DEVALUATIONS, OUTPUT, AND THE BALANCE SHEET EFFECT: A STRUCTURAL ECONOMETRIC ANALYSIS *

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Abstract

This paper analyzes the relative importance of different mechanisms through which devaluations affect output. This is done estimating a new open economy macroeconomic model for the South Korean economy. In contrast with previous studies a distinction is established between an equilibrium response of the nominal exchange rate to different shocks to the economy and that due to the central bank's policy of explicitly devaluing the currency. Devaluations are defined here as an increase in the central bank's nominal exchange rate target. The estimated model considers three main mechanisms through which devaluations affect output: The traditional expansionary expenditure-switching effect, the balance sheet effect which allows the possibility of contractionary effects when firms' debt are dollar-denominated, and a monetary channel associated to an interest rule that targets the nominal exchange rate. This paper constitutes the first attempt to estimate in a unified dynamic stochastic general equilibrium framework the parameters associated to the balance sheet effect. Results indicate that this mechanism plays a secondary role in the transmission of devaluations to output. Furthermore, evidence is found indicating that in the absence of any other shock to the economy a devaluation is expansionary. Finally, an implication of this is that the severity of output contraction in South Korea was not due to the balance sheet effect.

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1. INTRODUCTION

What are the effects of a devaluation of the nominal exchange rate on output? Traditional analysis in the Mundell-Fleming tradition, suggest that it has an expansionary effect on output. According to this perspective, a devaluation increases the cost of foreign produced goods relative to domestically produced goods. This induces domestic agents to consume more domestically produced goods and, hence, it induces an output expansion. This mechanism known as the "expenditure-switching" effect is the main expansionary channel of devaluations. However, this well established result in mainstream macroeconomics has been questioned following the devaluationary episodes experienced by Asian economies in the late 1990s. In these countries devaluations were associated with sharp output contractions.[1] The dramatic collapse of these economies has triggered a renewed interest on both academic and policy circles regarding the expansionary or contractionary nature of devaluations.

In a highly influential paper, Krugman (1999) suggested that the deterioration of firm's balance sheet as a result of the devaluation of the nominal exchange rate was the main driving force explaining the sharp output collapse observed. More precisely, he argued that when firms' revenues are denominated in domestic currency while their debts are dollar-denominated then unexpected changes in the nominal exchange rate deteriorates firms' balance sheets. This in turn affects their capacity to borrow and to invest. Furthermore, the adverse impact of a devaluation on output can be magnified if the cost of foreign borrowing increases. This mechanism is known in the literature as the "balance sheet" or the "financial accelerator" effect. Although Krugman (1999) developed this idea in a very simple framework, several authors have incorporated the balance sheet mechanism into more formal and elaborated open economy micro-founded settings. Indeed, Cespedes, Chang and Velasco (2002a, 2002b) where among the first to incorporate the balance sheet effect into a New Open Economy Macroeconomic (NOEM) model that allows for imperfect competition and nominal rigidities, and showed that under certain conditions the balance sheet could induce output contractions.. Similar results were found by Gilchrist, Gertler and Natalucci (2003) and Cook (2003) in more elaborate models.

The focus of these studies has been to replicate the dynamics of the Asian economies or to understand the role of different exchange rate regimes. However, they were not explicitly designed to answer whether devaluations are expansionary or contractionary in terms of output. As a result these studies fail to isolate the effects of a devaluation, understood as an exogenous policy decision, from the effects of other shocks to the economy. This is a fundamental distinction because it would be misleading to consider equilibrium increases in the exchange rate in response to different shocks to the economy as a devaluation of the nominal exchange rate. It turns out that to answer whether devaluations are expansionary

[1] The debate on whether devaluations are contrarionary or not is not new in the literature as reflected by the vast literature of the 1970s and 1980s. Here I do not intend to survey this literature (See Agenor and Montiel,1999). On the contrary, I want to focus on modern explanations for the posibility of contractionary devaluations. The key difference between the new and this old literature is that in the old literature contractions were explained through income effects rather than wealth effects.

or contractionary it is necessary to distinguish between the exchange rate response due to a pure devaluationary policy shock and that which takes place as a response to other shocks to the economy.

Tovar (2003) constructs a model that isolates the effect of a pure devaluationary policy shock. He considers the possibility of different transmission mechanisms through which devaluations can affect output, such as the expenditure switching effect, the balance sheet effect and a monetary channel associated to the fact that the monetary authority follows an interest rate rule that targets the nominal exchange rate among other variables. He finds that for reasonable parameters found in the literature a devaluationary policy shock, understood as an exogenous increase in the nominal exchange rate target set by the central bank, is expansionary in terms of output. Furthermore, he also finds that these output expansions are larger as the exchange rate regime becomes less flexible.

None of the studies mentioned above are estimated with formal econometric techniques. Furthermore, the calibration process is not the best way to answer what is the relative importance of the different mechanisms through which devaluations can affect output. This problem is critical in the case of the balance sheet effect, because the parameters involved in its transmission have never been estimated consistently in a general equilibrium framework. Indeed, despite the attention that the balance sheet effect had in understanding the Asian crises, we know very little about its empirical relevance. This is true not only at the aggregate level but also at more disaggregate ones. In fact, very few studies have analyzed empirically the role of firms' balance sheets in recent crises episodes. Using non-financial firm-level data, Luengnaruemitchai (2003) finds that the balance sheet effect does not appear to be the main driving force behind the sharp output contractions observed in the late 1990s in Asia. In fact, he finds evidence of a very weak balance sheet effect as reflected by the investment response of firms with foreign debt. He finds that firms tend to match their foreign currency debts to their revenue stream in foreign currency, and that firms with higher foreign debt levels are more profitable during crises episodes. Certainly, this phenomena comes at odds with the main explanation for the sharp output collapse during the Asian crises.

This paper asks empirically whether devaluations of the nominal exchange rate are expansionary or contractionary in terms of output. This is done in a NOEM setting that allows for imperfect competition and endogenous nominal rigidities, i.e. price and wage stickiness. For this purpose, the model developed by Tovar (2003) is estimated using maximum likelihood methods for the South Korean economy. The framework considers the relative importance of three different mechanisms through which devaluations can affect output. The paper makes several contributions to the literature. First, in modeling the expansionary or contractionary nature of devaluations, the impact of a pure devaluationary policy shock is carefully isolated from any other shock to the economy. Second, it is the first paper that estimates a dynamic stochastic general equilibrium model (DSGE) model which incorporates the balance sheet effect. Therefore, it can establish the relative importance of the balance sheet transmission mechanism when there is a devaluationary policy shock to the economy. It will also provide a consistent estimate of the parameters that determine the balance sheet mechanism which will be useful for other studies that calibrate models using the balance sheet mechanism in an open economy setting.

The paper is organized as follows. The model is presented in section 2. The econometric estimation strategy is then discussed in Section 3. This is followed by a section presenting the data used for estimation and its sources. Section 5 presents and analyses the econometric results from estimating the model using impulse response functions and variance decompositions. The paper ends with some concluding remarks.

2. A DSGE MODEL

The model employed for estimation follows Tovar (2003a,b), who extends Cespedes, Chang and Velasco (2002 a,b) by introducing several changes aimed at improving the fit of the model to the data. The model consists of four type of agents: firms, households, entrepreneurs and the monetary authority. In the model a continuum of monopolistically competitive firms rent capital from entrepreneurs and labor from households, and produce in each period a distinct perishable good. Each household has monopoly power over its own type of labor and faces a demand for their labor from firms. Entrepreneurs, which introduce the balance sheet effect, rent capital to firms and borrow from abroad to finance new capital.

The economy as a whole faces no trade barriers and capital flows are allowed. However, imperfections in international capital markets associated with informational asymmetries give rise to a risk premium that must be paid in addition to the international risk free interest rate to borrow money from abroad. As a result of the monopolistic competition assumption both firms and households operate setting prices and wages, respectively. Furthermore, this assumption gives rise to the possibility of nominal rigidities, which in the present framework take the form of price and wage adjustment costs.[2]

The economy is affected by six type of shocks. Firms are affected by a technology shock and a cost-push or mark-up shock. Households are subject to a preference shock that enters the Euler equation linking consumption with the real interest rate[3]. In addition there are shocks on export demand, on the international risk free interest rate and on the monetary policy rule. This last shock is key in our analysis as it is meant to capture a devaluation of the nominal exchange rate. Introducing these shocks help avoid the stochastic singularity problem that arises in the estimation of DSGE models using maximum likelihood methods.

2.1. Domestic Production: The Firms' Problem

The production of each variety of domestic goods is carried out by a continuum of monopolistically competitive firms indexed by $j \in [0, 1]$. Each firm rents capital, K_{jt}, at a rental rate R_t, and hires labor services, L_{it}, from a continuum of heterogeneous workers indexed by $i \in [0, 1]$, at a nominal wage rate W_{it} to produce home goods. Each firm chooses the price of the good they produce and its labor and capital demands, given the demand function for its own good, aggregate demand and the aggregate price level.

[2] In contrast with Cespedes, Chang and Velasco (2002 a,b) these rigidities are endogenously determined.

[3] See McCallum and Nelson (1999).

It is assumed that it is costly for firms to reset prices due to the presence of quadratic adjustment costs as captured by equation (2.5) below.[4] The specification adopted shows the percentage cost in terms of output of changing the price level. The cost size is a function of the parameter, ψ_p, and increases with the size of the price change and overall level of economic activity.[5] Intuitively, firms pay an adjustment cost if the increase in the price exceeds the steady-state gross inflation rate of domestic goods, $\bar{f}^p$. For simplicity, these adjustment costs are set to zero at steady-state. The problem faced by each firm is summarized by[6]:

$$\underset{L_{jt},K_{jt}}{Max}\ E_o \sum_{t=0}^{\infty} \Delta_t \left(P_{jt}Y_{jt} - \int_0^1 W_{ijt}L_{ijt}di - R_t K_{jt} - P_t AC_t^P \right) \tag{2.1}$$

s.t.

$$Y_{jt} = A_t K_{jt}^{\alpha} L_{jt}^{1-\alpha}, \qquad 0 < \alpha < 1 \tag{2.2}$$

$$L_{jt} = \left[\int_0^1 L_{ijt}^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}, \qquad \sigma > 1 \tag{2.3}$$

$$P_{jt} = \left[\frac{Y_{jt}}{Y_t} \right]^{-\frac{1}{\theta_t}} P_t, \qquad \theta_t > 1 \tag{2.4}$$

$$AC_t^P = \frac{\psi_p}{2} \left[\frac{P_{jt}}{P_{jt-1}} - \bar{f}^p \right]^2 Y_t \tag{2.5}$$

where Δ_t is the firm's stochastic discount factor. The production function captured by Equation (2.2) is Cobb-Douglas with a multiplicative technology shock captured by the parameter A_t, which is assumed to be common to all firms in the country and subject to shocks. As in the real business cycle literature, A_t follows a first-order autoregressive process:

$$\ln A_t - \ln \overline{A} = \zeta_A \left(\ln A_{t-1} - \ln \overline{A} \right) + \varepsilon_{At} \tag{2.6}$$

where $0 < \zeta_A < 1$ and $\varepsilon_{At} \tilde{} N(0, \sigma_A^2)$ is serially uncorrelated. A_t is observed at the beginning of period t.

The labor input captured by Eq.(2.3) is a C.E.S. aggregate of heterogenous labor services. Hence, σ is the elasticity of demand for worker i's services. In addition, firms face a demand for its product from domestic consumers, entrepreneurs and foreign consumers captured by (2.4). P_t stands for the aggregate price index for domestically produced goods. The index is defined in the next subsection.

[4] An alternative approach to model price rigidities is Calvo's (1983) staggered price setting. However, Rotemberg (1982) shows that a model with quadratic adjustment costs is equivalent, as far as aggregates are concerned, to a model such as Calvo's (1983). See Rotemberg (1996) and Hairault and Portier (1992) for models with convex costs of price adjustment. Empirical papers such as Kim (2000), Bergin (2004 and 2003) and Ireland (2004, 2002 and 2001) all use this quadratic adjustment approach.

[5] One could ask why are prices and not quantities the ones that incur in adjustment costs. The explanation is one of information costs. Price changes must be made known to consumers but it need not be the case for quantities changes (See Kim, 2000).

[6] The present formulation implies a dynamic profit maximization problem associated to the presence of price stickiness rather than the static profit maximization problem in CCV's paper.

