The time path of productivity convergence and the international allocation of capital

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A R T I C L E   I N F O

A B S T R A C T

Can cross-country heterogeneity in the time path of technological convergence account for observed allocation of international capital? The time path of technological convergence varies significantly across countries, whereas previous studies assume a common cross-country convergence path and one that is linear. We show that the time path of a country's technological convergence has important implications for the predicted size of capital inflows from the rest of the world. Accounting for this observed heterogeneity accounts for around 20 percent of the puzzling allocation of capital across developing economies relative to neoclassical predictions, without the introduction of additional distortions common in the existing literature. Cross country differences in convergence paths are not powerful enough to account for capital outflows observed in particularly fast-growing Asian economies, but go a long way in explaining why the fastest developing and converging economies are not receiving capital inflows in the magnitude predicted by the standard neoclassical model.

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1. Introduction

The allocation of international capital throughout the developing world has received considerable attention in international macroeconomics. A particular focus has been on the challenges for the workhorse neoclassical model to account for the observed size and direction of capital flows (for example, Caballero et al., 2008; Gourinchas and Jeanne, 2013; Prasad et al., 2007; Lucas, 1990). The neoclassical open economy framework makes the robust prediction that, absent capital market frictions, international capital will flow to where it is more scarce and to where productivity growth is higher.

From the perspective of these robust predictions, a puzzle emerges with respect to the allocation of capital across developing economies: capital has not been observed to be flowing into the fastest growing developing economies in the magnitude that the neoclassical model would predict and some fast-growing economies have experienced capital outflows; this is the "Allocation Puzzle" as deemed by Gourinchas and Jeanne (2013). They consider a frontier region and that productivity in developing economies converges towards or away from the frontier productivity. They show that allowing for the observed extent of average convergence—average productivity growth in excess of the frontier economy—in a sample of developing countries from 1980 to 2000, capital tends to flow more into countries that are converging less over the sample period. They assume a common, linear time path of convergence, or that convergence is equally distributed over time. We confirm their findings, but provide a channel, measured directly from the productivity convergence paths that can explain a reduction in

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the magnitude of capital flows observed empirically. We do so by accounting for the heterogeneity in convergence paths across countries.

In order to fix ideas, we consider the time path of convergence as the allocation of convergence over time. Whereas an average convergence would reflect whether, on average, an economy is growing faster or more slowly relative to the frontier. We are concerned with the transitional path over time. Said differently, if the growth rate is the rate of change of productivity over time, we are concerned with the acceleration of productivity. We consider the implications of this feature of the transition in the context of the standard neoclassical model, using the framework introduced in Gourinchas and Jeanne (2013), and derive the predictions for the size of capital flows between the developing world and the frontier. The main intuition follows from the fact that countries converging more quickly at the beginning of transition must finance consumption and investment in excess of current income for a shorter period of time, which operates through the current income catching up more quickly to permanent income. Thus, for countries exhibiting identical average growth rates of productivity over time, the country converging more quickly initially may indeed be experiencing a lower level of capital inflows relative to their counterpart with more protracted convergence dynamics. The time path of productivity convergence has important implications for the workhorse model's predictions for capital flows.

Our results indicate that when one considers cross country differences in time paths of convergence, the puzzling allocation of capital is diminished by about 20 percent. We provide a partial explanation for the allocation of capital that relies solely on differences in productivity convergence paths that can be measured directly from the data. Our mechanism affects how income is allocated through time in the economy in response to persistent productivity growth, meaning it operates via the savings behavior of agents, which is consistent with the main channel of the allocation puzzle (Gourinchas and Jeanne, 2013; Rothert, 2016).

This work contributes to the literature on the allocation puzzle along two main dimensions. First, several papers have documented that the most robust features of allocation puzzle go beyond the negative correlation between capital inflows and productivity growth. Gourinchas and Jeanne (2013) show through introducing wedges affecting saving and investment behavior, that a tax on saving is highly negatively correlated with productivity growth, and accounts for nearly all of the allocation puzzle. Rothert (2016) show that the negative correlation between productivity growth and capital inflows driven by the size of capital flows, rather than the direction. When six outliers, including several, albeit important, fast-growing Asian economies are removed, the correlation becomes positive. Importantly, the puzzling behavior of savings remains: after removal of the outliers, there is still a strong negative relationship between the tax on savings and productivity growth. The mechanism we propose is data-driven and operates directly through the savings channel of foreign debt accumulation during convergence. It is also robust to the exclusion of the six outliers driving the negative correlation between productivity convergence and capital inflows.

Second, the lack of robust cross-country evidence on the negative correlation is likely the result of the different correlations with public and private flows and productivity growth (Laura Alfaro et al., 2014; Gourinchas and Jeanne, 2013). Laura Alfaro et al. (2014) in a careful empirical exercise, find that private inflows are positively correlated with productivity growth, whereas it is official or public flows are negatively correlated with productivity growth. So the negative correlation in the data, must consider the role for official reserve accumulation or sovereign to sovereign flows. An open question remains as to why public flows are not offset by private flows. We provide an explanation for why the size of private capital flows might not offset public flows despite productivity convergence, without resorting to frictions on private flows.[1] This last point is particularly important, given that Gourinchas and Jeanne (2013) find the allocation puzzle is strongest for the most financially integrated economies.

Most explanations of the allocation puzzle place some friction on private capital flows, operating through financial underdevelopment or explicit restrictions on access to international capital markets by private households. Aguiar and Amador (2011) incorporate expropriation and default risk through political economy frictions in an open economy neoclassical model. The model can account for public capital outflows during productivity growth observed in the data, as the external assets act as collateral to foreign investors, but the interaction between public and private flows are not assessed, as domestic households are completely restricted from accessing international capital markets.

Various other forms of frictions are also put forth. If growth is positively correlated with idiosyncratic risk, financial underdevelopment that prevents the intermediation of risk can generate a negative relationship between growth and capital inflows (Benhima, 2013; Mendoza et al., 2009). Benhima (2013) takes a portfolio view in a model with uninsurable idiosyncratic risk, trade in bonds, and a distortion on the return to capital for investors. They show that a positive correlation between growth and capital outflows absent a capital wedge is present only for countries with a positive long run external position due to a portfolio growth effect. They argue that the capital wedge is the main driver of the allocation puzzle, since the positive correlation between outflows and productivity growth can be replicated independent of the long run external position. This paper offers a complementary explanation of the allocation puzzle once one relaxes the perfect substitutability between foreign and domestic capital present in the neoclassical model. Our focus is different, in that it focuses on private savings behavior of households and can generate a positive correlation between productivity growth and private capital inflows.

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[1] I thank an anonymous referee for making this point.

Coeurdacier et al. (2015) provide an explanation of the allocation puzzle that operates through a savings channel and accounts for intergenerational borrowing and differences in borrowing constraints between regions. They move beyond the small open economy neoclassical framework and study general equilibrium effects from a drop in the world interest rate due to the growing size of the developing region. Capital outflows emerge together with productivity growth when demographics generate an income effect of the middle aged cohort that dominates the increased borrowing of the young. This paper is important in understanding why faster growing Asian economies, particularly China, are not receiving capital inflows, despite growth and provides a novel explanation of the savings channel of the allocation puzzle. It's main focus is different than ours, as it is motivated by diverging savings rates, low interest rates, and capital outflows from fast-growing developing Asian economies. The broader cross-country evidence in support of the main mechanism to account of the allocation puzzle is not the main focus of the paper.

Other explanations considered introduce frictions that prevent the efficient allocation of capital within economies to the most productive firms (Song et al., 2011; Bacchetta and Benhima, 2015), and frictions in the formation of expectations (Cozzi and Davenport, 2017). To our knowledge, we are the first to consider the role of observed convergence paths on predicted capital flows in the workhorse neoclassical growth model. The novel channel proposed here can be viewed as an important and complementary starting point in allowing the neoclassical small open economy model to go as far as possible in describing the data, before amending its main assumptions.

The paper proceeds as follows. In the following section, we present motivating evidence for the research. Thereafter, the model is introduced together and first theoretical results are presented. In the next section, we present a quantitative exercise that brings our theory to the data. Finally, we carry out several robustness checks to our results. The final section concludes.

2. Motivating evidence

The workhorse open economy neoclassical model provides clear predictions for the size and the direction of capital flows with respect to persistent productivity changes over time. Productivity growth in excess of the frontier economy results in higher future income and a higher marginal product of capital. Thus, unconstrained, forward looking agents should increase consumption and investment in excess of current income and, absent capital market frictions, this should be supported by international borrowing, or capital inflows. For productivity growth below the frontier, a symmetric argument results in slower growth being associated with capital outflows.

As documented by Gourinchas and Jeanne (2013) there is evidence of a negative relationship between economic growth and accumulated capital inflows as a ratio to GDP shown in Fig. 1. This figure shows the relationship from 1980 to 2000 for a sample of 68 non-OECD countries.[2] The negative relationship is mainly driven by a group of outliers in the bottom right quadrant (Rothert, 2016). Removal of these outliers results in a positive slope of 0.70 that is significant at the 1 percent level. As will become clear, capital is not flowing into or out of developing economies in the order of magnitude predicted by the standard model. Such a model would predict that diverging countries would experience capital outflows and converging economies would experience inflows (the data points would be present in the first and third quadrants). Thus, there is essentially a lack of magnitude of observed capital flows than that which would be consistent with predictions from the standard model. This fact motivates the study of factors that limit the size of capital flows relative to the standard predictions of the neoclassical growth model.[3]

The exposition of total productivity convergence in Fig. 1 masks considerable cross-country variation in the path of convergence. The productivity parameter represented in Fig. 1 contains information on the average productivity growth in the economy relative to the frontier, calibrated to the United States, over the sample period. The time path of this variable then indicates how growth is allocated over time. A linear time path for convergence assumes that the convergence is equally distributed over time, i.e., there is a constant average change in relative convergence (divergence). A time path that deviates from a linear path reflects the extent to which the allocation of the productivity catch-up differs over time—occurs more towards the beginning of convergence or more later on.

Fig. 2 shows the time paths for a selection of 11 countries in the sample over 1980 to 2000. What is clear is that countries vary significantly in how the convergence or divergence is distributed over the sample period. Some countries experience larger changes towards the beginning, whereas others experience larger changes in relative productivity growth toward the end of the sample period. This non-linear convergence path is in stark contrast to the linear convergence shown in the solid, black line. Fig. 6 in the appendix shows the time paths relative to the linear path averaged across countries in our sample. It reflects the fact that most countries exhibit time paths above the linear path with larger changes toward the beginning of the transition.

