Aid, Growth, and Real Exchange Rate Dynamics*

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Abstract

We argue that if aid is about the future and recipients are able to plan consumption and investment decisions optimally over time, then the potential problem of an aid-induced appreciation of the real exchange rate (Dutch disease) does not occur. Furthermore, greater economic flexibility and an increasing degree of integration to the global economy will intensify the changes in the real exchange rate as well as investment, consumption and exports. This key result is derived without requiring additional assumptions such as exogenous or endogenous productivity growth. The economic framework is a standard neoclassical growth model, based on the familiar Salter-Swan characterization of an open economy, with full dynamic savings and investment decisions. It does require that the model is fully dynamic in both savings and investment decisions. An important assumption is that aid should be predictable for intertemporal smoothing to take place. If aid volatility forces recipients to be constrained and myopic, Dutch disease problems become an issue. In short, any unfavorable macroeconomic dynamics of scaled-up aid are the result of donor behavior rather than the functioning of recipient economies.

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Key Words: Real exchange rate; foreign aid; absorptive capacity; Dutch Disease

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The debate about the scaling up of aid and debt relief to poor countries is fundamentally about the future, linked closely to the attainment of the 2015 Millennium Development Goals (MDGs) of reducing extreme poverty and child mortality and of improving literacy and health (UN Millennium Development Project, 2005). These global initiatives have raised concerns about the effectiveness of aid in general and the macroeconomic consequences of large aid flows in particular. In addition, the scaling-up debate is taking place during a period of rapid globalization, which may mean that the effects of aid may differ from what they were during earlier periods.

On one side of the policy debate, those people who argue for substantial aid and debt relief are passionate about how aid on the scale of a Marshall Plan will bring about a significant supply side response and reduce poverty. They are generally optimistic about possible increases in productivity from aid-assisted public expenditures such as infrastructure and social spending and about possible complementarities between public and private capital.[2] The other side is a set of cautionary tales about the absorptive capacity for extensive aid in developing countries, its incentive effects, possible Dutch disease, and macroeconomic instability, as well as serious questions about the effectiveness of aid and the marginal productivity of public investment, especially public expenditures, in education, health, and infrastructure.[3]

Both sides of the debate are making statements about the future with scaled-up

[2] See, for example, Tyrangiel, (*Time*, 2005), Sachs (2005), and World Bank (2007). Berg et al. (2007) examine, for several country cases in Africa, whether recipient countries can use the transfer of external resources from donors (i.e. absorb the aid) so that consumption and investment are increased (i.e. spend the aid). The analysis indicates the importance of attempts to smooth aid flows. See also, for example, Gupta, Powell, and Yang (2006); Heller et al. (2006); IMF (2007a, 2007b); World Bank (2007), as well as Go et al. (2008).

[3] See, for example, Devarajan et al. (1996); Easterly (2001, 2003); Filmer et al. (2000); and Pritchett (2001). A recent survey of the conflicting perspectives is found in Roodman (2007).

aid. It would seem that one way to resolve the narrow issue of Dutch disease or real exchange rate appreciation would be to estimate the relevant parameters empirically. Unfortunately, data problems are severe, and there has been a general lack of reliable empirical estimates of crucial relationships and parameters. Recent surveys by Adam (2006) and Radelet et al. (2006) conclude that the consequences of aid on Dutch disease can vary widely using available econometric estimates.[4]

Partly because of the lack of solid empirical evidence, there is a parallel tradition of employing analytical and simulation models to assess the marginal effect of exogenous flows and shocks on the real exchange rate.[5] But the analytical debate about aid from this literature is also almost always cast in a static framework, and the time dimension is at best derived from recursive dynamics. [6]

The main contribution of this paper is to introduce choice and forward-looking behavior in a dynamic optimizing framework and to show how that may alter results, particularly about the Dutch disease issue. This paper takes seriously the notion that aid is about the future and asks, If agents respond to aid in the same way they make intertemporal choices, how will the economy respond? Will the results differ critically from what a static model would predict? If aid is about the future, the appropriate framework should be an intertemporally dynamic model to capture important aspects of the scaling up of aid not possible with static models. In a dynamic framework of an open economy, the real exchange rate—or the relative price of tradable and nontradable goods—not only is at the receiving end of the effect of aid and shocks, but is a vital price signal for the evolution of investment and consumption. Not only will investment and consumption behavior respond to immediate changes in the exchange rate and to the

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[4] Results generally depend on assumptions about the marginal productivity of additional aid and public expenditures or about the complementarities between public and private capital. Like the criticisms of growth regressions, the empirical bases of those assumptions are subject to further debate and statistical testing.

[5] The classic work on Dutch disease by Corden and Neary (1982) was quickly followed by several analyses using primarily a computable general equilibrium (CGE) framework, such as van Wijnbergen (1984), Gelb (1988), and Benjamin et al. (1989).

[6] For example, Adam (2006) and Adam and Bevan (2006) examine the supply side effects of aid flows in a traditional CGE framework. Even the recent absorptive capacity literature that investigates explicitly the links between public service delivery and MDGs and the allocation effects of public expenditures on social and infrastructure sectors over time—the maquette for MDG simulations in Bourguignon et al. (2008)—assumes that agents are myopic about intertemporal choices.

expectation of how those changes will evolve in the future, but the dynamics of the real exchange rate will, in turn, be affected by the supply-and-demand responses over time. Furthermore, exogenous flows and shocks will also likely not last forever, and the anticipation of a finite duration will have a very different dynamic effect than a permanent change.

We assume that investment is “productive” in the sense that it adds to the capital stock rather than being stolen or wasted[7] and that the economy is free to allocate the investment optimally over time, including investing abroad or paying off existing foreign debt. However, additional productivity, such as the idea that expanded exports and imports might be linked to increased total factor productivity (TFP) growth, either in export sectors or more broadly, are not introduced. Adding choice and intertemporal optimality eliminates the Dutch disease problem, even without introducing links between trade and TFP or additional complementarity between public and private capital.

Turnovsky and Chatterjjee (2004) examine the effect of aid and the complementarity between public and private capital in a dynamic context, but they do not distinguish between tradable and nontradable goods. Hence, they do not examine the effect of aid on the real exchange rate. Mirzoev (2007) is noteworthy in employing a stochastic general equilibrium model of a small and open economy that allows for intertemporal substitution in consumption and the inclusion of uncertainty in aid inflows, which is defined by an autoregressive AR(1) process. However, capital stock is fixed so that the framework is short term.[8] Addressing similar questions to those in this paper, Cerra et al. (2008) compare the effects of tied and untied aid in a dynamic model and likewise find that there is no appreciation of the real exchange rate when aid is untied. We focus on untied aid and discuss the role of aid volatility and trade shares.