There is a random shock to the elasticity of substitution between different varieties of goods, θ_t. This shock also known as a mark-up or cost-push shock, follows a first order autoregressive process[7]:

$$\ln \theta_t - \ln \overline{\theta} = \zeta_\theta \left(\ln \theta_{t-1} - \ln \overline{\theta} \right) + \varepsilon_{\theta t} \tag{2.7}$$

where $0 < \zeta_\theta < 1$ and $\varepsilon_{\theta t} \tilde{} N(0, \sigma_\theta^2)$ is serially uncorrelated. The relevance of this shock is that it provides an additional source of output and inflation fluctuations different to that of a technology shock alone. Following Gali (2003) it can be rationalized as the consequence of firm's periodic attempts to correct the mislignment between actual and desired mark-ups. Ireland (2002) has found for the US case that these shocks are more important than technology ones in explaining output, inflation and interest rates.

Observing that P_{jt} is a function of output, which in turn is a function of capital and labor. Defining for convenience $r_t \equiv \frac{R_t}{Q_t}$ and $w_t \equiv \frac{W_t}{Q_t}$, where Q_t is the economy's overall price index (defined in the next subsection), yields the first-order conditions for this problem with respect to capital and labor, respectively:

$$r_t = \alpha \left[1 - \frac{1}{e_{jt}^Y} \right] \frac{Y_{jt} P_{jt}}{K_{jt} Q_t} \tag{2.8}$$

$$w_t = (1 - \alpha) \left[1 - \frac{1}{e_{jt}^Y} \right] \frac{Y_{jt} P_{jt}}{L_{jt} Q_t} \tag{2.9}$$

where the minimum cost of a unit of aggregate labor L_{jt} and aggregate labor cost are given respectively by:

$$W_{jt} = \left[\int_0^1 W_{ijt}^{1-\sigma} di \right]^{\frac{1}{1-\sigma}} \quad ; \quad W_{jt} L_{jt} = \int_0^1 W_{ijt} L_{ijt} di \tag{2.10}$$

and where e_{jt}^Y is the output demand elasticity augmented with adjustment costs. Formally,

$$e_{jt}^Y \equiv \theta_t \left[\begin{array}{c} 1 - \psi_p \left(\frac{P_{jt}}{P_{jt-1}} - \bar{f}^p \right) \frac{P_t}{P_{jt-1}} \frac{Y_t}{Y_{jt}} \\ + \psi_p E_t \left[\frac{\Delta_{t+1}}{\Delta_t} \left(\frac{P_{jt+1}}{P_{jt}} - \bar{f}^p \right) \frac{P_{jt+1}}{P_{jt}^2} \frac{P_{t+1}}{Y_{jt}} Y_t \right] \end{array} \right]^{-1} \tag{2.11}$$

Both equations (2.8) and (2.9) are the standard conditions equating the marginal cost of capital and labor to its marginal revenue after considering the mark-up wedge between them, i.e. $\frac{e_{jt}^Y}{e_{jt}^Y - 1}$[8]. They imply an optimal trade-off between capital and labor inputs that depend on the relative cost of each:

$$w_t L_{jt} = \left(\frac{1 - \alpha}{\alpha} \right) r_t K_{jt} \tag{2.12}$$

[7] Clarida, Gali and Gertler (1999) refer to cost-push shocks as anything other than variations in excess demand that might affect expected marginal costs. Ireland (2002) introduces an additional shock that affects the Phillips curve specification, which is originated as an exogenous disturbance to the firm's desired markups of price over marginal cost. This is the interpretation followed here.

[8] In the absence of adjustment costs, the elasticity of output demand equals the elasticity of substitution between different varieties of domestic output. In such case, firm's problem FOCs yield the standard condition that in a symmetric monopolistic competition model equilibrium prices are set so that there is a mark-up over marginal costs.

2.2. Households' Problem

There is a continuum of heterogenous households indexed by $i \in [0, 1]$, who supply labor in a monopolistically competitive manner. Households have additively separable preferences over consumption, C_{it} and labor supply, L_{it}, in each period. Future utility is discounted at a rate of time preference β, and preferences are subject to a shock, a_t. Households derive income by selling labor at a nominal wage rate, W_{it} and hold two type of assets: non-contingent domestic bonds B_{it}, and non-contingent tradable foreign bonds, B^*_{it}. These bonds are denominated in home and foreign currency and yield a nominal return i_t and i^*_t, respectively.

Each household chooses the wage at which to sell its differentiated labor. They take as given the labor demand function for its labor type, as captured by Eq.(2.17) below, as well as the aggregate variables. Therefore, households care about their wage relative to the aggregate wage index. In addition, they face an adjustment cost of changing wages captured by Eq.(2.18) below, which depends on the parameter ψ_w.[9] As specified, the cost is increasing in deviations of actual wage inflation from its steady-state and in the overall wage level of the economy, and introduces the possibility of wage rigidities.

The optimization problem faced by each household is expressed as follows[10]:

$$\underset{C_{it},L_{it},B_{it},B^*_{it}}{Max} \; E_o \sum_{t=0}^{\infty} \beta^t a_t \left(lnC_{it} - \left(\frac{\sigma - 1}{\sigma}\right) \frac{1}{\nu} L^{\nu}_{it} \right) \tag{2.13}$$

$$0 < \beta < 1; \varepsilon > 0 \text{ and } \nu > 1$$

s.t.

$$C_{it} = \kappa \left(C^H_{it}\right)^{\gamma} \left(C^F_{it}\right)^{1-\gamma}, \; 0 < \gamma < 1 \tag{2.14}$$

$$P_t C^H_{it} + S_t C^F_{it} = Q_t C_{it} \tag{2.15}$$

$$B_{it} - B_{it-1} + S_t \left(B^*_{it} - B^*_{it-1}\right) = i_{t-1} B_{it-1} + S_t i^*_{t-1} B^*_{t-1} + W_{it} L_{it} - AC^w_t - Q_t C_{it} \tag{2.16}$$

$$W_{it} = \left(\frac{L_{it}}{L_t}\right)^{-\frac{1}{\sigma}} W_t \tag{2.17}$$

$$AC^w_t = \frac{\psi_w}{2} \left[\frac{W_{it}}{W_{it-1}} - \bar{\Omega}\bar{\pi} \right]^2 W_t \tag{2.18}$$

where γ is the share of home produced goods in total consumption, $\bar{\Omega}$ and $\bar{\pi}$ are the steady-state real wage inflation and consumer's price inflation respectively. $\kappa = \left[\gamma^{\gamma} (1 - \gamma)^{1-\gamma}\right]^{-1}$ is

[9] The quadratic specification follows Kim (2000). It captures imperfections in the labor market as it contains elements of search process. Similar specifications are found in Ireland (2001) and Bergin (2003 and 2002).

[10] The standard utility function used in the literature is adopted here (see Obstfeld and Rogoff, 2000).

an irrelevant constant. The elasticity of labor supply is captured by ν, and $\frac{\sigma-1}{\sigma}$ determines the marginal disutility of labor[11]. The preference shock a_t follows an autoregressive process:

$$\ln a_t = \zeta_a \ln a_{t-1} + \varepsilon_{at} \tag{2.19}$$

where $0 < \zeta_a < 1$, $\varepsilon_{at} \tilde{} N\left(0, \sigma_a^2\right)$ and serially uncorrelated.

Domestically produced goods, C_{it}^H, are aggregated through a C.E.S. function. This and its associated price index are given by:

$$C_{it}^H = \left[\int_0^1 C_{jt}^{\frac{\theta_t - 1}{\theta_t}} dj\right]^{\frac{\theta_t}{\theta_t - 1}} \quad ; \quad P_t = \left[\int_0^1 p_{jt}^{1-\theta_t} dj\right]^{\frac{1}{1-\theta_t}} \tag{2.20}$$

where θ_t is the elasticity of substitution between different domestic goods.

Imported goods, C_{it}^F, have a fixed price in terms of foreign currency and the law of one price is assumed to hold[12]. As a result, the price of imports in domestic currency is equal to the nominal exchange rate S_t.

The first-order conditions for the household's intra-temporal problem are[13]:

$$\left(\frac{1-\gamma}{\gamma}\right)\frac{C_t^H}{C_t^F} = \frac{S_t}{P_t} \equiv e_t \tag{2.21}$$

That is, this condition equates the demand for home versus foreign goods to the real exchange rate. The minimum cost of one unit of aggregate demand is then:

$$Q_t = P_t^\gamma S_t^{1-\gamma} \tag{2.22}$$

Define real wages as $w_{it} = \frac{W_{it}}{Q_t}$, real wage inflation as $\Omega_{it} \equiv \frac{w_{it}}{w_{it-1}}$, overall inflation (C.P.I..) as $\pi_{it} \equiv \frac{Q_t}{Q_{t-1}}$, nominal devaluation as $f_t^s \equiv \frac{S_t}{S_{t-1}}$and express the nominal wage growth as $\frac{W_{it}}{W_{it-1}} = \Omega_{it}\pi_{it}$. This allows to write the optimal inter-temporal conditions in a more convenient manner. The households' problem yield the standard inter-temporal Euler equations for consumption smoothing and an optimal wage setting equation:

$$\frac{1}{C_{it}} = \beta\left(1+i_t\right)E_t\left(\frac{a_{t+1}}{a_t}\frac{1}{\pi_{t+1}C_{it+1}}\right) \tag{2.23}$$

$$\frac{1}{C_{it}} = \beta\left(1+i_t^*\right)E_t\left(\frac{a_{t+1}}{a_t}\frac{f_{t+1}^s}{\pi_{t+1}C_{it+1}}\right) \tag{2.24}$$

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[11] L should be thought as efficiency labor rather than actual hours worked, H, with $H = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\nu}} L$. See Obstfeld and Rogoff (1996 and 2000).

[12] An important issue in the new open economy macroeconomics literature is departing from the law of one price assumption because evidence seems to reject it on the data. Departing from this assumption would require introducing additional features to the model, which is already very complicated. For instance, Kollman (2001) assumes pricing to market (PTM) to avoid the law of one price assumption.

[13] Formally, this is an equilibrium condition derived after imposing symmetry conditions.

$$-\left(\frac{1-\sigma}{\sigma}\right)L_{it}^{\nu-1}=\frac{w_{it}}{C_{it}}\left(1-\frac{1}{e_{it}^{L}}\right) \tag{2.25}$$

where e_{it}^{L} is the labor demand elasticity augmented with adjustment costs:

$$e_{it}^{L}\equiv\sigma\left[\begin{array}{c} 1-\frac{\psi_w}{L_{it}}\frac{w_t}{w_{it-1}}\pi_t\left(\Omega_{it}\pi_t-\bar{\Omega}\bar{\pi}\right) \\ +\beta\frac{\psi_w}{L_{it}}E_t\left[\frac{a_{t+1}}{a_t}\frac{C_{it}}{C_{it+1}}\frac{w_{it+1}}{w_{it}^{2}}w_{t+1}\pi_{t+1}\left(\Omega_{it+1}\pi_{t+1}-\bar{\Omega}\bar{\pi}\right)\right]\end{array}\right]^{-1} \tag{2.26}$$

This term can be thought of as a "wage mark-up" that captures frictions in wage-setting. Therefore it distorts the real wage from its competitive equilibrium value $w_{it}=C_{it}L_{it}^{\nu-1}$. Finally, in addition to the above optimality conditions, a non-Ponzi transversality condition for bonds holdings is imposed.

2.3. Entrepreneur's Problem

Entrepreneur's behavior is modeled as in CCV, which in turn is based on Bernanke, Gertler and Gilchrist's (1999) analysis of the role of credit market frictions in business cycles fluctuations in a closed economy.[14,15] For convenience, it is assumed that entrepreneurs' main activity is to decide how much to invest.[16] The analysis relies on the fact that entrepreneurs borrow from world capital markets to finance investment in excess of net worth. For this purpose they issue dollar denominated debt contracts, which due to imperfections in international financial markets, require a risk premium over the risk free international interest rate.

More specifically, assume that an entrepreneur is making the decision of how much to invest. This agent will then finance investment employing its own net worth and the remaining porting will be financed through debt. As a result the entrepreneurs' budget constraint is determined by:

$$P_tN_t+S_tD_{t+1}=Q_tK_{t+1} \tag{2.27}$$

where it is assumed full capital depreciation and that the price index for the cost of investment is the same as that for consumption as captured by Eq.(2.22).