The current paper considers this observed cross-country variation in convergence paths and determines how equilibrium capital flows are impacted in the standard neoclassical growth model.

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[2] The slope of the line shown in the graph is −1.40 and is significant at the 1 percent level.

[3] This point is also made by Rothert (2016) who shows that the allocation puzzle is driven by a lack of magnitude, rather than a direction of capital flows.
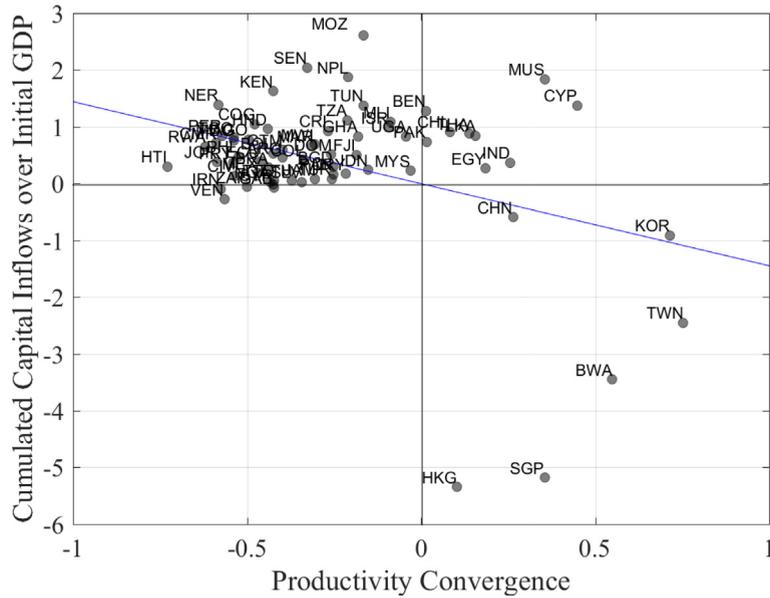
Fig. 1. Cumulated capital inflows and productivity convergence. The figure depicts the correlation between productivity convergence on the x-axis and the cumulated capital inflows over GDP on the y-axis. Productivity convergence is a derived measure, π_t, from Eq. (10), which reflects the total cumulated growth in productivity for the country depicted, relative to the US over the period 1980 to 2000. A positive value of convergence reflects catching up to the frontier, whereas a negative value reflects divergence. Cumulated capital flows are measured as the change in net external debt position from 1980 to 2000 divided by initial GDP in 1980. The derivation of this measure is shown in Section 3.4. The slope of the linear fit line is -1.40 and is significant at the 1 percent level. Source: author's calculation based on data from PWT 9.0 and External Wealth of Nations, Mark II (Lane and Milesi-Ferretti, 2007).
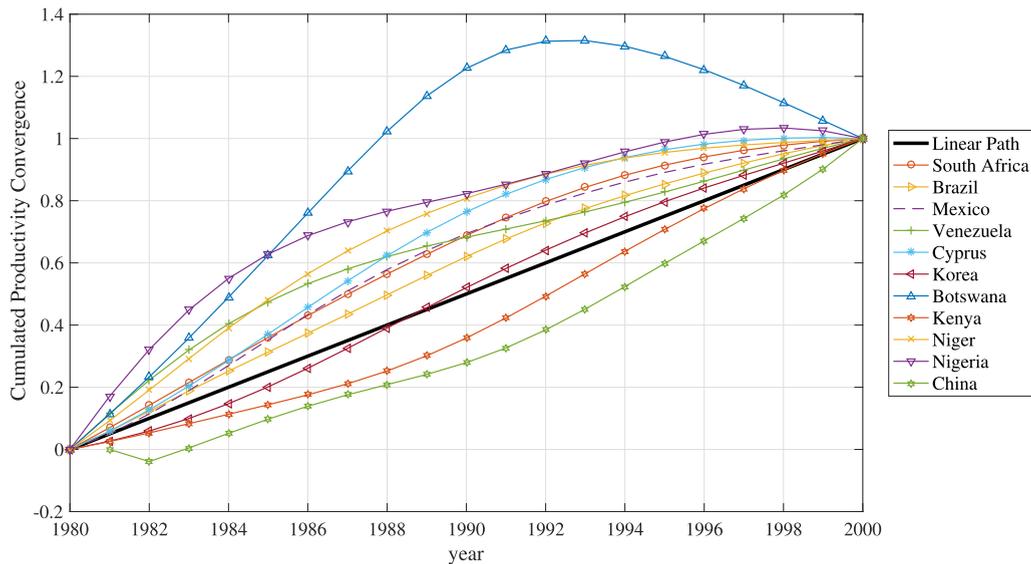

Fig. 2. The time path of productivity convergence. The figure depicts the time path for productivity convergence parameter for a selection of economies from 1980 to 2000. The time path is taken from Eq. (14), $\Psi_t = \pi_t/\pi_{2000}$, where π_t is a measure of productivity growth relative to the US, and π_{2000} is the value of the productivity parameter in the year 2000. The concept is introduced in detail in Section 3.4. A linear path of convergence is shown in the solid, black line. Source: author's calculations based on data. from PWT 9.0..

3. Model

In order to make the role of the time path of technological convergence more transparent, we begin with the neoclassical small open economy (SOE) model with productivity convergence as in Gourinchas and Jeanne (2013). We examine this economy over T periods in which convergence (divergence) occurs and derive analytical solutions for accumulated foreign debt over those periods.

3.1. Production

Firms in the soe model produce a single good, with world price P normalized to 1, according to a Cobb-Douglas production technology

$$Y_t = K_t^\alpha (A_t L_t)^{1-\alpha}, \tag{1}$$

where K_t is aggregate capital stock, A_t is a labor augmenting productivity parameter, L_t is aggregate labor supply and α is the elasticity of output with respect to capital.

Domestic capital and labor markets are perfectly competitive and factors are paid their marginal products,

$$mpk_t = \alpha \tilde{k}_t^{\alpha-1} \tag{2}$$
$$w_t = (1-\alpha)\tilde{k}_t^\alpha A_t \tag{3}$$

where $\tilde{k}_t = \frac{K_t}{A_t L_t}$ is capital stock per effective unit of labor, mpk_t is the marginal product of capital and w_t is the wage rate paid to households in each period.

3.2. Households

The economy is populated by measure L_t of identical households, with a representative household with lifetime utility

$$\sum_{s=0}^\infty \beta^s L_{t+s} u(c_{t+s}). \tag{4}$$

The population grows at an exogenous, constant gross rate n. We assume standard CES utility with parameter γ.

Households rent capital to firms and provide one unit of labor inelastically to firms. Households maximize utility with respect to consumption, subject to the flow per capita budget constraint given by

$$nd_{t+1} = R_t d_t + c_t + i_t - y_t, \tag{5}$$

where d_t is per capita debt at the beginning of period t, R_t is the gross rate at which households can borrow, c_t is per capita consumption, y_t is per capita income and i_t is investment per capita.

Households can save domestically in the physical capital stock, k_t or in foreign assets $-d_t$, with the law of motion for per capita capital stock

$$nk_{t+1} = i_t + (1-\delta)k_t, \tag{6}$$

where δ is the depreciation rate of physical capital.

In the neoclassical model, there are no impediments to the free flow of capital, such that the gross rate at which household borrow from international capital markets equals the gross rate of return, net of depreciation, on domestic capital stock, $R_t = \alpha k_t^{\alpha-1} A_t^{1-\alpha} + (1-\delta)$.

This, together with the assumptions of a Cobb-Douglas production and a representative household allows us to write the per capita flow budget constraint as follows

$$c_t + n(k_{t+1} - d_{t+1}) = R_t(k_t - d_t) + w_t, \tag{7}$$

where the wage w_t is the perfectly competitive wage rate paid by firms given in Eq. 3.

The equilibrium condition that takes perfect capital mobility into account is Euler equation describing optimal consumption growth:

$$c_t^{-\gamma} = c_{t+1}^{-\gamma} \beta R_{t+1} \tag{8}$$

Given the assumption of perfect capital mobility, one can consider a single Euler equation governing optimal consumption growth Eq. (8) and the condition $R_t = \alpha k_t^{\alpha-1} A_t^{1-\alpha} + (1-\delta)$.

3.3. The frontier

The rest of the world (row) is assumed to grow along a balanced growth path, with constant growth g^*.

Constant per capita consumption growth implies an interest rate along the balanced growth path of $R^* = g^{*\gamma}/\beta$. From the first order conditions of the household problem, Eq. (8), the steady state level of capital per efficient units of labor is,

$$\tilde{k}^* = \left(\frac{\alpha}{R^* - (1-\delta)}\right)^{1/1-\alpha}.$$

3.4. Productivity and convergence

We consider an SOE that experiences a transitional path over T periods, after which the economy grows along a balanced growth path with growth factor g^*. The balanced growth rate is equal to that of the frontier, but there is conditional convergence and the levels of productivity may differ and support a different steady state capital per effective unit of labor.

Assumption 1. Convergence begins at the beginning of period 1 and ends at the beginning of period T. Productivity growth g_t differs over the course of productivity convergence.The labor augmenting level of productivity evolves according to:

$$
\begin{aligned}
A_t &= g_t A_{t-1} \quad & for\ t = 1, 2, \ldots, T-1, \\
A_t &= g^* A_{t-1} \quad & for\ t \geqslant T,
\end{aligned}
\tag{9}
$$

$A_0 > 0$ given.

The highest level of productivity available at each time t is represented as A_t^*, the level of productivity in the frontier. As in Gourinchas and Jeanne (2013) define a convergence variable, π_t:

$$
\pi_t \equiv \frac{A_t}{A_0 g^{*t}} - 1.
\tag{10}
$$

This convergence parameter contains full information on the relative distance of the developing economy's productivity to the frontier. A country growing in excess of the frontier ($\pi_t > 0$) will be converging and a country growing more slowly will be diverging ($\pi_t < 0$). It is easy to show that the convergence variable is also equivalent to $(A_t/A_t^*)/(A_0/A_0^*) - 1$.

