How Does Openness to Capital Flows Affect Growth?

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Abstract

An average adjustment cost which is convex with respect to the rate of gross investment successfully calibrates a neoclassical growth model to match real world observables including the transition paths of convergence speed, the shadow value of capital, interest rates, and savings rates. Comparing the open-economy and closed-economy versions of the calibrated model shows that relaxing the constraint that domestic savings finance domestic investment effects only a small increase in the growth rate of output per capita: less than one percentage point per year for an economy with current output 20 percent its steady-state level and less than one-half percentage point for an economy with current output 60 percent its steady-state level. Rather than higher growth, the main effect of openness to capital flows is higher current levels of consumption financed by large trade deficits.

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1 Introduction

How does openness to trade and capital flows affect economic wealth? The question dates back at least to Adam Smith. A satisfactory answer still eludes us.

Theory suggests a number of reasons why openness should lead to long-term increases in wealth. Openness allows economies to specialize in the production of products for which they have a comparative advantage, either due to different factor endowments or different technologies. Openness increases competition. Openness facilitates the transfer of knowledge from technological leaders to technological laggards. Openness lets firms exploit increasing returns to scale both for current production and for technological development.

But openness may prevent the development of increasing returns-to-scale industries in which a country would eventually have a comparative advantage. Openness subjects an economy to the additional uncertainty of foreign shocks. Openness may lead to a dependence on foreign sources for critical goods. And certainly, openness may have far-reaching domestic distributional consequences.

Most economists agree that, on balance, theory suggests that the benefits of openness outweigh the costs. Such conventional wisdom notwithstanding, empirical evidence of a causal relationship from open trade policy to economic growth turns out to be ambiguous at best. On the one hand, Frankel and Romer (1998) persuasively establish a positive causal relation from trade volumes arising from geographic proximity to per capita income levels.[1] However as emphasized by Rodríguez and Rodrik (1999), the effects of geographic-based trade *volumes* are not necessarily the same as the effects of open trade *policies*. Critiquing the empirical literature linking open trade policies to economic growth, Rodríguez and Rodrik argue that constructed measures of trade policy openness often better capture alternative characteristics such as macroeconomic policy and geographic location.

The present paper addresses a more narrowly focused question: how does openness to capital flows — in the sense of relaxing the constraint that domestic savings finance domestic investment — affect the speed at which a developing economy's output grows towards its

[1] A decomposition additionally shows a positive effect from the geographic component of trade volumes to per capita income growth over the period 1960 to 1985.

steady-state level?

The neoclassical growth model developed by Ramsey (1926), Cass (1965) and Koopmans (1965) previously has been unable to assess the quantitative importance of openness on growth due to the difficulty of calibrating the model to match real world observables.[2] King and Rebelo (1993) argue that the Ramsey-Cass-Koopmans model, even after allowing for various modifications to preferences and production technologies, cannot match developing economy time series for growth rates, interest rates, and savings rates. In particular, the closed-economy Ramsey-Cass-Koopmans model predicts an implausibly high speed of convergence of output towards its steady state as well as implausibly high real interest rates for economies with output levels low relative to their steady state.

Barro and Sala-i-Martin (1995) counter that allowing for a broad interpretation of capital to include, for instance, human capital both slows the closed-economy model's speed of convergence and effects low interest rates for relatively poor economies. But moving to an open-economy framework, the additional assumption of borrowing constraints is required to maintain plausible speeds of convergence (Barro, Mankiw, and Sala-i-Martin, 1995).[3]

In contrast, a sufficiently convex adjustment cost to gross capital investment successfully calibrates both an open-economy and a closed-economy version of the Ramsey-Cass-Koopmans model. Comparing the two versions shows that openness to capital flows effects only a very small increase in transitional growth rates: less than one percentage point per year for an economy with current output 20 percent its steady-state level and less than one-half percentage point for an economy with current output 60 percent its steady-state level. Rather than increasing the growth rate of output, the main effect of openness to capital

[2]This difficulty contrasts with more successful efforts to calibrate real business cycle models. While the neoclassical underpinnings of RBC models make it difficult to distinguish a separate neoclassical "growth" model, for present purposes the distinction lies in the ability of a neoclassical framework to model development rather than cyclical phenomena. The present paper does rely on adjustment frictions rather than the time-to-build technology of Kydland and Prescott (1982). But international RBC models also introduce capital mobility frictions to dampen otherwise unrealistic swings in national capital stocks (Backus, Kehoe, and Kydland, 1992; Baxter and Crucini, 1993).

[3]Abstracting from the consumption-savings decision, Mankiw, Romer, and Weil (1991) show that the Solow (1956) model augmented to include the accumulation of human as well as physical capital can approximately match the cross-sectional distributions of income and growth rates across countries.

flows is to increase current consumption financed by large trade deficits.

Arguing that a modified Ramsey-Cass-Koopmans growth model can be calibrated to match observed development time series would seem to place the present paper firmly within the "neoclassical revival" literature. Even so, the paper's basic conclusion is the same as the critique of this literature: the dynamics of capital accumulation cannot explain important elements of the process of economic growth (Klenow and Rodriguez-Clare, 1997). The strength of the neoclassical framework lies in the paucity of its assumptions. Pushing the neoclassical framework to its limits helps demarcate where endogenous growth theory must begin and so complements efforts to understand long run growth.

The paper proceeds as follows: Section 2 reviews the Ramsey-Cass-Koopmans theoretical framework and introduces an adjustment cost to gross capital investment which generalizes previous linear specifications. Section 3 calibrates closed-economy and open-economy versions of the model. Section 4 shows that openness to capital flows mainly increases current consumption rather than increasing output growth, a result which is extremely robust to alternative parameterizations on the capital share of production, the level of adjustment cost, and the elasticity of intertemporal substitution. Section 5 concludes.

2 Theory: Generalizing Capital Adjustment Costs

The theoretical framework developed herein is just the standard Ramsey-Cass-Koopmans setup augmented by an adjustment cost to gross capital investment. The closed-economy version closely follows Abel and Blanchard (1983). The open-economy version is laid out in Barro and Sala-i-Martin (1995). The only novel feature is an adjustment function to gross capital investment that is slightly more general than the commonly used "quadratic" adjustment cost specification.

2.1 Firms

Assume an economy in which there are a large number of identical firms, each with access to a constant-returns-to-scale (CRS) Cobb-Douglas production function. As CRS implies an indeterminate firm size, I write instead the aggregate production function,

$$Y(t) = AK(t)^{\alpha} \left(L(t) \mathrm{e}^{xt} \right)^{1-\alpha} \quad (1)$$

Here, A captures aggregate total factor productivity while x measures the economy-wide rate of exogenous labor-augmenting technological progress.[4] Aggregate capital stock evolves according to,

$$\frac{d}{dt} K(t) = I(t) - \delta K(t) \quad (2)$$

Firms maximize the net present value of future cash flows,

$$V(t) = \int_t^{\infty} \left(Y(s) - w(s) L(s) - I(s) \left(1 + \frac{b}{1+\phi} \left(\frac{I(s)}{K(s)} \right)^{\phi} \right) \right) \mathrm{e}^{-\int_t^s r(v)\mathrm{d}v} \mathrm{d}s \quad (3)$$

Along the lines of Abel (1982) and Hayashi (1982), (3) assumes an *average* adjustment cost to installing capital, $\frac{b}{1+\phi} \left(\frac{I}{K} \right)^{\phi}$. The parameters b and ϕ respectively calibrate the upward slope and convexity of the average installation cost as investment increases. Letting $b = 0$ captures a world in which capital can be costlessly installed and uninstalled. Specializing $\phi = 1$ captures the case in which the average installation cost increases linearly with the rate of gross investment; a linearly increasing average cost to gross investment is commonly labeled as "quadratic" in the sense that the total cost of investment is indeed so. More generally, $\phi > 0$ corresponds to convex *total* adjustment costs or, equivalently, an average cost of installing capital which is increasing in the rate of gross investment. Henceforth, discussion of the convexity of the adjustment cost function will refer to the convexity of the *average* adjustment cost.[5]

Recent empirical and theoretical research has made great strides in understanding *firm-level* investment decisions by allowing for a fixed cost to adjustment. With fixed costs, the average cost of adjustment is decreasing for low rates of investment and so firm investment behavior tends to be "lumpy". Aggregate investment will retain some of this lumpiness if aggregate shocks cause a clustering of firms' investment decisions (Caballero, 1999). The

[4]Note that with Cobb-Douglas production, exogenous technological progress which is capital augmenting or which acts directly on total factor productivity can be rewritten in terms of labor-augmenting technological progress (Arrow and Kurz, 1970).

[5]Absent fixed costs, a linear average cost of adjustment implies a linear marginal cost of adjustment. More generally, average adjustment costs and marginal adjustment costs can differ in both slope and convexity.

present paper, in contrast, assumes a smooth upward sloping average adjustment cost function to *aggregate* investment which additionally is allowed to be convex.

Justifying such strong assumptions relies, first, on distinguishing between firm and aggregate investment. The substantial evidence supporting microeconomic lumpiness notwithstanding, Caballero (1999) speculates that general equilibrium considerations are likely to be among the main sources of a rising average adjustment cost in the short run. A rising average adjustment cost follows, for instance, if an increase across firms in demand for investment goods causes the price of investment goods to rise; Goolsbee (1998) finds empirical support for exactly such a mechanism.

As a motivating example, consider the bottlenecks confronting the U.S. television broadcast industry as it transitions from analog to high-definition digital technology. Doing so requires the construction of as many as seven hundred tall broadcast towers. But as of 1997, only about a half-dozen crews across the United States had the experience and training to erect the 1,500- to 2,000-foot structures. Over the few years prior to 1997, aggregate installation by these crews had been at a rate of ten to fifteen tall towers per year. Training a new crew is largely by apprenticeship and can take more than two years (*New York Times*, 1997).[6]

Moreover, even if there were an initial range over which aggregate average adjustment costs were decreasing, aggregate investment in developing economies would likely exceed this range. Within a business cycle context, the difference between firms' actual and ideal capital stocks tends to remain "moderate". Fixed costs to adjustment will cause firms to make infrequent investments but investments when they are made will be of a size so as to align actual and ideal capital stocks. In contrast, for an economy with actual capital stock far below its steady-state level, firms continually desire to make "large" investments for which fixed costs are probably much less important. That diminishing returns to high levels of firm investment eventually set in would not seem controversial. Even Rothschild (1971), one of the most frequently cited objectors to the use of upward sloping adjustment costs,

[6] Appealing to general equilibrium considerations to justify upward-sloping average adjustment costs suggests that (3) may not be the object which firms seek to maximize; that is, firms may take adjustment costs as given and so not internalize congestion effects.

agrees that at high levels, a firm's average adjustment costs are likely to rise "reflecting the increasing costs of disruption caused by large-scale hurried changes that we feel on a priori grounds are likely to be prevalent."

A priori, the convexity of average adjustment costs is less clear. For upward sloping average adjustment costs to be convex requires sufficiently high diminishing returns to short-run investment. Assuming a CRS Cobb Douglas installation function which takes an uninstalled output good and converts it into installed capital using a fixed-quantity installation input and a variable-quantity installation input, the necessary diminishing returns to effect a convex average adjustment cost requires that the coefficient on the fixed-quantity installation input exceed one half. (For the formalization, see the appendix.) Aggregate investment bottlenecks, rising investment input prices, and other external adjustment costs all lower this coefficient threshold.