In addition, this paper examines important aspects of modern economic development, such as globalization and changing capacity, and examines how they may affect the impact of scaling up foreign aid and the real exchange rate dynamics. More specifically, the second contribution of this paper is the introduction of “trends” in trade

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[7] An adjustment cost to investment is present, however, which raises the cost of investment as investment rises as a ratio to the capital stock. The feature follows the standard *q*-theory of investment in macroeconomics (see section 3) and also allows for smoother behavior in investment over time.
[8] See Go et al. (2008) for a more detailed discussion of some recent approaches and issues.

shares and elasticities to capture important observed historical trends or settings wherein the scaling up of aid takes place. Empirical findings about trade shares emerged long before the more recent talks about globalization and its effect on trade and growth. Although the direction of causality between trade and growth and the methodologies of many recent studies are still being debated, Winters et al. (2004) review the literature and conclude that the weight of evidence points strongly in the direction of trade openness (for example, higher trade shares) enhancing income levels.[9] Similarly, trends in trade elasticities may also be important empirically against the natural tendency of Dutch disease to shrink the traded sector. Empirical estimates in Devarajan et al. (1999), for example, show that although low-income countries generally have trade substitution elasticities that are lower than one, higher-income countries with greater capability to reallocate and substitute resources tend to have significantly higher elasticities that are greater than one. That pattern points to the potential importance of an initially low-income country that is, however, slowly gaining capacity and flexibility to compete with foreign goods and to integrate itself increasingly into the world economy. The interesting finding of this paper is that these trends will enhance the main results of the dynamic framework.

Following the debt literature, the dynamic model described in this paper includes an upward-sloping supply curve of external debt to mimic borrowing constraints in developing countries. This paper refrains, however, from any extraneous assumptions about productivity growth, whether exogenous or endogenous, including those that use production function links between public expenditures and various social and development outcomes, because they largely predetermine outcomes.

The Extended Basic 1-2-3 Model

In order to explore the various issues above and to account explicitly for how choice of model and its assumptions may change results, we employ a very standard neoclassical growth model called the 1-2-3 model in both its static and dynamic versions. The purpose

[9] The importance of the long-term rise in trade proportions and how that might be affected by country size and export concentration is alluded to in the early works of Kuznets (1959, 1966). The pattern is more

of this section is to introduce the basic 1-2-3 model and to extend its previous results.[10] Because the 1-2-3 model is now well documented, this section focuses on the key relationships and extends the previous algebraic results regarding the real exchange rate in Devarajan et al. (1990, 1993) and Devarajan et al. (1997) to allow for trade shares explicitly. In the Salter-Swan framework of an open economy, the familiar CES function employed for the aggregate supply and demand function is reformulated in terms of value or cost shares (θ) and greatly simplified further by indexing quantities relative to their base-year levels. This approach removes the usual CES shift and delta share parameters in the CES equation and its first-order conditions, a feature that becomes specially advantageous in the dynamic model for changing parameters over time within the same simulation. In particular,

$$\frac{Y}{Y_0} = [\theta(\frac{X1}{X1_0})^{-\rho} + (1-\theta)(\frac{X2}{X2_0})^{-\rho}]^{\frac{-1}{\rho}} \tag{1}$$

On the supply side, the economy is divided into two sectors: exports (E) and all other final goods produced, called domestic goods (D). There is a constant elasticity of transformation function similar to equation (1) that links the output in the two sectors, with the distribution of outputs determined by the relative price of exports to domestic goods ($\frac{P_e}{P_d}$) at the point of tangency.

$$\frac{E}{D} = \left[\frac{1-\theta_e}{\theta_e}\left(\frac{E_0}{D_0}\right)^{\rho_t}\frac{P_e}{P_d}\right]^{\Omega} \tag{2}$$

Equation (2) is the familiar optimal condition for the cost shares of exports (θ_e) and

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clearly established by the subsequent cross-country works of Chenery and Syrquin (1975, 1989).

[10] The model has been applied to a variety of policy issues, such as the pre-1994 overvaluation of the CFA franc in Devarajan (1997, 1999), regional integration in Devarajan et al. (1997), and export externalities in de Melo and Robinson (1992). Devarajan et al. (1999) also provided empirical estimates of the two critical elasticities for about 60 countries. A forward-looking version found in Devarajan and Go (1998) provides the intertemporal dynamics, which is expanded and discussed in the next section.

domestic goods ($1-\theta_e$). The CET transformation elasticity is $\Omega = 1/(\rho_e - 1)$. The price of exports (P_e) is exogenous by the small-country assumption. In symbols, $P_e = e_r p_{we}$, where e_r is the nominal exchange rate and p_{we} is the world price of exports.

Likewise on the demand side, the representative consumer has a constant elasticity of substitution utility in D and M, which is imports. M is the third good in the economy, hence the name, "one country, two sectors, three commodities." The level and distribution of demand are determined by the highest indifference curve at the point tangent to the consumer's budget line, that is,

$$\frac{M}{D} = \left[\frac{\theta_m}{1-\theta_m} \left(\frac{M_0}{D_0} \right)^{\rho_c} \frac{P_d}{P_m} \right]^{\sigma} \tag{3}$$

The price of imports P_m is exogenous and depends on the world price p_{wm} and the exchange rate. θ_m is the value share of imports, and the elasticity of substitution is $\sigma = 1/(\rho_m + 1)$.

