international technology spillover (captured by $\left(z_{t-1}^*\right)^{\varsigma}$) is, the more likely the more advanced foreign investment technology is to be adopted.*

Notably, with $n_{t+1}$, $p_t^*$, and $z_{t-1}^*$ exogenously given, the first equation of Eq. (17) represents the capital dynamics of the domestic investment technology, and the second equation is that of the foreign investment technology. As noted from the equations, when the relative price of FDI, $p_t^*$, is greater than the efficiency of the foreign investment technology, which is given by $\theta(z_{t-1}-\eta)^{\sigma-\varepsilon} \cdot \left(z_{t-1}^*\right)^{\varsigma+\varepsilon} / \left(\Omega A z_{t-1}^{\beta}\right)$, firms adopt the cheaper domestic investment technology, i.e., $z_t = h^D(z_{t-1})$. On the other hand, when $p_t^*$ is smaller than the efficiency of the foreign investment technology, they adopt the more advanced foreign investment technology, i.e., $z_t = h^F(z_{t-1})$. Not until Section 5 where we perform a numerical analysis with actual data do we omit the time subscripts from $n_{t+1}$, $p^*_t$, and $z^*_{t-1}$ as these variables are exogenously given.

We obtain a preliminary lemma regarding the intersection of the domestic and foreign technology curves as follows:

**Lemma 2.** *Suppose that Assumption 1 holds. Then, there exists a unique intersection between* $z_t = h^D(z_{t-1})$ *and* $z_t = h^F(z_{t-1})$.

*Proof.* See Appendix C.
We define $v$ as the value of $z_{t-1}$ in the intersection such that $h^D(v) = h^F(v)$ for the later discussion.

### 3.2 Potential steady states

The dynamical system for the capital stock given by Eq. (17) potentially has three nontrivial steady states. One is brought by the domestic investment technology and two by the foreign investment technology. Suppose that $z^D$ and $z^F_m$ $(m = 1, 2)$ are the potential steady states of the domestic and the foreign investment technologies, respectively, where $z^F_1 < z^F_2$. Then, $z^D$ always exists and is given by

$$z^D = \left(\frac{\delta\beta\Omega A}{n}\right)^{\frac{1}{1-\beta}}. \tag{18}$$

In contrast, $z^F_1$ and $z^F_2$ (if any) cannot be solved out in closed forms but satisfy the following equation:

$$z^F_m = \frac{\delta\beta\Theta}{np^*}(z^F_m - \eta)^{\sigma-\varepsilon}, \tag{19}$$

where $\Theta = \theta\,(z^*)^{\varsigma+\varepsilon}$. To derive the existence condition for the potential steady states of the foreign investment technology, we define $\hat{z}$ that satisfies $h^{F\prime}(\hat{z}) = 1$, or equivalently,

$$\hat{z} = \eta + \left(\frac{\delta\beta\,(\sigma-\varepsilon)\,\Theta}{np^*}\right)^{\frac{1}{1-(\sigma-\varepsilon)}}. \tag{20}$$

The gradient of the line tangent to $z_t = h^F(z_{t-1})$ at $(\hat{z}, h^F(\hat{z}))$ equals one. Therefore, the two steady states, $z^F_1$ and $z^F_2$, exist if and only if $\hat{z} < h^F(\hat{z})$. Formally, we have the following proposition.

**Proposition 3.** *The two potential steady states,* $z^F_1$ *and* $z^F_2$*, of the foreign investment tech-*

*nology exist if and only if*

$$\eta < (1-\sigma+\varepsilon)\,(\sigma-\varepsilon)^{\frac{\sigma-\varepsilon}{1-(\sigma-\varepsilon)}}\left(\frac{\delta\beta\Theta}{np^*}\right)^{\frac{1}{1-(\sigma-\varepsilon)}} =: \eta_1. \tag{21}$$

*Proof.* The two potential steady states, $z_1^F$ and $z_2^F$, exist if and only if $\hat{z} < h^F(\hat{z})$. By inserting Eq. (20) into $h^F(\hat{z})$, we have the desired conclusion. □

Other things being equal, inequality (21) is more likely to hold as the price of foreign investment goods decreases or technology spillover and gap become greater. For the sake of exposition, we focus on the case in which the two potential steady states, $z_1^F$ and $z_2^F$, always exist in what follows, assuming inequality (21).

**Assumption 2.** $\eta < \eta_1$.

## 4 Flying or trapped in the small open economy

Depending upon the positions of the domestic and foreign technology curves, $z^D$, $z_1^F$, and $z_2^F$ derived in the previous section may or may not be the effective steady states of the dynamical system, and there are various cases for the dynamic behavior of the capital stock in the small open economy. We start our discussion with a benchmark case.

### 4.1 A benchmark case

A benchmark of relative positions of the domestic and the foreign technology curves is depicted in Figure 3. It shows that when $0 \leq z_{t-1} < v$, the domestic investment technology is adopted and when $z_{t-1} > v$, the foreign investment technology is adopted. The parameter condition for the case of Figure 3 to hold is $z^D < h^F(z^D)$, or equivalently,

$$\eta < \left(\frac{\delta\beta\Omega A}{n}\right)^{\frac{1}{1-\beta}} - (\Omega A)^{\frac{1}{(1-\beta)(\sigma-\varepsilon)}}\left(\frac{\delta\beta}{n}\right)^{\frac{\beta}{(1-\beta)(\sigma-\varepsilon)}}\left(\frac{p^*}{\Theta}\right)^{\frac{1}{\sigma-\varepsilon}} =: \eta_2. \tag{22}$$

Inequality (22) is a sufficient condition for Assumption 2 to hold, which warrants the presence of the potential two steady states with the foreign investment technology. In inequality (22), technology spillover and gap and the relative price of FDI affect the likelihood of its establishment in a similar manner to inequality (21). Differing from inequality (21), however, inequality (22) is subject to the value of $\Omega A$. For inequality (22) to hold, the value of $\Omega A$ should be moderate. Regarding the dynamical system illustrated in Figure 3, there is only

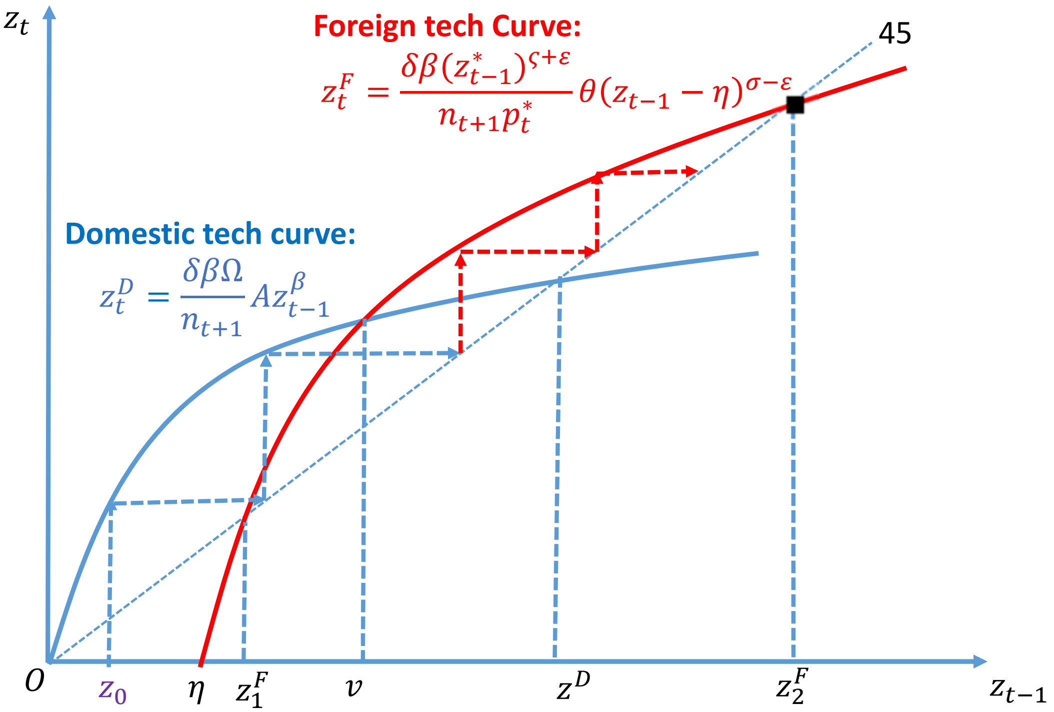

Figure 3: Capital dynamics with domestic and foreign technology curves

a high steady state, $z_2^F$. If the initial capital stock is very small, it evolves by applying the domestic investment technology at the early stage of development, but in a certain period when the capital stock accumulates beyond $v$, the economy switches to the foreign technology. Then, it continues to evolve until reaching the high steady state without being trapped.

What would happen if the relative price of FDI became very high while the barrier against the technology adoption remained constant and the efficacy of the foreign investment technology remained high? More concretely, suppose that the relative price of FDI, $p^*$, increases in a certain period, say, period $t = \hat{t}$, so that it holds that $z^D > h^F(z^D)$, or equivalently,

$$\eta_2 < \eta < \eta_1. \tag{23}$$

Figure 4 illustrates one such case under Assumption 2. As seen in the figure, if the initial capital stock is small, the economy uses the domestic investment technology at the early stage of development and changes to the foreign investment technology in a certain period as in the previous case. However, from period $t = \hat{t}$ onward, the economy no longer utilizes the foreign investment technology due to the rise in its relative price despite that its efficacy is very high. In this case, the economy converges to the domestic-technology steady state,

$Z^D$.

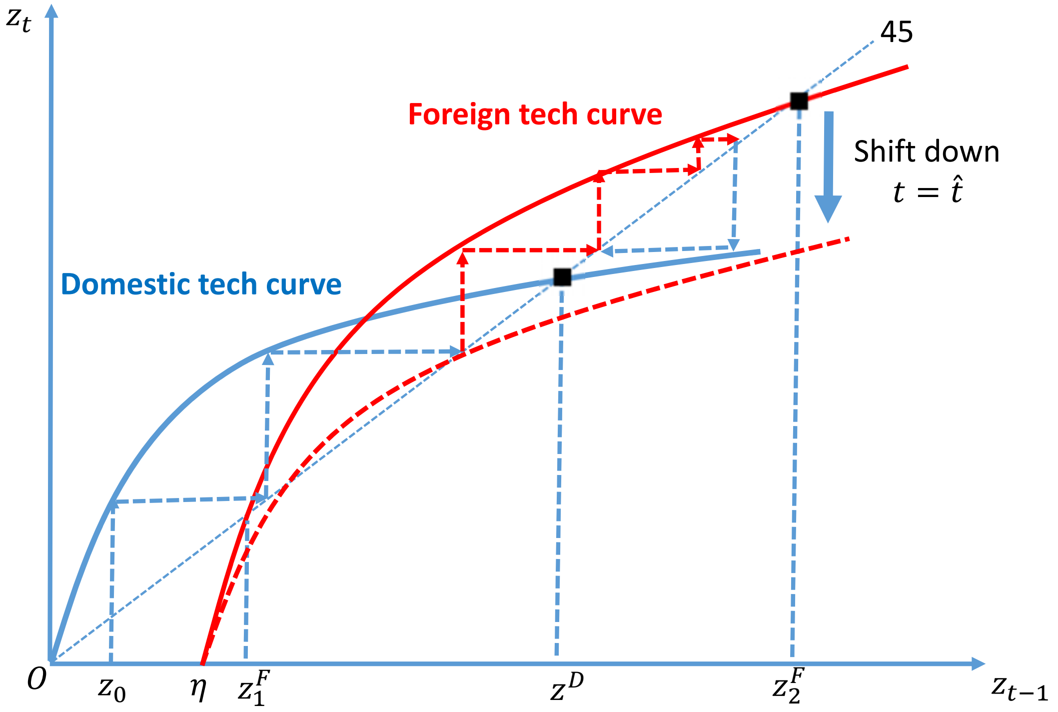

Figure 4: Trapped in the domestic-technology steady state, $Z^D$

We can thus combine Proposition 3, Lemma 2 and Figures 3 and 4 to establish the following:

**Proposition 4.** *Under Assumptions 1 and 2, a higher FDI conversion efficacy, a lower FDI barrier, or a stronger international technology spillover, in conjunction with a lower relative price of FDI can propel the economy to exhibit a flying geese paradigm.*

### 4.2 A small difference can make a big difference

In this section, we argue that the barrier is crucial for the economy to escape from a domestic technology trap. To intuitively capture an essence of this issue, compare two illustrative examples provided in Figures 5 and 6. The conditions to draw the solid curves in Figures 5 and 6 are given by

$$\begin{cases} \eta < z^D < \hat{z} \\ \eta_2 < \eta < \eta_1 \end{cases} \qquad \text{(Condition for Figure 5)} \tag{24}$$

and

$$z^D < \eta < \eta_1 \qquad \text{(Condition for Figure 6)}, \tag{25}$$

respectively. The solid curves with the foreign investment technology in Figures 5 and 6 are similar in that in both cases, if the economy starts with the low initial capital stock, it never adopts the foreign investment technology and converges to the domestic-technology steady state, $Z^D$. This is because the economy has too high a barrier, $\eta$, to adopt the foreign investment technology relative to the efficacy, $\Theta$, (including technology spillover and gap) and the relative price of FDI. However, the case of Figure 5 differs from that of Figure 6 in an important aspect. Other things being equal, especially with the barrier, $\eta$, remaining unchanged, the economy can escape from a domestic-technology trap in Figure 5 if the relative price of FDI drops, whereas it can never escape from the trajectory to the trap in Figure 6 regardless of how low the price falls. In the case of Figure 5, to the extent the barrier to technology adoption is infinitesimally smaller than the domestic-technology steady state, it is principally possible for the economy to escape from the trap by utilizing the foreign investment technology if the relative price of FDI drops sufficiently. In contrast, it is impossible for the economy to utilize the foreign investment technology even though the barrier is very close to the domestic-technology steady state in the case of Figure 6.

Our analysis shows that although the decrease in the world price of foreign investments is an advantageous shock for low- and middle-income countries, some countries can capitalize on this opportunity while others cannot, depending upon the level of the adoption barrier. In reality, we sometimes observe the case in which two countries (e.g., South Korea vs. the Philippines in the 1950s) with a similar per capita GDP level at the initial stage of development diverge away from each other over time. The former took off rapidly but the latter lagged behind. The property that a small difference can make a big difference as characterized by Figures 5 and 6 is consistent with this observation.

To wrap up, the crucial role played by the barrier to technology adoption echoes the emphasis by Borensztein, De Gregorio, and Lee (1998), Alfaro (2017), and Jude and Levieuge (2017), as any industrial policy or institutional reform toward removing such barriers can enable the host country's absorptive capability for adopting advanced foreign technologies to overcome a minimum threshold. Under this circumstance, it in turn supports Bajgar and Javorcik (2020) in that FDI can help developing countries escape from a middle-income trap. In this regard, our paper also complements a more recent and sprouting literature theoretically modeling the causes of middle-income traps, which may be a result of the

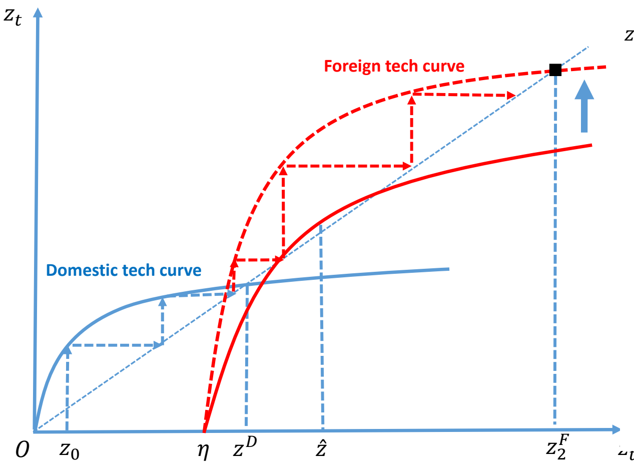

Figure 5: Escaping from the domestic-technology trap

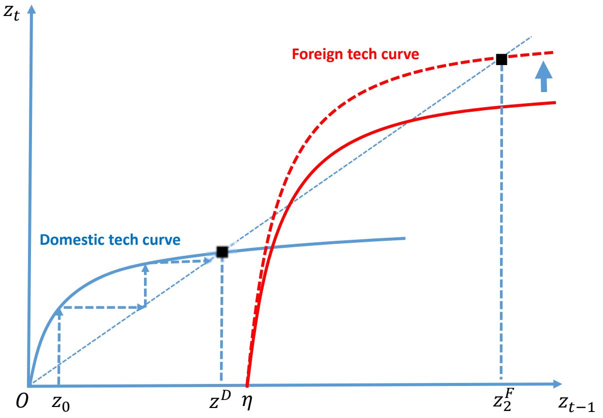

Figure 6: Never escaping from the domestic-technology trap

lack of industrial upgrading (cf. Ju, Lin, and Wang, 2015), the factor mismatch-induced ineffective technology assimilation (cf. Wang, Wong, and Yip, 2018a), or the barrier to human capital upgrading (cf. Hu, Kunieda, Nishimura, and Wang, 2023).

One may then inquire when and why this channel may play a significant role and how much it may help enhance capital accumulation and economic growth. These are ultimately quantitative questions to which we now turn.

## 5 Quantitative analysis

Whereas there are various cases of capital dynamics in our model, we have provided the typical cases in the previous section and demonstrated the possibility of domestic-technology traps. In this section, we first calibrate the parameter values of the foreign investment technology. Over the past fifty years, Asian countries have received a considerable amount of foreign direct investment from countries with state-of-art technologies, which means that they have been in positions to adopt such technologies in this period. We thus focus our quantitative analysis on eight representative Asian economies, including the four now-advanced Asian Tigers (Hong Kong, Singapore, South Korea, and Taiwan) and the four less-developed countries at various development stages (China, Malaysia, the Philippines, and Vietnam). Not only can we contrast the two groups by their development status, but we also cover economies with different sizes, degrees of openness, FDI intensities, and speeds of growth, which may provide further insight toward an understanding of the role played by FDI and foreign technology adoption.

To calibrate the parameter values, we first assume that Asian countries employ foreign investment technology and later discuss the technology choice based on the calibrated parameters. We collect yearly data for the period 1973-2018 depending upon the data availability for each country. For details on the data description, we refer the reader to Appendix D.

### 5.1 Calibrating parameters

Throughout the analysis, we assume that firms maintain a certain technology for each 5-year interval, to remove any unwanted short-run cyclicality that may distort the calibration. We denote by $\tau$ the $\tau$th technological episode. Under the hypothesis that the economy employs foreign investment technology, it follows from Eqs. (4), (6), and (7) with $\eta^* = 0$ that

$$\frac{n_{t+1} z_t}{i_t^*/y_t} = \theta (z_{t-1}^*)^{\varsigma+\varepsilon} (z_{t-1} - \eta)^{\sigma-\varepsilon}. \tag{26}$$

In Eq. (26), we assume that $\sigma$, $\varsigma$, and $\varepsilon$ are not time-varying throughout the investigation period. On the other hand, it is reasonable to assume that $\theta$ and $\eta$ are time-varying but constant within a certain duration in which the economy adopts a certain technology. Let $\theta_\tau$ and $\eta_\tau$ be the efficacy and barrier of the technology employed in the $\tau$th interval. We set the United States as the advanced foreign economy. For calibration purposes, we for the moment take $\eta_\tau$ as a linear function of the capital stock such that $\eta_\tau(z_{t-1}) = \tilde{\eta}_\tau z_{t-1}$. Eventually, we will obtain the $100,000$ sets of $(\theta_\tau, \tilde{\eta}_\tau)$ for each technological interval. Then, we will pair $\tilde{\eta}_\tau$ with the randomly chosen $z_{t-1}$ from the set of capital stock values within each interval and create $100,000$ of $\tilde{\eta}_\tau z_{t-1}$. By taking the average of $\tilde{\eta}_\tau z_{t-1}$, we obtain the calibrated $\eta_\tau$.

Inserting $\eta_\tau(z_{t-1}) = \tilde{\eta}_\tau z_{t-1}$ into Eq. (26) and taking the logarithm of both sides, we have

$$\ln\left(\frac{n_{t+1} z_t}{i_t^*/y_t}\right) = \ln\theta_\tau + (\sigma-\varepsilon)\ln(1-\tilde{\eta}_\tau) + (\sigma-\varepsilon)\ln z_{t-1} + (\varsigma+\varepsilon)\ln z_{t-1}^*. \tag{27}$$

Because $n$, $i^*/y$, $z$, and $z^*$ are observable, we can estimate $\varsigma+\varepsilon$ and $\sigma-\varepsilon$ by running a regression, although $\theta_\tau$ and $\tilde{\eta}_\tau$ cannot be identified without adopting further identification strategies. Thus, we begin by using Eq. (27) to set up the following regression model:

$$\ln\left(\frac{n_{t+1} z_t}{i_t^*/y_t}\right) = \sum_{\tau=1}^{\Upsilon} \gamma_\tau d_\tau + \alpha_1 \ln z_{t-1} + \alpha_2 \ln z_{t-1}^* + \xi_t, \tag{28}$$

where $d_\tau$ is the dummy variable that captures the $\tau$th technology level, $\Upsilon$ is the last technology duration, and $\xi_t$ is the error term. From Eqs. (27) and (28), we obtain

$$\hat{\alpha}_1 = \sigma - \varepsilon \tag{29}$$

and

$$\hat{\alpha}_2 = \varsigma + \varepsilon, \tag{30}$$

where $\hat{\alpha}_1$ and $\hat{\alpha}_2$ are the estimates of $\alpha_1$ and $\alpha_2$, respectively.

We apply the Bayesian method to estimate Eq. (28), and the regression results are reported in Table 1. Interestingly, for all eight economies under consideration, $\hat{\alpha}_1 + \hat{\alpha}_2 = \sigma + \varsigma$ is approximately 1.2, which suggests a technology adoption-technology spillover tradeoff. Moreover, based on Eq. (27), $\hat{\alpha}_1$ is associated with past domestic capital and adoption barriers and $\hat{\alpha}_2$ is associated with foreign capital. The results suggest that capital growth in Korea, Singapore, and Taiwan appears to be less responsive to the adoption barrier but more responsive to foreign capital, whereas China and Malaysia exhibit the opposite pattern.

We next turn to estimating $\theta_\tau$ and $\tilde{\eta}_\tau$. Note from Eq. (27) and (28) that $\ln \theta_\tau + \hat{\alpha}_1 \ln(1 - \tilde{\eta}_\tau)$ and $\hat{\gamma}_\tau$ are comparable for all $\tau$. We impose the condition that $\tilde{\eta}_\tau \geq 0$. In what follows, we intend to determine $\theta_\tau$ and $\tilde{\eta}_\tau$ by minimizing the distance between $\ln \theta_\tau + \hat{\alpha}_1 \ln(1 - \tilde{\eta}_\tau)$ and $\hat{\gamma}_\tau$ under the constraint of $\tilde{\eta}_\tau \geq 0$, but $\theta_\tau$ and $\tilde{\eta}_\tau$ cannot be identified as they are. Fortunately, in the Bayesian regression, we can obtain the posterior distributions of $\hat{\alpha}_1$ and $\hat{\gamma}_\tau$, and to resolve the identification problem, we perturb $\hat{\alpha}_1$ and $\hat{\gamma}_\tau$ by applying their means and standard deviations of the posterior distributions.