For many of the investments accompanying economic development, that "installation" is intensive in fixed-quantity inputs seems a reasonable proposition. Consider human capital formation: simply devoting more variable inputs to it (e.g. more time devoted to learning by current teachers and students, expanded student enrollment, more and fatter textbooks) beyond some point probably will not result in much additional human capital. Expanding human capital while avoiding extreme adjustment costs probably relies instead on longer run investments in fixed-quantity installation inputs such as prenatal care and improved infant nutrition, more and better teachers, societal values which emphasize and reward learning, et cetera. Other sorts of capital deepening which accompany development such as the growth of public institutions underlying the rule of law and learning by doing for new production techniques are similarly likely to be characterized by sharply diminishing returns to short-run investment.[7]

Empirical support for a convex, increasing average adjustment cost is provided by Barnett and Sakellaris (1998). Using firm-level data, they find a non-linear S-shaped relationship between proxies for the shadow value of capital (q) and investment: convex for low shadow values of capital but concave for high shadow values of capital. A convex average adjustment

[7] Complementarity among different vintages of capital, as in Kremer and Thomson (1998), serves as an alternative theoretical mechanism for effecting a convex increasing average adjustment friction.

cost effects exactly the latter concave investment response: increases in q from high levels elicit little incremental investment due to the very high associated adjustment costs. To the extent that *firm* average adjustment costs are convex increasing, a fortiori so too should *aggregate* average adjustment costs.

Writing firms' dynamic optimization problem in current-value Hamiltonian form and solving gives firms' desired levels of labor and investment. In particular, the gross rate of firm (and aggregate) investment can be written as an increasing function of the contemporary shadow value of installed capital, q. [8]

$$\frac{I(t)}{K(t)} = b^{-\frac{1}{\phi}} \left(q(t) - 1\right) \left(\left(q(t) - 1\right)^2\right)^{\frac{1-\phi}{2\phi}} \tag{4}$$

The evolution of capital per effective worker, $\hat{k}(t) \equiv K/(Le^{xt})$, and the shadow value of capital , $q(t)$, can then be solved as,

$$\frac{d}{dt}\hat{k}(t) = b^{-\frac{1}{\theta}} \left(\left(q(t) - 1\right) \left(\left(q(t) - 1\right)^2\right)^{\frac{1-\phi}{2\phi}} - \delta - x \right) \hat{k}(t) \tag{5}$$

$$\frac{d}{dt}q(t) = \left(r(t) + \delta\right) q(t) - \alpha A \hat{k}(t)^{\alpha - 1} - \frac{\phi \left(\left(q(t) - 1\right)^2\right)^{\frac{\phi+1}{2\phi}}}{b^{\frac{1}{\phi}} (\phi + 1)} \tag{6}$$

2.2 Individuals

Individual utility and asset accumulation are given by,

$$U(t) = \int_t^{\infty} \frac{c(s)^{1-\theta} - 1}{1 - \theta} \mathrm{e}^{-\rho(s-t)} \mathrm{d}s \tag{7}$$

$$\frac{d}{dt}\text{assets}(t) = r(t)\,\text{assets}(t) + w(t) - c(t) \tag{8}$$

Here, θ measures the reciprocal of the elasticity of intertemporal substitution (which in an expected utility framework equals the coefficient of relative risk aversion). A unitary elasticity of intertemporal substitution, $\theta = 1$, is equivalent to the case of log utility with

[8] While (4) can be simplified with respect to the terms in parentheses, it should not be. The first parenthesized term preserves the sign of gross investment (i.e., negative when the shadow value of capital falls below one). The second parenthesized term assures real-valued magnitudes for negative gross investment.

higher values of θ implying a greater desire by individuals to smooth consumption. The parameter ρ measures individuals' rate of time preference. Along with a standard transversality condition limiting the rate of asymptotic debt accumulation, maximizing individuals' optimal consumption path is given by the standard Euler equation,

$$\frac{d}{dt}\hat{c}(t) = \frac{1}{\theta}\left(r(t) - \rho - x\theta\right)\hat{c}(t) \tag{9}$$

2.3 Steady State

The asymptotic limit on the rate of debt accumulation implies that for both closed and open economies, steady-state consumption and capital stock must each grow at the rate of exogenous technological progress, x. Setting (9) and (5) equal to zero respectively implies a constant steady-state interest rate and a constant steady-state shadow value of capital. These and (6) then determine steady-state effective capital intensity.

$$r^* = \rho + x\theta \tag{10}$$

$$q^* = 1 + (\delta + x)^{\phi} \cdot b \tag{11}$$

$$\hat{k}^* = \left(\frac{\alpha(\phi + 1)A}{\widetilde{b}}\right)^{\frac{1}{1-\alpha}} \tag{12}$$

where

$$\widetilde{b} \equiv \theta x + \phi\theta x + \delta\phi + \rho\phi + \delta + \rho + (\theta x + \phi\theta x - \phi x + \rho\phi + \delta + \rho)(\delta + x)^{\phi} b$$

Remaining steady-state characteristics, in particular the *levels* of per capita consumption and asset wealth, differ between closed and open economies.

2.4 Closed Economy Equilibrium

The key characteristic defining a closed economy is the aggregate resource constraint that absorption (consumption plus investment plus adjustment costs) not exceed output:

$$C(t) + I(t)\left(1 + \frac{b}{1+\phi}\left(\frac{I(t)}{K(t)}\right)^{\phi}\right) = Y(K(t)) \tag{13}$$

The instantaneous real interest rate, $r_{\text{closed}}(t)$, assures this constraint holds.[9]

$$r_{\text{closed}} = \Bigg[\hat{k}\cdot\left(\hat{c}-(1-\alpha)\,A\hat{k}^{\alpha}\right)\cdot\left(\frac{(q-1)\left((q-1)^2\right)^{\frac{\phi-1}{2\phi}}}{b^{\frac{1}{\phi}}}\right)+\frac{\hat{k}\hat{c}(\rho+x\theta)}{\theta}$$

$$+\left(\frac{\hat{k}^2 q}{\phi b^{\frac{1}{\phi}}\left((q-1)^2\right)^{\frac{\phi-1}{2\phi}}}\right)\cdot\left(\frac{\phi\left((q-1)^2\right)^{\frac{\phi+1}{2\phi}}}{b^{\frac{1}{\phi}}(\phi+1)}+\alpha A\hat{k}^{\alpha-1}-q\delta\right)\Bigg]\cdot \tag{14}$$

$$\left(\frac{\hat{k}^2 q^2}{\phi b^{\frac{1}{\phi}}\left((q-1)^2\right)^{\frac{\phi-1}{2\phi}}}+\frac{\hat{k}\hat{c}}{\theta}\right)^{-1}$$

Constant steady-state effective capital intensity implies that the rate of gross investment must be the sum of the rate of capital depreciation plus the rate of labor augmenting technological progress, $\delta + x$. Steady-state effective per capita consumption can then be determined residually.

By assumption, all claims on domestic capital stock are held by domestic residents implying steady-state effective per capita asset wealth,

$$\widehat{\text{assets}}^{*}_{\text{closed}} = q^{*}\hat{k}^{*} \tag{15}$$

2.5 Small Open Economy Equilibrium

Within the present setup, the key characteristic defining an open economy is the ability of domestic residents and firms to borrow at a fixed world interest rate. Per capita effective net foreign liabilities are the difference between the current valuation of per capita effective domestic capital stock and per capita effective asset wealth.

$$\widehat{\text{net\_foreign\_liabilities}}\,(t) = q\,(t)\,\hat{k}\,(t) - \widehat{\text{assets}}\,(t) \tag{16}$$

The ability to borrow at a fixed world interest rate relaxes the aggregate resource constraint limiting domestic absorption to domestic production. The current account writes the

[9]Rearrange (13) moving $C_i(t)$ to right hand side; divide through by $K_i(t)$; divide left hand side numerator and denominator by $\exp(xt)$; take the derivative of both sides with respect to time; simplify.

difference between domestic production and domestic absorption as,

$$\begin{aligned}\widehat{\text{current\_account}}\,(t) &\equiv \text{net\_exports} - \text{net\_factor\_payments} + \text{adjustment} \\ &= \hat{y}\,(t) - \hat{c}\,(t) - \hat{\imath}\,(t) \cdot \left(1 + \left(\frac{b}{1+\phi}\right)\left(\frac{\hat{\imath}\,(t)}{\hat{k}\,(t)}\right)^{\phi}\right) \qquad (17) \\ &\quad - (r^* - x) \cdot \widehat{\text{net\_foreign\_liabilities}}\,(t)\end{aligned}$$

Net factor payments are just the interest payments to foreigners on outstanding net foreign liabilities. The "adjustment" term accounts for the change in *effective* net foreign liabilities due to technological progress.

The change in net foreign liabilities defines the capital account. Differentiating (16) with respect to time gives,

$$\begin{aligned}\widehat{\text{capital\_account}}\,(t) &\equiv \frac{d}{dt}\widehat{\text{net\_foreign\_liabilities}}\,(t) \\ &= \frac{d}{dt}q\,(t) \cdot \hat{k}\,(t) + \frac{d}{dt}\hat{k}\,(t) \cdot q\,(t) - \frac{d}{dt}\widehat{\text{assets}}\,(t) \qquad (18)\end{aligned}$$

Any current account deficits must be financed by an increase in net foreign liabilities, and so at all points in time the current and capital accounts will together sum to zero.

3 Calibration

Calibrating the neoclassical model laid out above and then comparing the growth rates implied by the open- and closed-economy versions shows that relaxing the aggregate resource constraint that domestic investment must be financed by domestic savings has only a small effect on per capita output growth. Rather than faster growth, the main effect of openness is to increase the level of current domestic consumption. Of course such a conclusion is premised upon a reasonably accurate calibration. To date, conventional wisdom has been that the neoclassical growth framework could not attain such a calibration. King and Rebelo (1993), in particular, argue that the Ramsey-Cass-Koopmans model implies transitional dynamics for growth rates, interest rates, savings rates, and asset prices which together can not match observed development patterns.

Successfully calibrating the Ramsey-Cass-Koopmans model in the present case relies on allowing for an average cost to capital adjustment which is convex with respect to the rate of gross investment. With the more conventional linear increasing average capital adjustment cost, the neoclassical framework indeed implies implausible transitional dynamics. For a closed economy, these include poor country real interest rates and rich country shadow values of capital which are "too high", speeds of convergence which are "too fast", and savings rates which seem implausible either in slope or in level. Moving to an open-economy framework exacerbates such problems. In contrast, a convex average cost to capital adjustment admits closed-economy transitional dynamics characterized by "low" real interest rates for poor economies, "low" shadow values of capital for rich economies, "slow" speeds of convergence, and a savings path that rises from "low" levels as countries develop.