The balance of trade need not be zero and can be financed by various foreign inflows B, such as external borrowing, exogenous foreign aid or grants, remittances, private foreign investments, and so forth.

$$p_{wm} M - p_{we} E = B \tag{4}$$

To solve the model algebraically, express foreign capital inflows as a proportion of exports, that is, $B = \lambda p_{we} E$, and take the logarithmic differentiation of the three equations:

$$\hat{M} - \hat{D} = \sigma \left[\hat{P}_d - \hat{p}_{wm} + \hat{\theta}_m^{'} \right] \tag{5}$$

$$\hat{E} - \hat{D} = \Omega\left[\hat{p}_{we} - \hat{P}_d - \hat{\theta}_e^{'}\right] \tag{6}$$

$$\hat{p}_{wm} + \hat{M} = \hat{p}_{we} + \hat{E} + \frac{\dot{\lambda}}{1+\lambda} \tag{7}$$

$\hat{\theta}_m^{'}$ and $\hat{\theta}_e^{'}$ are modified growth rates of the trade shares for imports and exports, respectively, that is,

$$\hat{\theta}_m^{'} = \hat{\theta}_m + \frac{\dot{\theta}_m}{1-\theta_m} \tag{8}$$

$$\hat{\theta}_e^{'} = \hat{\theta}_e + \frac{\dot{\theta}_e}{1-\theta_e} \tag{9}$$

Note that for trade shares that are positive, $\theta_m, \theta_e > 0$, the second-order effects (second terms) of both equations will also be positive if there are upward changes in the trade shares. Finally, the baskets of goods for exports and imports can be different in the 1-2-3 model, which is often the case for developing countries. Hence, unlike open-economy models with perfect substitution between foreign and domestic goods, changes in import prices and export prices can be independent of one another.

The incorporation of "trends" in trade shares is essentially an ad hoc way to capture the fact that actual import demand and export supply do not appear to have an "expenditure" elasticity of one (that is, homothetic), which is assumed in most trade functions in CGE modeling, such as the constant elasticity of substitution (CES) and constant elasticity of transformation (CET) functions described in this paper. Historically, the expansion of trade shares is much faster than can be explained by changes in relative prices alone. Similarly, although it is feasible to include trends in trade shares and elasticities in a recursive dynamic way as in the early work by Chenery et al. (1986), it has so far not been easy to allow for both at the same time in fully dynamic CGE modeling. Because dynamic simulations are often cast over an infinite horizon and the steady state is reached only over the long term, fixing trade shares and elasticities for low-income countries at their initial lower levels in the base year is a serious shortcoming that has long required attention. One early notable exception is the dynamic CGE model of Jorgenson and Ho (1994), which incorporates a logistic curve for export shares. The econometrically estimated translog equations in their work would, however, allow for only small changes in the neighborhood of the implied average trade elasticities and in an economy that is already developed and stable—the United States. Although ad hoc, our approach in this paper is simple and transparent; it keeps the model close to the "standard" 1-2-3 Salter-Swan model while capturing the important historical trends. Nonetheless, the new features introduced in this paper also extend dynamic modeling to include more systematic and significant shifts in trade shares and elasticities in trade-focused CGE models, creating a model more apposite for developing countries still undergoing significant economic transformation.

Consider the effects of various external shocks in the static model with explicit trade shares.

Case 1: *Import Price Shock:* $\hat{p}_{wm} > 0, [\hat{p}_{we}, \dot{\lambda} = 0]$

$$\hat{P}_d = \left(\frac{\sigma - 1}{\sigma + \Omega}\right)\hat{p}_{wm} - \frac{\sigma\hat{\theta}_m' + \Omega\hat{\theta}_e'}{\sigma + \Omega} \tag{10}$$

The first term is the standard result of the simple 1-2-3 model. How P_d responds to a terms-of-trade shock depends on the sign of $(\sigma - 1)$. For developing countries with limited trade substitution possibilities, $\sigma < 1$, P_d will fall (and the real exchange rate will depreciate). The direction of change in P_d then determines how the rest of the economy will adjust. In this case, exports will rise and production of domestic goods will fall. If, in addition, $(\sigma + \Omega) < 1$, the real exchange rate depreciation will intensify.

Macroeconomic dynamics are not easily shown in static models, but one key will be the evolution of the trade elasticities. Over time, as a country develops and becomes more diversified and flexible, the value of σ will increase. Hence, the theoretical derivations of the 1-2-3 model indicate that the amount of real depreciation in response to an import price shock should gradually subside.

The second term points to the possible effects of higher trade shares. It shows algebraically that as an economy becomes more open, its real exchange rate will have to depreciate more in response to an adverse import price shock. It is worth recalling that the point was not always established until several studies. For example, Balassa (1986) made the case that more outward and export-oriented developing countries tended to adjust better with respect to external shocks in the 1973–78 and 1978–83 periods by keeping their real exchange rate competitive. The point is more clearly seen in the simple case where the growth rates of trade shares of exports and imports are the same, $\hat{\theta}_m^{'} = \hat{\theta}_e^{'} = \hat{\theta}_{trade}$, so that

$$\hat{P}_d = \left(\frac{\sigma - 1}{\sigma + \Omega}\right)\hat{p}_{wm} - \hat{\theta}_{trade} \tag{11}$$

However, the real depreciation that rises with trade shares is ameliorated as domestic goods become more substitutable with foreign goods.

Case 2: *Export Price Shock:* $\hat{p}_{we} > 0, [\hat{p}_{wm}, \dot{\lambda} = 0]$

Likewise, the following effect may be derived for an export price shock:

$$\hat{P}_d = \left(\frac{1 + \Omega}{\sigma + \Omega}\right)\hat{p}_{we} - \frac{\sigma\hat{\theta}_m^{'} + \Omega\hat{\theta}_e^{'}}{\sigma + \Omega} \tag{12}$$

The standard 1-2-3 model result is also shown from the first term on the right-hand side. A sufficient condition for a real appreciation of the exchange rate relative to exports ($\hat{P}_d > \hat{p}_{we}$) is $\sigma < 1.$ Like the previous case, the effect will also tend to be less with rising $\sigma, \Omega,$ or $\theta.$

Case 3: *Scaling Up Aid Flows:* $\dot{\lambda} > 0, [\hat{p}_{wm}, \ \hat{p}_{we} = 0]$

For changes in exogenous aid or capital inflows, the following is derived:

$$\hat{P}_d = \left(\frac{1}{\sigma + \Omega}\right)\frac{\dot{\lambda}}{1+\lambda} - \frac{\sigma\hat{\theta}_m^{'} + \Omega\hat{\theta}_e^{'}}{\sigma + \Omega} \tag{13}$$

If the sum of the export and import substitution elasticities $(\sigma + \Omega)$ is much less than one, signifying low flexibility in the economy, the appreciation of the exchange rate will be more than proportionate to the change in capital inflows (expressed as a percentage share of exports); if the sum of the two parameters is equal to one, the real appreciation will be proportionate to the change in inflows; and if the sum is more than one, the real appreciation will be less than proportionate. Furthermore, as the trade shares rise, the real exchange rate appreciation will be dampened.