Consider the minimization of the loss function as

$$\min_{\theta_\tau, \tilde{\eta}_\tau} \left\{ \sum_{t \in T_\tau} \left[ \ln \theta_\tau + \tilde{\alpha}_{1,t} \ln(1 - \tilde{\eta}_\tau) - \tilde{\gamma}_t \right]^2 \right\}, \tag{31}$$

subject to

$$\tilde{\eta}_\tau \geq 0, \tag{32}$$

where $\tilde{\alpha}_{1,t}$ and $\tilde{\gamma}_t$ are the perturbed values of $\hat{\alpha}_1$ and $\hat{\gamma}_\tau$, respectively. $T_\tau$ is the set of years for the $\tau$th technological episode. By solving this minimization problem, we determine provisional $\theta_\tau$ and $\tilde{\eta}_\tau$, and based on the computing algorithm for $\theta_\tau$ and $\tilde{\eta}_\tau$ described in Appendix E, we obtain the $100,000$ sets of $(\theta_\tau, \tilde{\eta}_\tau)$ for the $\tau$th technology. For the efficacy of the technology, taking the average on $\theta_\tau$, we have their estimates as $\hat{\theta}_\tau$. We couple $\tilde{\eta}_\tau$ and the randomly chosen $z_{t-1}$ from the set of capital stock values in each technological episode

Table 1. Estimations

| Country | Prior | Variable | Mean | Std. Dev. | 95% Cred. Interval |
|---|---|---|---|---|---|
| **China** (Obs. 37) | $\alpha_1 = 1$ | $\ln z$ | 0.6467 | 0.1628 | [0.3287, 0.9652] |
| | $\alpha_2 = 1$ | $\ln z^*$ | 0.5266 | 0.1269 | [0.2780, 0.7758] |
| **Hong Kong** (Obs. 45) | $\alpha_1 = 1$ | $\ln z$ | 0.4810 | 0.0991 | [0.2869, 0.6728] |
| | $\alpha_2 = 1$ | $\ln z^*$ | 0.6454 | 0.1005 | [0.4505, 0.8453] |
| **S. Korea** (Obs. 45) | $\alpha_1 = 1$ | $\ln z$ | 0.4573 | 0.1318 | [0.2001, 0.7133] |
| | $\alpha_2 = 1$ | $\ln z^*$ | 0.8431 | 0.1232 | [0.6027, 1.0850] |
| **Malaysia** (Obs. 45) | $\alpha_1 = 1$ | $\ln z$ | 0.6426 | 0.2077 | [0.2347, 1.0440] |
| | $\alpha_2 = 1$ | $\ln z^*$ | 0.5162 | 0.1921 | [0.1437, 0.8927] |
| **Philippines** (Obs. 45) | $\alpha_1 = 1$ | $\ln z$ | 0.6212 | 0.2422 | [0.1441, 1.0899] |
| | $\alpha_2 = 1$ | $\ln z^*$ | 0.5949 | 0.2001 | [0.2073, 0.9896] |
| **Singapore** (Obs. 45) | $\alpha_1 = 1$ | $\ln z$ | 0.4128 | 0.2093 | [0.0030, 0.8183] |
| | $\alpha_2 = 1$ | $\ln z^*$ | 0.6817 | 0.2090 | [0.2773, 1.0924] |
| **Taiwan** (Obs. 45) | $\alpha_1 = 1$ | $\ln z$ | 0.5149 | 0.1833 | [0.1548, 0.8700] |
| | $\alpha_2 = 1$ | $\ln z^*$ | 0.7905 | 0.1739 | [0.4540, 1.1319] |
| **Vietnam** (Obs. 45) | $\alpha_1 = 1$ | $\ln z$ | 0.4624 | 0.1141 | [0.2388, 0.6863] |
| | $\alpha_2 = 1$ | $\ln z^*$ | 0.6546 | 0.0806 | [0.4969, 0.8140] |

*Notes.* We have applied the Gibbs sampling method with priors $\alpha_1 = \alpha_2 = 1$. One notes that the priors, $\alpha_1 = \alpha_2 = 1$, ex-ante assume that the right-hand side of Eq. (26) exhibits a elasticity of one with respect to both $z - \eta$ and $z^*$.

and create the $100,000$ of $\tilde{\eta}_{\tau} z_{t-1}$. By taking the average of $\tilde{\eta}_{\tau} z_{t-1}$, we obtain the calibrated $\eta_{\tau}$. The calibrated $\theta_{\tau}$ and $\eta_{\tau}$ together with the FDI/GDP ratio and the per capita growth rate for each technological episode are shown in Table 2.

Three remarks are in order. First, the level of foreign technology adoption barriers ($\eta_{\tau}$) is increasing in all eight economies. This result suggests that the scale barrier or minimum threshold becomes more difficult to overcome as an economy develops. This outcome is consistent with the rising complexity story in the adoption literature (e.g., Javorcik, Turco, and Maggioni, 2018). Second, the extent of such barriers relative to domestic capital ($\tilde{\eta}_{\tau}$) is approximately 0.2 on average and relatively stable over time, with China, Hong Kong, South Korea, and Taiwan being slightly higher than the other four economies. That is, there is a 20% scale barrier to overcome in these Asian economies, which is not increasing over time despite the rise in production complexity. This may serve to explain the observed rising FDI intensities. Third, the degrees of FDI conversion efficacy ($\theta_{\tau}$) are relatively stable in China, South Korea, Malaysia, and Taiwan but declining in Hong Kong, the Philippines, Singapore, and Vietnam. However, whether these patterns may lead to different forms of technology adoption would depend on the relative price of FDI, which will be measured in the next subsection.

### 5.2 Technology choice with actual data

It is difficult to perform technology choice using actual data because the ex-ante user price of the foreign investment technology is not observable. However, we can obtain the ex-post price under the hypothesis that the economy employs the foreign investment technology, which is given by $p_t^* = \tilde{\imath}_t / i_t^*$ where $\tilde{\imath}_t$ is the total investment as defined in 2.1. Moreover, if the economy employs the domestic investment technology, it follows that $\Omega = n_{t+1} z_t / \tilde{\imath}_t$. Then, from Eq. (17), the condition under which the economy employs the foreign (domestic) investment technology is given by

$$p_t^* = \frac{\tilde{\imath}_t}{i_t^*} < (>) \frac{\tilde{\imath}_t \theta (z_{t-1} - \eta)^{\alpha_1} \cdot \left(z_{t-1}^*\right)^{\alpha_2}}{n_{t+1} z_t y_t}, \tag{33}$$

or, equivalently,

$$\left(\frac{i_t^* / y_t}{n_{t+1} z_t}\right) \Gamma(z_{t-1}, z_{t-1}^*; \theta, \eta) > (<) 1. \tag{34}$$

Two remarks on inequality (34) are in order. First, one might argue that optimal investment is given by holding equality in inequality (34) in our theory. However, the actual investment

Table 2. Calibrated $\theta_j$ and $\eta_j$

| | | **mid 1970** | **late 70- -early 80** | **mid 1980** | **late 80- -early 90** | **mid 1990** | **late 90- -early 00** | **mid 2000** | **late 00- -early 10** | **mid 2010** |
|---|---|---|---|---|---|---|---|---|---|---|
| **China** | $\theta$ | | | 8.033 | 4.897 | 3.456 | 3.074 | 3.205 | 4.125 | 5.304 |
| | $\eta$ | | | 1.320 | 1.713 | 2.283 | 3.594 | 5.689 | 9.631 | 16.82 |
| | $\tilde{\eta}$ | | | 0.228 | 0.227 | 0.228 | 0.227 | 0.228 | 0.228 | 0.230 |
| | $i^*/y$ (%) | | | 0.332 | 0.826 | 3.618 | 4.280 | 3.236 | 2.251 | 1.390 |
| | growth rate (%) | | | 4.748 | 0.530 | 7.214 | 3.528 | 7.915 | 7.646 | 5.138 |
| **Hong Kong** | $\theta$ | 3.792 | 3.638 | 3.625 | 3.612 | 3.499 | 3.197 | 3.116 | 2.953 | 2.907 |
| | $\eta$ | 45.58 | 51.82 | 63.46 | 77.34 | 98.84 | 115.0 | 125.9 | 131.8 | 135.0 |
| | $\tilde{\eta}$ | 0.206 | 0.205 | 0.207 | 0.205 | 0.207 | 0.207 | 0.208 | 0.206 | 0.205 |
| | $i^*/y$ (%) | 2.475 | 3.466 | 4.499 | 4.820 | 5.905 | 15.15 | 18.63 | 29.71 | 37.26 |
| | growth rate (%) | 3.516 | 3.780 | 5.443 | 4.470 | 1.179 | 1.216 | 4.778 | 2.108 | 1.872 |
| **S. Korea** | $\theta$ | 3.522 | 4.080 | 3.641 | 3.640 | 3.613 | 2.752 | 2.932 | 3.215 | 3.459 |
| | $\eta$ | 7.968 | 12.13 | 17.58 | 25.00 | 38.64 | 53.19 | 64.40 | 75.01 | 81.95 |
| | $\tilde{\eta}$ | 0.217 | 0.216 | 0.217 | 0.216 | 0.217 | 0.217 | 0.219 | 0.217 | 0.216 |
| | $i^*/y$ (%) | 0.473 | 0.201 | 0.388 | 0.441 | 0.546 | 1.438 | 1.150 | 0.855 | 0.699 |
| | growth rate (%) | 6.350 | 4.219 | 7.118 | 5.667 | 5.073 | 4.450 | 3.474 | 2.446 | 1.850 |
| **Malaysia** | $\theta$ | 3.370 | 3.348 | 4.156 | 3.007 | 2.741 | 3.725 | 3.906 | 3.870 | 3.874 |
| | $\eta$ | 9.849 | 13.47 | 18.55 | 20.97 | 28.96 | 34.19 | 36.24 | 36.68 | 38.98 |
| | $\tilde{\eta}$ | 0.183 | 0.182 | 0.183 | 0.182 | 0.183 | 0.183 | 0.185 | 0.183 | 0.182 |
| | $i^*/y$ (%) | 3.532 | 3.808 | 2.713 | 5.584 | 6.759 | 3.645 | 3.113 | 3.138 | 3.243 |
| | growth rate (%) | 3.744 | 3.166 | 0.996 | 5.190 | 3.778 | 1.466 | 3.867 | $-0.086$ | 3.266 |
| **Philippines** | $\theta$ | 4.402 | 5.216 | 4.239 | 2.965 | 2.590 | 2.744 | 2.821 | 3.236 | 2.666 |
| | $\eta$ | 4.342 | 5.406 | 6.005 | 5.942 | 6.193 | 6.610 | 6.969 | 7.285 | 8.483 |
| | $\tilde{\eta}$ | 0.162 | 0.161 | 0.163 | 0.162 | 0.162 | 0.163 | 0.164 | 0.163 | 0.162 |
| | $i^*/y$ (%) | 0.631 | 0.449 | 0.717 | 1.401 | 1.793 | 1.605 | 1.440 | 1.077 | 1.768 |
| | growth rate (%) | 3.507 | 0.533 | $-3.815$ | $-0.282$ | 1.038 | 1.366 | 3.187 | 2.624 | 4.584 |
| **Singapore** | $\theta$ | 4.051 | 3.453 | 3.601 | 3.293 | 3.329 | 2.979 | 2.727 | 2.656 | 2.409 |
| | $\eta$ | 28.75 | 35.13 | 49.52 | 56.73 | 70.34 | 84.96 | 88.35 | 84.80 | 92.67 |
| | $\tilde{\eta}$ | 0.181 | 0.180 | 0.181 | 0.180 | 0.181 | 0.182 | 0.183 | 0.181 | 0.180 |
| | $i^*/y$ (%) | 5.454 | 8.196 | 8.715 | 10.71 | 11.48 | 15.02 | 16.85 | 17.07 | 21.36 |
| | growth rate (%) | 3.260 | 3.163 | 4.401 | 3.660 | 4.116 | 0.607 | 1.924 | 2.641 | 2.215 |
| **Taiwan** | $\theta$ | 3.694 | 4.067 | 3.659 | 3.146 | 3.716 | 3.118 | 2.961 | 3.456 | 3.211 |
| | $\eta$ | 11.28 | 16.35 | 21.55 | 28.85 | 41.99 | 58.30 | 67.38 | 70.01 | 71.68 |
| | $\tilde{\eta}$ | 0.203 | 0.202 | 0.203 | 0.202 | 0.203 | 0.204 | 0.205 | 0.203 | 0.202 |
| | $i^*/y$ (%) | 0.370 | 0.331 | 0.472 | 0.698 | 0.538 | 0.855 | 0.953 | 0.703 | 0.795 |
| | growth rate (%) | 6.003 | 4.989 | 5.933 | 6.021 | 5.466 | 3.711 | 3.667 | 2.478 | 1.782 |
| **Vietnam** | $\theta$ | 3.744 | 3.440 | 3.562 | 3.109 | 2.937 | 3.062 | 3.070 | 3.049 | 3.107 |
| | $\eta$ | 0.657 | 0.673 | 0.725 | 0.813 | 1.226 | 1.993 | 2.847 | 3.906 | 5.175 |
| | $\tilde{\eta}$ | 0.190 | 0.189 | 0.191 | 0.189 | 0.190 | 0.191 | 0.192 | 0.190 | 0.189 |
| | $i^*/y$ (%) | 0.029 | 0.238 | 0.124 | 3.000 | 8.286 | 4.940 | 4.837 | 6.698 | 5.777 |
| | growth rate (%) | 1.737 | 0.352 | 2.054 | 3.529 | 6.067 | 3.330 | 4.183 | 3.212 | 5.472 |