3.1 Closed Economy

Figure 1 shows the development paths for convergence speed, the shadow value of capital, the real interest rate, and the savings rate as an economy grows from an initial per capita effective output 10 percent its steady state level.[10] [11]

As enumerated on the right hand side, the figure's narrow-capital-share calibration assumes 33 percent of aggregate income accrues to the owners of capital ($\alpha = 0.33$), an elasticity of intertemporal substitution value of one half ($\theta = 2$), and a steady-state shadow value of capital five percent above materials costs ($q^* = 1.05$). Within each panel, three alternative development paths are shown: with an average cost of adjustment which increases linearly in the rate of gross investment ($\phi = 1$), which is moderately convex with respect to

[10]Distinguishing a "development" path from a time path is the relative output denomination (horizontal axis) of the former. To the extent that the growth rate of output is proportional to the distance of output from its steady state, economic transitions will be characterized by long time periods with high relative output. A development path compresses this high relative output time period (somewhat akin to denominating with respect to log time).

[11]Such a low initial relative output makes the present calibration somewhat more ambitious than that in King and Rebelo (1993) who seek to replicate dynamics for an economy with initial per capita effective output 38 percent its steady-state level

the rate of gross investment ($\phi = 3$), and which is strongly convex with respect to the rate of gross investment ($\phi = 9$).

With adjustment costs arising from a CRS Cobb Douglas installation function which takes an uninstalled output good and converts it into installed capital using a fixed-quantity installation input and a variable-quantity installation input, a linear average adjustment cost corresponds to a 0.50 installation share for each of these. The moderate-convexity and high-convexity adjustment costs correspond to respective installation shares for the fixed-quantity input of 0.75 and 0.90. (See appendix.) While these latter fixed-quantity installation shares seem large for installation activities relying on large quantities of raw labor (e.g., low-density residential construction), for activities requiring either very specialized capital (e.g., the HDTV television tower example in the theory section above) or very high levels of human capital (e.g., higher education), such shares seem more reasonable.

Implausibly high speeds of convergence typically characterize attempts to calibrate the Ramsey-Cass-Koopmans growth model. Formally defining the speed of convergence as the rate at which output closes the log gap to its steady state, $\Lambda \equiv \frac{-\frac{\mathrm{d}}{\mathrm{d}t}(\log y - \log y^*)}{\log y - \log y^*}$, Figure 1 Panel A, shows that a linear increasing average cost of adjustment, $\phi = 1$, implies an asymptotic convergence speed $\Lambda^* = 0.074$. For countries further away from their steady states, the speed of convergence is much quicker (i.e., the speed of convergence decreases into the steady state). For a country with current output 20 percent its steady-state level, $\phi = 1$ implies a convergence speed $\Lambda = 0.376$.

Increasing the convexity of average adjustment costs tends both to lower and to flatten the convergence speed development path. With moderate convexity, $\phi = 3$, convergence speed drops from $\Lambda = 0.073$ when the relative output is 20 percent its steady-state to $\Lambda = 0.071$ when relative output is 60 percent steady-state to $\Lambda = 0.068$ asymptotically. With high convexity, $\phi = 9$, convergence speed becomes increasing with respect to relative output; it rises from $\Lambda = 0.015$ at 20 percent relative output to $\Lambda = 0.019$ at 60 percent relative output to $\Lambda = 0.055$ asymptotically.

Conventional wisdom is that an economy converges towards its steady state at a constant two percent per year (Barro, 1991; Barro and Sala-i-Martin, 1991, 1992, 1995; Sala-i-Martin, 1994). A more recent panel methodology, which seeks to control for the endogeneity of initial income, estimates a constant speed of convergence in the range of four percent to ten percent per year (Islam, 1995; Caselli, Esquivel, and Lefort, 1996). However, neither the conventional wisdom nor this latter methodology consider the possibility that the speed of convergence may vary as economies develop towards their steady state.[12]

Nesting a constant speed of convergence in a more general framework which allows for a varying speed of convergence, Rappaport (2000) argues that the empirical evidence supports a speed of convergence which increases into the steady state. Reported point estimates correspond to a convergence speed when output is at 20 percent its steady-state level in the range $0.007 \leq \Lambda \leq 0.015$ and an asymptotic convergence speed in the range $0.040 \leq \Lambda \leq 0.049$. Allowing for one standard deviation around the point estimates widens the implied convergence speed range so that $0.002 \leq \Lambda \leq 0.029$ at 20 percent relative output and $0.024 \leq 0.064$ asymptotically.[13] The high-convexity convergence speed development path in Figure 1 Panel A closely matches these empirical estimates.

Implausibly high shadow values of capital present a second obstacle to calibrating the Ramsey-Cass-Koopmans model. For a given depreciation rate, rate of technological progress, and convexity of average adjustment costs, (11) implies that the parameter calibrating the *level* of investment adjustment costs, b, maps one-to-one with the steady-state shadow value of capital, q^*; hence the steady-state shadow value of capital can be considered a choice variable. Lower steady-state shadow values of capital imply higher speeds of convergence at all relative output levels.

Unfortunately, shadow values of capital are unobservable. Under certain restrictive conditions, however, the shadow value of installed capital corresponds to the average value of installed capital which in turn can be proxied by the ratio of the market value of firms

[12]Evans (1997) and Lee, Pesaran, and Smith (1998) allow the speed of convergence to differ across economies but continue to impose that these different speeds remain constant along transition paths.

[13]Rappaport (2000) estimates the functional form $\Lambda = (\lambda_r - \lambda_p) \cdot \exp(-\kappa |\log(y/y^*)|) + \lambda_p$. Here λ_p is equivalent to the limit of convergence speed as initial output goes to 0 and λ_r measures asymptotic convergence speed. The point estimates for λ_p range from 0.003 to 0.009. The point estimates for λ_r range from 0.040 to 0.049 with an additional outlier estimate, $\lambda_r = 0.269$. The one-standard-deviation intervals discussed in the paragraph are approximate and are not meant to correspond to confidence intervals. Their construction imposes zero as a lower bound for λ_p and excludes the outlier estimate for λ_r as well as an estimate of λ_p with an outlier standard error.

to their book value (Hayashi, 1981). Aggregate U.S. timeseries data for the period 1900 to 1990 constructed by Blanchard, Rhee, and Summers (1993) show the average value of installed capital remaining close to one.[14] Hence the choice herein of a conservative steady-state shadow value of capital $q^* = 1.05$. Barnett and Sakellaris (1998), in contrast, find much higher average values of installed capital; using panel data on firms over the period 1960 to 1987, they report a median average value of installed capital, $q = 1.23$ and a 75th-percentile average value, $q = 1.95$. Moreover, investment tax incentives, by encouraging increased capital intensity, may cause observed average values of installed capital to appear "low" relative to actual installation frictions. Adjusted for tax considerations, Barnett and Sakellaris report median and 75th-percentile average values of capital, $q = 1.79$ and $q = 3.21$ respectively.[15]

Higher steady-state shadow values of capital help to lower the implausibly high convergence speeds; but only partly. With a linear increasing average cost of adjustment and the narrow-capital-share calibration shown in Figure 1, raising the steady-state shadow value of capital from $q^* = 1.05$ to $q^* = 1.50$ to $q^* = 5$ causes the asymptotic convergence speed to decrease from $\Lambda^* = 0.075$ to $\Lambda^* = 0.054$ to $\Lambda^* = 0.035$. Further raising the steady-state shadow value of capital results in the asymptotic speed of convergence itself asymptoting to $\Lambda^* = 0.029$ so that a steady-state convergence speed of 2 percent cannot be achieved no matter how high the *level* of linear average adjustment costs. At output levels below the steady state, the respective shadow values of capital will be even higher. Only by introducing convexity to average adjustment costs can the calibration in Figure 1 achieve *both* a low steady-state shadow value of capital and a low asymptotic speed of convergence.

However, for a given steady-state shadow value of capital, more convex average adjust-

[14] Presumably, U.S. capital intensity over this period remained relatively close — at least from below — its contemporary steady-state level.

[15] Summers (1981) also reports aggregate U.S. timeseries for the average value of installed capital which are consistent with a higher steady-state shadow value of capital than is suggested by the Blanchard, Rhee, and Summers data. Unadjusted for tax considerations, the Summers (1981) data attains a high, $q = 2.07$ in 1937; other "local maximums" include $q = 1.54$ in 1931 and $q = 1.41$ in 1965. The corresponding average values of installed capital from Blanchard, Rhee, and Summers are $q = 1.15$ in 1937, $q = 0.71$ in 1931, and $q = 0.99$ in 1965.

ment costs imply higher shadow values of capital at output levels below the steady state. In Figure 1 Panel B, with linear adjustment costs ($\phi = 1$), the shadow value of capital falls from $q = 2.35$ when output is at 20 percent its steady-state level to $q = 1.19$ when output is at 60 percent its steady-state level (to the assumed $q = 1.05$ asymptotically). With high-convexity adjustment costs ($\phi = 9$), the shadow value of capital falls from $q = 36.6$ to $q = 3.36$ over this same range. (See also Figure 5 Panel C.) So while a high-convexity average adjustment cost solves the problem of a high steady-state shadow value of capital (while maintaining a plausible development path of convergence speed), it exacerbates the problem of high shadow values of capital at low relative output levels.[16]

A more traditional approach to slowing down the convergence speed within a Ramsey-Cass-Koopmans framework is to interpret capital broadly to include, for instance, human capital. With a broad capital share, diminishing returns to capital set in slowly and so firms in countries with low capital intensity are unwilling to incur adjustment costs significantly higher than firms in countries with high capital intensity.[17]

The broad-capital-share calibration shown in Figure 2 assumes $\alpha = 0.67$. Here, the speed of convergence for a poor economy remains low even with a linear average adjustment cost ($\Lambda = 0.037$ at 20 percent relative output with $\phi = 1$) and the shadow value of capital for a poor economy remains relatively low even with a high-convexity average adjustment cost ($q = 2.31$ at 20 percent relative output with $\phi = 9$). In fact, with a linear average adjustment cost, the closed-economy broad-capital-share calibration implies shadow values of capital for very poor economies which seem too low: for a an economy with current output 20 percent its steady-state level, the shadow value of installed capital is just 11 percent above

[16] An alternative way of solving the problem of a high steady-state shadow value of capital while maintaining a plausible development path of convergence speed is to assume that the adjustment cost friction applies to net effective investment rather than gross investment (e.g., that the adjustment cost is given by $\frac{(b/2)(I/K-\delta-x)^2}{I/K}$) in which case the steady-state shadow value of capital will always be $q^* = 1$ (Summers, 1981; Ortigueira and Santos, 1997). Such an approach will not slow the *asymptotic* speed of convergence. But at lower capital intensities, a sufficiently high "level" adjustment friction, b, will always be able to slow convergence to plausible levels.

[17] However, explicitly modeling human capital formation and physical capital formation separately within an endogenous growth framework, Ortigueira and Santos (1997) find that increasing human capital's share in production actually increases the speed of convergence.

the materials cost ($q = 1.11$). Such a low shadow value of installed capital is not consistent with the sorts of hurdles firms presumably face in investing in developing economies.

Implausibly high real interest rates for relatively poor economies present a third obstacle to calibrating the Ramsey-Cass-Koopmans model. Assuming a narrow capital share, Figure 1 Panel C shows that with $\phi = 1$, real interest rates fall from $r = 1.258$ when output is at 20 percent its steady-state level to $r = 0.215$ when output is at 60 percent to $r = 0.060$ asymptotically. As with convergence speed, these high real interest rates can be brought down either by increasing the convexity of adjustment costs or by assuming a broad capital share. With $\phi = 9$ (and retaining $\alpha = 0.33$), real interest rates fall from $r = 0.109$ at 20 percent relative output to $r = 0.081$ at 60 percent relative output to $r = 0.060$ asymptotically. With $\alpha = 0.67$ (and retaining $\phi = 1$), real interest rates fall from $r = 0.181$ to $r = 0.089$ to $r = 0.060$ over this same output interval (Figure 2 Panel C). Only the high-convexity development path, however, is close to matching the stylized fact that real interest rates remain relatively constant as an economy develops (Kaldor, 1961).