Entrepreneurs borrow abroad paying a risk premium, $1+\eta_t$, above the world risk free interest rate, $1+\rho_t$. It is assumed that the risk premium is an increasing concave function in the ratio of the value of investment to net worth:

[14] Bernanke, Gertler and Gilchrist's (1999) analysis is an optimal debt contract problem between a single entrepreneur and foreign lenders. These agents face a joint problem of choosing investment, a dollar loan and a repayment schedule so as to maximize profits. This problem can be transformed into one where the optimal contract maximizes the entrepreneur's utility by choosing the investment to net worth ratio and the optimal cutoff of a random variable required to make the project profitable enough to allow the repayment of the loan. See also Calstrom and Fuerst (1997).

[15] Details are discussed in Tovar (2003b).

[16] This assumption differs from Bernanke, Gertler and Gilchrist (1999) who rely on a more general setting that considers the possibility of consumption by these agents. This simplifies matters, as we need not care about their labor supply or the impact of their consumption on the economy.

$$1+\eta_t = \left(\frac{Q_t K_{t+1}}{P_t N_t}\right)^{\mu} \tag{2.28}$$

where μ is the elasticity of the risk premium to the ratio of investment to net worth.

Therefore, in equilibrium, the expected yield of capital in foreign currency must equal the cost of borrowing in international capital markets to finance capital investment:

$$\frac{E_t\left(R_{t+1}K_{t+1}/S_{t+1}\right)}{Q_t K_{t+1}/S_t} = \left(1+\rho_t\right)\left(1+\eta_t\right) \tag{2.29}$$

In addition it is assumed that the world interest rate follows a first-order autoregressive process:

$$\ln \rho_t - \ln \overline{\rho} = \zeta_\rho \left(\ln \rho_{t-1} - \ln \overline{\rho}\right) + \varepsilon_{\rho t} \tag{2.30}$$

where $0 < \zeta_\rho < 1$ and $\varepsilon_{\rho t} \tilde{} N\left(0, \sigma_\rho^2\right)$ is serially uncorrelated.

In Bernanke, Gertler and Gilchrist (1999), net worth is defined as the entrepreneurial equity of the firms that remain in business. That is the wealth accumulated from operating firms. Firms that fail in t consume the residual equity, which in our case is only imported goods. Entrepreneurs are assumed here to own domestic firms, so entrepreneurial equity equals gross earnings on holdings of equity from $t-1$ to t less repayment of borrowings. Therefore, net worth is defined to be:

$$P_t N_t = R_t K_t + \Pi_t - S_t D_t = \left[1 - \frac{\psi_p}{2}\left(\frac{P_t}{P_{t-1}} - \bar{f}^p\right)^2\right] P_t Y_t - W_t L_t - S_t D_t \tag{2.31}$$

2.4. Monetary Policy

The central bank's policy instrument is the short-term nominal interest rate. Therefore, the central bank follows an interest rate rule that targets different macroeconomic variables. It is known that the specification of such rules is more controversial in open economy settings than in closed economy ones, where most of the theoretical contributions have been made.[17] The reason is related to the wider set of variables to which monetary policy can react to. The specification adopted is such that the interest rate target reacts to deviations of expected C.P.I.. inflation, output and the nominal exchange rate from their long-run levels (i.e., steady-state levels).[18] Formally, the interest rate target is captured by:

$$\frac{1+\tilde{\imath}_t}{1+\bar{\imath}} = \left(\frac{E_t \pi_{t+1}}{\bar{\pi}}\right)^{\omega_\pi} \left(\frac{Y_t}{\bar{Y}}\right)^{\omega_y} \left(\frac{S_t}{\bar{S}_t}\right)^{\frac{\omega_s}{1-\omega_s}} \tag{2.32}$$

[17] See Woodford (2003) and Clarida, Gali and Gertler (1999) for a discussion of interest rate rules in a closed economy setting. For an open economy overview see Clarida, Gali and Gertler (2001), Beningno (2004) and Benigno and Benigno (2000).

[18] See Monacelli (2003).

where

$$\bar{S}_t = \frac{\bar{S} \cdot \bar{\chi}}{\chi_t} \tag{2.33}$$

and ω_π, ω_y and $\omega_s \in [0,1]$ are the weights on each of the target variables, and χ_t is a devaluationary policy shock which is discussed in detail below[19]. Since central banks tend to smooth changes in interest rates the actual interest rate is allowed to partially adjust to the target as follows[20]:

$$\frac{1+i_t}{1+\bar{\imath}} = \left(\frac{1+i_{t-1}}{1+\bar{\imath}}\right)^{\omega_i} \left(\frac{1+\tilde{\imath}_t}{1+\bar{\imath}}\right)^{1-\omega_i} \tag{2.34}$$

where the parameter $\omega_i \in [0,1]$ is the interest rate smoothing parameter.

Inflation and output targeting are standard in closed economy models. However, it is assumed that the central bank also targets the nominal exchange rate given the open economy nature of the model. Therefore, monetary policy is tightened by increasing the nominal interest rate if the nominal exchange rate exceeds its long-run level. Targeting the exchange rate is justified in the model because firms borrow in foreign currency (dollars) and external shocks may cause significant volatility of the exchange rate.[21]

Given this rule, a devaluation is defined to be an increase of the nominal exchange rate target, $\bar{S}_t$. Such policy induces a decrease in the interest rate. For this purpose a shock χ_t on this variable is introduced. Its motivation is that during crisis episodes the focus of monetary policy is on stabilizing the exchange rate. Formally, χ_t follows a first-order autoregressive process[22]:

$$\ln \chi_t - \ln \bar{\chi} = \zeta_\chi \left(\ln \chi_{t-1} - \ln \bar{\chi}\right) + \varepsilon_{\chi t} \tag{2.35}$$

where $0 < \zeta_{\chi t} \leq 1$, $\varepsilon_{\chi t}\tilde{\ } N\left(0, \sigma_\chi^2\right)$and serially uncorrelated.[23] For the purpose of this paper, it is reasonable to focus on the exchange rate as the main determinant of interest rate policy. This is particularly true of an economy involved in a crisis situation. Ultimately, the key is that a devaluation in the model is captured by a negative shock on $\varepsilon_{\chi t}$ that induces an exogenous decline in the interest rate.

Finally a word of caution. It is well known that interest rate rules are a commitment device. However, the shock on the exchange rate target introduces a discretionary behavior

[19] The coefficient ω_s has been restricted here to be less than 1. This follows the general perception, including that of the IMF, that an increasing exchange rate should induce the central bank to raise interest rates. Following the Asian crises there has been some arguments on whether this should be the case. This controversy is discussed in Cho and West (2003) and Furman and Stiglitz (1998).

[20] Clarida, Gali and Gertler (1998 and 2000) adopt this partial adjustment mechanism in their empirical analysis. Benigno (2004) shows that interest rate smoothing together with price rigidities can introduce additional inertia into the economy as it makes the real exchange rate more persistent.

[21] It could also be argued that in emerging markets with poor history of monetary stability, the exchange rate may act as a credibility device.

[22] For operational purposes the shock enters in a multiplicative form in the interest rule. Therefore a devaluation will be captured by a negative shock on $\varepsilon_{\chi t}$.

[23] See Cho and West (2003) for a similar approach.

on the part of the monetary authority. Although this might be subject of controversy I do not extend on it and simply assume that any monetary policy in the model is credible.[24]

The specification of the interest rate rule also allows to approximate the systematic behavior of monetary policy for a continuum of exchange rate regimes depending on the weight ω_s. Hence, for $\omega_s = 0$ the rule approximates a pure floating exchange rate regime while larger values of ω_s approximates a managed float regime. Finally, as shown by Benigno (2004) it is important to take into account that a greater weight on nominal exchange rate stabilization leads to a higher persitence in the real exchange rate.

2.5. Market-Clearing Condition

Provided that a proportion γ of output is spent on consumption and investment of domestic goods, that a fraction of output is used to cover price adjustment costs, and another fraction of domestic output is exported, then the market-clearing condition may be written as:

$$P_t Y_t = \gamma Q_t \left(K_{t+1} + C_t\right) + \frac{\psi_p}{2}\left(f_t^p - \bar{f}^p\right)^2 P_t Y_t + S_t X_t \tag{2.36}$$

where the last term stands for the home good value of exports to the rest of the world. For simplicity export demand is assumed to follow an autoregressive process:

$$\ln X_t - \ln \overline{X} = \zeta_x \left(\ln X_{t-1} - \ln \overline{X}\right) + \varepsilon_{xt} \tag{2.37}$$

where $0 < \zeta_x < 1$ and $\varepsilon_{xt}\tilde{\ } N\left(0, \sigma_x^2\right)$ is serially uncorrelated.

To close the model, firms' stochastic discount factor must be specified. In standard models, where firms are owned by households and where every agent has access to a complete competitive market for contingent claims, it is assumed that firms maximize their market value. Hence, there is a unique discount factor equivalent to the marginal utility to the representative household of an additional unit of profits received each period. However, in the present framework, firms are owned by entrepreneurs. Therefore for simplicity it is assumed that entrepreneurs discount profits at a rate equivalent to that of the marginal utility of consumption:

$$\frac{\Delta_{t+1}}{\Delta_t} = \beta \left(\frac{a_{t+1}}{a_t} \frac{C_t}{C_{t+1}}\right) \tag{2.38}$$

The system of equations describing this economy cannot be solved for analytically. As a result the system is log-linearized around the non-stochastic symmetric steady-state.[25] The existence and solution of the steady-state and the equations describing the log-linearized system (i.e., first order-conditions and the resource constraints) are presented in Appendix A and B, respectively.

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[24] It is well known that targets for different variables change over time and they need not affect the credibility on the interest rate rule. Fraga, Goldfajn and Minella (2003) present evidence on the evolution of inflation targets for both developed and emerging markets. They find that while the former countries have a constant inflation target over time they are decreasing for emerging markets.

[25] The symmetric equilibrium is discussed in Tovar (2003b). The existence and solution of the steady-state is presented in Appendix A.

3. ECONOMETRIC METHODOLOGY

The empirical properties of DSGE models are often analyzed using calibration methods. In contrast with this approach, the model discussed in the previous section is estimated using econometric methods. As discussed by Ruge-Murcia (2003) econometric estimation of a DSGE offer several advantages. First, the parameter estimates are obtained after imposing restrictions that are consistent with the model. Second, it is possible to obtain parameter estimates that may be difficult to obtain using disaggregate data. Third, parameter uncertainty can be incorporated in impulse response functions if confidence intervals are constructed. In this sense this paper makes an important contribution because it is to my knowledge the first study to estimate the parameters of a model that incorporates the balance sheet or financial accelerator mechanism in DSGE framework. In particular, it is the first time that the balance sheet effect is quantified at an aggregate level.

Recently, there has been a number of studies that estimate DSGE models. However, most of them have been applied to closed economies (Ireland, 2004a, 2002; Dib, 2003; Smets and Wouters, 2003, Ruge-Murcia, 2003 or Kim, 2000). Very few have been applied to small open economies (Ambler, Dib and Rebei, 2003; Bergin, 2003 and Lubik and Schorfheide, 2003)[26]. Furthermore, their main focus has been on relatively developed (Australia and New Zealand) or industrialized economies (Canada, US and UK). In this sense this paper also fills a gap in the literature by estimating a DSGE model for a "less" developed economy such as South Korea. Lubik and Shorfheide (2003) estimate a model in which the monetary authority reacts in response to output, inflation, and exchange rate movements. They find that only in the case of Canada the central bank responds to exchange rate movements. In the preset framework I will be able to extend these results. Indeed, not only does the model incorporate an interest rate rule, but also because the central bank responds to different variables, including the nominal exchange rate.

In the literature several methods have been proposed to estimate DSGE models. Some of the econometric methods proposed include Maximum Likelihood , Generalized Method of Moments or the Simulated Method of Moments among others. All have their own strengths and weaknesses.[27]

In this paper the method employed to estimate the model is Maximum Likelihood. A key issue that arises in the estimation of DSGE models using this methodology is the stochastic singularity problem. The issue here is that the model predicts that certain combinations of the endogenous variables will be deterministic. Therefore, if exact linear definitions established by the model do not hold in the data, then any attempt to estimate the model will fail. Two approaches have been proposed in the literature to address this. One, is to incorporate additional structural disturbances until the number of shocks equal the number of series employed in estimation. In the model discussed in the previous section, this would be captured by the six shocks that are incorporated in the model (technology, mark-up, preferences, interest rate rule, exports, risk free international interest rate). The second approach is to

[26] Bergin, 2004 estimates a two country model: the US and an aggregate of the G-7.