Given our assumption of productivity growth in Eq. (9), in period T, the convergence parameter will equal the constant $\bar{\pi}$ that reflects the extent of convergence or divergence that takes place over T periods. The transitional path for π_t will contain relevant information on the time allocation of convergence or divergence from frontier. In order to fix ideas, we assume that a transitional path to the constant $\bar{\pi}$ takes the form:

$$
\pi_t = \psi_t \pi_{t-1} + (1 - \psi_t)\bar{\pi} \quad for\ t = 1, 2, \ldots, T-1
\tag{11}
$$

$$
\pi_t = \bar{\pi} \quad\quad\quad for\ t \geqslant T.
\tag{12}
$$

where π_0 given and ψ_t is restricted to be a finite number.

To capture a more flexible form for productivity catch-up, we define a measure of speed of convergence at some point in time t:

$$
\psi_t \equiv \frac{(\pi_t - \bar{\pi})}{(\pi_{t-1} - \bar{\pi})}.
\tag{13}
$$

This definition of speed of convergence indicates how much of the distance from the convergence parameter is closed in each period.

A lower convergence parameter ψ_t increases the weight placed on fixed parameter, $\bar{\pi}$ and the change in the convergence is larger. The value of the time varying auto-regressive parameter ψ_t will determine whether a country is converging faster during initial stages of convergence or later.

It will become useful later to rewrite the convergence parameter during convergence,

$$
\pi_t = \bar{\pi} \sum_{s=1}^{t} (1 - \psi_s) \prod_{i=s+1}^{t} \psi_i = \left(1 - \prod_{s=1}^{t} \psi_s \right) \bar{\pi} \equiv \Psi_t \bar{\pi}.
\tag{14}
$$

3.5. Capital flows during productivity convergence

At the beginning of time in period 0 the SOE opens. Absent international capital market imperfections, there is an immediate adjustment of the physical capital per efficiency units from $\tilde{k}_0$ to $\tilde{k}^*$, reflective of the adjustment of the autarky rate of return to capital to the rate of return of the frontier. At the beginning of period $t = 1$, the economy begins productivity convergence to the parameter $\bar{\pi}$, reflecting productivity growth in Eq. (9). Upon opening, consumption growth in the SOE is reflected in the Euler equation:

$$
c_t^{-\gamma} = c_{t+1}^{-\gamma} \beta R^*,
\tag{15}
$$

which implies consumption per capita in the economy will grow by a factor equal to technological growth in the frontier g^*. This equation is derived from Eq. (8) after the initial capital scarcity adjustment such that $R_t = R^*$ for all $t = 1, 2, \ldots, T$.

As a starting point, we derive the expression for the cumulative debt over GDP from periods 0 to T from Gourinchas and Jeanne (2013) using the more general time path for convergence:

$$\frac{\Delta D}{Y_0} = \frac{(\tilde{k}^* - \tilde{k}_0)}{\tilde{y}_0}(ng^*)^T + \frac{\tilde{d}_0}{\tilde{y}_0}\left((ng^*)^T - 1\right) + \bar{\pi}\frac{\tilde{k}^*}{\tilde{y}_0}(ng^*)^T$$
$$+ \bar{\pi}\frac{\tilde{w}}{\tilde{y}_0}\frac{(ng^*)^T}{R^*}\sum_{s=0}^{T-1}\left(\frac{ng^*}{R^*}\right)^s(1 - \Psi_s), \tag{16}$$

where, $\tilde{k}_0, \tilde{d}_0$ and $\tilde{y}_0$ are capital, external debt and output per efficient unit of labor in period zero, $\tilde{w} = w_t/A_t = (1 - \alpha)\tilde{y}$ is the wage per effective unit of labor after opening in period zero. For clarification, the term ΔD in Eq. (16) and all subsequent equations is used to denote the cumulative debt during convergence from period 0 to period T.

The total cumulated external debt over initial GDP is comprised of four channels. External debt is increasing in the initial capital scarcity of the economy through a capital scarcity channel (first term). In the second term characterizing an initial debt channel, total cumulated external debt over initial GDP is increasing in initial debt to GDP ratio with a positive frontier growth $g^* > 0$. The first two channels are discussed thoroughly in Gourinchas and Jeanne (2013). They account for initial capital scarcity and the fact that initial debt may increase with productivity growth along a balanced growth path. They are not the source of the allocation puzzle and do not relate to the productivity convergence.

We focus on the two channels that are a function of both the convergence parameter, $\bar{\pi}$ and the time path of convergence $(1 - \Psi_t)$. First, the investment channel

$$\frac{\Delta D^I}{Y_0} = \bar{\pi}\frac{\tilde{k}^*}{\tilde{y}_0}(ng^*)^T \tag{17}$$

is increasing in the convergence parameter $\bar{\pi}$ for positive frontier growth $g^* > 0$. This reflects the higher level of investment in the domestic capital stock per capita with productivity growth in excess of the frontier. Upon opening, the capital stock per efficient units of labor is equal to that of the frontier: $\tilde{k}^* = \tilde{k}_t \forall t \geqslant 0$. If productivity in the SOE is greater than the frontier, investment in the domestic capital stock will need to be higher such that the condition holds. Second, the savings channel,

$$\frac{\Delta D^S}{Y_0} = \bar{\pi}\frac{\tilde{w}}{\tilde{y}_0}\frac{(ng^*)^T}{R^*}\sum_{s=0}^{T-1}\left(\frac{ng^*}{R^*}\right)^s(1 - \Psi_s), \tag{18}$$

is increasing in $\bar{\pi}$, but only if $\sum_{s=0}^{T-1}\left(\frac{ng^*}{R^*}\right)^s(\Psi_s) < \sum_{s=0}^{T-1}\left(\frac{ng^*}{R^*}\right)^s$. If this condition holds, a higher productivity convergence increases future income and an unconstrained household will borrow to increase consumption.[4] For a diverging economy, the economy will wish to save (accumulate external assets) due to the fact that current income exceeds permanent income. As we will see in Proposition 2 below, this effect is decreasing in the time path of productivity convergence.

Assumption 2. The convergence parameter follows a monotonic function for $t = 1, 2, \ldots T - 1$:

for $\bar{\pi} > 0$: $0 \leqslant \pi_{t-1} < \pi_t < \bar{\pi}$
for $\bar{\pi} < 0$: $\bar{\pi} < \pi_t < \pi_{t-1} \leqslant 0$.

This assumption gives us a bounded convergence parameter: $\psi_t \in (0, 1)$. By construction, this assumption also prevents the time path of convergence from reversing the direction of the relationship between convergence and capital flows. In Fig. 1, and as we will see in our quantitative results, there are developing economies that experience non-monotonic convergence, so that whether the sign can be reversed with non-monotonic transitional paths becomes an empirical question that is explored in Section 4.

Proposition 1. Given the result in Eq. (16), Assumptions 1 and 2, and positive frontier growth, $g^* > 0$ the magnitude of the ratio of accumulated external debt to initial output is increasing in productivity convergence $\bar{\pi}$.

Proof. The partial derivative of the change in external debt over initial GDP in the small open economy with respect to the convergence parameter $\bar{\pi}$ is:

$$\frac{\partial \Delta D/Y_0}{\partial \bar{\pi}} = \frac{\tilde{k}^*}{\tilde{y}_0}(ng^*)^T + \frac{\tilde{w}}{\tilde{y}_0}\frac{(ng^*)^T}{R^*}\sum_{s=0}^{T-1}\frac{ng^{*s}}{R^*}(1 - \Psi_s). \tag{19}$$

With the assumption of positive trend growth, $\frac{\tilde{k}^*}{\tilde{y}_0}(ng^*)^T > 0$. The second term is greater than or equal to zero if:

$$\sum_{t=0}^{T-1}\frac{ng^{*t}}{R^*}(1 - \Psi_t) \geqslant 0 \Rightarrow \sum_{t=0}^{T-1}\frac{ng^{*t}}{R^*} \geqslant \sum_{s=0}^{T-1}\frac{ng^{*s}}{R^*}(\Psi_s). \tag{20}$$

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[4] The only difference between Eq. (16) and Eq. 2.11 in Gourinchas and Jeanne (2013) is the term $(1 - \Psi_s)$ in the fourth term (the Savings Channel). This term incorporates the flexibility our definition for the speed of convergence given in Eq. (13) and will allow us to map difference convergence speeds, and time paths of convergence into model predictions for cumulative debt during convergence.

Where Eq. (14) can be rewritten as:

$$\Psi_t = \left(1 - \prod_{s=1}^{s=t} \psi_s\right). \tag{21}$$

The term $\Psi_t \leq 1 \forall t$ given Assumption 2 of monotonicity, which ensures that $\psi_t \in (0,1) \forall t$.

As long as countries are converging or diverging monotonically over time, the neoclassical model predicts that external debt accumulation and capital inflows are increasing in the extent of productivity convergence. However, if Assumption 2 does not hold and the convergence parameter along the path exceeds that of $\bar{\pi}$ to a large enough extent, this could result in a reversal of the neoclassical model's predictions of the sign of this relationship. We test this empirically in the quantitative exercise in Section 4.2.

Proposition 2. Given the result in Eq. (16) and Assumption 2 external debt accumulation is decreasing in the time path of convergence. The magnitude of the decline is reduced over time. This effect enters via the Savings Channel.

Proof. See appendix.

The time path of convergence or Ψ_t is decreasing in larger values of ψ_t, which lowers the convergence speed at time t. Thus, economies that are converging more quickly, will have larger values of Ψ_t and the model predicts less external debt accumulation. This is due to the fact that the economy will catch up more quickly to future income, requiring fewer periods for which the level of consumption necessitates external borrowing. The effect of convergence is diminished over time by two factors. First, future income is discounted by factor $\frac{ng^*}{R^*} < 1$[5], so that larger values of Ψ_t towards the end of the convergence period are discounted over a greater number of periods. Second, faster convergence (a lower ψ_t) towards the beginning of the period, will be compounded over a greater number of periods. This last effect can be seen by rewriting the Savings Channel as:

$$\bar{\pi} \frac{\tilde{w}}{\bar{y}_0} \frac{(ng^*)^T}{R^*} \sum_{s=0}^{T-1} \left(\frac{ng^*}{R^*}\right)^s \prod_{i=1}^s \psi_i.$$

Given the monotonicity assumption, for an economy converging more quickly towards the beginning of transition, the time path for convergence, Ψ_t will be everywhere above a linear time path. Conversely, an economy converging more slowly at the beginning of transition will be characterized by a time path for Ψ_t that is every where below a linear time path. Thus, we can regard fast convergence as exhibiting a more concave time path and more protracted convergence as exhibiting more convex time path.