The transitional behavior of savings rates represents a fourth observable development path to replicate. Two conceptually distinct issues regard the level and the slope of savings rates as an economy develops. Figures 1 and 2 Panel D illustrate narrow- and broad-capital-share steady-state savings rates of 21 percent and 42 percent, respectively. Both levels of savings seem plausible given the respective interpretations of capital. With the narrow capital share shown in Figure 1 Panel D, a linear adjustment cost ($\phi = 1$) effects a generally declining savings profile, a moderate-convexity adjustment cost ($\phi = 3$) effects a rising and then declining savings profile, and a high-convexity adjustment cost ($\phi = 9$) effects a generally rising savings profile. (In fact, all three savings profiles are "hump shaped" in that they are made up first of a rising and then a declining segment.) The broad-capital-share calibrations in Figure 2 Panel D show similar, if slightly flatter, corresponding savings profiles. While not conclusive, empirical evidence suggests a rising savings profile as an economy develops (Barro and Sala-i-Martin, 1995).

Summing up, the main difficulties calibrating the closed-economy Ramsey-Cass-Koopmans model are implausibly high levels for the speed of convergence, for the shadow value of capital, and for poor country real interest rates. Nevertheless, closed-economy development dynamics can be somewhat approximated either by assuming a high-convexity average adjustment cost or by assuming a broad capital share. Figure 5, Panels A, C, and D illustrate this for an economy with current output 60 percent its steady-state level. The main disadvantage to assuming a high-convexity adjustment cost (along with a narrow capital share) are the very high shadow values of capital implied for poor economies. The less glaring disadvantages to assuming a broad capital share (along with a linear average cost of adjustment) include the decreasing speed of convergence, low shadow values of capital for poor economies, and the declining-to-flat savings profile.

Moving to an open-economy framework, the high-convexity solution continues to successfully calibrate the Ramsey-Cass-Koopmans model whereas the broad capital share solution requires the additional assumption of borrowing constraints to do so.

3.2 Open Economy

Timeless development policy issues including the role of foreign investment, the advantages of various exchange rate regimes, and the ideal "international financial architecture" are indicative that most developing nations have at least some international trade and at least some access to international capital. Hence the importance that a successful calibrated Ramsey-Cass-Koopmans model effect plausible timeseries in an open-economy framework.

Open-economy transitional development paths for convergence speed and the shadow value of capital under narrow and broad interpretations of capital are shown in Figures 3 and 4 (Panels A and B), respectively. Opening an economy to foreign capital flows raises both convergence speed and the shadow value of capital at all relative output levels, regardless of capital share and regardless of the convexity of adjustment costs. For convergence speed, the result is intuitive given the relaxation that domestic savings must finance domestic investment. For the shadow value of capital, the result derives from the lower real interest rates discounting future marginal revenue.[18]

The magnitude of the increase in convergence speed is especially large under a broad

[18]Partly offsetting this interest rate effect is the faster convergence speed and hence quicker decline in the marginal revenue product of installed capital.

capital share, linear adjustment cost calibration; so much so, in fact, that a broad capital share no longer suffices to effect a plausible convergence speed development path. In Figure 4 Panel A, the linear adjustment cost open-economy convergence speed falls from $\Lambda = 0.378$ when output is at 20 percent its steady-state level to $\Lambda = 0.250$ when output is at 60 percent its steady-state level to $\Lambda = 0.210$ asymptotically. A high convexity adjustment cost, however, continues to suffice to slow the open economy system. With a broad capital share and $\phi = 9$, convergence speed rises from $\Lambda = 0.017$ to $\Lambda = 0.028$ as output increases from 20 percent to 60 percent its steady-state level to $\Lambda = 0.059$ asymptotically. With the narrow capital share shown in Figure 3 Panel A and retaining $\phi = 9$, convergence speed is only slightly higher: it rises from $\Lambda = 0.018$ to $\Lambda = 0.027$ to $\Lambda = 0.090$ over this same interval. The broad-capital-share transition path closely matches the empirical point estimates reported in Rappaport (2000) while the narrow-capital-share transition path remains well within two-standard-deviation confidence intervals of these.

The role of a high-convexity average adjustment cost to slow down the open-economy convergence speed is emphasized by Figure 5 Panel B. For an open economy with current output 60 percent its steady-state level and assuming a broad capital share, convergence speed remains above 6 percent per year for $\phi \leq 2$, above 4 percent per year for $\phi \leq 3$, and above 2 percent per year for $\phi \leq 6$. Moving to a narrow-capital-share calibration, the convexity thresholds rise. And for economies with lower current relative output, convergence speed becomes more sensitive to the convexity of adjustment costs. Even allowing for a much higher *level* for the capital adjustment cost, moderately high convexity remains necessary to slow down convergence. Assuming a capital friction such that the steady-state shadow value of capital, q^*, equals 2 (so that at the steady-state, realized adjustment costs equal materials costs, a twentyfold increase over the base calibration 5 percent realized adjustment cost shown in the figures) along with a broad capital share, convergence speed for an economy with current output 60 percent its steady-state level remains above 2 percent per year for $\phi \leq 3$.

An alternative way to slow high open-economy convergence speeds are borrowing constraints. In particular, Barro, Mankiw, and Sala-i-Martin (1995) suggest that the future labor earnings which accrue to human capital serve as a poor source of collateral for borrowing. Hence they allow developing economy individuals and firms to borrow from abroad to finance only physical capital accumulation. As long as the share of total capital which must be financed from domestic savings remains sufficiently large, the speed of convergence remains plausibly slow. While constraints on borrowing for human capital formation and even for physical capital formation surely must exist, that they are the key mechanism slowing open-economy convergence is less convincing. In particular, Kremer and Thomson (1998) point out that developing countries which have been able to devote large resources to human capital formation have not experienced rapid economic growth. And Duczynski (2000) argues that few countries have sufficiently high net indebtedness that borrowing constraints bind.

The small open-economy setting obviates the need to calibrate a real interest rate development path. By the consumption Euler equation, (9), and the assumption of perfect capital markets, domestic residents' consumption growth rate immediately jumps to its steady state, the rate of exogenous technological progress (x). Consumption levels and savings rates are then determined residually by the intertemporal budget constraint. For an economy with current output low relative to its steady state, borrowing by domestic residents to smooth consumption fuels large trade deficits which quickly accumulate into substantial net foreign liabilities.

In Figures 3 and 4, domestic residents are assumed to own all domestic capital upon the opening to capital flows of an economy with initial output 10 percent its steady-state level (so initial domestic asset wealth equals initial gross capital stock multiplied by the shadow value of capital immediately after opening). Panels C and D respectively show the development paths of the economy's trade balance and net foreign liabilities (in both cases, relative to output). Assuming a narrow capital share along with a linear average adjustment cost, the trade deficit upon opening is 1,100 percent current output! Thereafter, as the economy grows to 20 percent to 60 percent to 100 percent its steady-state output, the trade deficit falls to 500 percent to 100 percent current output to a surplus 17 percent current output. Net foreign liabilities relative to output rise monotonically asymptoting to 4.3 times output at the steady state.

A high-convexity adjustment cost (retaining a narrow capital share) effects smaller trade deficits but a cumulatively larger stock of debt. Upon opening, the trade deficit is 125 percent current output; as the economy grows from 20 percent to 60 percent to 100 percent its steady-state output, the trade balance moves from a deficit 17 percent of current output to surpluses 50 percent to 59 percent of output, respectively. Net foreign liabilities rise to a maximum level 18.0 times current output (at $y/y^* = 0.42$) before asymptoting down to 14.7 times current output at the steady state. The trade surpluses which arise during the latter stages of development finance interest payments on the large net foreign liabilities. The development paths of trade balances and net foreign liabilities are qualitatively similar under a broad-capital-share calibration.[19]

Such trade deficit and net foreign liability levels are clearly implausibly large. Rather than investment, they primarily finance high current levels of consumption. For instance, with a narrow capital share, a high convexity adjustment cost, and relative output 10 percent its steady-state level, domestic consumption for a newly open economy exceeds twice domestic output! The Barro, Mankiw, Sala-i-Martin (1995) critique on individuals' ability to finance human capital formation applies even stronger to individuals' ability to finance consumption. Domestic gross investment (including adjustment costs), in contrast, is equivalent to just 20 percent domestic output. As long as such investment results in tangible installed capital to back loans, it should be able to obtain financing (irrespective of magnitude given the forward-looking full-information specification herein). If so, the implausibly large trade deficits in no way undermine the paper's conclusion that openness to capital flows effects only a small increase in the growth rate of output. Individual liquidity constraints temper domestic borrowing while leaving the development path of domestic output unchanged. Put

[19]Upon opening, the current account equals the trade balance; thereafter the current account development path lies strictly below the trade balance development path by an increasing amount as the economy grows towards its steady state. The steady-state current account is always zero. While the current account is just the negative of the slope of the *time* path of net foreign liabilities, it cannot be inferred from Panel C of Figures 3 and 4 due both to the relative output denomination of the horizontal scale as well as to the normalization by output of the vertical scale. The slower convergence speed effected by high convexity adjustment costs reconciles the associated smaller initial trade deficits but higher asymptotic net foreign liabilities. With low-convexity average adjustment costs, economies intially run much higher trade deficits; but because such economies grow very quickly, they accumulate less debt. (See also footnote 10.)

differently, there is complete "Fisherian separation" between investment and consumption decisions.

As discussed above, however, with a broad capital share liquidity constraints may limit investment as well as consumption. If so, the open-economy speed of convergence associated with a broad capital share will be somewhat lower than shown in Figure 4 Panel A.

In summary, high convexity adjustment costs along with individual borrowing constraints turn out to be the key to successfully calibrating an open-economy Cass-Koopmans-Ramsey model. For the purpose of examining the effect of openness to capital flows on growth, such borrowing constraints can be ignored so long as a narrow-capital-share calibration is used. With a broad-capital-share calibration, imposing borrowing constraints will slow the open-economy speed of convergence; hence the broad-capital-share calibration may exaggerate the effect of openness to capital flows on growth.

4 The Effect of Openness to Capital Flows

So, how does openness to capital flows affect economic growth?

Comparing closed-economy and open-economy versions of the calibrated Ramsey-Cass-Koopmans model shows that openness, in the sense of relaxing the constraint that domestic savings finance domestic investment, contributes to only a small increase in the growth rate of output. While this insensitivity result depends critically on assuming a moderate-to-high convexity for the average cost to gross capital investment, it is extremely robust to alternative assumptions for nearly every other parameter including the capital share of output, the steady-state shadow value of capital, and the elasticity of intertemporal substitution.