[27] See the discussion in Ruge-Murcia (2003) for possible weaknesses and advantages of each approach.

add measurement errors. This is motivated by the fact that such errors would capture the movements and co-movements in the data that the model, because of its simplified structure, cannot explain. An advantage of this approach is that it can exploit information on a larger set of variables to estimate the parameters of the model. [28]

The estimation process consists of four steps. First, the linear rational expectations model is solved for the reduced form state equation in its predetermined variables. Second, the model is written in state-space form, and measurement errors are incorporated in the observation equation. Third, the Kalman filter is used to construct the likelihood function. Finally, the parameters are estimated by maximizing the likelihood function. In the present framework, as in Ireland (2004) both structural shocks and measurement errors are incorporated to deal with the stochastic singularity problem.

3.1. Solving the model

The estimation of the model starts by representing the DSGE model described in Section 2 in state-space form. For this purpose the system is log-linearized around the non-stochastic symmetric steady-state and solved with the method of undetermined coefficients described by Uhlig (1997)[29]. For estimation purposes two definitional equations were added $\hat{\imath}_t = \hat{\imath}_t$ and $\hat{s}_t = \hat{\varrho}_t$.[30] With this in mind, let $\tilde{x} = \left[\hat{k}\ \hat{e}\ \hat{w}\ \hat{d}\ dB^*\ \hat{\imath}\ \hat{s}\right]'$ be the endogenous state vector, $\tilde{y} = \left[\hat{\pi}\ \hat{y}\ \hat{l}\ \hat{r}\ \hat{c}\ \hat{f}^s\ \hat{\imath}\ \hat{\varrho}\right]'$ the vector of endogenous variables, and $\tilde{z} = \left[\hat{\rho}\ \hat{x}\ \hat{A}\ \hat{\theta}\ \hat{\chi}\ \hat{a}\right]'$the vector of exogenous stochastic processes so that the system is written as:

$$0 = \Gamma_A \tilde{x}_t + \Gamma_B \tilde{x}_{t-1} + \Gamma_C \tilde{y}_t + \Gamma_D \tilde{z}_t \tag{3.1}$$

$$0 = E_t[\Gamma_F \tilde{x}_{t+1} + \Gamma_G \tilde{x}_t + \Gamma_H \tilde{x}_{t-1} + \Gamma_J \tilde{y}_{t+1} + \Gamma_K \tilde{y}_t + \Gamma_L \tilde{z}_{t+1} + \Gamma_M \tilde{z}_t] \tag{3.2}$$

$$\tilde{z}_{t+1} = \Gamma_N \tilde{z}_t + \tilde{\varepsilon}_{t+1} \tag{3.3}$$

$$E_t\left[\tilde{\varepsilon}_{t+1}\right] = 0 \tag{3.4}$$

where Γ_C is of size (8×8), and of rank 8, Γ_F is of size (7×8) and Γ_N has only stable eigenvalues. The solution expresses all variables as linear functions of a vector of endogenous variables $\tilde{x}_{t-1}$ and exogenous variables $\tilde{z}_t$ given at date t, which are usually state or predetermined variables, so that the recursive equilibrium law of motion becomes:

$$\tilde{x}_t = \Gamma_P \tilde{x}_{t-1} + \Gamma_Q \tilde{z}_t \tag{3.5}$$

$$\tilde{y}_t = \Gamma_X \tilde{x}_t = \Gamma_R \tilde{x}_{t-1} + \Gamma_S \tilde{z}_t \tag{3.6}$$

[28] Ruge-Murcia (2003) analyzes alternative methods to estimate a particular DSGE and finds that parameter estimates are more efficient when measurement errors are incorporated.

[29] The symmetric equilibrium, the existence and solution of the steady-state and the loglinearized system of equations are discussed in Tovar (2003b). The solution method and its implementation for the model are discussed in appendix E.

[30] This allows to exploit information about the nominal exchange rate and the interest rate in the estimation process.

where Eq. (3.5) is the state equation and Eq. (3.6) is the observation equation. Formally, the idea is to obtain matrices $\Gamma_P, \Gamma_Q, \Gamma_R$ and Γ_S so that the equilibrium is stable.[31] Also notice that these matrices are nonlinear functions of the model's structural parameters.

3.2. Adding Measurement Errors

The state-space model can be augmented with error terms by adding serially correlated residuals to the observation equation. Although this is usually done to deal with the stochastic singularity problem, its motivation here is to improve the model's fit to the data. Formally, the state-space model is transfomed so that in addition to Eqs. 3.5 and 3.3, the observation equation Eq. 3.6 is now replaced by:

$$\tilde{y}_t = \Gamma_X \tilde{x}_t + u_t \tag{3.7}$$

$$u_t = D u_{t-1} + \xi_t \tag{3.8}$$

where u_t is an (8×1) vector of shocks of measurement errors that are allowed to follow a first-order vector autoregression, with a serially uncorrelated innovation $\xi_t \sim N(0, V)$ where $V = E\left(\xi_t \xi_t^{'}\right)$. It is further assumed that the measurement error contains no information about current or futures shocks to the economy, that is $E\left(\tilde{z}_t \xi_t\right) = 0$. Notice that since the observation equation (3.7) contains some identities, the variables $\hat{f}^s$, $\hat{\imath}$ and $\hat{\varrho}$ have no measurement errors attached to them. More precisely, u_t and ξ_t are defined as follows:

$$u_t = [u_{\pi t}\ u_{yt}\ u_{lt}\ u_{rt}\ u_{ct}\ 0\ 0\ 0]' \tag{3.9}$$

$$\xi_t = \left[\xi_{\pi t}\ \xi_{yt}\ \xi_{lt}\ \xi_{rt}\ \xi_{ct}\ 0\ 0\ 0\right]' = [\xi_t^{*\prime}\ 0_{1\times 3}] \tag{3.10}$$

with matrices D and V :

$$D = \begin{bmatrix} d & 0_{5\times3} \\ 0_{3\times5} & 0_{3\times3} \end{bmatrix} \text{ where } d = \begin{bmatrix} d_{\pi\pi} & d_{\pi y} & d_{\pi l} & d_{\pi r} & d_{\pi c} \\ d_{y\pi} & d_{yy} & d_{yl} & d_{yr} & d_{yc} \\ d_{l\pi} & d_{ly} & d_{ll} & d_{lr} & d_{lc} \\ d_{r\pi} & d_{ry} & d_{rl} & d_{rr} & d_{rc} \\ d_{c\pi} & d_{cy} & d_{cl} & d_{cr} & d_{cc} \end{bmatrix} \tag{3.11}$$

$$V = \begin{bmatrix} V^* & 0_{5\times3} \\ 0_{3\times5} & 0_{3\times3} \end{bmatrix} \text{ where } V^* = E\left(\xi_t^* \xi_t^{*\prime}\right) = \begin{bmatrix} v_\pi^2 & v_{\pi y} & v_{\pi l} & v_{\pi r} & v_{\pi c} \\ v_{\pi y} & v_y^2 & v_{yl} & v_{yr} & v_{yc} \\ v_{\pi l} & v_{yl} & v_l^2 & v_{lr} & v_{lc} \\ v_{\pi r} & v_{yr} & v_{lr} & v_r^2 & v_{rc} \\ v_{\pi c} & v_{yc} & v_{lc} & v_{rc} & v_c^2 \end{bmatrix} \tag{3.12}$$

The structural parameters of the model are constrained to satisfy the theoretical restrictions discussed in Section 2. In addition the eigenvalues of the matrix D are constrained to

[31] Details for the conditions under which this can be achieved are discussed in Uhlig (1997). The method is equivalent to Blanchard and Kahn (1980) and employs Sims' (2000) QZ decomposition, which is numerically more stable.

lie inside the unit circle. As result the residuals in u_t must be stationary. Finally, the covariance matrix V is constrained to be positive definite. This is done calculating a Choleski decomposition $V = \tilde{V}\tilde{V}'$ where $\tilde{V}$ is a lower triangular matrix.

Let $\tilde{S}_t = [\tilde{x}_t' \; \tilde{z}_t']'$ so that Eqs.(3.5) and (3.3) are summarized by a single equation:

$$\tilde{S}_t = \Gamma_\Pi \tilde{S}_{t-1} + \Gamma_W \tilde{e}_t \tag{3.13}$$

where

$$\tilde{e}_t = \begin{bmatrix} 0_{7\times 1} \\ \tilde{\varepsilon}_t \end{bmatrix} ; \Gamma_\Pi = \begin{bmatrix} \Gamma_P & \Gamma_Q \\ 0_{6\times 7} & \Gamma_N \end{bmatrix} ; \Gamma_W = \begin{bmatrix} 0_{7\times 7} & 0_{7\times 6} \\ 0_{6\times 7} & I_{6\times 6} \end{bmatrix} \tag{3.14}$$

Now define the following (21×1) vector to track the model's unobserved state variables:

$$\tilde{h}_t = \left[\tilde{S}_t' \; u_t'\right]' \tag{3.15}$$

This allows to re-write the model in compact state-space form as follows:

$$\tilde{h}_t = \Gamma_V \tilde{h}_{t-1} + v_t \tag{3.16}$$

$$\tilde{y}_t = \Gamma_Z \tilde{h}_t \tag{3.17}$$

where

$$\Gamma_V = \begin{bmatrix} \Gamma_\Pi & 0_{13\times 8} \\ 0_{8\times 13} & D \end{bmatrix} \tag{3.18}$$

$$v_t = \begin{bmatrix} \Gamma \tilde{e}_t \\ \xi_t \end{bmatrix} \tag{3.19}$$

$$\Gamma_Z = [\Gamma_X \; 0_{8\times 6} \; I_{8\times 8}] \tag{3.20}$$

Here, the serially uncorrelated innovation vector, v_t, has variance-covariance matrix equal to:

$$E\left(v_t v_t'\right) = Q = \begin{bmatrix} \Gamma_W \Omega \Gamma_W' & 0_{13\times 8} \\ 0_{8\times 13} & V \end{bmatrix} \tag{3.21}$$

where $\Omega = E\left(\tilde{e}_t \tilde{e}_t'\right) = \begin{bmatrix} 0_{7\times 7} & 0_{7\times 6} \\ 0_{6\times 7} & \Lambda \end{bmatrix}$ and $\Lambda = E\left[\varepsilon_t \varepsilon_t'\right]$ is the (6×6) diagonal variance-covariance matrix for the shock's innovations..

3.3. Kalman Filter and Maximum Likelihood Function

With the model in state-space form as captured by Eqs. (3.16) and (3.17) it is possible to construct the likelihood function using the Kalman Filter.[32] For this purpose, first collect the structural parameters in the (30×1) vector:

$$\Theta = \left[\alpha \; \gamma \; \beta \; \psi_p \; \psi_w \; \sigma \; \mu \; \nu \; \eta \; \omega_i \; \omega_\pi \; \omega_y \; \omega_s \; A \; \theta \; a \; \chi \; \rho \; x \; \zeta_A \; \zeta_\theta \; \zeta_\alpha \; \zeta_\chi \; \zeta_\rho \; \zeta_x \; \sigma_A \; \sigma_\theta \; \sigma_a \; \sigma_\chi \; \sigma_\rho \; \sigma_x\right]' \tag{3.22}$$

[32] See Chapter 13 in Hamilton (1994a).

Observe that in addition to the structural parameters, the maximum likelihood function incorporates 25 elements of the matrix D that governs the persistence of the measurement errors and 15 elements of the variance-covariance matrix V associated to the measurement error residuals. Furthermore assume as in Ireland (2004) and Ruge-Murcia (2003) that the state vector is unobserved, and let the observed data obtained through date $t-1$ be summarized by the vector:

$$\aleph_{t-1} \equiv \left(\tilde{y}'_{t-1},\ \tilde{y}'_{t-2}, ..., \tilde{y}'_{1}\right)' \tag{3.23}$$

Now define $\hat{h}_{t|t-1} = E\left(\tilde{h}_t|\aleph_{t-1}\right)$ as the best estimate of the unobservable state vector $\tilde{h}_t$ for period t based on past observations of $\tilde{y}_t$, and let

$$\Sigma_{t|t-1} = E\left\{\left(\tilde{h}_t - \hat{h}_{t|t-1}\right)\left(\tilde{h}_t - \hat{h}_{t|t-1}\right)'\right\} \tag{3.24}$$

be the associated forecast error covariance matrix. Finally, let the best forecast of $\tilde{y}_t$ based on past observations be $\hat{y}_{t|t-1} = E\left(\tilde{y}_t|\aleph_{t-1}\right)$.