*Notes.* The minimization of the loss function given by Eq. (31) determines provisional $\theta_\tau$ and $\tilde{\eta}_\tau$. The computing algorithm for $\theta_\tau$ and $\tilde{\eta}_\tau$ described in Appendix E generates $100,000$ sets of $(\theta_\tau, \tilde{\eta}_\tau)$ for the $\tau$th technology. For the efficacy of the technology, taking the average on $\theta_\tau$, we have their estimates as $\hat{\theta}_\tau$. By coupling $\tilde{\eta}_\tau$ and the randomly chosen $z_{t-1}$ from the set of capital stock in each technological interval, we can create $100,000$ values of $\tilde{\eta}_\tau z_{t-1}$. By taking the average of $\tilde{\eta}_\tau z_{t-1}$, we obtain the calibrated $\eta_\tau$ for which we report the down-scaled values and the actual values are $\eta_\tau \times 10^3$.

observed in the data may not be all at the optimal level. Second, although the technology is modeled as a discrete choice from foreign and domestic technologies, $i_t^*$ can be observed in actual data even though the left-hand side of inequality (34) is less than 1. This is because, in reality, some firms employ domestic technology while others adopt foreign technology. Therefore, it is more appropriate to present the likelihood of which technology is chosen in the economy. Then, from inequality (34), we formally establish the following judgment regarding the technology choice based on the actual data:

- If $\Gamma(z_{t-1}, z_{t-1}^*; \theta, \eta)\,(i_t^*/(y_t n_{t+1} z_t)) < 1$, the economy is more likely to employ the domestic investment technology.
- If $\Gamma(z_{t-1}, z_{t-1}^*; \theta, \eta)\,(i_t^*/(y_t n_{t+1} z_t)) > 1$, the economy is more likely to employ the foreign investment technology.

As such, we regress $\Gamma(z_{t-1}, z_{t-1}^*; \theta, \eta)\,(i_t^*/(y_t n_{t+1} z_t))$ on the technological duration dummies, $d_\tau$, by applying the Bayesian method and obtain its simulated distribution for each technological episode. Based on the simulated distribution, we judge that the foreign investment technology becomes more likely to be adopted when the median of $\Gamma(z_{t-1}, z_{t-1}^*; \theta, \eta)\,(i_t^*/(y_t n_{t+1} z_t))$ increases. In particular, if the median is greater than 1, the likelihood that the foreign investment technology is adopted is greater than 50%.

Figure 7 shows the median of the simulated distribution of $\Gamma(z_{t-1}, z_{t-1}^*; \theta, \eta)\,(i_t^*/(y_t n_{t+1} z_t))$ for each country and each technological episode. Two conclusions can be drawn. First, the results suggest that overall most economies are likely to adopt foreign investment technology with likelihood exceeding 50%. Second, such adoption is especially more likely after the mid-1990s. These findings again confirm the observed rise in FDI intensities in the eight economies in recent decades. We will apply the criterion of a 50% foreign investment technology likelihood to growth accounting analyses in the next three subsections.

### 5.3 Capital growth accounting

We are now prepared to conduct growth accounting exercises. We begin by performing a *capital* growth accounting analysis to examine the importance of the long-run technological advances and the relative price of FDI. From the second equation of Eq. (17), it follows that

$$\ln z_t = \ln(\delta\beta) + \ln\theta_\tau + (\varsigma + \varepsilon)\ln z_{t-1}^* + (\sigma - \varepsilon)\ln(z_{t-1} - \eta_\tau) - \ln n_{t+1} - \ln p_t^*. \qquad (35)$$

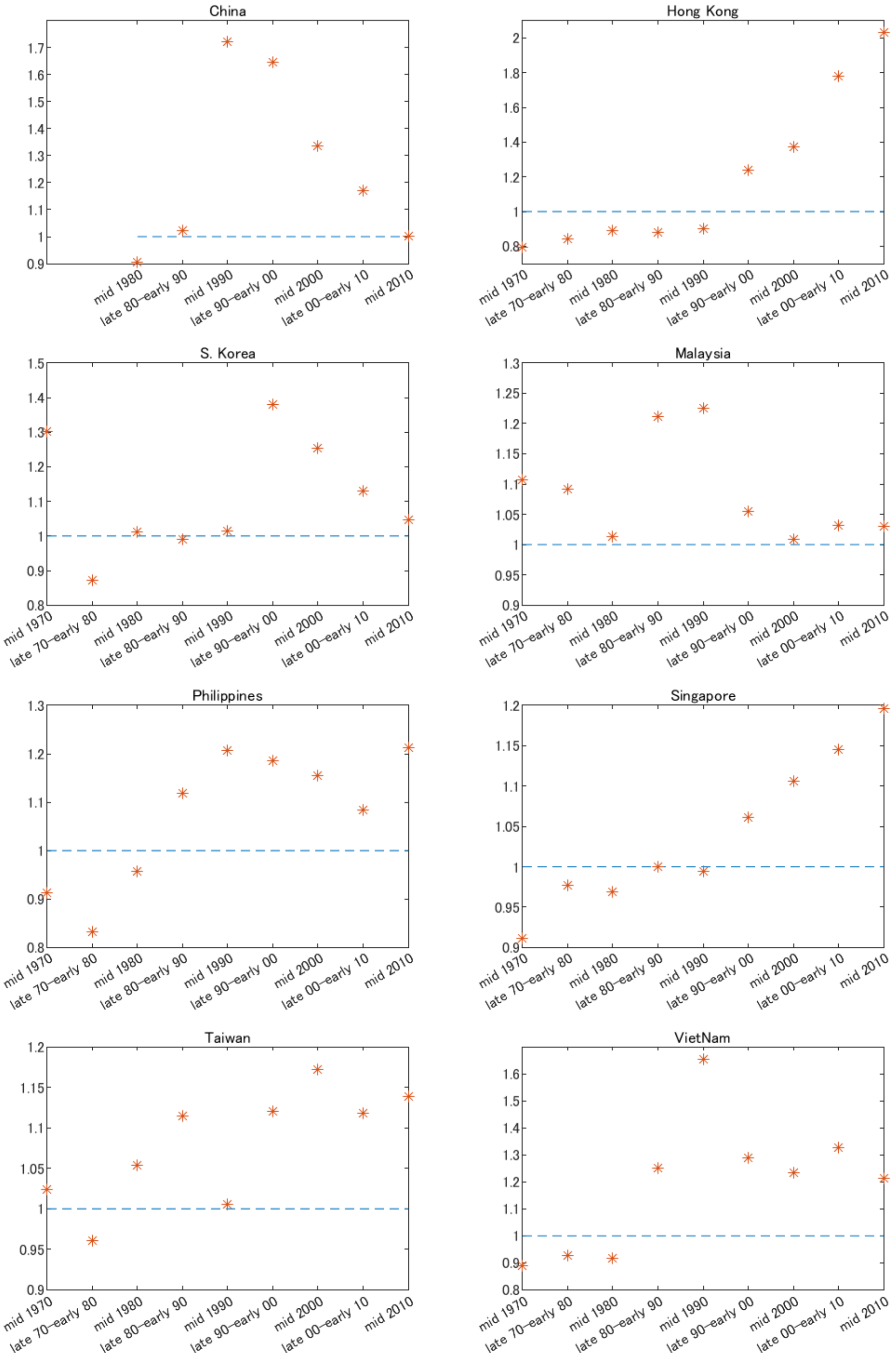

Figure 7: Technology choice with actual data

*Notes.* The asterisk indicates the median of the simulated distribution generated from the Bayesian regression of the left-hand side of Eq. (34) on the technological duration dummies where the Gibbs sampling method has been applied with the prior for the coefficient being 1. The results suggest that overall most economies are likely to adopt foreign investment technology with likelihood exceeding 50%, and such adoption is especially more likely after the mid-1990s.