Figure 6 Panel C depicts the development paths of output growth for an open and a closed economy under a narrow-capital-share, high-convexity calibration; Figure 7 Panel C does the same under a broad-capital-share, high-convexity calibration. In both cases, the open-economy growth development path lies only slightly above the closed-economy growth development path. With a narrow capital share, an open economy's growth rate exceeds that of a closed economy by 0.4 percentage points when output is at 20 percent its steady-state level falling to a 0.1 percentage point advantage when output is at 60 percent its steady-state level; with a broad capital share, the extra growth due to openness falls from 0.7 percentage points to 0.5 percentage points over this same interval.

Underlying the insensitivity of growth to openness is that high-convexity adjustment costs cause aggregate gross investment demand to become relatively inelastic with respect to interest rates. In a closed economy, increased investment requires eliciting increased savings via higher interest rates; realized investment occurs where downward-sloping aggregate investment demand intersects upward-sloping aggregate savings supply. Moving to an open economy, individuals' desire to smooth consumption no longer serves as a check on investment; savings supply becomes horizontal at the steady-state interest rate.

The more inelastic is aggregate gross investment demand, the smaller the effect of openness on aggregate gross investment. Figure 6 Panel A shows the development path of gross investment for both an open and a closed economy assuming a narrow capital share; Figure 7 Panel A does the same assuming a broad capital share. For an economy with a relative output level close to its steady state, the marginal gross investment effected by openness with the narrow-capital-share calibration is relatively small. But more generally, openness is associated with moderately high increase in gross investment. For an economy with initial output 20 percent its steady-state level, under a narrow-capital-share calibration gross investment rises from 7.4 percent in a closed economy to 14.8 percent in open economy; under a broad-capital-share calibration, it rises from 30.9 percent to 41.2 percent.

Two additional forces underlie the insensitivity of growth to openness. A first tempering force is that a large part of the marginal gross investment attributable to openness represents higher incurred adjustment costs. Figures 6 and 7 Panel B illustrate that openness' effect on the growth rate of installed effective capital stock (i.e., net capital investment) is much smaller than its effect on gross capital investment; the difference is "spent" on adjustment as indicated by much higher open-economy shadow values of capital. For an economy with initial output 20 percent steady-state level, under a narrow-capital-share calibration, $q_{\text{closed}} = 36.6$ versus $q_{\text{open}} = 74.5$; under a broad-capital-share calibration, $q_{\text{closed}} = 2.3$ versus $q_{\text{open}} = 4.0$.

A second tempering force is the diminishing returns algebraic relationship that the difference between the closed-economy and open-economy growth rates of output will be the difference between the growth rates in installed capital stock multiplied by the fractional Cobb Douglas coefficient on capital in output production (i.e. α). Hence the magnitude of the effect of openness on output growth is one-third and two-thirds its magnitude on capital stock growth under the narrow and broad capital interpretations, respectively (Figures 6 and 7, Panel C). That diminishing returns set in less quickly the higher the capital share in production largely accounts for the slightly larger effect of openness on growth under the broad capital interpretation. Even this slight difference, however, is likely to be exaggerated given the possibility of borrowing constraints.

With a high-convexity average adjustment cost, the insensitivity of growth to capital openness is extremely robust. Figure 8 illustrates that with $\phi = 9$, growth due to openness for an economy with current output 60 percent its steady-state level remains below one percentage point per year for both the narrow and broad capital share, regardless of the level of the adjustment cost, q^*, and regardless of the elasticity of intertemporal substitution, θ.

In contrast, the effect of capital openness on growth is extremely sensitive to the convexity of average adjustment costs. Figure 8 also illustrates that with a moderate-convexity adjustment cost, $\phi = 3$, either a low level adjustment cost (q^* close to 1) or a low elasticity of intertemporal substitution (θ high) is sufficient for openness to effect a large increase in growth. With a linear adjustment cost, $\phi = 1$, the effect of openness on growth is large for both the narrow and broad capital share, regardless of the level of the adjustment cost and regardless of the elasticity of intertemporal substitution.

Of course, as discussed at length in the previous two sections, the low convexity-calibrations which imply a large effect of openness on growth also tend to imply strongly counterfactual development series. In particular, a low-convexity narrow-capital-share calibration effects implausibly high speeds of convergence and implausibly high real interest rates; these would seem to make the associated effect of openness on growth irrelevant. For a low-convexity broad-capital-share calibration, rejecting the large effect of openness on growth based on the implausibly high open-economy speed of convergence would seem tautological. Here, instead, it is the presumed inability of broad capital to serve as collateral against borrowing which makes the associated effect of openness on growth irrelevant. An additional objection to the broad-capital-share calibration are the implausibly low closed-economy shadow values of capital for relatively undeveloped economies.

For all relevant calibrations, the effect of openness to capital flows on growth always remain small.

5 Conclusions

This paper has argued that an average adjustment cost to capital formation which is increasing and convex with respect to the rate of gross investment successfully calibrates the Ramsey-Cass-Koopmans neoclassical growth model. For a closed economy, a high-convexity adjustment cost effects plausible real interest rates and an increasing savings rate development path. For both a closed economy and an open economy, a high convexity adjustment cost effects a slow, increasing convergence development path. A first main weakness of the high-convexity calibration is the extremely high shadow values of capital for undeveloped economies when assuming a narrow capital share; but moving to a broader interpretation of capital results in more reasonable developing-economy shadow values of capital. A second weakness of the high-convexity calibration is the extremely high trade deficits and net foreign liability levels; here, imposing that foreign borrowing must be backed by capital brings such deficits and debt levels down to reasonable levels.

Comparing the open-economy and closed-economy versions of the calibrated model shows that openness to capital flows causes only a very small increase in the rate of per capita output growth. This insensitivity result holds for all relevant calibrations. While it does depend on a high-convexity average adjustment cost, it is extremely robust to a wide range of assumptions on the capital share of output, the steady-state shadow value of capital, and the elasticity of intertemporal substitution. Alternative calibrations which instead suggest a large effect of openness on growth either generate strongly counterfactual closed-economy development series or depend on the unrealistic assumption that individuals can borrow against future labor earnings (or both).

The limited effect of capital openness on economic growth in no way implies that a broader notion of openness is unimportant for economic growth. As stated in the introduction, there are a slew of reasons why openness may matter: comparative advantage, competition, technology transfer, increasing returns to scale. The present result is just that if openness matters, it is not due to relaxing the constraint that domestic savings finance domestic investment: *with well-functioning domestic credit markets*, domestic savings should be sufficient to finance relatively high levels of domestic investment. An important implication is that for developing countries where domestic investment is thought to depend critically on access to foreign capital, public policy might seek institutional reform which improves individuals' access to efficient savings technologies. Such a recommendation is consistent with empirical results reported in Levine, Loayza, and Beck (2000). They find that the exogenous component of financial intermediary development has a large positive impact on economic growth.

A second policy implication is that if high levels of net foreign liabilities are thought for some reason to have negative implications for a country, so long as the country has well-functioning domestic credit markets, enacting a small "Tobin" tax on capital inflows should impose negligible economic costs.

More generally, successfully calibrating the Ramsey-Cass-Koopmans model presages that neoclassical growth theory still has much to teach us. While the welfare implications of transitional dynamics may be swamped by those of long run endogenous technological change and productivity growth, demarcating the limits of neoclassical theory helps clarify where endogenous growth theory must begin and so complements efforts to understand long run growth.

Appendix

A A Convex Average Cost of Adjustment

To get some intuition on the convexity of average adjustment costs, consider the case of a CRS Cobb-Douglas installation function which takes $Y_I(t)$ units of uninstalled output and converts them into $I(t)$ units of installed capital using a fixed-quantity input, K_I, and a variable-quantity input, $L_I(t)$.

$$I(t) = \min \left(\underbrace{Y_I(t)}_{\substack{\Uparrow \\ \text{raw} \\ \text{materials}}} \quad , \quad \underbrace{\mathrm{B} K_I^{\beta} L_I(t)^{1-\beta}}_{\substack{\Uparrow \\ \text{installation} \\ \text{function}}} \right) \tag{A.1a}$$

Note that is important to distinguish between "output capital" and "installation capital". "Output capital" refers to capital used in the production of the numeraire good in the main text above; the gross addition to output capital is the result of the production function (A.1a) . "Installation capital" refers to K_I, an input of the present production function. Like output capital, at any point in time the stock of installation capital is fixed. Unlike output capital, the evolution of installation capital will not be modeled and so its contribution to installation costs will be ignored. One possible interpretation is that a firm's installation capital is just proportional to its output capital; another is that installation capital is a congestible public good available to firms in proportion to their rate of gross investment.

The average adjustment cost of gross investment then is just the average cost arising from installation labor. By assumption, the price of installation labor, w, is given exogenously (for instance, by its reservation value in the non-installation market). With the quantity of installation capital, K_I, predetermined, (A.1a) gives the average adjustment cost arising from installation labor as,

$$\frac{w \cdot L_I(t)}{I(t)} = \frac{w}{B^{\frac{1}{1-\beta}}} \cdot \left(\frac{I(t)}{K_I} \right)^{\frac{\beta}{1-\beta}} \tag{A.1b}$$

Note that (A.1b) is increasing and convex with respect to realized gross investment, $I(t)$, so long as $\beta > \frac{1}{2}$. In other words the convexity parameter from the main text above, ϕ, is greater than or less than one as the coefficient on installation capital, β, is greater than or less than one half.