Therefore, observe that these results and Eq. (3.17) imply that $\hat{y}_{t|t-1} = \Gamma_Z \hat{h}_{t|t-1}$

The Kalman filter is an algorithm for calculating the sequence $\left\{\hat{h}_{t|t-1}\right\}_{t=1}^{T}$ and $\left\{\Sigma_{t|t-1}\right\}_{t=1}^{T}$, where T is the sample size. These sequences can be calculated using the following formulas [33]:

$$\hat{h}_{t+1|t} = \Gamma_V \hat{h}_{t|t-1} + \tilde{K}_t\left(\tilde{y}_t - \Gamma_Z \hat{h}_t\right) \tag{3.25}$$

$$\Sigma_{t+1|t} = \Gamma_V \Sigma_{t|t-1} \Gamma'_V - \tilde{K}_t \Gamma_Z \Sigma_{t|t-1} \Gamma'_V + Q \tag{3.26}$$

where $\tilde{K}_t \equiv \Gamma_V \Sigma'_{t|t-1} \Gamma'_Z \left(\Gamma_Z \Sigma_{t|t-1} \Gamma'_Z\right)$ is "Kalman gain" or "gain matrix".

To start the recursion described by the Kalman filter the values are initialized with the unconditional mean and variance of $\tilde{h}_1$:

$$\hat{h}_{1|0} = 0 \tag{3.27}$$

$$\Sigma_{1|0} = E\left\{\left(\tilde{h}_1 - \hat{h}_{1|0}\right)\left(\tilde{h}_1 - \hat{h}_{1|0}\right)'\right\} \tag{3.28}$$

where $\Sigma_{1|0}$ is calculated using the following formula[34]:

$$vec\left(\Sigma_{1|0}\right) = \left[I_{21^2\times 21^2} - \Gamma_V \otimes \Gamma_V\right]^{-1} \cdot vecQ \tag{3.29}$$

where the expression in brackets is assumed to be non-singular.

Now, let the innovations of the model be normally distributed, it follows that the density of $\tilde{y}_t$ conditional on $\aleph_{t-1}$ is:

$$f\left(\tilde{y}_t|\aleph_{t-1}, \Theta\right) = N\left(\Gamma_Z \hat{h}_{t|t-1}, \Gamma_Z \Sigma_{t|t-1} \Gamma'_Z\right) \tag{3.30}$$

[33] The full derivation of the Kalman filter is discussed in Appendix C.

[34] This is obtained after using the following result: $vec(ABC) = (C' \otimes A) \cdot vec(B)$.

Therefore, the Maximum Likelihood estimator of Θ is:

$$\hat{\Theta}_{ml} = \max_{\{\Theta\}} \; L(\Theta) \tag{3.31}$$

where $L(\Theta)$ denotes the log likelihood function:

$$L(\Theta) = -\frac{Tn}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}\ln\left|\Gamma_Z \Sigma_{t|t-1}\Gamma_Z'\right| - \frac{1}{2}\sum_{t=1}^{T}\left(\tilde{y}_t - \Gamma_Z \hat{h}_t\right)'\left(\Gamma_Z \Sigma_{t|t-1}\Gamma_Z'\right)^{-1}\left(\tilde{y}_t - \Gamma_Z \hat{h}_t\right) \tag{3.32}$$

where $n = 8$ the number of observed variables in $\tilde{y}_t$.

It is possible to evaluate the likelihood function for any given set of parameters. Therefore, a search algorithm can be used to find the parameter values that maximizes it. To implement the procedure the model's structural parameters are transformed so that they can take any value on the real line.[35]

4. DATA

The model is fit for South Korea. The eight series used are inflation, output, labor, private consumption, devaluation of the nominal exchange rate, interest rate and the nominal exchange rate. The last two variables were introduced as definitional variables in the observation equation to exploit the information they contain. All data are seasonally adjusted quarterly series for the period 1982:3 to 2003:3. GDP, population, employment and private consumption were obtained from Datastream, while the consumer price index, money market interest rate and the nominal exchange rate were obtained from the IMF's International Financial Statistics. Output and consumption are measured in per capita terms. All data was logged and then the Hodrick-Prescott filter was applied to it.[36] Figure G.1 shows the data employed for estimation.

5. EVALUATING THE MODEL

To estimate the model successfully several parameters are calibrated. The calibrated values are summarized in Table 5.1. Parameter values for preferences and technology are standard in the literature so no major comments are necessary. An exception is the elasticity of substitution between different varieties of goods, $\theta = 6$, which was chosen following Gali and Monacelli (2002) so that the steady-state mark-up equals 20%.

Table 5.2 reports the maximum likelihood estimates and the corresponding standard

[35] See Appendix F for a detailed discussion of the estimation procedure and standard errors calculations.

[36] This approach has been employed here for simplicity. It is common in the literature to detrend the data running a regression with linear trend. Possibly it would be more desirable to incorporate the trend into the model by adding a labor-augmenting technology shock.

Preferences	-Discount factor, $\beta = 0.99$ -Elasticity of labor supply, $\nu = 2$ -Consumption share of home goods, $\gamma = 0.65$ -Elasticity of substitution between different varieties, $\theta = 6$
Technology	-Capital share, $\alpha = 0.4$ -Elasticity of labor demand, $\sigma = 2$

Table 5.1: Benchmark Parameter Values

Parameters		Estimates	Standard Errors
Degree of price rigidity	ψ_p	5.69540	0.69672
Degree of wage rigidity	ψ_w	1.35920	0.32488
International capital market imperfections	μ	0.40796	0.04356
Interest rate response to:			
- Lagged interest rate	ω_i	0.74992	0.03066
- Expected inflation	ω_p	2.60610	0.58025
- Output	ω_y	1.40660	0.96648
- Nominal exchange rate	ω_s	0.79997	0.05510

Table 5.2: Model's Main Structural Parameters Estimates and Standard Errors

errors of 7 key structural parameters of the model[37]. These parameters capture the degree of nominal rigidities (ψ_p, ψ_w), the balance sheet effect (μ), and the parameters associated to the interest rate rule (ω_i, $\omega_p, \omega_y, \omega_s$). The point estimates appear to be quite reasonable. Results suggest that there is an important degree of nominal rigidities, and wage rigidities appear to be quantitatively smaller than price rigidities. The point estimates for ψ_p indicates that a 2% increase on the inflation rate above its steady-state level implies a 0.1% price adjustment cost in terms of domestic output for firms.

The parameter for the balance sheet effect, i.e. the elasticity of the risk premium to the investment-net worth ratio, which captures the degree of international capital market imperfections falls within the upper range of what is considered normal in the literature. According to Carlstrom and Fuerst (1997) this parameter should lie within a value range of 0.2 to 0.4. The estimated value of $\mu = 0.4$ reflects that the balance sheet was strong in the South Korean economy.

The parameters for the interest rate rule indicate that interest rates in South Korea have been adjusted quite smoothly as captured by ω_i. The estimate for the weight on the expected inflation satisfies the *Taylor principle*, which indicates that the optimal policy response to a rise in inflation is to increase interest rates sufficiently as to induce an increase of real interest

[37]Standard errors are calculated following Ireland (1994). They correspond to the square roots of the diagonal elements of minus one times the inverted matrix of second derivatives of the maximized log-likelihood function. See Appendix F for futher details.

Persistence Parameters		Estimates	Standard Errors
-Technology	ζ_A	0.75731	0.21200
-Mark-up	ζ_θ	0.95164	0.00058
-Preferences	ζ_a	0.19833	2.79140
-Devaluationary policy	ζ_χ	0.70724	0.07222
-International risk free interest rate	ζ_ρ	0.97727	0.01084
-Exports	ζ_x	0.67179	0.09137
Standard Deviation			
-Technology	σ_A	0.18344	0.02143
-Mark-up	σ_θ	0.28992	0.02289
-Preferences	σ_a	0.03564	0.36334
-Devaluationary policy	σ_χ	0.22594	0.02642
-International risk free interest rate	σ_ρ	0.19539	0.01996
-Exports	σ_x	0.11976	0.02018

Table 5.3: Structural Shock's Persistence and Standard Deviation Estimates

rates. Therefore, ω_p should exceed unity. The value estimated for this parameter indicates that, ceteris paribus, a one percentage increase in quarterly expected inflation induces a 160 basis point increase in the quarterly real interest rate. The estimated weight on output, ω_y, implies that holding everything else constant, an increase in output is compensated by the monetary authority with a 140 basis point increase in the quarterly nominal interest rate. Finally, recall that in section 2.4 it was shown that a value $\omega_s = 0$ would capture a flexible exchange rate regime, while $\omega_s = 1$ would indicate that the exchange rate regime is completely fixed. The estimated value of $\omega_s = 0.79$ indicates a high degree of intervention by the central bank during the period of analysis, which is well known to be the case for the South Korean economy.

Point estimates for the persistence parameters of the shocks and its standard error are reported in Table 5.3. Estimates indicate that shocks on technology, the mark-up and the international interest rate are very persistent shocks, while export and preference shocks appear to be less persistent. The devaluationary policy shock in turn appears to have moderate persistence. Therefore it suggests that the monetary authorities are not continuously pursuing a devaluationary policy, but rather this is more like a one time policy move. This conclusion is further supported by a high volatility of monetary policy innovations.

Other parameter estimates related to the measurement error dynamics are reported in Tables 5.4 and 5.5. Table 5.4 reports the persistence and cross-correlations among the measurement errors for different variables. Results indicate that some of the residuals u_t are quite persistent. Table 5.5 shows the estimates for the standard deviations on the measurement errors innovations, ξ_t. Results show that standard errors for these innovations are in general smaller that those associated to the standard innovations of the structural shocks reported in Table 5.3. The main exception is that associated to the preference shock.

	Estimates	Standard Errors
$d_{\pi\pi}$	-0.45032	0.27128
$d_{\pi y}$	-0.08308	0.45714
$d_{\pi l}$	1.16410	0.19991
$d_{\pi r}$	1.62170	0.10208
$d_{\pi c}$	-1.16190	0.33235
$d_{y\pi}$	3.21800	1.62140
d_{yy}	-0.20090	1.58340
d_{yl}	-0.60675	0.88232
d_{yr}	2.57230	0.50659
d_{yc}	-1.19340	0.33730
$d_{l\pi}$	2.22130	1.56100
d_{ly}	-0.16508	1.10630
d_{ll}	1.15960	0.75864
d_{lr}	3.31880	0.39500
d_{lc}	-1.80150	0.30935
$d_{r\pi}$	0.45866	0.92773
d_{ry}	-0.60586	0.74194
d_{rl}	-1.10540	0.55559
d_{rr}	-2.53960	0.47408
d_{rc}	1.74410	0.53392
$d_{c\pi}$	-0.32944	0.52576
d_{cy}	0.16810	0.36421
d_{cl}	0.23261	0.50553
d_{cr}	0.81599	0.47265
d_{cc}	0.03989	0.28112

Table 5.4: Structural Shock's Persistence and Standard Deviation Estimates

	Estimate	Standard Error
v_{π}^2	0.04755	0.00714
$v_{\pi y}$	0.00046	0.00153
v_y^2	0.15236	0.00861
$v_{\pi l}$	−0.00134	0.00116
v_{yl}	−0.01457	0.00396
v_l^2	0.14226	0.02455
$v_{\pi r}$	−0.00123	0.00056
v_{yr}	0.00635	0.00170
v_{lr}	−0.00360	0.00248
v_r^2	0.07827	0.01244
$v_{\pi c}$	−0.00006	0.00149
v_{yc}	−0.00068	0.00077
v_{lc}	0.00126	0.00131
v_{rc}	0.00040	0.00186
v_c^2	0.05042	0.00830

Table 5.5: Structural Shock's Persistence and Standard Deviation Estimates

5.1. Impulse Response

This section evaluates the model's performance using the calibrated and estimated values for the structural parameters. For this purpose four exercises using impulse response functions are performed. First, the impulse response function of the model to a devaluationary policy shock is analyzed. This provides the key piece of evidence to answer the main question of the paper, i.e., whether devaluations of the nominal exchange rate, in isolation to any other shock, are expansionary or contractionary in terms of output. Next, the behavior of the model is analyzed when the economy is exposed to adverse external shocks. Two type of shocks are considered here: an increase in the international risk free interest rate and an adverse shock on export demand. The motivation for this is to see whether the model can explain key empirical features observed during the Asian crises and the literature has traditionally considered adverse external shocks as trigger mechanism (see for instance, Krugman, 1999). Furthermore, it also intends to highlight that devaluationary policies are not necessarily the driving force for output collapses, and observed negative correlations between exchange rates an output are simply an equilibrium response to the shock. To be more precise, it will be shown that devaluations are not contractionary. Finally, the model is used to draw some policy lessons. In particular, it is reasonable to ask whether the monetary authority should devalue the currency in response to an adverse external shock. To answer this question the impulse response functions of the model to a joint adverse external shock and devaluationary policy are considered.