Figs. 3 and 4 provide an illustration of the effect of the time paths of convergence on the Savings Channel in Eq. (16). Panel (a) depicts the term $1 - \Psi_t$ over time for a case with concave convergence path in the blue, dashed line and the same for a convex convergence path in the dotted, red line. The linear convergence path is depicted in the solid gray line. It is clear that the path is everywhere above (below) the linear path for the convex (concave) paths. The last term in the Savings Channel in Eq. (16), is approximated in Panel (b) as the area under the curves. Here the effect of discounting is seen clearly. The area under the blue, dashed curve is less than that of the red, dotted curve, but the differences between the two curves diminishes over time. This is reflected in Fig. 4, which depicts the differences in the two curves in Panel (b) in Fig. 3 from a linear path over T periods.

Corollary 1. A small open economy exhibiting a strictly concave (strictly convex) time path of convergence variable Ψ_t accumulates less (more) external debt relative to a small open economy assumed to have a linear convergence path.

Proof. See appendix.

Corollary 1 predicts that developing small open economies that are converging on a non-linear, concave time path will accumulate less external debt than those converging along a linear time path. Are the observed cross country differences in convergence paths in our Stylized Facts in Fig. 2 powerful enough to significantly change the neoclassical model's prediction for capital flows during convergence? We determine this in the quantitative exercises that follow.

4. Quantitative exercise

In the quantitative exercises that follow, for a sample of 67 developing economies, we measure the impact of not only the extent of convergence or divergence embodied in the parameter $\bar{\pi}$ but also the time path of the transition, embodied in Ψ_t directly from the data. Using these measures, we simulate the model introduced in the previous section for both measured time paths Ψ_t and assuming a linear time path of convergence. We compare the main simulation results and determine if the introduction of non-linear, data-driven time paths of convergence makes a significant difference in the predicted level of accumulated external debt.

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[5] This is the condition for finite utility of the representative household maximization problem.
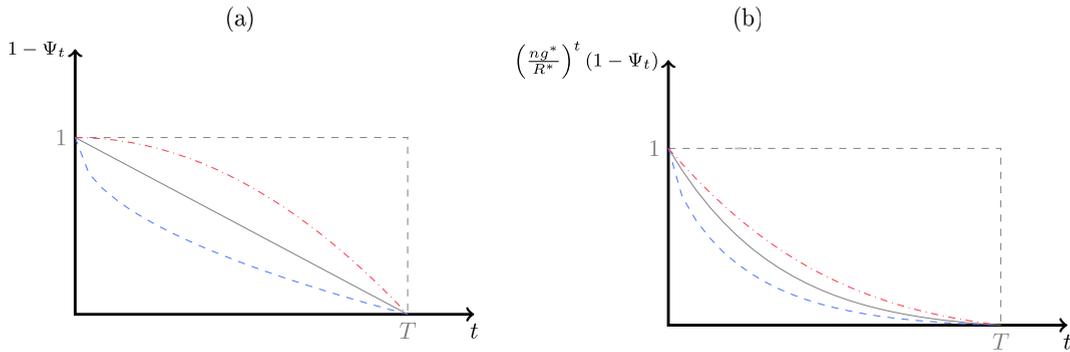
Fig. 3. Convergence Paths, graphical illustration. The figure depicts the term $1 - \Psi_t$ in Panel (a) and the term $\left(\frac{ng^*}{R^*}\right)^t (1 - \Psi_t)$ in Panel (b). An assumed linear convergence path is depicted in the solid, gray line. A concave convergence path is shown in the dashed, blue line and a convex path in the dotted, red line. Source: Author's calculations..
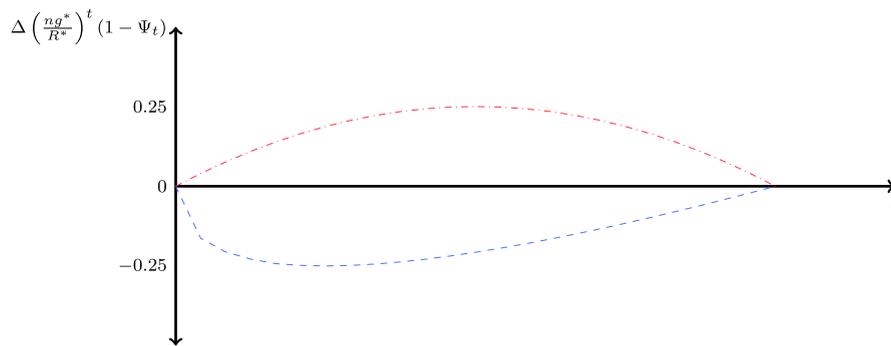

Fig. 4. Difference in convergence paths, relative to linear convergence. The figure depicts the difference between linear path and convex and concave paths in the dotted red and dashed blue lines, respectively..

4.1. Calibration

Labor augmenting productivity is derived using an approach common in growth and development accounting literature (Hsieh and Klenow, 2010; Caselli, 2005). Namely, from our production function in Eq. (1) the labor augmenting productivity is:

$$A_t = \left(\frac{y_t}{k_t^\alpha}\right)^{1/1-\alpha}, \tag{22}$$

where y_t and k_t are real GDP and capital stock per employed labor from PWT 9.0. Our measure for productivity is the trend component of A_t, estimated using a Hodrick-Prescott filter.[6] The growth rate of the frontier is proxied by the average growth rate of trend productivity in the United States of 1.02 from 1980 to 2000: $g^* = \exp\left(\ln\left(\frac{\overline{A}^*_{2000}}{\overline{A}^*_{1980}}\right)/(2000 - 1980)\right)$.

Equipped with a time series for trend productivity across countries, $\overline{A}_t$ and growth rate of the frontier, g^*, we can calculate the convergence parameter $\bar{\pi}$ or the value of π_t in year 2000 across countries using Eq. (10).

Next, we find values for the time series of π_t from Eq. (10) and generate a time series for Ψ_t the time path of convergence from Eq. (14), assuming an initial value of $\pi_0 = 0$.

The world interest rate, $r^* = R^* - 1$ is taken as the interest rate along a balanced growth path. From Eq. (15) and assuming that all variables grow at exogenous rate g^* along the balanced growth path, we have that $r^* = (g^*)^\gamma/\beta - 1$. Considering the frontier growth of 1.02, a CRRA parameter of one, and assuming a subjective discount factor in the utility function of $\beta = 0.96$, this gives us a world interest rate of 6.25 percent, which is slightly lower than the long-run average return on capital markets as measured for developing countries of 6.9 percent (Caselli and Feyrer, 2007).

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[6] We use a smoothing parameter of $\lambda = 100$ but our results also hold for other recommended parameter values for use on annual data, 6.25 and 38. In Section 5.1, we show results assuming a smoother time trend with parameter $\lambda = 1600$.

The remaining parameters are taken from standard values in the literature. We assume a positive rate of depreciation of 6 percent, a capital share of $\alpha = 0.3$ and an inverse elasticity of substitution parameter, $\gamma = 1$.[7] All parameter values used in the simulation exercise are shown in Table 1.

For each country in our sample, the change in debt over initial GDP is calculated using data from the External Wealth of Nations (EWN) database (Lane and Milesi-Ferretti, 2007). We take the negative of the initial net international investment position in 1980 as the initial debt position of country i, D_0^i. To abstract from valuation effects over productivity convergence, which we do not model explicitly, we subtract cumulated current accounts as subsequent capital inflows to the initial debt position to generate the ending debt position D_T^i and divide by initial GDP in 1980 taken from PWT 9.0 data. This generates the cumulated debt over initial GDP from period 0 to T:

$$\frac{D_T}{Y_0} = \frac{D_0^i - \sum_{t=1}^{T} CA_t^i}{Y_0}. \tag{23}$$

A more detailed presentation of the construction of this variable and our other main variables is given in Appendix B.

4.2. Results

As we have shown analytically in Section 3, the standard neoclassical SOE model predicts first, that converging economies—growing in excess of the frontier—will borrow from the rest of the world and that diverging economies—growing a slower rates relative to the frontier—will lend to the rest of the world, assumed to represent the productivity frontier (Proposition 1). Second, it predicts that the magnitude of borrowing and lending is reduced in magnitude by a time path of productivity transition that exhibits a higher speed at earlier phases of transition; the magnitude is increased for economies exhibiting more protracted transitional dynamics (Proposition 2). We test these theoretical predictions by calibrating the model for a sample of 67 developing economies from 1980 to 2000 for two cases: a baseline that measures productivity transitional paths directly from the data, and one that assumes a linear and common transitional path of productivity across countries. We then compare the simulated model predictions for accumulated external debt as a ratio to initial GDP.

Fig. 5 depicts the relationship between average productivity convergence $\bar{\pi}$ and accumulated external debt as a ratio of initial GDP from 1980 to 2000 across countries in the sample. The relationship in the data from our stylized facts is shown in the downward sloping line. The upward sloping, lighter blue line depicts a linear fit of the model predictions for the savings channel assuming a linear convergence path that is common across countries. The upward sloping dark line is the linear prediction of the neoclassical model for the savings channel allowing for cross-country differences in convergence paths. Accounting for cross-country differences in productivity convergence reduces the slope of the line from 15.96 to 12.85, or accounting for the slope in the data of -1.40, a reduction in the puzzle of around 20 percent. Table 2 shows that the differences in slopes of the two linear prediction lines are statistically significant at the five percent level. [8]

In Table 2 we see that cross country differences in initial capital scarcity and initial debt outweigh the effects of the savings channel alone, so that the impact of the non-linear and heterogeneous convergence paths does not result in significant differences in model predictions for total cumulated debt over initial GDP. The point estimate is reduced by around 15 percent, which reflects the impact of the reduced size of the savings channel in our model, but the two estimates are not significantly different from one another, indicated by the confidence intervals in Table 2 in Columns (3) and (4).