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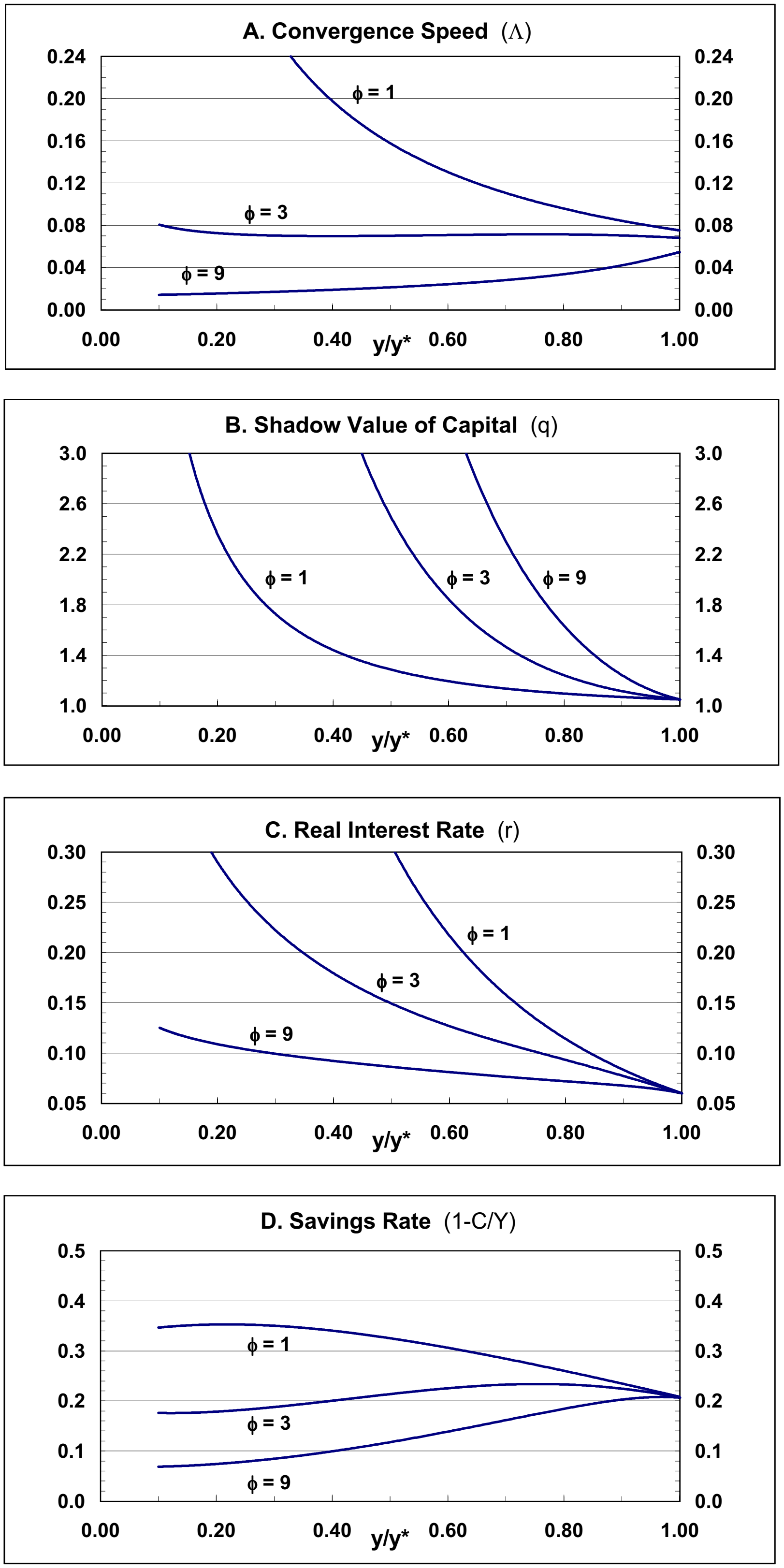
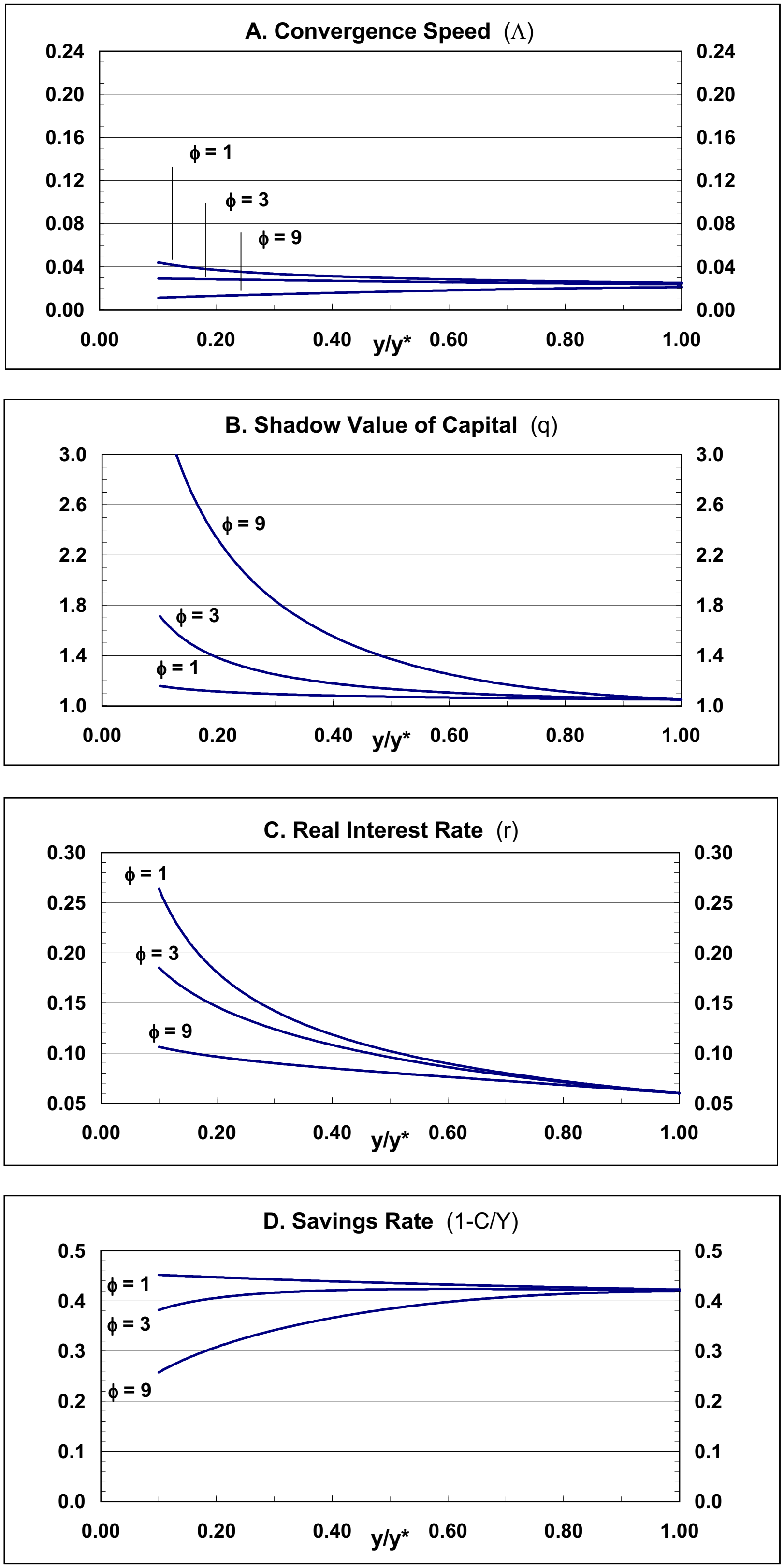
Figure 1: Closed Economy Transitional Dynamics, Narrow Capital Share



Parameters:

Capital Share	$\alpha = 0.33$
Elasticity of Intertemporal Substitution (Reciprocal)	$\theta = 2$
Steady-State Shadow Value of Capital	$q^* = 1.05$
Rate of Time Preference	$\rho = 0.02$
Rate of Capital Depreciation	$\delta = 0.05$
Rate of Exogenous Technological Progress	$x = 0.02$
Steady State Interest Rate	$r^* = 0.06$
Capital Adjustment Cost	$\sim (I/K)^{\phi}$

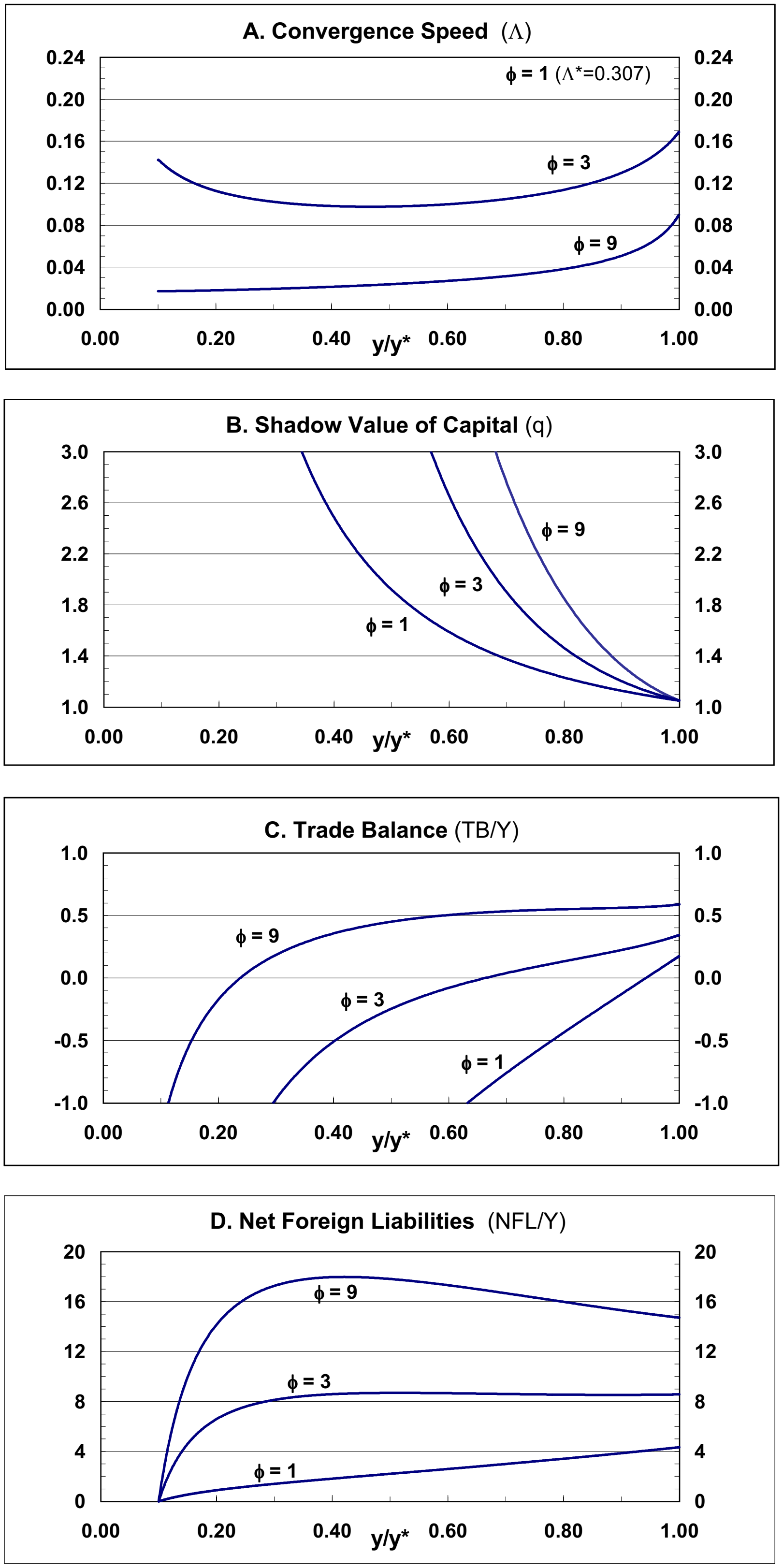
Figure 2: Closed Economy Transitional Dynamics, Broad Capital Share



Parameters:

Capital Share	$\alpha = 0.67$
Elasticity of Intertemporal Substitution (Reciprocal)	$\theta = 2$
Steady-State Shadow Value of Capital	$q^* = 1.05$
Rate of Time Preference	$\rho = 0.02$
Rate of Capital Depreciation	$\delta = 0.05$
Rate of Exogenous Technological Progress	$x = 0.02$
Steady State Interest Rate	$r^* = 0.06$
Capital Adjustment Cost	$\sim (I/K)^{\phi}$