5.1.1. Devaluationary Policy Shock

Impulse response functions to a one percent devaluation of the nominal exchange rate target are reported in Figures G.2 to G.5. This shock induces an overshooting of the nominal exchange rate and output expands in the three quarters that follow the shock (See Figure G.3).This output behavior is indicative of a expenditure-switching effect that dominates the contractionary balance sheet mechanism. Simulations of the model (See Tovar, 2003a) indicate that it is the low degree of flexibility of the exchange rate regime that allows the monetary authority to exploit the expansionary impact of the expenditure-switching effect.

Observe in Figure G.4 that the balance sheet mechanism is operating in a contractionary manner. The devaluationary policy causes net worth to fall and the risk premium rises. As a result of this, capital investment collapses during the year and a half that follows the devaluation (See Figure G.3). Also notice that the interest response to the shock is very weak. As shown in Tovar (2003a) the endogeneity of the risk premium alters the response of the monetary authority as it gets concerned about an exchange rate overshooting. In particular, the increase in the risk premium has a feedback effect that reverses the initial decline in interest rates induced by the shock.

It is important to stress that output expansion is achieved at a cost of inducing a higher inflation rate and also, because of wage rigidities, at the expense of deteriorating workers' income (See Figures G.2 and G.5, respectively). The inflationary trade-off associated to this policy is a very delicate issue in most emerging economies and should carefully be taken into account if the country has an inflationary history.

It is important to mention that it has been assumed that monetary policy and,thus, the exchange rate regime is fully credible. In other words, the model presented in this paper is not one of speculative attacks and hence it cannot account for a switch in the exchange rate regime. Although this would be a desirable feature to make the model more realistic it is left for future research.

Overall, it is possible to conclude two things. First, that a devaluation of the nominal exchange rate, in isolation from any other shock to the economy, is expansionary in terms of output. Second, that the most important transmission mechanism from a devaluation to output is the expenditure-switching effect. A corollary of this is that the balance sheet effect, despite its contractionary effects, plays a secondary role in the transmission of devaluations to output. This is also true of the monetary channel, but in this case it is due to the endogeneity of the risk premium.

5.1.2. Adverse External Shocks

Krugman (1999) argues that the reversal of capital flows was the main cause behind the output collapse and real exchange rate depreciation observed in the Asian financial crises of the late 1990s. To capture this reversal of capital flows within the model described in section 2 consider two shocks: an increase in the international interest rate and a decrease in export demand. Analyzing the behavior of the economy to these shocks and comparing it to the case in which there is only a devaluationary policy shock provides two interesting results. First, it illustrates that the model can explain the main trends in the behavior of the Korean economy during the Asian crises. Second, it highlights the importance of distinguishing between a devaluationary policy and an equilibrium response of the exchange rate to different shocks to the economy.

International Interest Rates Impulse response functions to a one percent increase in the international risk free interest rate are reported in Figures G.6 to G.9. An increase in the international interest rate induces upon impact an increase of the nominal exchange rate via the interest parity condition. This higher level of the nominal exchange rate translates into a higher aggregate inflation rate and into an increase of the domestic interest rate. The higher levels of expected returns on capital lead to a decline in capital investment and the higher cost of external funds forces firms to finance capital with its own resources rather than relying on external debt (See Figure G.8). Consumption also falls as real interest rates rise. Despite the collapse in aggregate demand, output does not decline immediately (See Figure G.7). Therefore, this suggests an expenditure-switching effect that delays output contraction, which only takes place starting a quarter later.

Notice then that the model is capable of explaining key features observed during the Asian crises, such as the output and aggregate demand collapse and the exchange rate increase. Equally important, it demonstrates that it is not the devaluation of the currency that triggered the output collapse but rather a completely different shock. An important empirical implication of this is that it would be misleading to conclude from the observed negative correlation between the nominal exchange rate and output that devaluations are contractionary.

Export Demand The behavior of the model to a one percent adverse shock on export demand is reported in Figures G.10 through G.13. The shock induces an immediate decline in output. Ceteris paribus this would induce domestic interest rates to decline. However, endogenous feedbacks of the model associated with the interest rate rule and to the interest parity condition forces the nominal exchange rate to overshoot and the risk premium to rise, which ultimately explains the observed increase in the domestic interest rate (see G.10). Observe also that aggregate demand collapses in response to the hike in interest rates and this forces inflation to fall.

Again, the key feature here is that in the model a collapse in export demand is able to reproduce the negative correlation between the exchange rate and output, as well as the collapse in aggregate demand experienced by South Korea during the Asian crises. As before this implies that it is not a devaluationary shock what triggers the output collapse. Therefore, it would be misleading to conclude that devaluations are contractionary.

5.1.3. Adverse External Shocks and Devaluationary Policies

Given the impulse response functions reported above it is reasonable to ask what are the policy implications that can be drawn from the analysis. In particular, one might whether it is desirable for the monetary authorities to devalue its currency in response to an adverse external shock. In what follows consider the case in which the economy is hit by an adverse external shock and at the same time the monetary authority responds with a devaluation on the nominal exchange rate.

International Interest Rate and Devaluations Impulse response functions to a one percent shock increase in the international interest rate shock jointly with a one percent devaluationary shock are shown in Figure G.14 through G.17. The most relevant feature here is that the nominal exchange rate overshoots beyond the levels observed in Figure G.6. This behavior is mainly the consequence of the devaluationary policy. Also observe that aggregate demand collapses immediately after the shock, while output increases initially and then declines with a lag. This initial output expansion together with a decline in the aggregate demand is indicative of a strong expenditure-switching effect induced by the devaluation of the nominal exchange rate. The simple comparison of output behavior between Figures G.7 and G.15 illustrates that monetary authorities can play a stabilizing role in terms of output if they devalue the currency at the time of the shock. That is, in the short run a devaluationary policy can mitigate the contractionary effects induced by the shock on international interest rates. However, it is important to observe that there are important trade-offs that may arise such as the inflationary pressures and the decline in workers' income.

It is worth mentioning that the short lived effects of a devaluation are also reflected in a short-lived contractionary balance sheet effect. Figure G.16 shows that it is only immediately after the shock that the risk premium rises and net worth falls. This behavior is quickly reversed after two quarters mostly due to the decline of external debt, and to a lesser extent to the slow return of the exchange rate to the steady state, which perpetuates for some quarters the benefits of the expenditure-switching effect.

Export Demand and Devaluations The economy's behavior following an adverse external shock jointly with a devaluationary policy shock are shown in Figures G.18 through G.21. As before the key result here is that the output collapse induced by the adverse export demand shock can be partially reversed in the short run with a devaluation of the nominal exchange rate. Therefore, monetary authorities can play a stabilizing role in terms of output.

A key difference between the export demand shock and the shock on international interest rates is that here the contractionary balance sheet effect works with more strength in the sense that the increase in the risk premium and the collapse of net worth are more persistent.

5.2. Variance Decompositions

The contribution of the different shocks in the model to the forecast error variance of the observable endogenous variables at various horizons is reported together with its standard errors in Tables 5.6 and 5.7.[38] The reported forecast error variance is attributed to seven

[38]Standard errors are calculated as in Runkle (1987).

shocks: six structural shocks and the measurement error shocks, ${\xi_t}$[39]. The main purpose of this section is two fold. First, to answer how much of the output variation is explained by a devaluationary policy shock. Second, analyze the performance of the model.

First, focus on the determinants of aggregate output. Estimates indicate that structural shocks account for a non-negligible 50% of the one-quarter-ahead forecast error variance of aggregate output. Of this portion, three quarters of the variance is explained by the mark-up shock. The technology shock follows in order of importance, but its contribution is very low and at odds with the standard real business cycle. Gali (1999 and 2003) argues that in models with imperfect competition and sticky prices, a favorable technology shock is likely to induce a decline in employment. This behavior is precisely the impulse response behavior (not shown) obtained in the present framework for the estimated parameters. Therefore the estimates here support Gali's view, as well as results found by Smets and Wouters (2003) in an estimated DSGE model for the Euro area, who conjecture that technology shocks are not the main source of aggregate fluctuations. The devaluationary policy shocks account for 3.4 percent of output's unconditional forecast-error variance.

It is important to notice that the reported forecast-error variance decompositions include the combined effects of the five measurement error shocks captured by ξ_t. The impact of measurement errors are far from negligible, and for longer forecast horizons they rapidly absorb all the variance in the forecast errors. Their significance are not surprising given that they capture the effects of all other shocks that have been omitted from the model (e.g. fiscal policy shocks).

The forecast-error variance decomposition for the nominal exchange rate shows that the single most important variable explaining the behavior of the nominal exchange rate at all forecast horizons is the devaluationary policy shock[40]. This shock accounts for three fourths of the one-quarter ahead forecast-error variance and its relevance declines monotonically from there on but remains very high after four years. Technology shocks appear to play an important role at short horizons, but its relevance disappears over time. The mark-up and the international interest rate shocks show an opposite pattern, with a contribution that increases as the forecast horizon increases.

The model does a much better job in explaining over short horizons other variables in the model such as inflation, employment, the real interest rate or consumption. Roughly 90 percent of the one-quarter ahead forecast error variance of these variables is explained by the model. The mark-up shock appears to be the most relevant shock in the model. For one-quarter and four-quarter ahead forecast horizons this shock accounts for 80 percent of inflation and labor variance. Results for inflation are consistent with results reported by Ireland (2002) and Smets and Wouters (2003). Variance decompositions show no major role for the consumers' preferences shock nor for the export shock. This is a major drawback, in particular in accounting for output and consumption variance, given that these shocks are the main shifting variables for the corresponding IS curve in the present framework (See

[39] The contributiuon of each component of the measurement error residuals is aggregated into a single component in the variance decomposition exercise.

[40] Recall that since this was a definitional observable variable no measurement error was attached to it.

	Technology		Mark-up		Preferences		Devaluations	
	coef.	s.e.	coef.	s.e	coef.	s.e	coef.	s.e.
Output								
1	8.03	1.5100	37.45	7.4180	0.05	0.0579	3.40	0.6365
4	3.80	1.0860	17.80	4.3700	0.01	0.0085	0.36	0.0788
8	0.02	0.0060	0.13	0.0322	0.00	0.0000	0.00	0.0003
16	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Inflation								
1	2.59	0.4383	81.84	3.4480	0.12	0.1238	4.16	0.6768
4	1.17	0.2840	77.72	2.4567	0.03	0.0270	1.00	0.1777
8	0.02	0.0128	6.23	0.8245	0.00	0.0006	0.02	0.0049
16	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Labor								
1	2.71	0.4714	80.60	4.1877	0.12	0.1238	2.75	0.4495
4	1.23	0.3131	65.55	4.8965	0.02	0.0270	0.61	0.0763
8	0.02	0.0093	3.48	0.2515	0.00	0.0006	0.01	0.0023
16	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Real Interest Rate								
1	25.33	3.0127	63.51	4.7579	0.11	0.1092	0.74	0.0842
4	7.73	1.3978	71.70	4.0641	0.03	0.0300	0.84	0.1340
8	0.15	0.0711	7.62	1.1211	0.00	0.0015	0.02	0.0071
16	0.00	0.0000	0.00	0.0001	0.00	0.0000	0.00	0.0000
Consumption								
1	38.50	6.6688	26.95	2.4357	0.00	0.0030	3.09	0.3815
4	13.12	4.1905	6.43	0.4120	0.00	0.0014	0.78	0.1356
8	0.03	0.0140	0.02	0.0047	0.00	0.0000	0.00	0.0006
16	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Devaluation Rate								
1	3.01	0.3200	86.37	2.6166	0.11	0.1089	9.67	2.0217
4	1.19	0.2542	96.02	0.8051	0.04	0.0383	2.54	0.6185
8	0.33	0.0811	98.59	0.3835	0.01	0.0132	0.52	0.1400
16	0.06	0.0150	98.65	0.4678	0.00	0.0049	0.10	0.0290
Nominal Interest Rate								
1	24.70	5.8698	39.03	3.0203	0.01	0.0032	16.50	4.7820
4	23.07	5.7121	48.40	1.0399	0.02	0.0182	16.44	4.1387
8	9.80	2.3194	64.38	2.4107	0.02	0.0149	10.49	2.5550
16	4.74	1.0266	71.06	3.6266	0.01	0.0070	5.17	1.4220
Nominal Exchange Rate								
1	19.06	0.4974	3.31	1.4648	0.00	0.0022	75.10	6.0255
4	17.00	0.2036	5.76	1.5184	0.01	0.0077	68.30	2.4615
8	13.84	1.0787	19.67	4.8111	0.00	0.0058	51.53	3.1937
16	10.63	0.8532	31.93	8.4181	0.00	0.0049	38.21	1.1191