Cross-country heterogeneity in time paths of convergence are not powerful enough to overturn the direction of the neoclassical model's prediction of the relationship on average across countries. In fact, there are only five countries in the sample for which the direction of the savings channels is reversed: Benin, Hong Kong, Mozambique, Pakistan and Uganda. However, the average impact of non-linear convergence is quite large: for an economy with an average convergence of 10 percent (cumulative growth in excess of the frontier of 10 percent) the model predicts cumulated debt flows of 129 percent of initial GDP versus 160 percent predicted by the model imposing common and linear convergence path.

The cross-country results mask differences in the impact of non-linear convergence paths across regions and income levels. Table 3 shows the model predictions for total debt flows, the four channels shown in Eq. (16), and the average productivity parameter averaged across the total sample of countries, and sub-groups by region and income level taken from the World Bank historical classification by income level as of 1990. Column (5) shows the average magnitude of the saving channel for a model with linear convergence path in parentheses. Africa and Latin-America exhibit the largest changes in the savings channel with the inclusion of non-linear convergence paths, with increases of 27 and 29 percent, respectively. The increase in the savings channel relative to the linear convergence case reflects the fact that on average these regions experienced divergence from the frontier, with average convergence parameters of -0.27 and -0.35. When examining countries by income level, there are average increases of around 37 percent for low, 18 percent for low-middle income classifications

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[7] Our assumption of log utility is not essential for our results. We explore the impact on our results of increasing the intertemporal elasticity of substitution in Section 5.2.

[8] Importantly, this finding remains if we also consider a sample that removed the six outliers driving the negative correlation between capital inflows and productivity convergence. The slope is reduced from 15.74 to 12.95. Accounting for the positive slope in the data of 0.70, this is a reduction in the puzzle of around 20 percent.

Table 1

Parameters used for simulation.

| Calibrated Parameters			
Frontier productivity growth	g^*	1.023	calculated from PWT 9.0 data
Initial convergence parameter	π_0	0	normalization
Final convergence parameter	$\bar{\pi}$		Eq. (10) from PWT 9.0 data
Path convergence	ψ		from Eq. (14) & PWT 9.0 data
Standard Parameter Values			
Depreciation rate	δ	0.06	Caselli and Feyrer (2007)
Capital share of income	α	0.30	Gourinchas and Jeanne (2013)
Discount factor	β	0.96	Gourinchas and Jeanne (2013)
CRRA parameter	γ	1.00	log utility
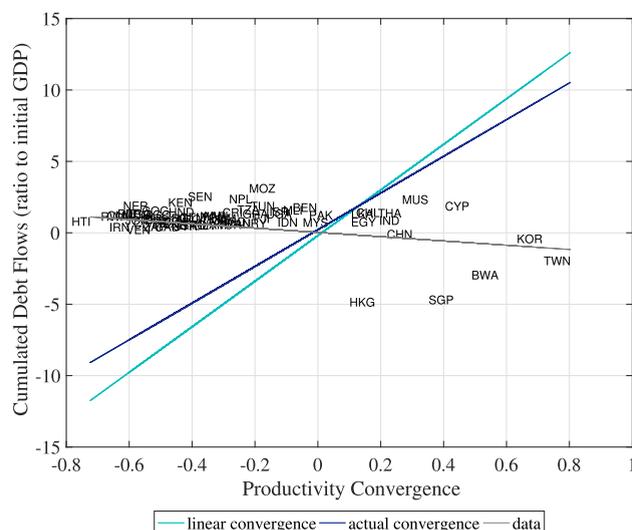
Fig. 5. Savings channel and productivity convergence. Cross-country productivity convergence against cumulated debt inflows over initial GDP for a sample of 67 non–OECD countries for the period 1980 to 2000. The downward sloping gray, reflects the regression line in the data, shown in Fig. 1. The lighter, blue upward sloping line reflects the neoclassical model predictions for the savings channel with the assumption of a linear and common rate of productivity convergence across countries. The slope is 15.96 and is significant at the 1 percent level. The upward sloping, solid dark line depicts our model's predictions allowing for cross-country differences in paths of convergence measured directly from the data. The slope of this line is 12.85 and significant at the 1 percent level. Source: author's calculations using data from PWT 9.0 and External Wealth of Nat.ions Database..

and an increase of around 50 percent for the upper middle income classifications. The effect on fast-growing economies in Asia is smaller in magnitude decreasing the saving channel by just 4 percent.

Simply allowing for the variation in cross-country convergence speeds can go a long way in reducing the neoclassical model's predictions about the relationship between productivity convergence and capital inflows. It is not powerful enough to reverse the model's predictions on the direction of the relationship, particularly for the fastest-growing east Asian economies.

Table 2

Debt Flows over GDP and productivity convergence, correlations.

	(1) Linear, $\frac{\Delta D^s}{Y_0}$	(2) Non-linear, $\frac{\Delta D^s}{Y_0}$	(3) Linear, $\frac{\Delta D}{Y_0}$	(4) Non-linear$\frac{\Delta D}{Y_0}$	(5) Data, $\frac{\Delta D}{Y_0}$
$\bar{\pi}$	15.96***	12.85***	20.36***	17.25***	−1.40*
95% CI	[14.83,17.09]	[10.99,14.70]	[16.54,24.19]	[13.14,21.36]	[-2.61,-0.19]
Obs.	67	67	67	67	67
R^2	0.85	0.75	0.72	0.62	0.15
95% confidence intervals in brackets					
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$					

Coefficients and confidence intervals are the result of a regression of the savings channel for linear convergence (Column 1) and non-linear convergence (Column 2) on the convergence parameter $\bar{\pi}$; a regression of model predictions for total cumulated debt over initial GDP for linear convergence (Column 3) and non-linear convergence (Column 4) on the convergence parameter $\bar{\pi}$; and a regression of the total cumulated debt flows over initial GDP from the data on the convergence parameter (Column 5). All standard errors used in the calculations are robust standard errors. Source: author's calculations using data from model predictions and data from PWT 9.0.

Table 3
Channel decomposition, by region and income level.

	(1) Total	(2) Scarcity	(3) Debt	(4) Investment	(5) Savings	(6) π	(7) Obs.
Full Sample	-5.28	-1.99	0.30	-1.28	-2.32 (-3.34)	-0.20	67
By region:							
Asia	2.09	-1.22	0.08	0.92	2.31 (2.40)	0.16	14
Africa	-7.76	-2.83	0.43	-1.85	-3.51 (-4.81)	-0.27	24
Latin-America	-7.51	-1.98	0.34	-2.05	-3.82 (-5.38)	-0.35	20
By income level:							
Low	-5.24	-1.41	0.35	-1.58	-2.61 (-4.16)	-0.21	22
Low-Middle	-5.96	-1.34	0.34	-1.59	-3.38 (-4.14)	-0.27	26
Upper-Middle	-7.29	-3.97	0.19	-1.52	-1.98 (-4.01)	-0.28	8

The table shows a decomposition of total cumulated debt over initial GDP into the four channels in Eq. (5), the model's prediction for the savings channel with linear convergence paths is shown in parentheses in Column (5) as well as the convergence parameter and number of observations. The geographical classifications are taken from the World Bank and income classifications are as of 1990 classification system from the World Bank.

5. Robustness

The mechanism that we highlight operates through a non-linear time path of technological convergence that impacts the requisite borrowing from the rest of the world assumed to be at the technology frontier. For countries converging more quickly towards the beginning of convergence, income will become closer to its balanced growth path more quickly, such that the optimal consumption path is supported with domestic income throughout more of the transition. Conversely, a slow start of convergence relative to a linear path will prolong the periods for which optimal consumption path must be supported by foreign borrowing. The same is true of investment, although, as our results indicate, the main mechanism operates through a savings channel. Given this mechanism, of course the shape of the time path for convergence as well as model parameters governing consumption growth and intertemporal substitution will play an important role. Each of these are discussed in turn.

5.1. Measurement of the trend component of productivity

The trend component of productivity is estimated by an HP filter, which estimates a trend $\overline{A}_t$ by minimizing a loss function comprised of squared deviations of the series from the trend and penalties to squared accelerations of the time trend, or non-linear time trends (King and Rebelo, 1993):

$$\min_{\overline{A}_t} \sum_{t=1}^{T} \left[\left(A_t - \overline{A}_t \right)^2 + \lambda \left(\left(\overline{A}_{t+1} - \overline{A}_t \right) - \left(\overline{A}_t - \overline{A}_{t-1} \right) \right)^2 \right].$$

The weight of the penalties on accelerations of the trend is governed by the smoothing parameter λ. Larger values of this parameter penalize time varying trends and result in more time-invariant time trend, i.e., a trend that is more linear.

Fig. 7 in the appendix shows the time paths for productivity convergence for a select sub-sample of countries from 1980 to 2000 for trend estimation with a smoother time trend with parameter $\lambda = 1600$. The time paths are clearly more linear by construction, but the large deviations from a linear trend are still present.

Column (2) of Table 4 in Appendix A shows the point estimates and confidence intervals for regression of average productivity convergence on the model predicted savings channel for trend productivity estimation carried out with an HP filter with parameter 1600. The point estimates are reduced in our model with non-linear convergence, with a reduction in the correlation by around 11 percent. However, the two point estimates are no longer statistically significantly different from one another at the 90 percent level. This is not surprising. The higher smoothing parameter used in the filter estimation results in a more linear trend and brings our model more in line with a model that assumes a linear convergence path. This supports the assumption made in (Gourinchas and Jeanne, 2013) of a higher smoothing parameter together with a linear convergence path.

In light of our research question that highlights the role of a non-linear trend of productivity convergence, we think it more fitting to apply a more standard value of 100 for the smoothing parameter based on a calibration of annual data. We also find that our results hold for other values for the smoothing parameter consistent with annual calibration (Backus and Kehoe, 1992; Ravn and Uhlig, 2002).

5.2. Elasticity of intertemporal substitution

Within the SOE framework in the baseline model, consumption growth during the transition is governed by the interest factor of the frontier R^* and will equal the growth rate of the frontier. Therefore, increasing the CRRA parameter will not

affect our results through diminished size of the substitution effect relative to an income effect from changing interest rates, but from income and wealth effects that are affected by the world interest rate.

Recall the world interest rate reflects that of the frontier: $R^* = g^{*\gamma}/\beta$. Thus an increase in γ for positive trend growth will be to increase the interest rate and this will have two effects: first, there will be a negative wealth effect reducing the present discounted value of income over the transition; second the income effect will reduce the magnitude of borrowing (saving) for converging (diverging) economies. Thus, the magnitude of the correlation between productivity convergence and the model predictions for accumulated external debt should be reduced with the assumption of a CRRA parameter greater than one.