Looking at Dutch disease possibilities, how does a change in aid flows compare with a change in export price? For $\hat{p}_{we}$ and $\frac{\dot{\lambda}}{1+\lambda}$ more or less similar in magnitude, nominal $\hat{P}_d$ in the case of an increase in aid flows appears to be slightly less compared with the case of an export price change (that is, smaller multiplier in the first term). However, in the case of the aid flows, $\hat{P}_d$ will translate fully into a real exchange rate change ($\hat{P}_d$ - $\hat{p}_{we}$) since $\hat{p}_{we} = 0$ in that case. Hence, the real exchange rate appreciation will in general be significantly higher in the case of $\dot{\lambda} > 0$ for any equivalent large changes in λ and p_{we}.

Finally, if the export price shock is coming from a mineral sector that is an enclave in the economy, it should be treated as a large capital inflow within the framework of the 1-2-3 model. In contrast, if the export boom is from a sector more integrated into the economy with transformation possibilities with domestic goods (for example, coffee or other agricultural activities), the Dutch disease effect is best represented by the second case, $\hat{p}_{we} > 0$.

So far, aggregate output is taken as fixed in the static 1-2-3 model. The next section presents the dynamic version in which this constraint is relaxed.

The Extended Dynamic 1-2-3 Model

The dynamic simulation framework is an expanded version of the 1-2-3t model developed in Devarajan and Go (1998), where producer and consumer decisions are both intra- and intertemporally consistent. The representative consumer maximizes the present value of the utility of consumption; producers maximize the present value of profits. The resulting forward-looking investment, together with its adjustment cost function, is similar to Abel (1980), Hayashi (1982), and Summers (1981). The parsimonious structure of the model is achieved with the basic 1-2-3 model at its core. With export and import prices exogenous, there is only one endogenous price per period to be solved (the price of the domestic or nontradable good), and the simplified structure is ideal for isolating the evolution of the real exchange rate expressed as the relative price of foreign and domestic goods. The implementation allows for three types of import goods, each assessed with its own import duty. Final imports compete with the domestic good. Output is a fixed coefficient combination of intermediate imports and value added, while capital imports are fixed coefficients of investment. Value added is a CES composite of labor and installed capital. A government sector is present. Government revenue comes from import tariffs, domestic indirect tax, income tax, and foreign official grants, while public expenditures include public consumption, transfers, and subsidies, all of which are normally assumed to be exogenous. Given its structural breakdown, the model can be calibrated with national and fiscal accounts data only; it can also be used to look at trade liberalization and macroeconomic and fiscal adjustments to exogenous shocks. The framework was implemented using data from Madagascar, Mozambique, and the Philippines, which was the original country case in the 1-2-3t model.

New features of the economic framework relate to the introduction of changing or exogenous trends in the trade shares and trade substitution elasticities within the same dynamic run. Increasing the share of exports in aggregate output is akin to a change in technology, which may be brought about by greater integration and by access to the world markets. Likewise, increasing the share of imports in aggregate demand is like a change in consumer preferences that may be brought about by the availability of more types of imports through greater trade. In both cases, rising trade shares are likely to be consistent with greater capacity and flexibility in the economy, which are also linked to greater substitution elasticities between foreign and domestic goods. Modeling implementation of such flexible trade shares and elasticities is greatly simplified with the use of the share and index form of the CET and Armington functions as formulated in the previous section (see equations [40] and [45] in the annex). The calibration of the model is straightforward. One thing to note is that the reference values of the components for the index form of the CET or CES functions will change every time as the shares of the components are adjusted to satisfy the base-year budget constraint at base-year prices.[11] That recalibration can easily be included in the system of equations of the model (see equations [42], [43], [47], [48] in the annex). Several sensitivity tests were run, and the results are consistent with the conceptual conclusions of the preceding sections.

In addition, the external debt accumulation is carefully specified in order to examine issues of foreign aid and borrowing in developing countries. Foreign aid can come in the form of concessional loans (subsidized interest rate) or outright foreign official grants (no interest charges or repayment required). Following the literature regarding borrowing constraints or imperfect debt market for developing countries,[12] an upward-sloping supply curve of external debt is used, and there is a risk premium that rises with external debt. More specifically,

$$i(Debt) = i^* + \omega(Debt/GDP); \quad \omega' > 0 \tag{14}$$

where the world interest rate i^* is a weighted average of the interest for concessional and commercial loan—equation [28] in the annex. The risk premium ω rises with foreign debt as a ratio to the capacity to pay as indicated by gross domestic product (GDP) (equation [27] in the annex).[13]

[11] When changing trade shares, it is assumed that the base utility from the consumption bundle stays at the initial value.
[12] See, for example, Bardhan (1967); Eaton and Gersovitz (1981); Obsfeld (1982); Sachs and Cohen (1982); Kletzer (1994); Bhandari et al. (1990); and van der Ploeg (1996).
[13] Concessionary loans are assumed to have an interest rate of 2.5 percent, which is similar to the effective interest rate for International Development Association–type loans over 40 years at the World Bank. Risk-

Like the 1-2-3t model, the domestic interest rate affecting consumption and investment is a form of risk-adjusted interest parity reflecting the cost of foreign borrowing. Hence, the domestic discount rate will depend on both i and the forward evolution of the real exchange rate. For the consumer, the appropriate real exchange rate is the relative price of imports and domestic goods; for the producer, it is the relative price of exports and domestic goods. In the steady state, the economy reaches a balanced-growth path, the change in the real exchange rate ceases, and the domestic discount rate settles back to i. In a forward-looking framework and for dynamic consistency, the consumer correctly anticipates this and its single rate of time preference adjusts immediately in the first period and is used throughout the time horizon. The difference between this expanded framework and the previous 1-2-3t model is that $i(Debt)$ could change at the steady state or terminal period and will not necessarily be the risk free i^*. Hence, the rate of time preference may also change with each simulation.

The simulations distinguish between two types of countries.[14] The first type refers to an economy with a growing and functioning private sector, and the full-scale model with endogenous and forward-looking investment and consumption is deployed. Subject to an upward-sloping supply of debt, the current account, or more precisely external borrowing, is an integral part of the optimal decisions of the consumer and producer and adjusts dynamically to bridge the gap between investment and savings. This country is referred to as the flexible dynamic country (simulations 1 and 2).