Table 3. Capital growth accounting

| | Technology | ($\theta$) | (Spillover) | Past Knowledge with Barrier | Labor | Price | (World Price) | (Price Wedge) |
|---|---|---|---|---|---|---|---|---|
| **China** | | | | | | | | |
| $\Delta\ln(z) = 0.662$ (1986-1996) | **−117.9%** | (−127.3%) | (9.4%) | **63.9%** | **2.2%** | **151.8%** | (3.8%) | (148%) |
| $\Delta\ln(z) = 0.498$ (2006-2016) | **50.7%** | (50.5%) | (0.2%) | **66.0%** | **0.5%** | **−17.2%** | (45.8%) | (−63.0%) |
| **Hong Kong** | | | | | | | | |
| $\Delta\ln(z) = 0.152$ (1998-2008) | **−5.1%** | (−76%) | (70.9%) | **49.6%** | **5.1%** | **50.4%** | (−248.7%) | (299.1%) |
| $\Delta\ln(z) = 0.07$ (2008-2018) | **−32.9%** | (−100.3%) | (67.4%) | **55.9%** | **1.7%** | **75.3%** | (431.5%) | (−356.2%) |
| **S. Korea** | | | | | | | | |
| $\Delta\ln(z) = 0.764$ (1983-1993) | **−3.0%** | (−15.0%) | (12.0%) | **45.9%** | **−1.5%** | **58.6%** | (17.8%) | (40.8%) |
| $\Delta\ln(z) = 0.222$ (1998-2018) | **101.5%** | (74.2%) | (27.3%) | **47.5%** | **−0.9%** | **−48.1%** | (133.6%) | (−181.7%) |
| **Malaysia** | | | | | | | | |
| $\Delta\ln(z) = 0.662$ (1974-1984) | **40.3%** | (31.6%) | (8.7%) | **66.8%** | **1.2%** | **−8.3%** | (6.8%) | (−15.1%) |
| $\Delta\ln(z) = 0.137$ (2008-2018) | **21.1%** | (−6.0%) | (27.0%) | **65.3%** | **−1.9%** | **15.5%** | (−51.9%) | (67.4%) |
| **Philippines** | | | | | | | | |
| $\Delta\ln(z) = 0.091$ (1988-1998) | **−456.8%** | (−535.6%) | (78.7%) | **58.9%** | **1.3%** | **496.6%** | (−128.9%) | (625.5%) |
| $\Delta\ln(z) = 0.350$ (2008-2018) | **−3.9%** | (−16.1%) | (12.2%) | **55.6%** | **3.7%** | **44.6%** | (0.7%) | (43.9%) |
| **Singapore** | | | | | | | | |
| $\Delta\ln(z) = 0.361$ (1988-1998) | **1.2%** | (−21.7%) | (22.9%) | **37.5%** | **1.9%** | **59.4%** | (128.9%) | (−69.5%) |
| $\Delta\ln(z) = 0.215$ (2008-2018) | **−34.6%** | (−57.4%) | (22.8%) | **40.6%** | **21.5%** | **72.5%** | (52.6%) | (19.9%) |
| **Taiwan** | | | | | | | | |
| $\Delta\ln(z) = 0.601$ (1983-1993) | **−28.3%** | (−42.6%) | (14.3%) | **49.4%** | **2.0%** | **76.9%** | (56.4%) | (20.5%) |
| $\Delta\ln(z) = 0.073$ (2008-2018) | **187.9%** | (110.4%) | (77.5%) | **53.1%** | **−1.8%** | **−139.2%** | (100.2%) | (−239.4%) |
| **Vietnam** | | | | | | | | |
| $\Delta\ln(z) = 0.814$ (1988-1998) | **−13.9%** | (−23.7%) | (9.8%) | **44.0%** | **0.3%** | **69.6%** | (73.0%) | (−3.4%) |
| $\Delta\ln(z) = 0.649$ (2008-2018) | **9.2%** | (1.9%) | (7.3%) | **43.9%** | **7.0%** | **39.9%** | (37.7%) | (2.2%) |
| | | | | | | | | |
| **Four Tigers average** | | | | | | | | |
| first ten years | **−6.4%** | | | **44.6%** | **2.5%** | **59.3%** | | |
| last ten years | **46.5%** | | | **48.6%** | **6.7%** | **−1.8%** | | |
| **Taiwan & S. Korea average** | | | | | | | | |
| first ten years | **−16.8%** | | | **47.8%** | **0.4%** | **68.6%** | | |
| last ten years | **148.5%** | | | **50.5%** | **−1.4%** | **−97.7%** | | |
| **Hong Kong & Singapore average** | | | | | | | | |
| first ten years | **−1.7%** | | | **43.2%** | **3.4%** | **55.2%** | | |
| last ten years | **−33.9%** | | | **47.1%** | **13.0%** | **73.7%** | | |
| | | | | | | | | |
| **Four non-Tigers average** | | | | | | | | |
| first ten years | **−117.0%** | | | **61.5%** | **1.3%** | **154.2%** | | |
| last ten years | **21.3%** | | | **61.1%** | **0.7%** | **16.9%** | | |
| **China & Philippines average** | | | | | | | | |
| first ten years | **−328.7%** | | | **60.8%** | **1.6%** | **366.2%** | | |
| last ten years | **25.0%** | | | **61.1%** | **2.0%** | **11.9%** | | |
| **Malaysia & Vietnam average** | | | | | | | | |
| first ten years | **29.0%** | | | **62.0%** | **1.0%** | **8.0%** | | |
| last ten years | **18.7%** | | | **61.0%** | **−0.1%** | **20.4%** | | |

*Notes.* We focus on the periods in which the likelihood of adopting foreign technology is not persistently less than 50%: China from the late 1980s, Hong Kong from the late 1990s, South Korea from the mid-1980s, Malaysia from the mid-1970s, the Philippines from the late 1980s, Singapore from the late 1980s, Taiwan from the mid-1980s, and Vietnam from the late 1980s. The averages are weighted by each economy's per capita GDP.

Note that there is a difference between $p_t^*$ and the actual price of foreign investment goods, probably reflecting some institutional effect or installation cost. Thus, we let $p_t^* = \omega_t \tilde{p}_t$ where $\tilde{p}_t$ is the world price of foreign investment goods relative to the price of domestic goods, which is observable.[7] Henceforth, we call $\omega_t$ the *wedge* of the price of foreign investment goods. Substituting $p_t^* = \omega_t \tilde{p}_t$, $\alpha_1 = \sigma - \varepsilon$, and $\alpha_2 = \varsigma + \varepsilon$ into Eq. (35) and taking the time difference, we have

$$1 = \frac{\triangle \ln \theta_\tau}{\triangle \ln z_t} + \alpha_2 \frac{\triangle \ln z_{t-1}^*}{\triangle \ln z_t} + \alpha_1 \frac{\triangle \ln (z_{t-1} - \eta_\tau)}{\triangle \ln z_t} - \frac{\triangle \ln n_{t+1}}{\triangle \ln z_t} - \frac{\triangle \ln \tilde{p}_t}{\triangle \ln z_t} - \frac{\triangle \ln \omega_t}{\triangle \ln z_t}, \tag{36}$$

which is the basic equation for capital growth accounting. The logged differences are the growth rates of the variables. To investigate a relatively longer structural growth effect, we consider the ten-year growth rate in capital growth accounting. There are six components on the right-hand side of Eq. (36), and other than $\omega_t$, they are observable. The last term, which is a contribution of the wedge, can be computed as a residual of the capital growth accounting. Note that the first three components capture technological advances in the capital conversion multiplier: the first is the technological efficacy, the second is a spillover effect from a country with state-of-art technologies, and the third is an adoption barrier channel whereby the barrier to technology adoption is eased when the past capital accumulation exceeds the minimum threshold. Interestingly, past domestic capital not only contributes to domestic capital accumulation but also mitigates the scale barrier to enable foreign technology adoption. Unfortunately, we cannot disentangle these two channels in our growth accounting exercises. The fourth is a typical labor growth effect. The last two components are the relative price effects in installing the foreign technologies: $\triangle \ln \tilde{p}_t / \triangle \ln z_t$ is the actual price contribution, and $\triangle \ln \omega_t / \triangle \ln z_t$ is the wedge contribution that reflects unobserved shadow costs, government policy, the quality of institutions, and the international connections between countries.

Table 3 presents the results of capital growth accounting. In each country, we focus on the periods in which the likelihood of adopting foreign technology is not persistently less than 50%: China from the late 1980s, Hong Kong from the late 1990s, South Korea from the mid-1980s, Malaysia from the mid-1970s, the Philippines from the late 1980s, Singapore from the late 1980s, Taiwan from the mid-1980s, and Vietnam from the late 1980s. The table reports the results for the first and last ten-year periods. Two findings are of par-

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[7] Practically speaking, one can regard $1/\tilde{p}_t$ as the terms of trade of the home country with the US because we use the relative price of US output to domestic output, which can be computed from the Penn World Table 10.0.

ticular interest. First, overall technology barrier reduction explains approximately half of capital growth and more in non-Tigers than in Tigers. This suggests that removing such barriers is more likely to stimulate faster capital accumulation in less developed countries, possibly due to issues concerning minimum scale requirements for absorptive capacity (à la Borensztein, De Gregorio, and Lee, 1998) and institutional barriers (à la Jude and Levieuge, 2017). Second, FDI conversion efficacy plays an increasingly more important role in South Korea and Taiwan, contributing positively to capital growth and more than offsetting the negative effect of relative prices in the last ten years. In contrast, in the first ten years of the development process in China and the Philippines, FDI conversion efficacy contributes negatively to capital growth, offsetting a major portion of the positive effect of price competitiveness. That is, while FDI conversion efficacy is primarily responsible for FDI's ability to enhance capital growth in South Korea and Taiwan, it is the favorable relative price of FDI that induces the capital growth effect of FDI in China and the Philippines.

### 5.4 Growth accounting

By combining capital growth accounting with conventional growth accounting, we can decompose various sources of economic growth. It follows from the output per worker formula that

$$\ln y_t = \ln A_t + \beta \ln z_{t-1}, \tag{37}$$

which implies

$$1 = \frac{\triangle \ln A_t}{\triangle \ln y_t} + \beta \left( \frac{\triangle \ln z_{t-1}}{\triangle \ln y_t} \right). \tag{38}$$

Table 4 shows the results of conventional growth accounting based on Eq. (38), where we provide the first and last ten years of results as in Table 3. Not surprisingly, in most cases in different economies in different time, TFP plays a major role, more important than capital accumulation. The contribution of TFP is particularly strong in the Tigers, consistently over 70%. While the contribution of TFP in developing Asian countries in the last decade is comparable to that in the Tigers, that in the first decade is below 30%, substantially less than the contribution of capital accumulation.

Substituting Eq. (35) into Eq. (37) yields

$$\ln y_t = \ln A_t + \beta \left[ \ln(\delta\beta) + \ln \theta_\tau + \alpha_2 \ln z^*_{t-2} + \alpha_1 \ln(z_{t-2} - \eta_\tau) - \ln n_t - \ln p^*_{t-1} \right]. \tag{39}$$

Table 4. Conventional growth accounting

| | TFP | Capital per capita |
|---|---|---|
| **China** | | |
| $\Delta\ln(y) = 0.391$ (1986-1996) | **43.5%** | **56.5%** |
| $\Delta\ln(y) = 0.606$ (2006-2016) | **72.6%** | **27.4%** |
| **Hong Kong** | | |
| $\Delta\ln(y) = 0.292$ (1998-2008) | **82.6%** | **17.4%** |
| $\Delta\ln(y) = 0.179$ (2008-2018) | **87.2%** | **12.8%** |
| **S. Korea** | | |
| $\Delta\ln(y) = 0.620$ (1983-1993) | **58.9%** | **41.1%** |
| $\Delta\ln(y) = 0.202$ (2008-2018) | **63.4%** | **36.6%** |
| **Malaysia** | | |
| $\Delta\ln(y) = 0.337$ (1974-1984) | **34.7%** | **65.3%** |
| $\Delta\ln(y) = 0.170$ (2008-2018) | **73.2%** | **26.8%** |
| **Philippines** | | |
| $\Delta\ln(y) = 0.028$ (1988-1998) | **−6.6%** | **106.6%** |
| $\Delta\ln(y) = 0.387$ (2008-2018) | **69.9%** | **30.1%** |
| **Singapore** | | |
| $\Delta\ln(y) = 0.387$ (1988-1998) | **68.9%** | **31.1%** |
| $\Delta\ln(y) = 0.219$ (2008-2018) | **67.2%** | **37.8%** |
| **Taiwan** | | |
| $\Delta\ln(y) = 0.604$ (1983-1993) | **66.8%** | **33.2%** |
| $\Delta\ln(y) = 0.212$ (2008-2018) | **88.4%** | **11.6%** |
| **Vietnam** | | |
| $\Delta\ln(y) = 0.477$ (1988-1998) | **43.2%** | **56.8%** |
| $\Delta\ln(y) = 0.474$ (2008-2018) | **54.4%** | **45.6%** |
| | | |
| **Four Tigers average** | | |
| first ten years | **71.6%** | **28.4%** |
| last ten years | **76.3%** | **25.3%** |
| **S. Korea & Taiwan average** | | |
| first ten years | **63.3%** | **36.8%** |
| last ten years | **77.0%** | **23.0%** |
| **Hong Kong & Singapore average** | | |
| first ten years | **75.3%** | **24.7%** |
| last ten years | **75.8%** | **27.1%** |
| | | |
| **Four non-Tigers average** | | |
| first ten years | **26.6%** | **73.4%** |
| last ten years | **70.2%** | **29.8%** |
| **China & Philippines average** | | |
| first ten years | **12.3%** | **87.7%** |
| last ten years | **71.3%** | **28.7%** |
| **Malaysia & Vietnam average** | | |
| first ten years | **36.5%** | **63.5%** |
| last ten years | **69.5%** | **30.5%** |

*Notes.* We perform conventional growth accounting based on Eq. (38), focusing on the periods in which the likelihood of adopting foreign technology is not persistently less than 50% as in Table 3. The averages are weighted by each economy's per capita GDP. Not surprisingly, in most cases, in different economies in different time, the total factor productivity (TFP) plays a major role, more important than capital accumulation.