This conjecture is confirmed in the main results of our quantitative exercises carried out with a CRRA parameter $\gamma = 2$, reported in Table 4, Column (1) in the appendix. The magnitude of the correlation of average productivity convergence and the size of the predicted savings channel is 12.68 with linear convergence path and 10.47 with a non-linear convergence path, a reduction of around 17 percent and only slightly less than our baseline results. The point estimates are also significantly different from one another, evidence by the confidence intervals shown in the results table, albeit the level of significance is reduced to 10 percent. A higher interest rate also increases the discount rate, so that deviations that occur further after the start of the transition are discounted more heavily, further reducing the impact on the deviations from a linear path.

5.3. Further robustness

We carry out additional robustness checks of our results by extending the sample period to 2007 and by excluding government aid flows from the data measure of accumulated external debt. The main results of these robustness checks are shown in Table 4 in the appendix. The alternative sample period takes into account more recently available data and confirms the allocation puzzle for a longer time period. We exclude years after 2007 due to the effect of the financial crisis starting in 2008, which has been characterized by a retrenchment in capital flows. This induced relatively large capital outflows from the developing world, particularly emerging market economies and likely affects the measured accumulation of external debt over that period (Milesi-Ferretti and Cedric Tille, 2011). Considering this longer period, we find a reduced correlation between the model predicted savings channel and productivity parameter is increased. This is not surprising, since the transition is studied over a longer number of periods. The introduction of the non-linear convergence path reduces this correlation from 26.12 to 21.78, a decline of around 16 percent. This difference is significant at the 10 percent level. The remaining results remain largely unchanged.

In the standard neoclassical model presented, foreign aid payments do not play a role. One might expect that the main drivers of foreign aid payments to developing economies may differ significantly from those driving private sector flows. For example, diverging economies may receive humanitarian aid to a greater extent than economies that are converging. Since these flows would be recorded as capital inflows, this could be driving the main results of the allocation puzzle. We check the robustness of our results to the exclusion of official aid flows from the calculation of external debt accumulation. Official aid flow data are taken from the overseas development assistance series published by country by the OECD.

We find that the exclusion of aid flows leaves the main results largely unchanged. The reduction in correlation between productivity convergence parameter and accumulated debt though the savings channel is reduced from 15.96 to 12.85, a reduction of 20 percent. The exclusion of aid flows reduces the negative relationship between productivity convergence and capital inflows to -1.21 and the relationship is significant only at the 10 percent level.

6. Conclusion

In a standard SOE neoclassical growth model, we have shown that when countries are converging to the technological frontier, allowing for cross-country heterogeneity in the time path of the transition is an important factor in explaining the international allocation of capital. This channel does not rely on additional assumptions on market imperfections in the developing economy, but is taken as a feature observed directly from the data. Thus the inclusion of this additional flexibility is an important first step in measuring the extent of the puzzling allocation of capital across developing economies and a logical precursor to the inclusion of aggregate distortions in the model in order to rationalize why converging economies are not receiving the amount of capital that be predicted.

We have shown—both analytically and through simple quantitative exercises—that this effect operates via a reduction in the level of the predicted accumulated external debt, by reducing the amount of borrowing required to support an optimal consumption path over the transition. The channel is not powerful enough, at least not on average across countries, to reduce the direction of relationship between productivity convergence and cumulated capital inflows. However, cross country heterogeneity in time paths of convergence reduces the positive correlation between productivity convergence and accumulated external debt over GDP—one feature of the allocation puzzle—by around 20 percent. These findings are robust to alternative model specifications, including a longer time horizon, allowing a CRRA parameter in excess of one, but are diminished significantly if the trend estimation in the productivity parameter imposes trend that is too linear.

We find that, on average, countries in the sample exhibit a more concave convergence path. When combined with the fact that countries on average in our sample are diverging from the frontier, a time path for the labor augmenting level of productivity emerges that is consistent with an s-shape transitional path for productivity common in the literature on techno-

logical diffusion: countries initially grow more slowly towards the beginning of transition, with growth accelerating thereafter.

Throughout our analysis, we have stayed true to the neoclassical model's assumption of an exogenously given and deterministic technological process. Thus, we have purposefully abstracted from stochastic features of the macroeconomic landscape in developing economies, important in the international business cycle literature. For example Aguiar and Gopinath (2007) document large fluctuations in the trend component of labor-augmenting productivity growth. Future work should distinguish between effects of a deterministic trend that is non-linear and non-linearities that emerge due to the stochastic properties of productivity trends in the developing world. This would require a stochastic version of our model that allows agents in the economy to save precautionarily against such large fluctuations. This may generate an excess saving in the model that is also consistent with the documented non-linear time paths across countries in our sample.

Our results also indicate that the relationship between capital inflows and productivity growth should be studied at higher frequencies. Future research should more carefully measure this relationship using annual, or even quarterly data on a cross-section of developing economies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Results and Figures

Figs. 6,7 and Tables 4,5.
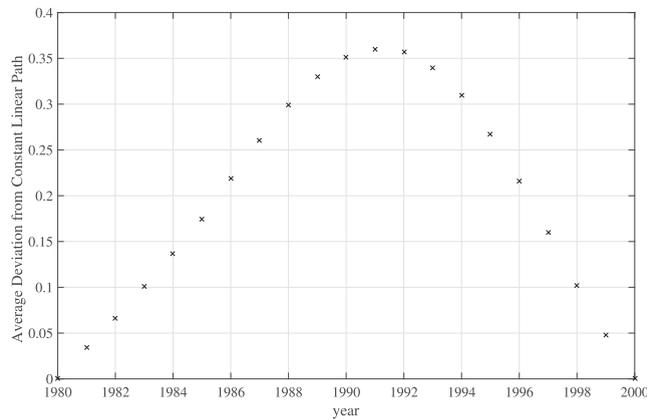
Fig. 6. Average deviation from linear convergence across Countries, 1980–2000. The figure shows the average deviation from linear convergence paths across 67 developing countries in our sample from 1980 to 2000. Source: author's calculations using data from PWT 9.0..
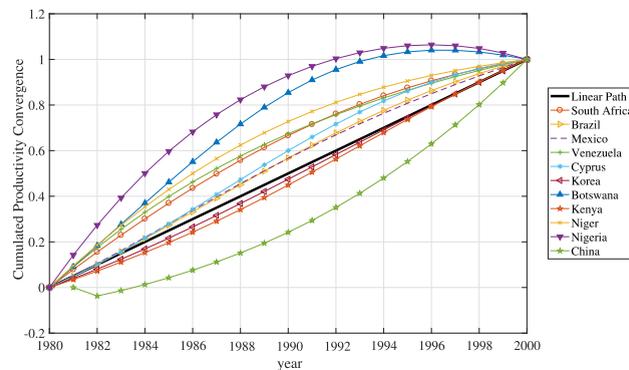
Fig. 7. The time path of productivity convergence, $\lambda = 1600$. The figure depicts the time path for productivity convergence parameter for a selection of economies from 1980 to 2000. The time path is taken from Eq. (14), $\Psi_t = \pi_t / \pi_{2000}$, where π_t is a measure of productivity growth relative to the US, and π_{2000} is the value of the productivity parameter in the year 2000. The concept is introduced in detail in Section 3.4. A linear path of convergence is shown in the solid, black line and the non-linear time paths are calculated using an HP filter with smoothing parameter $\lambda = 1600$. Source: author's calculation based on data. from PWT 9.0..

Table 4
Debt flows over GDP and productivity convergence, correlations various robustness checks.

Productivity Convergence, $\bar{\pi}$	(1) $\gamma = 2$	(2) $\lambda = 1600$	(3) 1980–2007	(4) No Aid Flows
Linear, $\frac{\Delta D^s}{Y_0}$	12.68***	15.27***	26.12***	15.96***
	[11.92, 13.43]	[14.45, 16.10]	[24.92, 27.32]	[14.83, 17.09]
Non-linear, $\frac{\Delta D^s}{Y_0}$	10.47***	13.49***	21.78***	12.85***
	[9.28, 11.64]	[12.30, 14.69]	[19.18, 24.39]	[10.99, 14.70]
Linear, $\frac{\Delta D}{Y_0}$	15.82***	20.19***	32.21***	20.27***
	[12.86, 18.79]	[17.24, 23.13]	[28.82, 35.61]	[16.41, 24.13]
Non-linear $\frac{\Delta D}{Y_0}$	13.61***	18.41***	27.87***	17.16***
	[10.51, 16.72]	[15.28, 21.54]	[23.31, 32.43]	[12.99, 21.32]
Data, $\frac{\Delta D}{Y_0}$	−1.49*	−1.70 *	−2.55*	−1.21+
	[-2.57, −0.42]	[-2.83, −0.58]	[-4.31, −0.79]	[-0.68, 0.26]
Observations	67	67	67	67
90% confidence intervals in brackets				
+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$				

Coefficients and confidence intervals are the result of a regression of the savings channel or the sum of all channels on productivity parameter for the model with linear and common convergence and our model with heterogeneous convergence paths across countries. All standard errors used in the calculations are robust standard errors. Source: author's calculations using data from model prediction and data from PWT 9.0.

Table 5
Main cross country results.