There are many reasons to believe that some agents, even those in developed countries, are credit constrained. This paper takes this case to mean a country facing severe constraints in savings and external borrowings. A significant source of savings is derived from external financing and comes in the form of foreign aid to finance much-needed public capital. Without public expenditures and investments financed by aid, many of these countries are likely stuck at a low-level equilibrium. This second case uses a modified version where the forward-looking behavior of investment is rendered

free commercial loans are assumed to have an interest rate of 5.0 percent. Premium rate ω is calibrated so that i is exactly the average interest paid on the country's external debt in the base year.

[14] In reality, there is a range of countries, with the two extreme cases being (1) completely flexible and (2) credit-constrained agents. The two extremes are presented in this section.

inoperative and investment in each period adjusts to available savings. External financing is exogenous and two options are considered for consumption: (1) consumption is forward-looking and dynamic because foreign aid is available and stable (simulation 3), and (2) no forward planning is feasible in consumption (consumers are myopic and optimize in each time period; there are recursive dynamics but no intertemporal decisions about consumption) because foreign aid is unpredictable and volatile (simulation 4).

The paper annex lists the equations of the full dynamic framework, called the 1-2-3Aid model. Except for the new features, calibration and implementation follow Devarajan and Go (1998).

Simulations[15]

Economy with Forward-Looking Investment and Consumption

Simulation 1: *Foreign official grants increase by 2 percent of output permanently*

A significant increase in foreign grants will not necessarily lead to a real exchange rate appreciation or a Dutch disease problem.[16] In any economy with an active private sector undertaking significant investment but facing an existing debt stock and an upward-sloping supply of debt, the effect is to increase investment, consumption, and output over time as expected (see figures 1 and 2). However, the dynamically optimal decisions in investment and consumption will result in the real exchange rate depreciating immediately (rather than appreciating), as well as the external debt stock declining over time (see figures 3 and 4). The effects are interrelated.

FIGURE 1 HERE

FIGURE 2 HERE

FIGURE 3 HERE

[15] All simulations are presented as deviations to the levels in the reference run (equals 1.0), which is defined as a balanced growth or steady-state run.
[16] This result is consistent with Cerra et al. (2008) who find that untied foreign aid does not cause Dutch disease effects.

FIGURE 4 HERE

With a permanent increase in aid, domestic agents will consume and invest it optimally. To the extent that some of it is invested, the domestic price has to increase in the future to make the investment profitable (recall that the world price is exogenous). For the domestic price to rise in the future, it has to fall in the present, so that the trajectory is upward-sloping, to justify the investment. For investment to jump and increase, the returns to the firm must also improve to reach a new asset market equilibrium; hence, the market discount rate affecting supply behavior will have to increase immediately (equations [29] and [30] in the annex). The firm's real exchange rate in the 1-2-3t model is Pe / Pd , and the relative price of domestic goods (relative to exports) must fall to cause the forward depreciation of the real exchange rate required to change the firm's discount rate. In the absence of an external shock, the fall in the relative price of domestic goods is brought about by an immediate contraction of consumption. As a result, the real exchange rate affecting consumption, Pm/Pd, also rises, which increases the demand-side discount rate, postponing consumption immediately but causing an increasing growth rate in consumption over time. The rise in consumption and investment will eventually lead to a gradual amelioration of the initial depreciation, ultimately restoring the real exchange rates to the same pre-shock level at the steady-state terminal period.

In the face of an upward-sloping supply curve of external debt, another optimal outcome is to substitute and pay back in effect the pre-existing external debt with the interest-free foreign grants. Agents want to invest, and the highest return in the early period is to retire existing debt (effectively getting a return equal to the interest rate on foreign debt). The trade balance improves and the real exchange rate depreciates. Investment is allocated between debt reduction and capital formation, with the depreciation increasing the return to investment in exportables. As growth occurs, debt retirement ceases, domestic investment increases, and the exchange rate appreciates, returning finally to its initial level. External debt gradually declines to almost zero over 40 years, supporting the notion that foreign grants and debt relief are essentially equivalent. Over time, the decline in debt also reduces the premium paid for borrowing, hence the discount rate directly, as well as shifts down the rate of time preference for the consumer, spurring consumption and slowing the growth of further investment slightly.

Sensitivity tests were completed by imposing different rising trends in trade shares and trade substitution elasticities to signify greater openness and integration into the world economy and greater economic capacity and flexibility over time. The effects of globalization as defined are to improve the outcomes—growth of exports, investment, consumption, and output are all increased much more rapidly (see figures 1 and 2). In the long run (that is, the steady state), the level of exports is about 21 percent higher; likewise, investment, consumption, and output are 2.5 to 4 percent higher. The initial decline of consumption and the initial depreciation (see figure 3) are higher, and the external debt is also reduced much more quickly.

With respect to the real exchange rate, the contrast to the static case is worth emphasizing. In the basic 1-2-3 model where aggregate output or supply is essentially fixed, the effect of an exogenous inflow is always an appreciation of the real exchange rate; the appreciation becomes less as trade shares and elasticities increase. Here, the intertemporal behavior in consumption and investment, how they are affected by the real exchange rate, plus an upward-sloping credit supply function, alter the outcome altogether. Increasing both trade shares and elasticities make the dynamic model more sensitive.

The absorption of scaled-up aid and its effect on the real exchange rate are uniquely products of the intertemporal decisions of investment and consumption. Consumption smoothing is the usual outcome of a Ramsey intertemporal savings function, and the rate of exchange governing present and future consumption determines household demand for goods and services over time (equation [15]). However, the intertemporal supply response also adds another dimension. Investment is endogenous and inherently productive, but it is dependent on present and future relative prices and how they affect the stream of profits over time and the adjustment cost to additional capital.[17] More precisely, at each point in time, as long as the present value of the marginal returns to investment is greater than the replacement cost of capital in a Tobin's q-type formulation, investment will rise (equations [16]–[22]). However, investment expenditure automatically ceases whenever the marginal cost–benefit ratio becomes unfavorable. Likewise, the supply response is not an instantaneous jump due to adjustment costs, and no additional productivity gains are assumed or needed to the story about the real exchange rate, growth, and debt.

Any doubts from the aid literature about the effect of incremental aid with respect to the supply response, absorption, and the real exchange rate are likely because of additional assumptions regarding the lack of productivity of investment, as well as the lack of dynamic behavior, particularly about investment. Additional savings are poured altogether toward capital accumulation despite decreasing marginal returns. In this case, there is no intertemporal path in consumption and investment to suggest that a debt reduction combined with an initial depreciation may be optimal.