Table 5.6: Forecast-error variance

	Intl. Interest		Exports		Meas. Error	
	coef.	s.e.	coef.	s.e	coef.	s.e
Output						
1	0.00	0.0096	0.15	0.0171	50.93	6.5974
4	0.27	0.0659	0.02	0.0033	77.75	3.8447
8	0.00	0.0002	0.00	0.0000	99.85	0.0262
16	0.00	0.000	0.00	0.0000	100.00	0.0000
Inflation						
1	0.23	0.1410	0.56	0.1546	10.51	1.3004
4	0.05	0.0572	0.12	0.0291	19.91	0.9410
8	0.02	0.0889	0.00	0.0005	93.71	0.8692
16	0.00	0.0000	0.00	0.0000	100.00	0.0000
Labor						
1	0.08	0.0835	0.09	0.0145	13.66	2.7310
4	0.02	0.0365	0.03	0.0041	32.55	4.2689
8	0.01	0.0049	0.00	0.0001	96.49	0.2031
16	0.00	0.0000	0.00	0.0000	100.00	0.0000
Real Interest Rate						
1	0.00	0.0030	1.78	0.3660	8.53	1.0489
4	0.37	0.1856	0.22	0.0520	19.12	4.2689
8	0.02	0.0058	0.00	0.0008	92.19	0.2031
16	0.00	0.0000	0.00	0.0000	100.00	0.0000
Consumption						
1	16.13	2.1876	1.98	0.3465	13.35	1.6546
4	3.79	0.9791	0.62	0.0574	75.27	5.3270
8	0.03	0.0171	0.00	0.0003	99.91	0.0360
16	0.00	0.0000	0.00	0.0000	100.00	0.0000
Devaluation Rate						
1	0.84	0.3230	0.00	0.0004	0.00	0.0000
4	0.20	0.0760	0.01	0.0023	0.00	0.0000
8	0.53	0.2720	0.01	0.0032	0.00	0.0000
16	1.18	0.4371	0.01	0.0019	0.00	0.0000
Nominal Interest Rate						
1	17.92	2.0979	1.84	0.3647	0.00	0.0000
4	10.29	1.2749	1.77	0.3479	0.00	0.0000
8	14.45	2.8130	0.87	0.1731	0.00	0.0000
16	18.62	2.2471	0.40	0.0838	0.00	0.0000
Nominal Exchange Rate						
1	2.11	1.3140	0.42	0.0850	0.00	0.0000
4	8.70	1.2988	0.24	0.0678	0.00	0.0000
8	14.80	1.8406	0.15	0.0430	0.00	0.0000
16	19.12	4.9048	0.11	0.0310	0.00	0.0000

Table 5.7: Forecast-error variance

Tovar, 2003a). Ireland (2002) and Smet and Wouters (2003) report a more significant role for preference shocks. However, neither of these studies incorporate measurement errors. This could reflect to some extent that in these author's estimates the preference shock operates as a measurement error shock. Bergin (2004) reports variance decompositions for his model applied to Australian data where preference shocks account for less than one percent at all horizons in all of his endogenous variables, with the exception of the current account, where they account for over 80 percent. The author argues that this reflects the inability of his model to explain current account dynamics and that the preference shock accounts for this.

Overall, variance decompositions indicate that the model performs better in explaining output fluctuations over short rather than over longer horizons that exceed two years. Although the model's performance is not exceptional, it is reasonably good for short-horizons. It was also shown that a devaluationary policy shock plays a non-negligible role in explaining output and consumption dynamics.

6. CONCLUSIONS

This paper developed and estimated a model using data from South Korea to answer an old question in macroeconomics: whether devaluations of the nominal exchange rate are expansionary or contractionary in terms of output. The framework employed had two main purposes. First, to develop a structural model that would allow to study the effects of an explicit devaluationary policy shock in isolation from any other shock to the economy. Second, to study the relative importance of the different mechanisms through which devaluations affect output. For this purpose, the model incorporated three transmission channels: the traditional expenditure-switching effect, the balance sheet effect, and a monetary channel associated to the fact that monetary authorities follows a interest rate rule that targets the nominal exchange rate.

In answering these questions the paper makes several contributions to the literature. First, impulse response functions analyses of the model allows to conclude that in the absence of any other shock to the economy, a devaluation is expansionary in terms of output. A key implication that follows is that the balance sheet mechanism plays a secondary role in the transmission of a devaluation to output. Or to put it differently, the dominating transmission mechanism in the model is the expenditure-switching effect given that the monetary channel has limited effects due to endogenous feedbacks between the nominal exchange rate and the risk premium. Second, very few attempts have been made in the literature to estimate with econometric methods a NOEM model. Furthermore, this is to my knowledge the first paper that estimates in a DSGE framework the parameters associated to the balance sheet mechanism. The relevance of this is twofold. On one hand, because parameter estimates show that in South Korea the balance sheet effect was operating with significant strength, as reflected by parameter estimates that fall in the upper value range of what has been considered normal in the literature. Despite this strength, the balance sheet effect was still unable to induce a contractionary effect that could dominate the expenditure-switching effect. This result coincides with recent microeconomic level studies that find a missing balance sheet effect (See Luengnaruemitchai, 2003). On the other hand, these parameter estimates will be useful for future calibration studies.

It was also shown that the model is able to capture key patterns observed in Asian countries during the financial crisis of the late 1990s. In this regard, it was emphasized how important it is to distinguish among different sources of shocks before any conclusion is made about the contractionary or expansionary effects of a devaluation. It would be misleading to conclude that devaluations are contractionary from the simply observation of a negative correlation between the nominal exchange rate and output. Impulse response exercises showed that a negative correlation among these variables could occur if the economy is hit by an adverse international shock that triggers capital outflows, rather than from an explicitly devaluationary policy shock, which I just argued would lead to the opposite correlation pattern.

Some policy lessons were drawn from the analysis. A devaluation in response to an adverse external shock (as captured either by an increase in the international interest rate or by an adverse export demand shock) can play in the short-run a stabilizing role in terms of output. In essence a devaluation lets the economy exploit the "benefits" of the expenditure-switching effect. However, output gains associated to this policy face inflationary and income distribution trade-offs. The inflationary trade-off is a very delicate issue in most emerging economies and should be seriously be taken into account if the country has a recent history of high inflation. It is for this reason that no policy stance is taken here on whether a devaluationary policy should be the best alternative to face an adverse external shock. Furthermore, the income distribution trade-off, as captured by a deterioration of worker's income, indicates that devaluationary policies can be politically very difficult to implement an sustain, and certainly important considerations should be taken to this in emerging markets, where income distribution and poverty is already a complicate problem.

There are aspects of the model which could improve the results obtained here. It would be useful to incorporate additional mechanisms which are central in an economy that is experiencing a devaluation say for instance, fiscal policy. Also alternative assumptions should be considered on some key features of the model, possibly the most important of which is modifying the assumption of perfect pass-through of exchange rates to inflation. Finally some additional extensions would be interesting, such as incorporating a mechanism that could endogenously determine a switch in the exchange rate regime when the economy is hit by a shock.

Some readers might find the results regarding the balance sheet as evidence to disregard the third generation crises models. However, this would be an erroneous way of reading the results. Notice that it has been shown that the balance sheet is indeed operating in a contractionary manner, hence the mechanism is operating in the "right" direction. The issue is that it is not strong enough to overturn the expenditure-switching mechanism. If we really think that the balance sheet mechanism is behind contractionary devaluations, then it is maybe because the balance sheet effect is operating through other sectors of the economy and not only through an investment channel, say for instance, through the banking sector as highlighted by Choi and Cook (2004). With no doubt future research must focus on this.

References

[1] Agénor, Pierre-Richard and Peter Montiel, 1999. *Development macroeconomics*. Second edition. Princeton University Press. Princeton, New Jersey.

[2] Ambler, Steve, Ali Dib and Nooman Rebei, 2003. "Nominal rigidities and exchange rate pass-through in a structural model of a small open economy". Working Paper 2003-29. Bank of Canada.

[3] Benigno, Gianluca, 2004. "Real exchange rate persistence and monetary policy rules". Journal of Monetary Economics. Vol. 51. pp. 473-502.

[4] Benigno, Gianluca and Pierpaolo Benigno, 2000. "Monetary Policy Rules and the exchange rate". Center for Economic Policy Research Discussion Papers No. 208.

[5] Bergin, Paul, 2004. "How well can the New Open Economy Macroeconomics explain the exchange rate and current account?". NBER Working Paper No. 10356.

[6] Bergin, Paul, 2003. "Putting the "New Open Economy Macroeconomics" to a test". Journal of International Economics. Vol. 60. Issue 1. May.

[7] Bernanke, Ben, Mark Gertler and Simon Gilchrist, 1999. "The financial accelerator in a quantitative business cycle framework" in J.E. Taylor and M. Woodford (Eds.) Handbook of Macroeconomics. Volume 1C. North-Holland.

[8] Blanchard, Olivier and Charles Kahn, 1980. "The solution to linear difference models under rational expectations". Econometrica. Vol. 48. Issue 5, July. pp1305-1312.

[9] Carlstrom, Charles and Timothy Fuerst, 1997. "Agency costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis". The American Economic Review, Vol. 87, Issue 5. December. pp. 893-910.

[10] Cespedes, Luis, Roberto Chang and Andrés Velasco, 2003. " IS-LM-BP in the Pampas". IMF Staff Papers, Vol. 50. pp. 143-156.

[11] Cespedes, Luis, Roberto Chang and Andrés Velasco, 2002. "Balance Sheets and exchange rate policy". Forthcoming American Economic Review.

[12] Cho, Dongchul and Kenneth D. West, 2003. "Interest rates and exchange rates in the Korean, Philippine and Thai exchange rate crises". In M.P. Dooley and J.A. Frankel (Ed.) *Managing currency crises in emerging markets*. NBER-Chicago University Press.

[13] Choi, Woon and David Cook, 2004. "Liability dollarization and the bank balance sheet channel". Forthcoming Journal of International Economics.

[14] Clarida, Richard, Jordi Gali and Mark Gertler, 1999. "The science of monetary policy: A new Keynesian perspective". Journal of Economic Literature. Vol. XXXVII. December. pp. 1661-1707.

[15] Clarida, Richard, Jordi Gali and Mark Gertler, 2001. "Optimal monetary policy in open versus closed economies: an integrated approach". American Economic Review, Papers and Proceedings Vol. 91 No. 2. May. pp. 248-252.

[16] Clarida, Richard, Jordi Gali and Mark Gertler, 2000."Monetary policy rules and macroeconomic stability: evidence and some theory". Quarterly Journal of Economics. Vol. 105. February. pp. 147 -180.

[17] Clarida, Richard, Jordi Gali and Mark Gertler, 1999. "The science of monetary policy: A new Keynesian perspective". Journal of Economic Literature. Vol. XXXVII. December. pp. 1661-1707.

[18] Clarida, Richard, Jordi Gali and Mark Gertler, 1998. "Monetary policy rule in practice: some international evidence". European Economic Review. Vol. 42. pp. 1033 -1067.

[19] Dib, Ali, 2001. "An estimated Canadian DSGE model with nominal and real rigidities". Canadian Journal of Economics, Vol. 36. No. 4. pp. 949-972.

[20] Fraga, Arminio, Ilan Goldfajn and André Minella, 2003. "Inflation targeting in emerging market economies". NBER Working Paper No. 10019. October.

[21] Galí, Jordi, 2003. "New perspectives on Monetary policy, Inflation and the Business Cycle". Advances in Economic Theory, edited by: M. Dewatripont, L. Hansen, and S. Turnovsky, vol. III, 151-197, Cambridge University Press.