Taking the time difference of Eq. (42) and rearranging it, we obtain

$$\begin{aligned}1 = \quad & \frac{\triangle \ln A_t}{\triangle \ln y_t} + \beta \left( \frac{\triangle \ln z_{t-1}}{\triangle \ln y_t} \right) \left[ \frac{\triangle \ln \theta_\tau}{\triangle \ln z_{t-1}} + \alpha_2 \frac{\triangle \ln z^*_{t-2}}{\triangle \ln z_{t-1}} + \alpha_1 \frac{\triangle \ln (z_{t-2} - \eta_\tau)}{\triangle \ln z_{t-1}} \right. \\ & \left. - \frac{\triangle \ln n_t}{\triangle \ln z_{t-1}} - \frac{\triangle \ln \tilde{p}_{t-1}}{\triangle \ln z_{t-1}} - \frac{\triangle \ln \omega_{t-1}}{\triangle \ln z_{t-1}} \right]. \qquad (40)\end{aligned}$$

In Table 5, we conduct the growth accounting analysis based on Eq. (40). Again, the table reports the first and last ten years of results. In it, in addition to the conventional TFP channel, we have an adoption barrier channel, two technology advancement channels through FDI conversion efficacy and foreign technology spillover, and two price channels through the relative price and the associated wedge of FDI.

Notably, in the two most advanced economies, Hong Kong and Singapore, which face the highest complexity in technology advancement, the rise in foreign technology spillover essentially offsets the slowdown in FDI conversion efficacy. As a result, in addition to TFP, the reduced adoption barrier and the price channel contributed to the entirety of economic growth over the past three decades. In the remaining two Tigers, South Korea and Taiwan, while the contribution of the reduced adoption barrier to growth is consistent throughout, it is the price channel that plays a more crucial role in the first ten-year period and the FDI conversion efficacy-technology spillover channel in the last ten years, each accounting for approximately one-quarter of economic growth in the respective period.

In the four non-Tigers, the reduced adoption barrier is far more significant to growth, explaining approximately 45% on average in the first ten years and 18% in the last ten years. During the first ten years, the favorable price channel roughly offsets the sluggish conversion efficacy-foreign technology spillover channel in China and the Philippines; these two channels, however, diminished substantially during the last ten years. Foreign technology conversion efficacy and spillover and price channels never play a significant role in the remaining two less-developed Asian economies, Malaysia and Vietnam, which is consistent with the panel study by Kunieda, Okada, Sawada, and Shibata (2021) that finds a significant role of technology transfer for Asian countries' growth only in the later stage of economic development.

## 5.5 Counterfactual analysis

The growth accounting exercises performed in the previous subsection only present a conservative lower bound for the contribution of FDI. This is because we used TFP data directly, which by construction rule out any potential impact of FDI on aggregate TFP, a critical

Table 5. Growth accounting decomposition

| | TFP | Technology | ($\theta$) | (Spillover) | Past Knowledge with Barrier | Labor | Price | $\left(\text{World Price}\right)$ | $\left(\text{Price Wedge}\right)$ |
|---|---|---|---|---|---|---|---|---|---|
| **China** | | | | | | | | | |
| $\Delta\ln(y) = 0.391$ (1986-1996) | **43.5%** | **−66.6%** | (−71.9%) | (5.3%) | **36.1%** | **1.3%** | **85.7%** | (2.1%) | (83.6%) |
| $\Delta\ln(y) = 0.606$ (2006-2016) | **72.6%** | **13.9%** | (13.8%) | (0.1%) | **18.1%** | **0.1%** | **−4.7%** | (12.5%) | (−17.2%) |
| **Hong Kong** | | | | | | | | | |
| $\Delta\ln(y) = 0.292$ (1998-2008) | **82.6%** | **−0.9%** | (−13.2%) | (12.3%) | **8.6%** | **0.9%** | **8.8%** | (−43.2%) | (52.0%) |
| $\Delta\ln(y) = 0.179$ (2008-2018) | **87.2%** | **−4.2%** | (−12.8%) | (8.6%) | **7.2%** | **0.2%** | **9.6%** | (55.1%) | (−45.5%) |
| **S. Korea** | | | | | | | | | |
| $\Delta\ln(y) = 0.620$ (1983-1993) | **59.0%** | **−1.2%** | (−6.1%) | (4.9%) | **18.8%** | **−0.6%** | **24.0%** | (7.3%) | (16.7%) |
| $\Delta\ln(y) = 0.202$ (2008-2018) | **63.4%** | **37.2%** | (27.2%) | (10.0%) | **17.4%** | **−0.3%** | **−17.7%** | (48.9%) | (−66.6%) |
| **Malaysia** | | | | | | | | | |
| $\Delta\ln(y) = 0.337$ (1974-1984) | **34.7%** | **26.4%** | (20.7%) | (5.7%) | **43.6%** | **0.7%** | **−5.4%** | (4.5%) | (−9.9%) |
| $\Delta\ln(y) = 0.170$ (2008-2018) | **73.2%** | **5.7%** | (−1.6%) | (7.3%) | **17.5%** | **−0.5%** | **4.1%** | (−13.9%) | (18.0%) |
| **Philippines** | | | | | | | | | |
| $\Delta\ln(y) = 0.028$ (1988-1998) | **−6.6%** | **−487.2%** | (−571.1%) | (83.9%) | **62.8%** | **1.4%** | **529.6%** | (−137.4%) | (667.0%) |
| $\Delta\ln(y) = 0.387$ (2008-2018) | **69.9%** | **−1.1%** | (−4.8%) | (3.7%) | **16.7%** | **1.1%** | **13.4%** | (0.2%) | (13.2%) |
| **Singapore** | | | | | | | | | |
| $\Delta\ln(y) = 0.387$ (1988-1998) | **68.9%** | **0.4%** | (−6.8%) | (7.2%) | **11.7%** | **0.6%** | **18.4%** | (40.1%) | (−21.7%) |
| $\Delta\ln(y) = 0.219$ (2008-2018) | **67.2%** | **−11.3%** | (−18.8%) | (7.5%) | **13.3%** | **7.1%** | **23.7%** | (17.2%) | (6.5%) |
| **Taiwan** | | | | | | | | | |
| $\Delta\ln(y) = 0.604$ (1983-1993) | **66.8%** | **−9.4%** | (−14.2%) | (4.8%) | **16.4%** | **0.7%** | **25.5%** | (18.7%) | (6.8%) |
| $\Delta\ln(y) = 0.212$ (2008-2018) | **88.4%** | **21.7%** | (12.7%) | (9.0%) | **6.1%** | **−0.2%** | **−16.0%** | (11.6%) | (−27.6%) |
| **Vietnam** | | | | | | | | | |
| $\Delta\ln(y) = 0.477$ (1988-1998) | **43.2%** | **−7.9%** | (−13.5%) | (5.6%) | **25.0%** | **0.1%** | **39.6%** | (41.5%) | (−1.9%) |
| $\Delta\ln(y) = 0.474$ (2008-2018) | **54.4%** | **4.2%** | (0.9%) | (3.3%) | **20.0%** | **3.2%** | **18.2%** | (17.2%) | (1.0%) |
| | | | | | | | | | |
| **Four Tigers average** | | | | | | | | | |
| first ten years | **71.6%** | **−1.9%** | | | **12.5%** | **0.5%** | **17.3%** | | |
| last ten years | **76.3%** | **8.0%** | | | **10.9%** | **2.2%** | **2.5%** | | |
| **S. Korea & Taiwan average** | | | | | | | | | |
| first ten years | **63.3%** | **−5.7%** | | | **17.5%** | **0.1%** | **24.8%** | | |
| last ten years | **77.0%** | **28.8%** | | | **11.2%** | **−0.2%** | **−16.8%** | | |
| **Hong Kong & Singapore average** | | | | | | | | | |
| first ten years | **75.3%** | **−0.2%** | | | **10.2%** | **0.7%** | **13.9%** | | |
| last ten years | **75.8%** | **−8.3%** | | | **10.7%** | **4.1%** | **17.7%** | | |
| | | | | | | | | | |
| **Four non-Tigers average** | | | | | | | | | |
| first ten years | **26.6%** | **−122.6%** | | | **45.0%** | **0.9%** | **150.0%** | | |
| last ten years | **70.2%** | **6.0%** | | | **17.8%** | **0.4%** | **−4.7%** | | |
| **China & Philippines average** | | | | | | | | | |
| first ten years | **12.3%** | **−328.2%** | | | **52.7%** | **1.4%** | **361.8%** | | |
| last ten years | **71.3%** | **6.8%** | | | **17.4%** | **0.6%** | **3.8%** | | |
| **Malaysia & Vietnam average** | | | | | | | | | |
| first ten years | **36.5%** | **19.2%** | | | **39.7%** | **0.6%** | **4.0%** | | |
| last ten years | **69.5%** | **5.4%** | | | **18.0%** | **0.2%** | **−10.6%** | | |

*Notes.* The results of growth accounting based on Eq. (40) are presented in which we again focus on the periods in which the likelihood of adopting foreign technology is not persistently less than 50%. In addition to the conventional TFP channel, we have an adoption barrier channel, two technology advancement channels through FDI conversion efficacy and foreign technology spillover, and two price channels through the relative price and the associated wedge of FDI. The averages are weighted by each economy's per capita GDP.