These results tend to support recent historical policy responses to the external debt problems in developing countries. During the debt crisis of developing countries in the 1980s, many countries first availed themselves of long-term concessionary loans to effectively replace the more short-term and costly commercial debt. Policy conditions partly required the undertaking of much-needed policy reforms as well as economic and trade liberalization. However, growth and debt sustainability remained fragile in the 1990s so that significant debt relief came from the Heavily Indebted Poor Countries Initiative, the Multilateral Debt Relief Initiative (MDRI), and the recent trend toward pure grants. As long as there is a risk associated with increased foreign borrowing as well as continuing signs of possible debt distress, the results confirm that it is optimal to draw down the external debt with outright debt relief or foreign grants. Conversely, it also suggests that aid and debt relief will not lead to a renewed and unwanted external debt accumulation, because doing so may be far from optimal and sustainable.

Simulation 2: *Foreign official grants increase by 2 percent of output temporarily—for 10 years*

What if foreign grants are temporary, lasting for only 10 years, and are expected to be so? Here, there is a uniform upward shift to investment; that is, it increases immediately and stays at more or less the same level over the simulation period. Over time, the additional

[17] See, for example, the works of Abel (1980), Hayashi (1982), and Summers (1981).

investment raises output. However, investment and output levels are all below simulation 1 throughout (see figure 1). Consumption declines initially and increases over time; the initial decline and subsequent increases are also less than simulation 1 (see figure 2).

In addition, it is still optimal to pay back debt significantly while the interest-free foreign grants last, amounting to more than half the grants each year. As a result, debt stock is reduced by about 20 percent by the 10th year. After the 10th year, the trajectory of consumption, investment, and output, as well the pre-shock levels of exogenous flows from other sources, will allow the continuation of debt repayments. Debt at the steady-state terminal period is reduced by a third of the original level.

Relative to a permanent increase in foreign aid (simulation 1), the real exchange rate response for a temporary aid shock depends much more on the magnitude and length of the shock. Keeping the magnitude of the shock similar to simulation 1 and the length of the aid shock at 10 years, the real exchange rate remains practically constant throughout. If anything, there is a slight appreciation that is hardly perceptible. However, if the aid shock lasts longer, 15 or more years (instead of 10), the real exchange rate will depreciate immediately, albeit much less than in simulation 1 (see figure 3).

Sensitivity tests were also completed by imposing different rising trends in trade shares and trade substitution elasticities. Like simulation 1, the effect is to intensify the changes in consumption, investment, output, and debt. There is also now a slight and immediate depreciation, which is ameliorated over time (similar the case of a permanent increase in foreign aid, simulation 1).

Economy with Severe Borrowing Constraint and Dearth of Public Capital

Simulation 3: *Foreign official grants increase by 2 percent of output*

In an economy with a severe borrowing constraint, the current account balance is rigid or exogenous. Because aid is permanent, consumers still make optimal intertemporal consumption choices (equation [15] in the annex). Investment decisions, however, are not based on a comparison of the marginal returns to additional capital relative to its replacement cost. Instead, investment is completely driven by the intertemporal decision to consume or save (hence, equations [16]–[21] are rendered inoperative). Additional resources from the exogenous inflows will bid up prices of domestic goods so that the real exchange rate appreciates immediately (see figure 5). The higher prices and the forward exchange rate favor postponing consumption, and, hence, consumption falls in the initial years (see figure 6). Investment rises throughout from additional savings, and over time, income and consumption also rise as a result of the increased supply (see figure 7). The increased supply will slowly reduce the initial appreciation of the exchange rate. This is the kind of story that is behind much of the standard thinking about the effect of aid. Because the inflows are grants and borrowing is fixed (zero), no debt story is relevant in this simulation.

FIGURE 5 HERE

FIGURE 6 HERE

FIGURE 7 HERE

Sensitivity tests of rising trends in trade shares and trade substitution elasticities result in amplifying somewhat the effect on investment and output while consumption is almost identical or very slightly more (figure 6). The appreciation of the exchange rate is more at every point in time. The eventual reduction of the initial appreciation is, therefore, also relatively less over time (figure 5—as what would be expected from the static case of changing shares and elasticities).

Much concern has also been made regarding the differences in effect between exogenous flows financing pure government consumption rather than investment. Although not directly productive,[18] the expansion of government consumption as an exogenous component of aggregate demand has a Keynesian effect on prices and income. If the same amount in foreign grants all go to government consumption rather than investment, prices will still be bid up in the same way and the consumer will face the same kind of Ramsey saving decision. Hence, the results with regard to the real exchange rate (see figure 5), investment (see figure 7), and output are essentially the same as the

[18] Except for public expenditures on social sectors, which potentially may raise human capital in the long run. Because the trade-offs regarding investments for the development of human and physical capital are not the focus of this paper, government consumption is considered to be pure consumption expenditures for goods and services.

investment case. The only difference is that with total absorption or aggregate demand also behaving the same way, the consumption curve over the simulation period will shift down to make room for the exact amount of increase in government consumption (see figure 6).

Simulation 4*: Foreign official grants increase by 2 percent of output, myopic case*

The only way for the case of financing government consumption to differ from the investment case is for the representative consumer to be completely myopic so that no optimization is made about present versus future consumption. The results are confirmed by setting up a recursively dynamic 1-2-3 model. If aid all goes to government consumption, the real exchange appreciation is highest, by as much as 12 percent initially (see figure 8), because there is no longer any substitution across time for consumption or supply to moderate the results. As current consumption from the government sector raises domestic prices and causes the exchange rates (equations [31] and [32] in the annex) to appreciate, the latter are no longer linked to the discount rates (equations [29] and [30]) to affect present and future consumption choices (equation [15]) or supply decisions (equations [16]–[21]). Furthermore, aid does not go to the savings pool to raise investment directly. There is, however, a Keynesian-like expansion from the additional demand, which will raise investment, output, and consumption over time, albeit only marginally. Because the supply response is limited, depreciation remains at 10.5 percent relative to the reference case some 40 years after.