	(1) beg.	(2) end	(3) Data, $\frac{\Delta D}{Y_0}$	(4) $\bar{\pi}$	(5) Invest.	(6) Saving	(7) τ_k	(8) τ_s	(9) $\Delta\tau_s$	(10) $\Delta\Psi_t$
Full Sample	1980	2011	0.32	-0.20	−1.28	−2.32	−0.027	0.025	−0.003	0.49
Angola	1985	2011	0.77	−0.47	−1.68	−1.91	−0.08	.05	−0.005	0.55
Argentina	1970	2011	0.46	−0.37	−2.25	−4.11	−0.02	0.03	−0.006	0.54
Bangladesh	1973	2011	0.29	−0.23	−1.52	−2.73	0.02	0.02	−0.004	0.50
Benin	1970	2011	1.28	−0.00	−0.02	0.11	−0.05	0.03	−0.000	0.94
Bolivia	1970	2011	0.53	−0.39	−2.61	−4.10	−0.00	0.03	−0.008	0.68
Botswana	1974	2011	−3.45	0.57	3.38	2.22	−0.04	−0.02	0.022	0.99
Brazil	1970	2011	0.28	−0.41	−2.01	−4.58	−0.07	0.03	−0.003	0.17
Cameroon	1970	2011	0.72	−0.59	−4.22	−10.21	−0.02	0.06	−0.003	−0.09
Chile	1970	2011	0.92	0.20	1.13	4.52	0.02	0.00	−0.004	−1.16
China	1981	2011	-0.59	0.30	2.05	6.27	−0.01	−0.01	−0.004	−0.38
Colombia	1970	2011	0.42	−0.29	−1.64	−4.20	−0.02	0.03	−0.000	0.11
Congo (Rep.)	1970	2011	1.05	−0.47	−3.56	−11.07	−0.02	0.05	0.004	−0.47
Costa Rica	1970	2011	0.93	−0.24	−1.51	−1.91	−0.01	0.02	−0.006	0.93
Cyprus	1973	2011	1.38	0.48	1.86	3.55	−0.08	−0.01	0.005	0.33
Côte d'Ivoire	1970	2011	0.14	−0.52	−2.69	−4.54	−0.09	0.00	−0.008	0.61
Dominican Republic	1970	2011	0.51	−0.26	−1.70	−2.57	−0.03	0.07	−0.006	0.60
Ecuador	1970	2011	0.39	−0.42	−2.33	−5.26	−0.05	0.03	−0.003	0.18
Egypt	1970	2011	0.27	0.18	1.71	0.90	0.15	0.01	0.006	1.12
El Salvador	1970	2011	0.03	−0.32	−2.35	−2.20	0.02	0.02	−0.011	1.15
Ethiopia	1970	2011	0.06	−0.37	−1.73	−2.99	−0.04	0.05	−0.005	0.45
Fiji	1977	2011	0.50	−0.15	−0.88	−1.57	−0.05	0.01	−0.002	0.71
Gabon	1970	2011	-.07	−0.44	−2.57	−5.30	−0.06	0.03	−0.004	0.44
Ghana	1970	2011	0.83	−0.16	−0.67	−0.12	−0.06	0.03	−0.005	1.77
Guatemala	1970	2011	0.59	−0.36	−1.99	−3.68	-.03	0.03	-.005	0.48
Haiti	1970	2011	0.30	−0.72	−4.77	−10.51	−0.04	0.07	−0.007	0.21
Honduras	1970	2011	0.96	−0.39	−2.13	−5.06	−0.05	0.05	−0.002	0.14
Hong Kong	1979	2011	-5.35	0.18	0.89	-0.39	−0.05	−0.01	0.011	1.57
India	1970	2011	0.37	0.26	1.43	4.61	−0.03	0.00	−0.002	−0.39
Indonesia	1970	2011	0.24	−0.06	−0.34	−2.51	−0.06	0.00	0.006	−2.26
Iran	1970	2011	−0.10	−0.60	−5.08	−6.97	−0.05	0.03	−0.018	0.89
Israel	1970	2011	0.99	−0.09	−0.51	−1.02	−0.05	0.01	−0.001	0.55
Jamaica	1970	2011	0.07	−0.29	−1.23	−2.49	−0.08	0.05	−0.001	0.63
Jordan	1970	2011	0.38	−0.54	−3.36	−7.95	−0.04	0.04	−0.003	−0.06
Kenya	1970	2011	1.63	−0.40	−2.38	−7.13	−0.02	0.05	0.002	−0.23
Korea	1971	2011	−0.91	0.71	4.89	12.85	−0.02	−0.03	0.000	−0.07
Madagascar	1970	2011	0.76	−0.53	−3.66	−7.24	0.09	0.05	−0.007	0.40
Malawi	1970	2011	0.69	−0.29	−7.54	−15.73	0.08	0.03	−0.003	0.30
Malaysia	1970	2011	0.23	0.03	0.23	1.04	−0.03	−0.001	−0.001	−1.86
Mali	1970	2011	1.09	−0.05	−0.31	−0.51	−0.003	0.02	−0.001	0.56
Mauritius	1970	2011	1.84	0.35	1.92	5.55	−0.05	−0.01	-.001	-.27
Mexico	1970	2011	0.18	−0.44	−2.71	−5.71	−0.04	0.03	−0.005	0.24
Morocco	1970	2011	0.66	−0.29	−1.43	−3.49	−0.07	0.03	−0.001	0.12

Table 5 (*continued*)

	(1) beg.	(2) end	(3) Data, $\frac{AD}{Y_0}$	(4) $\bar{\pi}$	(5) Invest.	(6) Saving	(7) τ_k	(8) τ_s	(9) $\Delta\tau_s$	(10) $\Delta\Psi_t$
Mozambique	1980	2011	2.62	−0.14	−0.96	3.63	0.15	0.02	−0.02	3.69
Nepal	1970	2011	1.87	−0.21	-1.68	−3.50	0.02	0.02	−0.002	0.44
Niger	1970	2011	1.39	−0.54	−1.98	−3.37	−0.09	0.11	−0.001	0.52
Nigeria	1970	2011	0.03	−0.38	−2.63	−3.68	−0.02	0.02	−0.01	0.83
Pakistan	1970	2011	0.74	0.05	0.29	−1.27	−0.01	0.02	0.005	3.71
Panama	1970	2011	0.16	-0.21	−1.29	−3.00	−0.04	0.01	−0.001	0.08
Paraguay	1970	2011	0.36	-0.48	−3.13	−7.74	−0.03	0.04	−0.002	0.04
Peru	1970	2011	0.85	-0.56	−3.88	−6.91	−0.01	0.05	−0.01	0.46
Philippines	1970	2011	0.48	−0.48	-2.73	−4.87	−0.05	0.04	−0.008	0.48
Rwanda	1970	2011	0.65	−0.60	−5.16	−11.05	0.05	0.05	−0.007	0.10
Senegal	1970	2011	2.05	−0.34	−1.76	−4.21	−0.05	0.04	−0.001	0.06
Singapore	1970	2011	−5.18	0.43	2.18	5.41	−0.06	−0.06	0.002	−0.02
South Africa	1970	2011	−0.06	−0.48	-2.67	−5.50	−0.05	0.04	−0.005	0.29
Sri Lanka	1970	2011	0.84	0.18	0.97	3.19	−0.03	0.003	0-.002	−0.35
Syrian Arab Republic	1970	2011	−0.02	−0.38	−2.32	−3.69	−0.007	0.03	−0.008	0.52
Taiwan	1977	2011	−2.45	0.80	4.77	11.49	−0.03	−0.03	0.003	0.06
Thailand	1970	2011	0.88	0.26	1.44	2.75	−0.05	−0.006	0.004	0.17
Togo	1970	2011	0.81	−0.53	−2.71	-5.42	−0.05	0.05	−0.006	0.45
Trinidad and Tobago	1970	2011	0.06	-0.36	−1.24	−0.25	−0.09	0.09	0.002	1.26
Tunisia	1970	2011	1.38	−0.14	−0.62	-0.45	−0.07	0.01	−0.004	1.02
Turkey	1970	2011	0.08	−0.24	−1.85	−4.77	0.002	0.02	−0.000	0.09
Tanzania	1970	2011	1.12	−0.19	−0.74	−0.63	−0.07	0.05	−0.003	1.10
Uganda	1970	2011	0.83	−0.08	−0.63	3.18	0.00	0.00	−0.01	5.15
Uruguay	1970	2011	0.17	−0.16	-.72	−1.49	−0.05	0.03	−0.001	0.63
Venezuela	1970	2011	−0.28	−0.53	−2.55	−5.10	−0.07	0.06	−0.005	0.45

Appendix B. Data sources and variable definitions

The main data sources used are Penn World Table (PWT) 9.0 (Feenstra et al., 2015) and the External Wealth of Nations, Mark II (EWN) database (Lane and Milesi-Ferretti, 2007). The section below outlines the treatment of the major variables used in the analysis.

Productivity Real variables in PWT 9.0 are reported in 2011 international dollars, constructed from purchasing power parity (PPP) exchange rates based on prices across countries for benchmark years as part of the International Comparisons Program (ICP) (Feenstra et al., 2015). We compute a productivity parameter for each country in each time $t = 1980, 1981, \ldots 2000$ using the assumed Cobb Douglas production function in Eq. (1):

$$A_t = \left(\frac{Y_t/L_t}{(K_t/L_t)^\alpha} \right)^{1/1-\alpha}.$$

Y_t/L_t is real GDP (*rgdpna*) divided by working age population (aged 15 to 64) for each country using data from the United Nations Population Prospects, and K_t/L_t is real capital stock (*rkna*) divided by working age population.

The variable for real capital stock is taken from PWT 9.0 and is estimated using cumulative and depreciated past investment using the perpetual inventory method as described in Inklaar and Timmer (2013).

From the time series for A_t we calculate the trend component $\bar{A}_t$ using an HP filter with smoothing parameter $\lambda = 100$. From this trend series for productivity, we calculate frontier growth, g^* from the productivity series for the United States over the period 1980 to 2000 as:

$$g^* = \left(\frac{\bar{A}_{2000}}{\bar{A}_{1980}} \right)^{1/(2000-1980)}.$$

The convergence parameters for each country over time are, $\pi_t = \frac{\bar{A}_t}{\bar{A}_0 g^{*(t-1980)}} - 1$, where $\bar{A}_t$ is the time series for trend productivity and $\bar{A}_{1980}$ is the level of trend productivity in year 1980. From the series for π_t, we measure each $\bar{\pi}$ as the value of π_t for $t = 2000$ and the corresponding time path for productivity is, $\Psi_t = \frac{\pi_t}{\bar{\pi}}$.

Change in External Debt

Real variables in PWT 9.0 are reported in 2011 US dollars and data from EWN reports data in current US dollars. We deflate data from the EWN to make the series comparable over time.

PWT publishes values for price levels of the components of GDP. We use the price level associated with the investment component, as it is more likely to reflect goods that are internationally traded (Gourinchas and Jeanne, 2013). The price level for investment is defined as $p_t^i \equiv \frac{PPP_t^i}{xr_t}$, where PPP_i is the purchasing power parity exchange rate—the ratio of nominal investment in a country over the investment in current international dollars, and xr is the nominal exchange rate. Therefore, divid-

ing a series that is in current US dollars by the variable p_t^i will return a series that is converted to current international dollars. In order to convert the series into real international dollars, we then divide by the ratio of GDP in current international dollars to GDP in 2011 international dollars. The deflator applied to convert current US dollars into real 2011 international dollars is, $\chi_t = p_t^i x_t$, where $x_t = CGDP_t / RGDP_t$ is the ratio of GDP in current international dollars to GDP in 2011 international dollars.