Table 6. GDP level and growth contribution of foreign investment technology

| | **mid 1970** | **late 70- -early 80** | **mid 1980** | **late 80- -early 90** | **mid 1990** | **late 90- -early 00** | **mid 2000** | **late 00- -early 10** | **mid 2010** |
|---|---|---|---|---|---|---|---|---|---|
| **China** | | | | | | | | | |
| Level contribution | | | | 66.8% | 74.0% | 76.5% | 77.9% | 79.7% | 81.8% |
| Growth contribution | | | | 81.9% | 74.3% | 71.7% | 63.8% | 61.9% | 64.5% |
| **Hong Kong** | | | | | | | | | |
| Level contribution | | | | | | 46.7% | 45.4% | 45.1% | 45.5% |
| Growth contribution | | | | | | 100.5% | 65.4% | 58.9% | 54.3% |
| **S. Korea** | | | | | | | | | |
| Level contribution | | | 86.3% | 89.1% | 90.2% | 90.3% | 90.0% | 90.0% | 90.2% |
| Growth contribution | | | 88.1% | 81.7% | 77.4% | 70.3% | 65.5% | 64.6% | 64.1% |
| **Malaysia** | | | | | | | | | |
| Level contribution | 61.3% | 70.5% | 74.4% | 75.1% | 74.8% | 74.8% | 75.0% | 75.4% | 75.8% |
| Growth contribution | 79.9% | 79.4% | 80.3% | 67.5% | 60.5% | 60.5% | 55.3% | 57.1% | 51.7% |
| **Philippines** | | | | | | | | | |
| Level contribution | | | | 66.9% | 74.1% | 76.6% | 78.0% | 79.6% | 80.5% |
| Growth contribution | | | | 83.2% | 84.5% | 82.0% | 75.6% | 74.1% | 64.6% |
| **Singapore** | | | | | | | | | |
| Level contribution | | | | 43.3% | 50.6% | 47.1% | 41.3% | 38.3% | 35.7% |
| Growth contribution | | | | 82.6% | 69.1% | 52.9% | 28.6% | 31.9% | 21.7% |
| **Taiwan** | | | | | | | | | |
| Level contribution | | | 84.1% | 87.8% | 89.3% | 89.6% | 89.5% | 89.5% | 89.5% |
| Growth contribution | | | 87.9% | 80.0% | 75.2% | 69.2% | 63.3% | 61.5% | 58.6% |
| **Vietnam** | | | | | | | | | |
| Level contribution | | | | 31.1% | 40.4% | 45.1% | 48.0% | 50.9% | 53.2% |
| Growth contribution | | | | 42.0% | 47.2% | 47.0% | 45.1% | 47.3% | 41.3% |

| | **first ten years** | **last ten years** |
|---|---|---|
| **Four Tigers average** | | |
| Level contribution | 66.7% | 65.5% |
| Growth contribution | 81.9% | 52.0% |
| **S. Korea & Taiwan average** | | |
| Level contribution | 86.8% | 89.8% |
| Growth contribution | 84.4% | 62.2% |
| **Hong Kong & Singapore average** | | |
| Level contribution | 46.5% | 41.2% |
| Growth contribution | 79.4% | 41.7% |
| | | |
| **Four non-Tigers average** | | |
| Level contribution | 60.6% | 72.1% |
| Growth contribution | 71.6% | 57.8% |
| **China & Philippines average** | | |
| Level contribution | 70.5% | 80.4% |
| Growth contribution | 81.0% | 66.3% |
| **Malaysia & Vietnam average** | | |
| Level contribution | 50.8% | 63.8% |
| Growth contribution | 62.1% | 49.4% |

*Notes.* The average per capita income level and growth gains for each five-year technological episode are presented. Again, for a valid comparison, we focus on the periods in which the likelihood of adopting foreign technology is not persistently less than 50%. The level contribution is computed by averaging $(y_t - y_t^C)/y_t$ over five years within each technological episode. For the growth contribution, we first compute the average annual growth rates of both $y_t$ and $y_t^C$ from the initial year until the end year of each technological episode, and then the use of them computes $(\triangle \ln y_t - \triangle \ln y_t^C)/\triangle \ln y_t$. The first and last ten-year averages are computed by simply averaging over economies in each group.

channel emphasized by Borensztein, De Gregorio, and Lee (1998). To address this issue, we now conduct a counterfactual analysis by comparing economic growth outcomes with and without foreign technology adoption.

When adopting foreign technology, it follows from Eq. (35) and $y_t = A_t z_{t-1}^{\beta}$ that

$$\ln y_t = \ln A_t + \beta \left[ \ln(\delta\beta) + \ln\theta_\tau + \alpha_2 \ln z_{t-2}^{*} + \alpha_1 \ln\left( \left( \frac{y_{t-1}}{A_{t-1}} \right)^{1/\beta} - \eta_\tau \right) - \ln n_t - \ln p_{t-1}^{*} \right], \tag{41}$$

and when adopting domestic technology, it follows from Proposition 2 that $z_{t-1}^{C} = (\delta\beta\Omega/n_t) A_{t-1} (z_{t-2}^{C})^{\beta}$, which is rewritten by using $y_t^C = A_t (z_{t-1}^C)^{\beta}$ as

$$\ln y_t^C = \ln A_t + \beta \left[ \ln(\delta\beta) + \ln\Omega + \ln y_{t-1}^C - \ln n_t \right], \tag{42}$$

where we label variables in the counterfactual scenario when adopting domestic technology with a superscript $C$. In what follows, we analyze both the GDP level and growth contributions of technology-embodied FDI. To do so, we first produce model-based time series of $y_t$ and $y_t^C$. We then measure the GDP level contribution by $(y_t - y_t^C)/y_t$ and the GDP growth contribution by $(\triangle \ln y_t - \triangle \ln y_t^C)/\triangle \ln y_t$.

A few remarks regarding the data used in the analysis are in order. First, for $p^*$ in Eq. (41), we use the actual world price of foreign investment goods relative to the price of domestic goods without the wedge, which better reflects the contribution of technology-embodied FDI. Second, since $\Omega$ is constant, it does not impact the GDP growth contribution but does influence the GDP level contribution. To measure the value of $\Omega$, we refer to Eq. (5), which is rewritten as $Z_t = \Omega I_t$ under the assumption that the economy employs only domestic technology. Aggregating $Z_t = \Omega I_t$ over the entire period, $\Xi$, under investigation, one can compute $\Omega = \sum_{t\in\Xi} Z_t / \sum_{t\in\Xi} I_t$. Third, we perform a counterfactual exercise given the same initial condition. That is, we set $y_0^C = y_0$ in the initial year under the counterfactual scenario.[8]

Table 6 presents the average per capita income level and growth gains for each five-year technological episode. Again, for a valid comparison, we focus on the periods in which the likelihood of adopting foreign technology is not persistently less than 50%, as shown in Section 5.3 above. The level contribution is computed by averaging $(y_t - y_t^C)/y_t$ over five years

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[8] Alternatively, one may remove foreign investment starting from the initial year by applying $y_0^C = y_0 - p_0 i_0^*$. The results of this counterfactual analysis are very similar to those obtained in the current exercise and are thus not reported for the sake of brevity.

within each technological episode. To obtain the growth contribution, we first compute the average annual growth rates of both $y_t$ and $y_t^C$ from the initial year until the end year of each technological episode. This enables us to compute $(\triangle \ln y_t - \triangle \ln y_t^C)/\triangle \ln y_t$. Accordingly, each figure entered in the rows marked "Growth contribution" indicates the average annual growth contribution over each technological episode.

The results indicate a significant role played by foreign technology adoption. Overall, the adoption of foreign investment technology exhibits prolonged growth effects. The level gains range from 31.1% (Vietnam in the late 1980s - the early 1990s) to 90.3% (S. Korea in the late 1990s - the early 2000s), larger in two larger Tigers (S. Korea and Taiwan) than other Asian countries. While the growth gains range from 21.7% (Singapore in the mid-2010s) to 100.5% (Hong Kong in the late 1990s - the early 2000s), those in two larger Tigers, China, and the Philippines record the greatest gains on average. Overall, the technology-embodied FDI contributes to 65.6% of economic growth in the Tigers and 64.6% in the less-developed Asian countries. The larger contribution of technology-embodied FDI echoes the emphasis by Borensztein, De Gregorio, and Lee (1998). Moreover, it confirms that foreign technology adoption serves as a flying propeller in these Asian economies.

## 6 Concluding Remarks

In this paper, we developed a dynamic general equilibrium model of FDI and endogenous foreign technology adoption that captures the host country's capability with a nonhomothetic minimum threshold, international technology spillover, and potential advantages from a favorable relative price of FDI. We established that a higher FDI conversion efficacy, a lower adoption barrier, or a higher international technology spillover, in conjunction with a lower relative price of FDI, can enable an economy to feature a flying geese paradigm with sustained growth. By calibrating the model to eight representative Asian economies and performing growth accounting, we found that while the TFP, the FDI conversion efficacy, and the foreign technology spillover account for Asian Tigers' growth miracle, the reduced adoption barrier and the favorable relative price of FDI are more important for driving the growth of less-developed Asian economies.

An immediate policy prescription is to provide high-quality institutions to mitigate foreign technology adoption barriers and to assure favorable relative price advantages for technology-embodied FDI. Such a policy can serve to attract FDI from more advanced countries with better technologies, thereby ensuring continual growth and avoiding middle-income traps.

Along these lines, some natural inquiries arise. Would human capital institutions interact with FDI-technology adoption institutions? If so, how and how significant would such interactive effects be? Additionally, to further advance a country's aggregate technology, how would research and development (R&D) activity complement FDI? Not only substantive generalization of the model but innovative strategies to calibrate the model are required to provide solid answers to these questions, which we leave to future work.

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## References

[1] Acemoglu, D., P. Aghion, and F. Zilibotti, 2006. Distance to frontier, selection, and economic growth. *Journal of European Economic Association* 4(1): 37–74.

[2] Akamatsu, K., 1962. A historical pattern of economic growth in developing countries. *The Developing Economies* 1 (March-August): 3–25.

[3] Alfaro, L., 2017. Gains from foreign direct investment: macro and micro approaches. *World Bank Economic Review* 30(1): S2–S15.

[4] Alfaro, L. and M.X. Chen, 2012. Surviving the global financial crisis: foreign ownership and establishment performance. *American Economic Journal: Economic Policy* 4(3): 30–55.

[5] Alviarez, V., J. Cravino, and N. Ramondo, 2019. Accounting for cross-country productivity differences: new evidence from multinational firms. 2019 Meeting Papers 1188, Society for Economic Dynamics.

[6] Azariadis, C. and A. Drazen, 1990. Threshold externalities in economic development. *Quarterly Jouranl of Economics* 105(2): 501–526.

[7] Bajgar, M. and B.S. Javorcik, 2020. Climbing the rungs of the quality ladder: FDI and domestic exporters in Romania. *Economic Journal* 130(628): 937–955.

[8] Barrell, R. and N. Pain, 1997. Foreign direct investment, technological change, and economic growth within Europe, *Economic Journal* 107(445): 1770–1786.

[9] Borensztein, E., J. De Gregorio, and J. W. Lee, 1998. How does foreign direct investment affect economic growth?. *Journal of International Economics* 45(1): 115–135.

[10] Buera, F. J. and E. Oberfield, 2020. The global diffusion of ideas. *Econometrica* 88(1): 83–114.

[11] Caselli, F. and W. J. Coleman, 2006. The world technology frontier. *American Economic Review* 96(3): 499–522.

[12] Eaton, J. and S. Kortum, 1999. International technology diffusion: theory and measurement. *International Economic Review* 40(3): 537–570.

[13] Feenstra, R.C., R. Inklaar, and M.P. Timmer, 2015. The next generation of the Penn World Table. *American Economic Review* 105 (10): 3150–3182.

[14] Fons-Rosen, C., S. Kalemli-Ozcan, B. Sorensen, C. Villegas-Sanchez, and V. Volosovych, 2021. Quantifying the productivity gains from foreign investment. *Journal of International Economics* 131 Article 03456.

[15] Gourinchas, P.O. and O. Jeanne, 2006. The elusive gains from international financial integration. *Review of Economic Studies* 73(3): 715–741.

[16] Harrison, A. and A. Rodríguez-Clare, 2010. Trade, foreign investment, and industrial policy for developing countries. In: Rodrik, D. and Rosenzweig, M.R., Eds., *Handbook of Development Economics* 4039–4214. Elsevier, Amsterdam.

[17] Hu, Y., T. Kunieda, K. Nishimura, and P. Wang, 2023. Flying or trapped?. *Economic Theory* 75(2): 341—388.

[18] Javorcik, B.S., 2004. Does foreign direct investment increase the productivity of domestic firms? In search of spillovers through backward linkage. *American Economic Review* 94 (3): 605–627.