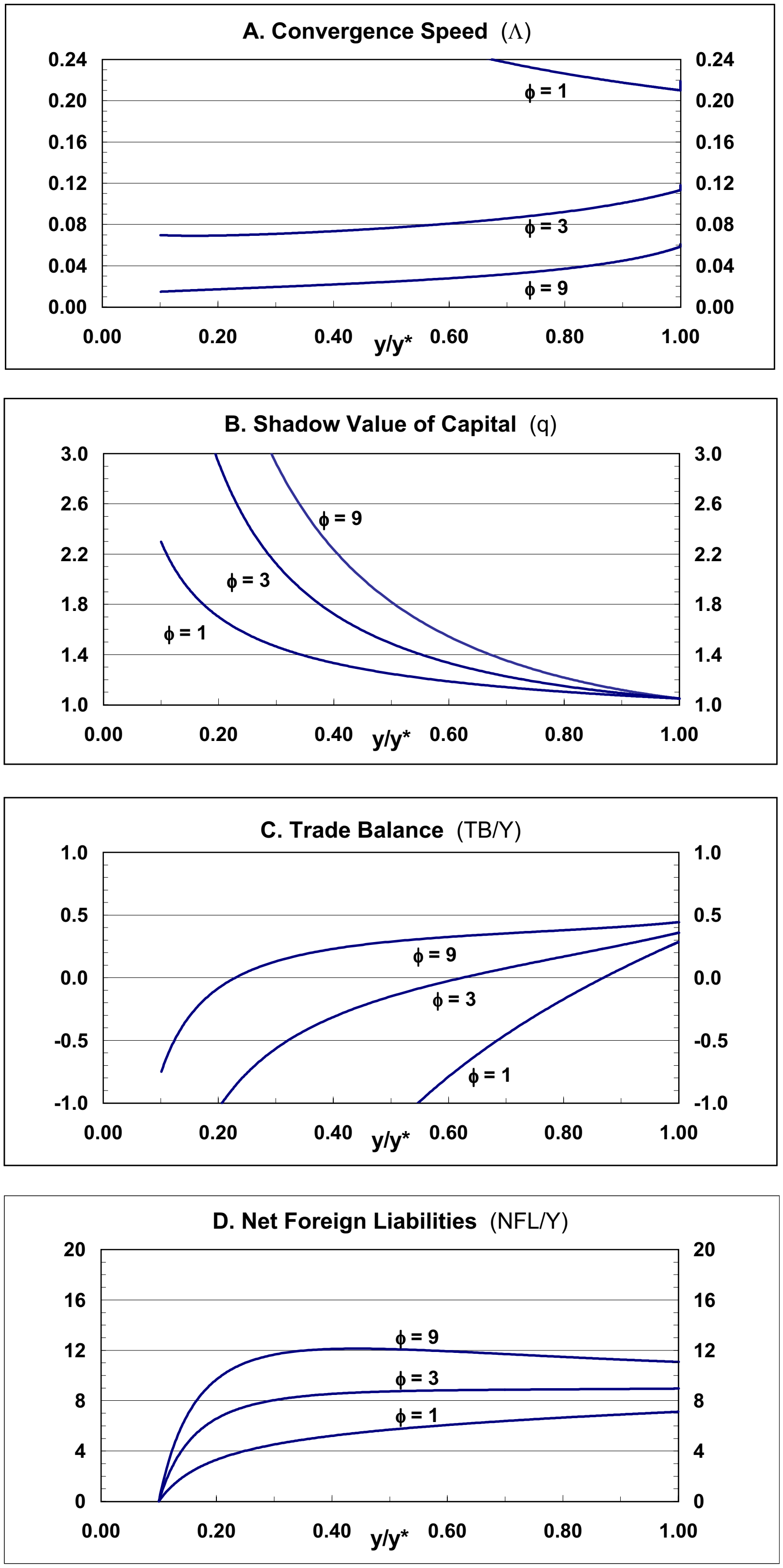
Figure 3: Open Economy Transitional Dynamics, Narrow Capital Share



Parameters:

Capital Share	$\alpha = 0.33$
Elasticity of Intertemporal Substitution (Reciprocal)	$\theta = 2$
Steady-State Shadow Value of Capital	$q^* = 1.05$
Rate of Time Preference	$\rho = 0.02$
Rate of Capital Depreciation	$\delta = 0.05$
Rate of Exogenous Technological Progress	$x = 0.02$
Steady State Interest Rate	$r^* = 0.06$
Capital Adjustment Cost	$\sim (I/K)^{\phi}$

Figure 4: Open Economy Transitional Dynamics, Broad Capital Share



Parameters:

Capital Share	$\alpha = 0.67$
Elasticity of Intertemporal Substitution (Reciprocal)	$\theta = 2$
Steady-State Shadow Value of Capital	$q^* = 1.05$
Rate of Time Preference	$\rho = 0.02$
Rate of Capital Depreciation	$\delta = 0.05$
Rate of Exogenous Technological Progress	$x = 0.02$
Steady State Interest Rate	$r^* = 0.06$
Capital Adjustment Cost	$\sim (I/K)^{\phi}$

Figure 5: Varying the Convexity of Average Adjustment Costs

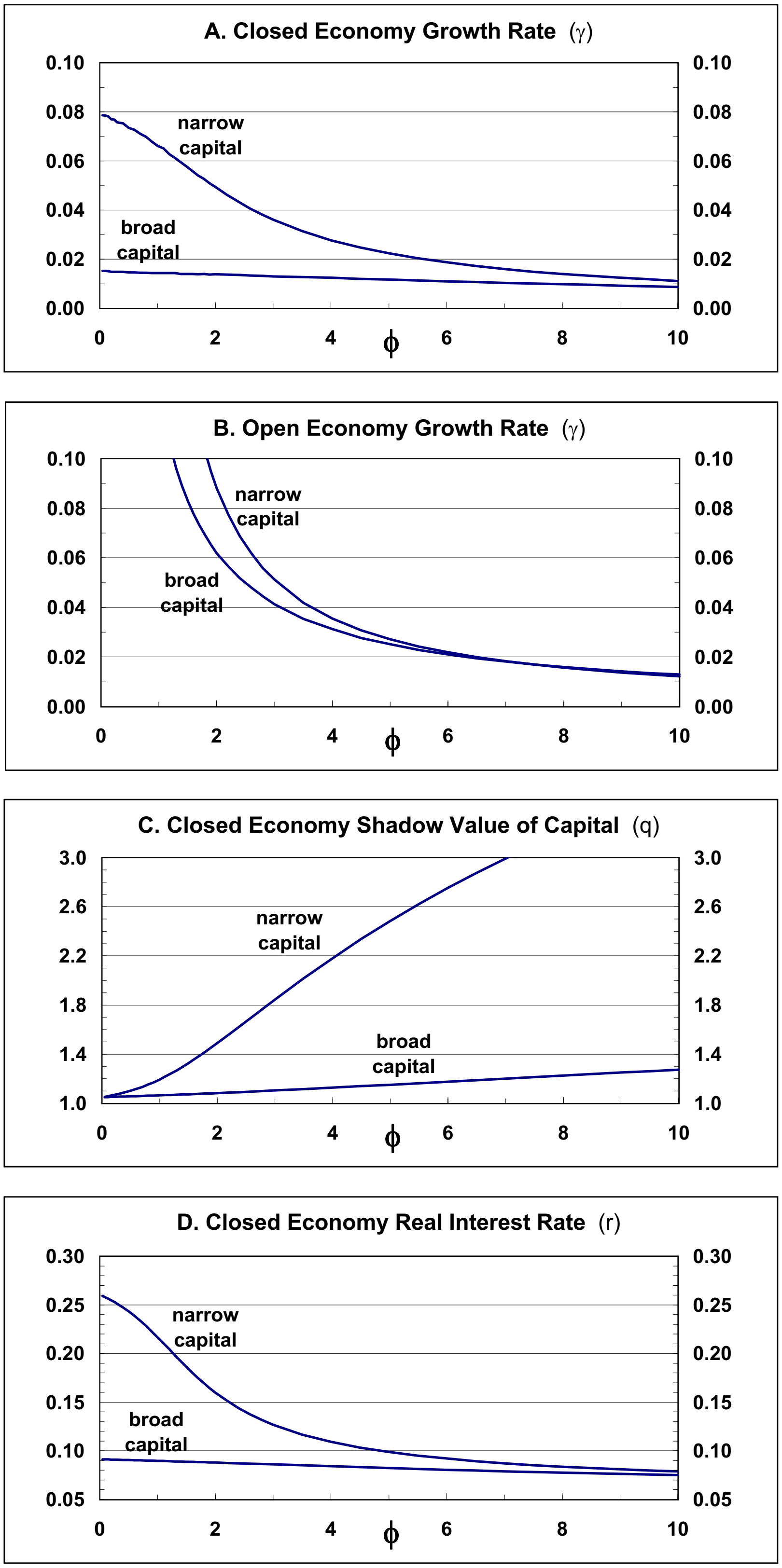
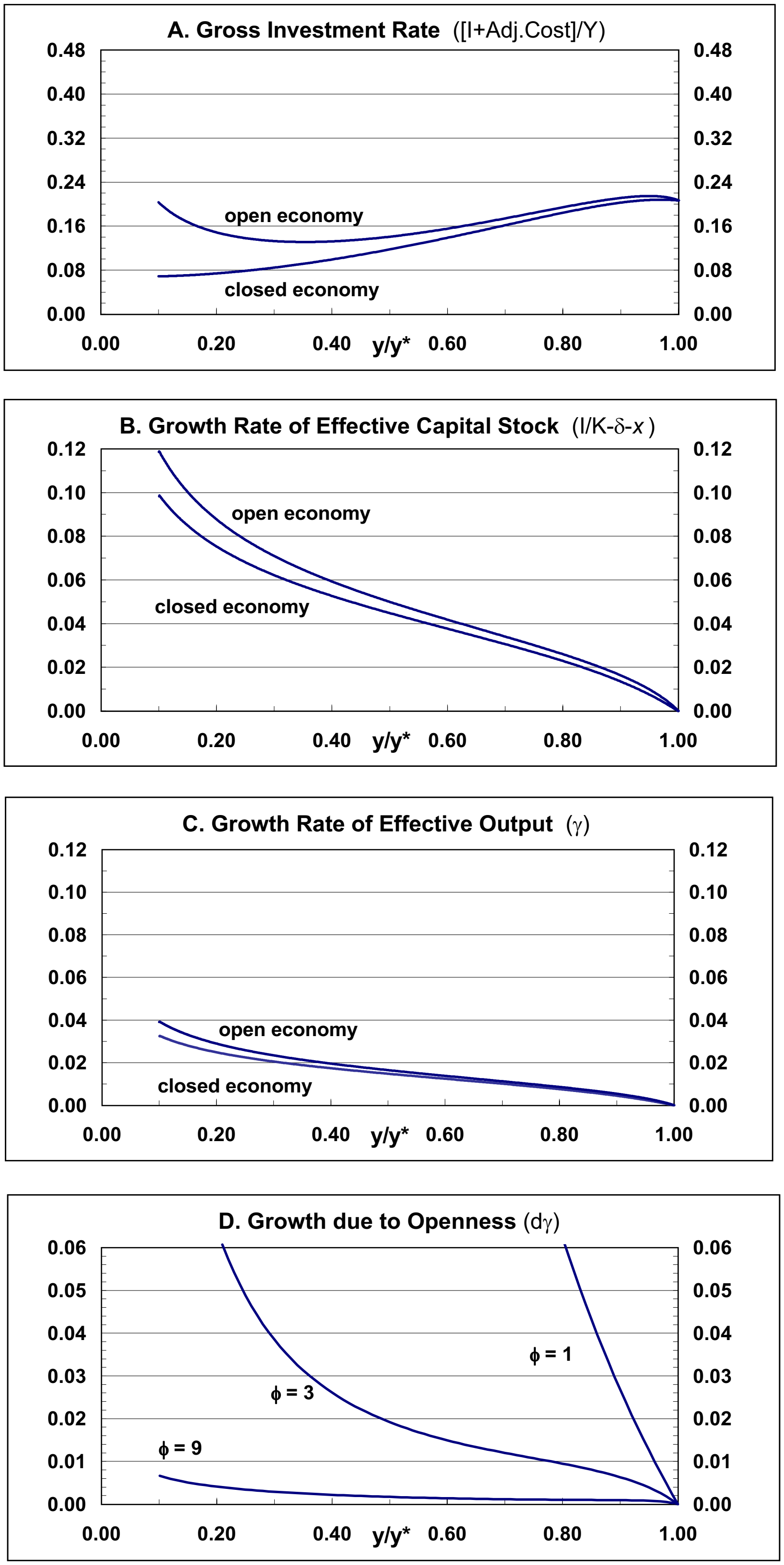


Figure shows the effects of varying the convexity of average adjustment costs on the growth rate of output, the shadow value of capital, and the real interest rate for an economy with current income 60% its steady-state level.