Our analysis is carried out in a model that does not account for valuation effects. We construct the cumulated debt flows by subtracting cumulated current accounts, deflating the series to real international 2011 dollars and accounting for net errors and omissions as unobserved capital inflows. Net errors and omissions are in current US dollars and taken from International Financial Statistics from the IMF.

An initial debt position is taken as the negative of the net foreign asset position in the first year available in the EWN database. For most countries in the sample this is 1970. The debt position in 2011 international dollars evolves over time as:

$$\frac{D_t}{\chi_t} = \frac{D_{t-1}}{\chi_t} - \frac{CA_t}{\chi_t} + \frac{EO_t}{\chi_t},$$

where CA_t is the current account in period $t = 1970, 1971, \ldots, 2000$ and EO_t are net errors and omissions. The change in external debt over from 1980 to 2000:

$$\Delta D \equiv \frac{D_{2000}}{\chi_{2000}} - \frac{D_{1980}}{\chi_{1980}} = D_{1980}\left(\frac{1}{\chi_{2000}} - \frac{1}{\chi_{1980}}\right) - \frac{1}{\chi_{2000}}\sum_{i=1980}^{2000}[CA_i - EO_i].$$

Appendix C. Proofs

C.1. Derivation of $\frac{\Delta D}{Y_0}$

Define the change in external debt of initial GDP:

$$\frac{\Delta D}{Y_0} \equiv \frac{D_T - D_0}{Y_0} = \frac{\tilde{d}_T A_T L_T - \tilde{d}_0 A_0 L_0}{\tilde{y}_0 A_0 L_0}. \tag{A24}$$

Rewrite Eq. (A24) using definition of the convergence parameter given in Eq. (10):

$$\frac{\Delta D}{Y_0} = \frac{\tilde{d}_T(1+\bar{\pi})(ng^*)^T - \tilde{d}_0}{\tilde{y}_0}. \tag{A25}$$

The period T debt per effective unit of labor $\tilde{d}_T$ is derived from the per capita budget constraint in Eq. (7) divided by the productivity level A_t in time t:

$$\tilde{c}_t + ng_{t+1}\left(\tilde{k}_{t+1} - \tilde{d}_{t+1}\right) = R_t\left(\tilde{k}_t - \tilde{d}_t\right) + \tilde{w}, \tag{A26}$$

where $g_{t+1} = A_{t+1}/A_t$ and $\tilde{w} = (1-\alpha)\tilde{k}^{*\alpha}$. The gross interest rate adjusts immediately to R^*. This implies that in period $t = 0$ $\tilde{k}_0$ moves immediately to $\tilde{k}^*$, inducing an adjustment of $\tilde{d}_0$ to $\tilde{d}_0^+ = \tilde{d}_0 + \tilde{k}^* - \tilde{k}_0$. This affects the period 0 budget constraint. For periods, $t > 0$ the following budget constraint applies:

$$\tilde{c}_t + ng_{t+1}\left(\tilde{k}^* - \tilde{d}_{t+1}\right) = R_t\left(\tilde{k}^* - \tilde{d}_t\right) + \tilde{w}, \tag{A27}$$

where $g_{t+1} = A_{t+1}/A_t$ and $\tilde{w} = (1-\alpha)\tilde{k}^{*\alpha}$. At the beginning of period T the convergence process stops and the small open economy grows by factor g^*. Therefore for $t \geqslant T$ and $\tilde{d}_t = \tilde{d}_T, \tilde{c}_t = \tilde{c}_T$. This assumption combined with Eq. (A27) gives us:

$$\tilde{d}_T = \tilde{k}^* + \frac{\tilde{w} - \tilde{c}_T}{R^* - ng^*}, \tag{A28}$$

and

$$\tilde{c}_T = \frac{c_T}{A_T} = \frac{c_0 g^{*T}}{(1+\bar{\pi})A_0 g^{*T}} = \frac{\tilde{c}_0}{(1+\bar{\pi})}. \tag{A29}$$

We can derive $\tilde{c}_0$ from Eq. (7). With positive trend growth $g^* > 0$ and the condition $(ng^*/R^*) < 1$ for finite discounted utility of consumption and assuming the no-ponzi condition holds:

$$\lim_{t \to \infty}\left(\frac{n}{R^*}\right)^t (k_t - d_t) \geqslant 0. \tag{A30}$$

The intertemporal budget constraint becomes:

$$\frac{1}{R^*}\sum_{s=0}^{\infty}\left(\frac{n}{R^*}\right)^s c_s = (k_0 - d_0) + \frac{1}{R^*}\sum_{s=0}^{\infty}\left(\frac{n}{R^*}\right)^s w_s. \tag{A31}$$

Using the fact that per capita consumption grows by constant factor g^* implies $c_t = c_0 g^{*t}$ and rewriting $w_t = \tilde{w} A_t$ and that $A_t = (1 + \pi_t) A_0 g^{*t}$ from Eq. (10), we solve for consumption in efficiency units in period 0:

$$\tilde{c}_0 = (R^* - ng^*)\left(\tilde{k}_0 - \tilde{d}_0\right) + \frac{(R^* - ng^*)}{R^*}\tilde{w}\sum_{s=0}^{\infty}\left(\frac{ng^*}{R^*}\right)^s (1 + \pi_s). \tag{A32}$$

Substituting Eq. (A32) into Eq. (A29) and the result into Eq. (A28) yields:

$$\tilde{d}_T = \tilde{k}^* + \frac{\tilde{w}}{R^* - ng^*} - \frac{\left(\tilde{k}_0 - \tilde{d}_0\right)}{1 + \bar{\pi}} - \frac{\tilde{w}}{R^*(1 + \bar{\pi})}\sum_{s=0}^{\infty}\left(\frac{ng^*}{R^*}\right)^s (1 + \pi_s), \tag{A33}$$

where $\frac{\tilde{w}}{R^* - ng^*} = \frac{\tilde{w}}{R^*}\sum_{s=0}^{\infty}\left(\frac{ng^*}{R^*}\right)^s$, Eq.(A33) can be rewritten as:

$$\tilde{d}_T = \tilde{k}^* - \frac{\left(\tilde{k}_0 - \tilde{d}_0\right)}{1 + \bar{\pi}} + \frac{\tilde{w}}{R^*(1 + \bar{\pi})}\left[\sum_{s=0}^{\infty}\left(\frac{ng^*}{R^*}\right)^s (1 + \bar{\pi}) - \sum_{s=0}^{\infty}\left(\frac{ng^*}{R^*}\right)^s (1 + \Psi_s \bar{\pi})\right].$$

Finally, inserting resulting Eq. (A33) above into Eq. (A24) and rearranging results in the expression for the change in external debt over T periods as a ratio to initial GDP:

$$\frac{\Delta D}{Y_0} = \frac{\left(\tilde{k}^* - \tilde{k}_0\right)}{\tilde{y}_0}(ng^*)^T + \frac{\tilde{d}_0}{\tilde{y}_0}\left((ng^*)^T - 1\right) + \bar{\pi}\frac{\tilde{k}^*}{\tilde{y}_0}(ng^*)^T + \bar{\pi}\frac{\tilde{w}}{\tilde{y}_0}\frac{(ng^*)^T}{R^*}\sum_{s=0}^{T-1}\left(\frac{ng^*}{R^*}\right)^s (1 - \Psi_s). \tag{A34}$$

Appendix D. Proof of Proposition 2

Proposition 2 Given the result in Eq. (16) and Assumption 2 external debt accumulation is decreasing in the time path of convergence. The magnitude of the decline is reduced over time. This effect enters via the Savings Channel.

Proof. Assumption 2 guarantees that $0 < \psi_t < 1 \; \forall \; t$. From Eq. (14) this assumption implies that $\Psi_t > 0 \; \forall \; t$. We can see this from:

$$\Psi_t = 1 - \prod_{s=1}^{t}\psi_t < 1 \Rightarrow -\prod_{s=1}^{t}\psi_t < 0. \tag{A35}$$

From Eq. (16) and given that $0 < \Psi_t < 1 \forall t$, the cumulated external debt is decreasing in the term:

$$\sum_{s=0}^{T-1}\left(\frac{ng^*}{R^*}\right)^s \Psi_s$$

.

$$\frac{\partial \Delta D/Y_0}{\partial \psi_t} = \left(\bar{\pi}\frac{\tilde{w}}{\tilde{y}_0}\frac{(ng^*)^T}{R^*}\left(\frac{ng^*}{R^*}\right)^t\right)\left(\prod_{s=1}^{t-1}\psi_s\right). \tag{A36}$$

The effect of increasing ψ_t or slowing convergence at time t increases net external debt accumulation by an amount that is proportional to the productivity convergence parameter $\bar{\pi}$. The effect is diminishing over time, since both $\frac{ng^*}{R^*} < 1$ and $\psi_s < 1$. The time path of convergence only enters Eq. (16) through the savings channel.

Appendix E. Proof of Corollary 1

Corollary 1 A small open economy exhibiting a strictly concave (strictly convex) time path of convergence variable Ψ_t accumulates less (more) external debt relative to a small open economy assumed to have a linear convergence path.

Proof. Proposition 2 has shown that external debt accumulation is decreasing in the time path of convergence given by Ψ_t. A linear time path of convergence exhibits the following relationship for any value of $\lambda \in [0, 1]$:

$$\Psi_{\lambda t + 1 - \lambda(t+1)} = \lambda \Psi_{t-1} + (1 - \lambda)\Psi_{t+1}. \tag{A37}$$

Given the definition of strict concavity and strict convexity, respectively:

$$\Psi_{\lambda t+1-\lambda(t+1)} > \lambda\Psi_{t-1} + (1-\lambda)\Psi_{t+1} \tag{A38}$$

$$\Psi_{\lambda t+1-\lambda(t+1)} < \lambda\Psi_{t-1} + (1-\lambda)\Psi_{t+1}, \tag{A39}$$

it must be true that for a small open economy exhibiting concave (convex) time path of convergence external debt accumulation is less (greater) than a small open economy with a linear time path of convergence.

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