[19] Javorcik, B.S., A.L. Turco, and D. Maggioni, 2018. New and improved: does FDI boost production complexity in host countries?. *Economic Journal* 128(614): 2507–2537.

[20] Ju, J., J.Y. Lin, and Y. Wang, 2015. Endowment structures, industrial dynamics, and economic growth. *Journal of Monetary Economics* 76: 244–263.

[21] Jude, C. and G. Levieuge, 2017. Growth effect of foreign direct investment in developing economies: The role of institutional quality. *World Economy* 40(4): 715–742.

[22] Keller, W., 2000. Do trade patterns and technology flows affect productivity growth? *World Bank Economic Review* 14(1): 17–47.

[23] Kunieda, T., K. Okada, Y. Sawada, and A. Shibata, 2021. On the two catching-up mechanisms in Asian development. *Asian Development Review* 38(2): 31–57.

[24] Perla, J., C. Tonetti, and M. Waugh, 2019. Equilibrium technology diffusion, trade, and growth. NBER Working Paper #20881.

[25] Prasad, E.S., R.G. Rajan, and A. Subramanian, 2007. Foreign capital and economic growth. *Brookings Papers on Economic Activity* 38(1): 153–230.

[26] Peters, M. and F. Zilibotti, 2021. Creative destruction, distance to frontier, and economic development. NBER Working Paper #29333.

[27] Romer, P.M., 1986. Increasing returns and long-run growth. *Journal of Political Economy* 94(5): 1002–1037.

[28] Vandenbussche, J., P. Aghion, and C. Meghir, 2006. Growth, distance to frontier and composition of human capital. *Journal of Economic Growth* 11(1): 97–127.

[29] Wang, P., T.-N. Wong, and C.K. Yip, 2018a. Mismatch and assimilation. NBER Working Paper #24960.

[30] Wang, P., T.-N. Wong, and C.K. Yip, 2018b. Institutional barriers and world income disparities, *Review*, FRB in St. Louis.

## Not-for-Publication Appendices

### Appendix A: Proof of Lemma 1

From Eqs. (2)-(6), if $\Gamma(\bar{z}_{s-1}, \bar{z}^*_{s-1}; \theta, \eta)/\bar{y}_s > p^*_s\Omega$, the representative agent optimally chooses the foreign investment technology, and if $\Gamma(\bar{z}_{s-1}, \bar{z}^*_{s-1}; \theta, \eta)/\bar{y}_s < p^*_s\Omega$ or the degenerate case with $\bar{z}_{s-1} < \eta$ occurs, she optimally chooses the domestic investment technology. Then, Eq. (9) holds. $\square$

### Appendix B: Proof of Proposition 1

From Eqs. (12) and (14), it follows that

$$\lambda_t A z^{\beta}_{t-1} = 1 + \lambda_t M_t n_{t+1} z_t. \tag{B.1}$$

Define $q_t := \lambda_t M_t n_{t+1} z_t$. Then, Eqs. (13) and (B.1) yield

$$q_t = \delta\beta q_{t+1} + \delta\beta. \tag{B.2}$$

From Eq. (B.2), we obtain

$$q_t = (\delta\beta)^s q_{t+s} + \delta\beta + (\delta\beta)^2 + \cdots + (\delta\beta)^s \tag{B.3}$$

for all $s \geq 0$. Because the transversality condition implies $\lim_{s\to\infty} (\delta\beta)^s q_{t+s} = 0$, Eq. (B.3) becomes

$$q_t = \lambda_t M_t n_{t+1} z_t = \frac{\delta\beta}{1-\delta\beta} \tag{B.4}$$

for all $t \geq 0$.

Combining Eq. (B.4) with Eq. (12) yields the relationship between $c_t$ and $z_t$ as follows:

$$(1-\delta\beta) M_t n_{t+1} z_t = \delta\beta c_t. \tag{B.5}$$

Applying (B.5) to substitute away $c_t$ from (14), we obtain a dynamical system of the model economy on $z_t$:

$$z_t = \frac{A\delta\beta}{M_t n_{t+1}} z_{t-1}^{\beta},$$

or, equivalently,

$$z_t = \frac{A\delta\beta}{\min\left\{\frac{1}{\Omega}, \frac{p_t^* y_t}{\Gamma(z_{t-1}, z_{t-1}^*; \theta, \eta)}\right\} n_{t+1}} z_{t-1}^{\beta}, \tag{B.6}$$

where we have used equilibrium conditions such that $z_{t-1} = \bar{z}_{t-1}$, $z_{t-1}^* = \bar{z}_{t-1}^*$, and $y_t = \bar{y}_t$. $\square$

## Appendix C: Proof of Lemma 2

Consider an equation for $x \geq 0$ such that $h^D(x) = h^F(x)$, which can be rewritten as

$$H(x) := x - \left(\frac{\Omega A p^*}{(z^*)^{\varsigma+\varepsilon}\theta}\right)^{\frac{1}{\sigma-\varepsilon}} x^{\frac{\beta}{\sigma-\varepsilon}} - \eta = 0. \tag{C.1}$$

By differentiating $H(x)$, we have

$$H'(x) = 1 - \frac{\beta}{\sigma-\varepsilon}\left(\frac{\Omega A p^*}{(z^*)^{\varsigma+\varepsilon}\theta}\right)^{\frac{1}{\sigma-\varepsilon}} x^{\frac{\beta-(\sigma-\varepsilon)}{\sigma-\varepsilon}}. \tag{C.2}$$

Note from Assumption 1 that $H'(x)$ is an increasing function with respect to $x$ with $\lim_{x\downarrow 0} H'(x) = -\infty$ and $\lim_{x\to\infty} H'(x) = 1$. Then, there exists an $\bar{x}$ such that $H'(\bar{x}) = 0$, $H'(x) < 0$ for $0 < x < \bar{x}$, and $H'(x) > 0$ for $\bar{x} < x$. Note also that $H(0) = -\eta < 0$ and $\lim_{x\to\infty} H(x) = \infty$. Therefore, there exists a unique positive solution for $h^D(x) = h^F(x)$. $\square$

## Appendix D: Data Description

Throughout the quantitative analysis, we draw all the data, except the FDI intensity, from Penn World Table 10.0 (PWT 10.0, Feenstra, Inklaar, and Timmer, 2015). To obtain the per worker output ($y$) and the per worker capital ($z$ and $z^*$), we use the real GDP at constant 2017 national prices (rgdpna), the capital stock at constant 2017 national prices (rnna), and the number of persons engaged (emp) in PWT 10.0. The world price of foreign investment goods relative to the price of domestic goods (see Section 5.3) is computed by using the "Price level of CGDPo (PPP/XR)" in PWT 10.0 (pl_gdpo). The number of persons engaged is also used to compute the labor growth rate (n). The data on the FDI intensity ($i^*/y$) are collected from UNCTAD STAT, where the database "Foreign direct investment: inward and outward flows and stock, annual" is contained in the folder of the balance of payments. We can directly obtain the data on "inward" for the FDI intensity from the database. To eliminate short-run fluctuations, we take the 3-year moving average of the per worker output, the per worker capital, the labor growth rate, and the relative world price of foreign investment goods. We take the 5-year moving average of the FDI intensity because its volatility is considerably higher than other variables. We then prepare the annual data for the Asian economies over the period 1973-2018, although the starting year for China is 1981 because of data availability on FDI intensity.

## Appendix E: Computing algorithm for $\theta_\tau$ and $\tilde{\eta}_\tau$

The computing algorithm for the calibration of $\theta_\tau$ and $\eta_\tau$ is as follows.

### Step 1

From the Bayesian estimation, we have the means and standard deviations of the posterior distributions of $\hat{\alpha}_1$ and $\hat{\gamma}_\tau$. We then perturb $\hat{\alpha}_1$ and $\hat{\gamma}_\tau$ around each mean by one standard deviation with the normal distribution and prepare the same size of $\hat{\alpha}_1$ and $\hat{\gamma}_\tau$ as that of the data observations, denoted as $\tilde{\alpha}_1$ and $\tilde{\gamma}_\tau$, respectively.

### Step 2

The Lagrangian for the minimization of the loss function is

$$\hat{\mathcal{L}}_t := \sum_{t \in T_\tau} \left[\ln \theta_\tau + \tilde{\alpha}_{1,t} \ln(1 - \tilde{\eta}_\tau) - \tilde{\gamma}_t\right]^2 + \mu \tilde{\eta}_\tau, \tag{E.1}$$

where $\mu$ is the Lagrange multiplier associated with inequality (32). The optimal solutions for $\theta_\tau$ and $\tilde{\eta}_\tau$ are obtained as in the following two cases depending upon whether the inequality constraint is binding.

### Case 1: No constraints binding

$$\theta_\tau = \exp\left(\frac{\sum_{t \in T_\tau} \tilde{\gamma}_t \cdot \sum_{t \in T_\tau} (\tilde{\alpha}_{1,t})^2 - \sum_{t \in T_\tau} \tilde{\alpha}_{1,t} \cdot \sum_{t \in T_\tau} (\tilde{\alpha}_{1,t} \tilde{\gamma}_t)}{m \cdot \sum_{t \in T_\tau} (\tilde{\alpha}_{1,t})^2 - (\sum_{t \in T_\tau} \tilde{\alpha}_{1,t})^2}\right) \tag{E.2}$$

and

$$\tilde{\eta}_\tau = 1 - \exp\left(\frac{-\sum_{t \in T_\tau} \tilde{\gamma}_t \cdot \sum_{t \in T_\tau} \tilde{\alpha}_{1,t} + m \cdot \sum_{t \in T_\tau} (\tilde{\alpha}_{1,t} \tilde{\gamma}_t)}{m \cdot \sum_{t \in T_\tau} (\tilde{\alpha}_{1,t})^2 - (\sum_{t \in T_\tau} \tilde{\alpha}_{1,t})^2}\right). \tag{E.3}$$

where $m = |T_\tau|$.

**Case 2: $\tilde{\eta}_\tau \geq 0$ binding**

$$\theta_\tau = \exp\left(\frac{1}{m}\sum_{t\in T_\tau}\tilde{\gamma}_t\right) \tag{E.4}$$

and

$$\tilde{\eta}_\tau = 0. \tag{E.5}$$

**Step 3**

By iterating Step 1 and Step 2 $100,000$ times, we obtain the $100,000$ sets of $(\theta_\tau, \tilde{\eta}_\tau)$ for the $\tau$th technology. Among the $100,000$ sets, there appear a few outliers of $\theta_\tau$ and $\tilde{\eta}_\tau$ that exhibit extremely high values. Although the number of such $\theta_\tau$ and $\tilde{\eta}_\tau$ is only a few relative to $100,000$, they often significantly bias $\theta_\tau$'s and $\tilde{\eta}_\tau$'s averages.[9] Thus, such outliers are trimmed as follows: if the values of $\theta_\tau$ and $\tilde{\eta}_\tau$ deviate more than three times their standard deviations from their means, we replace such values with the mean of their adjacent two values.

**Step 4**

$\theta_\tau$'s estimates are produced as $\hat{\theta}_\tau$ by taking the average of $100,000$ values of $\theta_\tau$. Furthermore, we couple $\tilde{\eta}_\tau$ and the randomly chosen $z_{t-1}$ from the set of capital stock in each technological interval and create $100,000$ values of $\tilde{\eta}_\tau z_{t-1}$. By taking the average of $\tilde{\eta}_\tau z_{t-1}$, the calibrated $\eta_\tau$'s are obtained.

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[9] In some cases depending upon economies, the presence of such outliers enlarges the average by more than the order of two digits.