FIGURE 8 HERE

FIGURE 9 HERE

FIGURE 10 HERE

If aid all goes to investment so that supply responds directly over time, the real exchange rate appreciation is less at 7.5 percent initially (see figure 8). Relative to the reference path, investment rises by 11.0 percent initially and eventually to 22.5 percent at the end of 40 years (see figure 9). Output and consumption both increase eventually by about 10 percent of the reference level (see figure 10). However, all the levels regarding investment, consumption, and output are below simulations 1 (permanent aid, no borrowing constraint) and 3 (permanent aid, borrowing constraint). The ideal case is simulation 1 when investment is only undertaken strictly on a merit basis (as in cost–benefit calculations) and the current account balance is part of the intertemporal optimization. Nonetheless, the comparison of these simple experiments to simulation 3 touches on an important policy implication. If there is a severe borrowing constraint and if donor aid flows are unpredictable so that the representative consumer is unable to smooth consumption over time (for example, myopic or constrained), even if future aid disbursements every year turned out to be constant and at a significant level, the level of consumption and investment (see figure 9) and output will still be below the case when these aid flows are fully committed and expected at the outset to allow for expenditure smoothing. In this case, outright debt relief such as the MDRI, which secures a definite resource flow with regard to debt service being forgiven, should be preferable to uncertain aid flows.

If aid is temporary, the results in a myopic case are trivial—all shifts and changes because of aid cease when aid ceases.

Conclusions

By comparing static and dynamic effects of exogenous flows, this paper contributes to the aid debate by isolating the implications of intertemporal choices. If aid is about the future and recipients can plan consumption and investment decisions optimally over time, aid will not only bring about better economic outcomes in output, consumption, and investment but the potential problem of an aid-induced appreciation of the real exchange rate (Dutch disease) does not appear. This result is true not only for a permanent aid shock but also for a temporary aid shock over a period of about 10 years (for a reasonable set of parameters). With greater economic flexibility and an increasing degree of integration to the global economy, the results will be even more dramatic.

This key result does not require extreme assumptions. The economic framework is a standard neoclassical growth model, based on the familiar Salter-Swan characterization of an open economy, with full dynamic savings and investment decisions. It does require that the model is fully dynamic in both savings and investment decisions. The consumption and savings trade-offs follow the usual Ramsey formulation, while supply incorporates the dynamic behavior of firms that is now standard in dynamic macroeconomics. The latter is important in the sense that investment is undertaken only up to the point where the present value of its marginal returns matches the replacement cost of capital; excess aid beyond that point is optimally used to reduce or retire interest-bearing debt.

An important assumption is that aid should be predictable for intertemporal smoothing to take place. If aid volatility forces recipients to be constrained and myopic, Dutch disease problems become an issue. In this case, the levels of consumption, investment, and output are also below the flexible dynamic case. In this constrained and myopic world, greater economic flexibility and an increasing degree of integration into the global economy will reduce the Dutch disease problems as expected and will also improve economic outcomes (but still less than in the flexible dynamic case).

In short, any unfavorable macroeconomic dynamics of scaled-up aid are the result of donor behavior rather than the functioning of recipient economies.

Annex: The 1-2-3Aid Model

Equations

Consumption

$$\frac{C_{t+1}}{C_t} = \left(\frac{PC_{t+1}(1+\rho)}{PC_t(1+r_{t+1}^c)} \right)^{-\frac{1}{\upsilon}} \tag{15}$$

Investment and Tobin's *q*

$$\frac{I_t}{K_t} = \alpha + \frac{1}{\beta} Q_t^T \tag{16}$$

$$Q_t^T = \left[\frac{q_t}{PK_t} - (1 - bb - tc_t) \right] \tag{17}$$

$$r_t q_t = R_k(t) + \Delta q - \delta q_{t+1} \tag{18}$$

$$J_t = [1 - tc + \theta_t(I/K)]I_t \tag{19}$$

$$R_k(t) = rk_t - PK_t(I_t/K_t)^2 \theta_t'(I/K) \tag{20}$$

$$\theta(x_t) = \left(\frac{\beta}{2}\right)\frac{(x_t - \alpha)^2}{x_t} \tag{21}$$

$$K_t = (1-\delta)K_{t-1} + I_{t-1} \tag{22}$$

Terminal Conditions

$$\frac{I_{tf}}{K_{tf}} = \delta^R \tag{23}$$

$$PC_{tf} C_{tf} = Y_{tf} \tag{24}$$

$$r_{tf}^c \equiv r_{tf}^p \equiv i_{tf}^* \tag{25}$$

$$\rho \equiv i_{tf}^* \tag{26}$$

Cost of Borrowing and Transformation Rates

$$i_t^{debt} = i_t^w + \omega\left(\frac{DEBT_t\, er}{Q_t\, PQ_0}\right) \tag{27}$$

$$i_t^* = s_{aid} i_t^{aid} + (1 - s_{aid}) i_t^{debt} \tag{28}$$

$$r_t^p = i_t^* + \frac{\dot{e}_t^p}{e_t^p} \tag{29}$$

$$r_t^c = i_t^* + \frac{\dot{e}_t^c}{e_t^c} \tag{30}$$

$$e_t^p = \frac{PE_t}{PD_t} \tag{31}$$

$$e_t^c = \frac{PM_t}{PD_t} \tag{32}$$

Prices

$$PE_t = \frac{pe_t^* er}{1 + te_t} \tag{33}$$

$$PM_t = pm_t^* (1 + tm_t^c) er \tag{34}$$

$$PMK_t = pmk_t^* (1 + tm_t^k) er \tag{35}$$

$$PMN_t = pmn_t^* (1 + tm_t^n) er \tag{36}$$

$$PK_t = [a_k PMK_t + (1 - a_k) P_t](1 + \phi_t tx_t) \tag{37}$$

$$PC_t = P_t (1 + tx_t) \tag{38}$$

Armington CES Function

$$P_t X_t = PD_t D_t + PM_t M_t \tag{39}$$

$$X_t = X_0 \left[\delta_t^c \left(\frac{M_t}{M_t^{ref}} \right)^{-\rho_t^c} + (1-\delta_t^c) \left(\frac{D_t}{D_t^{ref}} \right)^{-\rho_t^c} \right]^{-1/\rho_t^c} \tag{40}$$

$$\frac{M_t}{D_t} = \left[\frac{\delta_t^c}{(1-\delta_t^c)} \frac{PD_t}{PM_t} \right]^{1/(1+\rho_t^c)} \tag{41}$$