Parameters:

Relative Income	$Y/Y^* = 0.60$
Narrow Capital Share	$\alpha = 0.33$
Broad Capital Share	$\alpha = 0.67$
Steady-State Shadow Value of Capital (Panels A and B)	$q^* = 1.05$
Elasticity of Intertemporal Substitution (Reciprocal) (Panels C and D)	$\theta = 2$
Capital Adjustment Cost	$\sim (I/K)^{\phi}$

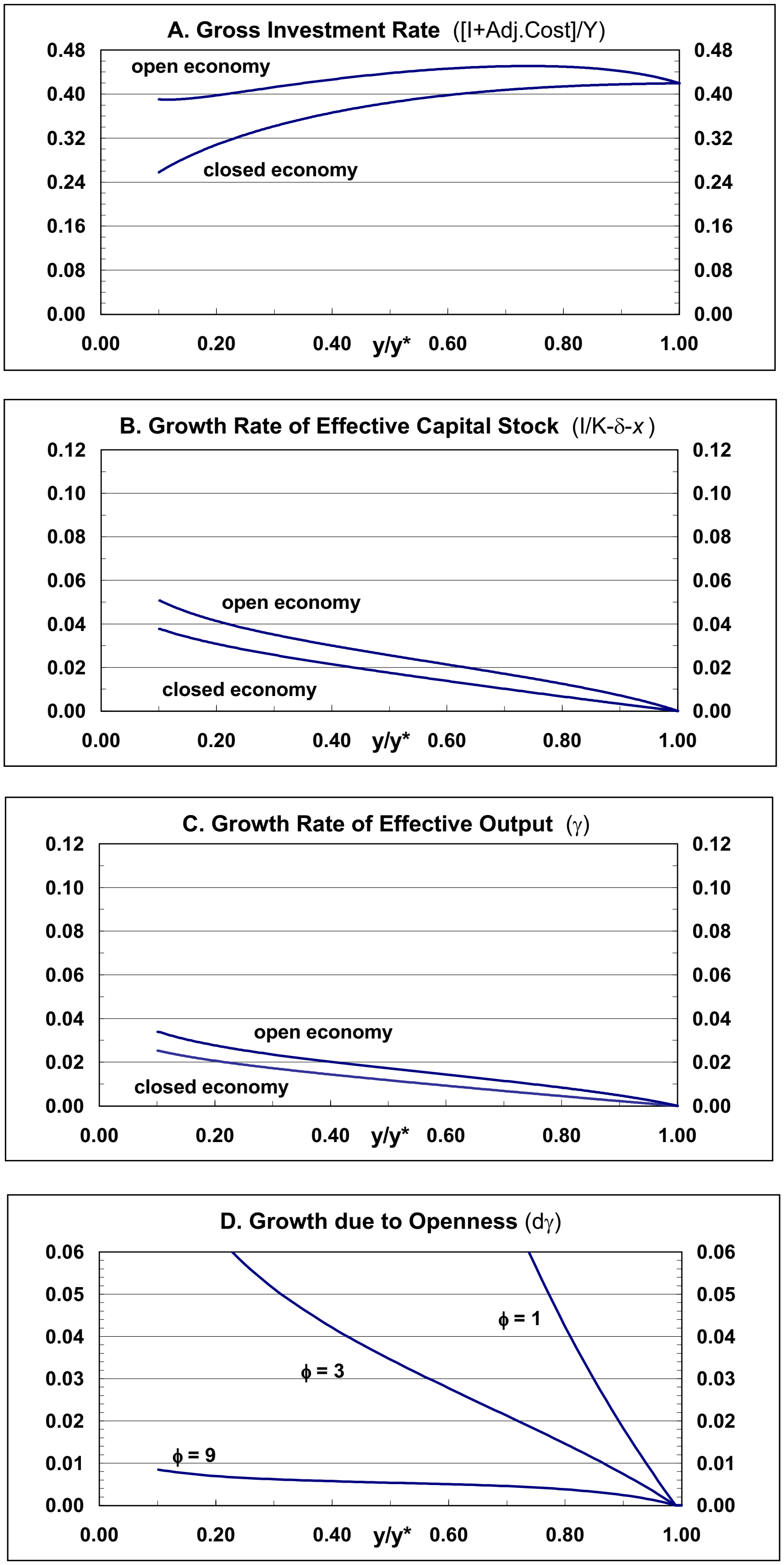
Figure 6: Openness and Growth, Narrow Capital Share with High Convexity



Parameters:

Capital Share	$\alpha = 0.33$
Elasticity of Intertemporal Substitution (Reciprocal)	$\theta = 2$
Steady-State Shadow Value of Capital	$q^{*}= 1.05$
Rate of Time Preference	$\rho = 0.02$
Rate of Capital Depreciation	$\delta = 0.05$
Rate of Exogenous Technological Progress	$x = 0.02$
Steady State Interest Rate	$r^{*} = 0.06$
Convexity of Average Adjustment Cost (Panels A, B, and C)	$\phi = 9$
Capital Adjustment Cost	$\sim (I/K)^{\phi}$

Figure 7: Openness and Growth, Broad Capital Share with High Convexity



Parameters:

Capital Share	$\alpha = 0.67$
Elasticity of Intertemporal Substitution (Reciprocal)	$\theta = 2$
Steady-State Shadow Value of Capital	$q^* = 1.05$
Rate of Time Preference	$\rho = 0.02$
Rate of Capital Depreciation	$\delta = 0.05$
Rate of Exogenous Technological Progress	$x = 0.02$
Steady State Interest Rate	$r^* = 0.06$
Convexity of Average Adjustment Cost (Panels A, B, and C)	$\phi = 9$
Capital Adjustment Cost	$\sim (I/K)^{\phi}$

Figure 8: Growth Due to Openness, the Elasticity of Intertemporal Substitution, and the Steady-State Shadow Value of Capital

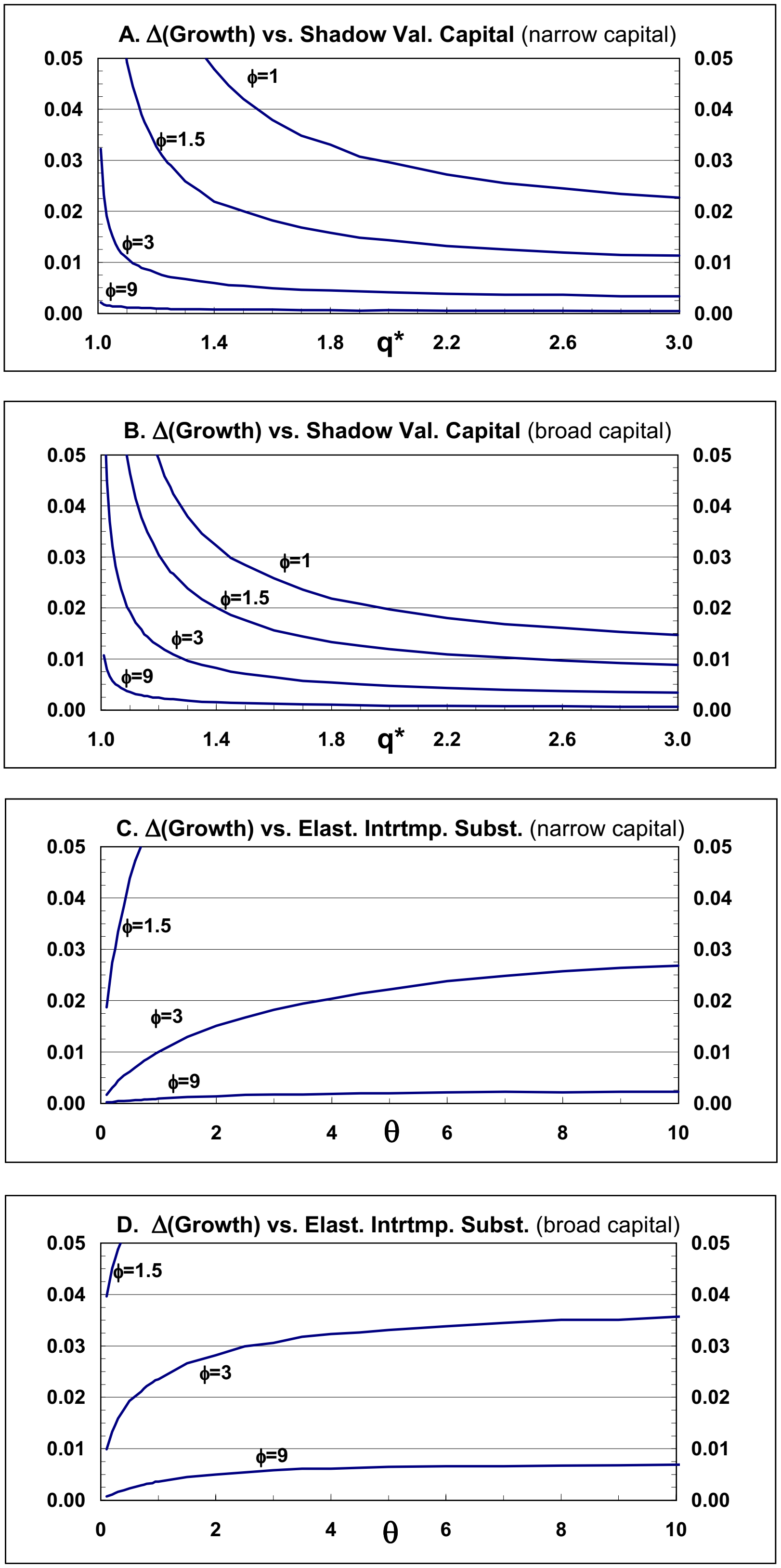


Figure shows the change in growth rate effected by relaxing the constraint that domestic savings finance domestic investment for an economy with current income 60 percent its steady-state level. Panels A and B vary the level of the capital installation function as measured by the steady-state shadow value of capital. Panels C and D vary the reciprocal of the elasticity of intertemporal substitution, θ. Remaining parameters are the same as in previous figures.

Parameters:

Relative Income	Y/Y* = 0.60
Narrow Capital Share	α = 0.33
Broad Capital Share	α = 0.67
Elasticity of Intertemporal Substitution (Reciprocal) (Panels A and B)	θ = 2
Steady-State Shadow Value of Capital (Panels C and D)	q*= 1.05
Capital Adjustment Cost	~ $(I/K)^{\phi}$