$$PM_0 M_t^{ref} = \delta_t^c P_0 X_0 \tag{42}$$

$$PD_0 D_t^{ref} = (1-\delta_t^c) P_0 X_0 \tag{43}$$

CET Transformation

$$PQ_t Q_t = PD_t D_t + PE_t E_t \tag{44}$$

$$Q_t = Q_0 \left[\delta_t^e \left(\frac{E_t}{E_t^{ref}} \right)^{\rho_t^e} + (1-\delta_t^e) \left(\frac{D_t}{D_t^{ref}} \right)^{\rho_t^e} \right]^{1/\rho_t^e} \tag{45}$$

$$\frac{E_t}{D_t} = \left[\frac{(1-\delta_t^e)}{\delta_t^e} \frac{PE_t}{PD_t} \right]^{1/(\rho_t^e - 1)} \tag{46}$$

$$PE_0 E_t^{ref} = \delta_t^e PQ_0 Q_0 \tag{47}$$

$$PD_0 D_t^{ref} = (1-\delta_t^e) PQ_0 Q_0 \tag{48}$$

Value Added

$$PV_t = PQ_t / (1+ts_t) - a_n PMN_t \tag{49}$$

$$PV_t Q_t = w_t L_t + rk_t \overline{K}_t \tag{50}$$

$$Q_t = \alpha_v [\delta_v L_t^{-\rho_v} + (1-\delta_v)\overline{K}_t^{-\rho_v}]^{-1/\rho_v} \tag{51}$$

$$\frac{L_t}{\overline{K}_t} = \left[\frac{\delta_v}{(1-\delta_v)} \frac{rk_t}{w_t} \right]^{1/(1+\rho_v)} \tag{52}$$

Household Budget

$$\begin{aligned} YH_t = {} & w_t L_t + rk_t K_t \\ & + GTRS_t P_t \\ & + EFLOWS_t er \\ & -(1-d_g) i_t^* DEBT_t er \end{aligned} \tag{53}$$

$$Y_t = (1-ty) YH_{t \quad tt \quad t \quad t} \tag{54}$$

Government Budget

$$\begin{aligned} TAX_t = {} & tm_t^c (M_t \; pm_t^* \; er) \\ & + tm_t^k (MK_t \; pmk_t^* \; er) \\ & + tm_t^n (MN_t \; pmn_t^* \; er) \\ & + te_t (E_t \; pe_t^* \; er) \\ & + tx_t [P_t (C_t + G_t + J_t] \\ & + ty_t \left[YH_t - (PK_t J_t - B_t er - SAVG_t) \right] \end{aligned} \tag{55}$$

$$
\begin{aligned}
SG_t = TAX_t + ts_t/(1+ts_t)PQ_tQ_t \\
+FGRS_t\, er - d_g i_t^* DEBT_t er \\
-G_t\, PC_t - GTRS_t\, P_t
\end{aligned} \tag{56}
$$

Balance of Payments

$$pm_t^* M_t + pmk_t^* MK_t + pmn_t^* MN_t + i^* DEBT_t \equiv pe_t^* E_t + FGRS_t + EFLOWS_t + B_t \tag{57}$$

$$DEBT_t = DEBT_{t-1} + B_t \tag{58}$$

$$MN_t = a_n Q_t \tag{59}$$

$$MK_t = a_k J_t \tag{60}$$

Labor Market

$$L_t \equiv \overline{LS}_t \tag{61}$$

Goods Market

$$X_t \equiv C_t + G_t + J_t(1-ak) \tag{62}$$

Glossary

Parameters

α_v	shift parameter in the CES function for V
a_n	coefficient of intermediate imports
a_n	coefficient of capital imports

d_g share of public external debt

δ depreciation rate of capital

δ_t^c cost share parameter in the CES function for Q

δ_t^e cost share parameter in the CET function for Q

δ_v share parameter in the CES function for V

α parameter in the adjustment cost function

er nominal exchange rate, price numeraire

g growth rate

i_t^* weighted average of interest rates for commercial debt and concessionary loans

i_t^{aid} interest rate for concessionary loans

i_t^{debt} world interest rate inclusive of risk premium

i_t^w world interest rate

ϕ parameter in the purchase price of investment goods

ρ rate of consumer time preference

ρ_t^c exponent parameter in the CES function for Q

ρ_t^e exponent parameter in the CET function for Q

ρ_v exponent parameter in the CES function for V

pe_t^* world export price

pm_t^* world price of final imports

pmk_t^* world price of capital imports

pmn_t^* world price of intermediate imports

s_{aid} share of concessionary loans in external debt

tc_t rate of new tax credits to investment

te_t export tax or subsidies rate

ty_t direct income tax

tm_t^c	import duty for final goods
tm_t^k	import duty for capital goods
tm_t^n	import duty for intermediate goods
tx_t	domestic indirect tax rate
ω	adjustment parameter for risk premium in debt

Prices

P_t	price of supply
PD_t	price of domestic goods
PE_t	domestic price of exports
PK_t	price of capital
PMC_t	domestic price of final imports
PMK_t	domestic price of capital imports
PMN_t	domestic price of intermediate imports
PQ_t	price of gross output
PV_t	price of value added
e_t^p	real exchange rate for supply
e_t^c	real exchange rate for demand
q_t	shadow price of capital
Q_t^T	tax adjusted Tobin's *q*
r_t^p	discount rate for supply
r_t^c	discount rate for demand
rk_t	gross rate of return to capital
μ_t	discount factor
w_t	wage rate

Quantities

C_t	aggregate consumption at time t
D_t	domestic goods
D_t^{ref}	reference domestic goods adjusted for changing trade share
E_t	exports
E_t^{ref}	reference exports adjusted for changing export share
G_t	government consumption
I_t	investment
K_t	capital stock
L_t	labor demand
L_0	base-year labor supply
LS_t	labor supply at time t
M_t	final imports
M_t^{ref}	reference final imports adjusted for changing import share
MK_t	capital imports
MN_t	intermediate imports
Q_t	gross output
V_t	value added
Rk_t	marginal net revenue product of capital
X_t	aggregate supply

Values

B_t	foreign borrowings or capital inflows
$DEBT_t$	outstanding foreign debt at time t
$EFLOWS_t$	net exogenous flows from abroad (excluding grants and new borrowings)
$FGRS_t$	foreign grants (interest free)

SG_t	government savings
$GTRS_t$	government transfers to households
J_t	total investment expenditures, including adjustment cost
$\theta(x_t)$	adjustment cost function

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