[22] Gali, Jordi, 1999. "Technology, employment and the business cycle: do technology shocks explain aggregate fluctuations". American Economic Review. Vol. 89. No.1. March. pp 249-271.

[23] Hairault, Jean-Olivier and Franck Portier, 1993. "Money, New Keynesian macroeconomics and the business cycle". European Economic Review. Vol. 37, pp. 1533-1568.

[24] Hamilton, James, 1994a. *Time series analysis.* Princeton University Press. Princeton.

[25] Hamilton, James, 1994b. "State Space Models". In R.F. Engle and D.L. McFadden (Eds.) *Handbook of Econometrics.* Volume IV. Elsevier Science.

[26] Ireland, Peter, 2004. "A method for taking models to the data". Journal of Economic Dynamics and Control. Volume 28, Issue 6, March. Pp. 1205 - 1226.

[27] Ireland, Peter, 2002. "Technology Shocks in the New Keynesian Model". Mimeo, Department of Economics, Boston College. Available at http://www2.bc.edu/~irelandp/tshocks.pdf

[28] Ireland, Peter, 2001. “Sticky-price models of the business cycle: specification and stability”. Journal of Monetary Economics. Vol. 47 No. 1. pp 3-18.

[29] Kim, Jinill, 2000. “Constructing and estimating a realistic optimizing model of monetary policy”. Journal of Monetary Economics. Vol 45. pp 329-359.

[30] Krugman, 1999. “Balance sheets, the transfer problem, and financial crises” in P. Isard, A. Razin and A. Rose (Eds.) International Finance and Financial Crises: Essays in Honor of Robert Flood. Kluwer Academic Publishers-IMF.

[31] Lubik, Thomas and Frank Schorfheide, 2003. “Do central banks respond to exchange rate movements? A structural investigation”. Available at: http://www.econ.upenn.edu/~schorf/papers/soe.pdf

[32] Luengnaruemitchai, Pipat, 2003. “The Asian crises and the mystery of the missing balance sheet effect”. Job Market Paper. University of California - Berkeley.

[33] McCallum, Bennett and Edward Nelson, 1999. “An optimizing IS-LM specification for monetary policy and business cycle analysis”. Journal of Money Credit and Banking, Vol. 31, No. 3 Part 1, pp.296-316. August.

[34] Monacelli, Tommaso, 2004. “Into the Mussa Puzzle: Monetary policy regimes and the real exchange rate in a small open economy”. Journal of International Economics. Vol. 62 Issue 1, pp. 191-217. January.

[35] Rotemberg, Julio, 1996. “Price, output, and hours: An empirical analysis based on a sticky price model”. Journal of Monetary Economics. Vol. 37. Pp. 505-533.

[36] Rotemberg, Julio, 1982. “Sticky prices in the United States”. Journal of Political Economy. Vol. 90. Pp. 1187-1211.

[37] Ruge-Murcia, Francisco, 2003. “Methods to estimate dynamic stochastic general equilibrium models”. Département de sciences économiques and C.I.R.E.Q., Université de Montréal. September. Available at: http://www.cireq.umontreal.ca/online/frm-Methods2-03-09-24.pdf

[38] Runkle, David, 1987. “Vector autoregressions and reality”. Journal of Business and Economic Statistics 5. pp. 437-442.

[39] Sims, Christopher, 2001. “Solving linear rational expectations models”. Computational Economics. Vol. 20. pp. 1-20.

[40] Tovar, Camilo, 2003a. ”Devaluations, output, and the balance sheet effect”. Mimeo. Department of Economics. University of Wisconsin - Madison. Available at: http://www.ssc.wisc.edu/~ctovar

[41] Tovar, Camilo, 2003b. "Technical appendix for: "Devaluations, output, and the balance sheet effect". Mimeo. Department of Economics. University of Wisconsin - Madison. Available at: http://www.ssc.wisc.edu/~ctovar

[42] Uhlig, Harald, 1997. "A toolkit for analyzing nonlinear dynamic stochastic models easily". Available at: http://www.wiwi.hu-berlin.de/wpol/html/toolkit/toolkit.pdf

[43] Woodford, 2003. *Interest and prices: foundations of a theory of monetary policy*. Princeton University Press.

APPENDICES

A. Non-Stochastic Steady-State

This appendix describes the initial non-stochastic steady-state for this economy in which net foreign asset position is zero i.e. $B_t^* = \bar{B}^* = 0$. In the absence of shocks the economy converges to a steady-state in which $C_t = \bar{C}$, $Y_t = \bar{Y}$, $K_t = \bar{K}$, $L_t = \bar{L}$, , $N_t = \bar{N}$, $D_t = \bar{D}$, $i_t = \bar{\imath}$, $\bar{\imath}_t^* = \bar{\imath}^*$, $\eta_t = \bar{\eta}$, $w_t = \bar{w}$, $r_t = \bar{r}$, $e_t = \bar{e}$, $\pi_t = \bar{\pi}$, $f_t^s = \bar{f}^s$. Steady-state values $\bar{A}$, $\bar{\theta}$, $\bar{a}$, $\bar{\chi}$, $\bar{\rho}$, and $\bar{X}$ are determined from Eqs.(2.6), (2.7), (2.19), (B.25), (2.30) and (2.37).

Using the fact that $e^Y = \bar{\theta}$ and $e^L = \sigma$, observing that the stationarity of real wages implies that $\bar{\Omega} = 1$ and imposing steady-state values, it is possible to summarize the non-stochastic steady-state conditions corresponding to the symmetric equilibrium, including the definitional condition implied by Eq.(B.13):

$$(1 + \bar{\imath}^*) = (1 + \bar{\rho})(1 + \bar{\eta}) \tag{A.1}$$

To solve for the non-stochastic steady-state assume that steady-state inflation is exogenously determined. Next, combine C.P.I. and real exchange rate equations to obtain $\pi_t = \frac{Q_t}{Q_{t-1}} = \frac{e_t^{1-\gamma}}{e_{t-1}^{1-\gamma}} \frac{P_t}{P_{t-1}} = \frac{e_t^{1-\gamma}}{e_{t-1}^{1-\gamma}} f_t^p$. Given the steady-state stationary behavior of the real exchange rate it follows that $\bar{f}^p = \bar{\pi}$. Furthermore, the same argument implies that $\bar{f}^s = \bar{\pi}$. That is, steady-state overall domestic inflation equals the steady-state inflation rate of domestically produced goods and also the steady-state nominal devaluation rate.

So far it is possible to summarize the steady-state equilibrium conditions as:

$$\bar{Y} = \bar{A}\bar{K}^{\alpha}\bar{L}^{1-\alpha} \tag{A.2}$$

$$\bar{r} = \alpha\left(1 - \frac{1}{\bar{\theta}}\right)\frac{\bar{e}^{\gamma-1}\bar{Y}}{\bar{K}} \tag{A.3}$$

$$\bar{w} = (1-\alpha)\left(1 - \frac{1}{\bar{\theta}}\right)\frac{\bar{e}^{\gamma-1}\bar{Y}}{\bar{K}} \tag{A.4}$$

$$\bar{f}^s = \bar{\pi} \tag{A.5}$$

$$\bar{C} = \bar{w}\bar{L} \tag{A.6}$$

$$1 + \bar{\imath} = \frac{\bar{\pi}}{\beta} \tag{A.7}$$

$$1 + \bar{\imath}^* = \frac{\bar{\pi}}{\beta\bar{f}^s} \tag{A.8}$$

$$\bar{L}^{\nu-1} = \frac{\bar{w}}{\bar{C}} \tag{A.9}$$

$$\bar{e}^{\gamma-1}\bar{N} + \bar{e}^{\gamma}\bar{D} = \bar{K} \tag{A.10}$$

$$1+\bar{\eta}=\left(\frac{\bar{K}}{\bar{e}^{\gamma-1}\bar{N}}\right)^{\mu} \tag{A.11}$$

$$\frac{\bar{r}\bar{\pi}}{\bar{f}^{s}}=(1+\bar{\rho})(1+\bar{\eta}) \tag{A.12}$$

$$\bar{e}^{\gamma-1}\bar{N}=\bar{e}^{\gamma-1}\bar{Y}-\bar{w}\bar{L}-\bar{e}^{\gamma}\bar{D} \tag{A.13}$$

$$\bar{e}^{\gamma-1}\bar{Y}=\gamma\bar{K}+\gamma\bar{C}+\bar{e}^{\gamma}\bar{X} \tag{A.14}$$

Plus equation (A.1). Thus the system contains 13 equations and 13 unknowns: $\bar{Y}$, $\bar{K}$, $\bar{L}, \bar{C}$, $\bar{r}$, $\bar{e}$, $\bar{w}$, $\bar{f}^{s}$, $\bar{\imath}$, $\bar{\imath}^{*}$, $\bar{N}$, $\bar{D}$ and $\bar{\eta}$.

The system is solved as follows. First, the steady-state interest rate on domestic bonds is determined by Eq.(A.7). Next, use Eq.(A.5) to eliminate $\bar{f}^{s}$. In particular, Eqs.(A.5) and (A.8) imply that:

$$1+\bar{\imath}^{*}=\frac{1}{\beta} \tag{A.15}$$

Combining Eqs.(A.7) and (A.8) results in a steady-state uncovered interest parity condition:

$$(1+\bar{\imath})=(1+\bar{\imath}^{*})\,\bar{\pi} \tag{A.16}$$

Now, use Eq.(A.12) together with the Eq. (A.1) and Eq.(A.15) to obtain:

$$\bar{r}=\frac{1}{\beta} \tag{A.17}$$

That is, in steady-state the real return to capital equals the gross interest rate on international denominated bonds. Notice also that Eq.(A.17) together with Eq.(A.7) can be used to establish a steady-state Fisher relationship between the real return on capital and the nominal interest rate for domestic bonds. That is:

$$\bar{r}=\frac{1+\bar{\imath}}{\bar{\pi}} \tag{A.18}$$

Eqs.(A.1) and (A.17) imply that:

$$1+\bar{\eta}=\{\beta(1+\bar{\rho})\}^{-1} \tag{A.19}$$

Next, combine Eq.(A.3) and (A.4) and use Eq.(A.17) to obtain:

$$\bar{w}=\frac{1-\alpha}{\alpha\beta} \tag{A.20}$$

On the other hand, combine Eqs.(A.6) and (A.9) to get the steady-state labor supply, i.e.

$$\bar{L}=1 \tag{A.21}$$

this implies that $\bar{C}=\bar{w}$, as can be seen from Eq.(A.6).

Use the previous results to substitute $\bar{D}$ out of the system by combining Eqs.(A.10) and (A.13), so that we can write:

$$\bar{K} = \bar{e}^{\gamma-1}\bar{Y} - \frac{1-\alpha}{\alpha\beta} \tag{A.22}$$

This result together with Eq.(A.14) and substituting $\bar{w}\bar{L}$ out yields:

$$\bar{Y} = \frac{\bar{X}\bar{e}}{1-\gamma} \tag{A.23}$$

Observe that this results in a positive linear relation between output and the real exchange rate, which is key to solve the remaining portion of the system. In particular, everything will now be expressed in terms of these two variables. But first it is necessary to obtain a second relationship between Y and e. Which can be derived as follows. Combine Eq.(A.3) and Eq.(A.17) so that:

$$\bar{K} = \Lambda\bar{e}^{\gamma-1}\bar{Y} \tag{A.24}$$

where $\Lambda = \alpha\beta\left(1 - \frac{1}{\theta}\right)$. Now replace $\bar{K}$ into the production function and rearrange terms so that:

$$\bar{Y} = \left[\bar{A}^{\frac{1}{\alpha}}\Lambda\bar{e}^{\gamma-1}\right]^{\frac{\alpha}{1-\alpha}} \tag{A.25}$$

This is the second equation required to solve for $\bar{e}$ and $\bar{Y}$. Formally, they are obtained from Eqs.(A.23) and (A.25) so that:

$$\bar{e} = \left[\bar{A}\Lambda^{\alpha}\left(\frac{\bar{X}}{1-\gamma}\right)^{\alpha-1}\right]^{\frac{1}{1-\alpha\gamma}} \tag{A.26}$$

and

$$\bar{Y} = \left[\bar{A}\Lambda^{\alpha}\left(\frac{\bar{X}}{1-\gamma}\right)^{\alpha(1-\gamma)}\right]^{\frac{1}{1-\alpha\gamma}} \tag{A.27}$$

Now $\bar{e}$ and $\bar{Y}$ can be employed to obtain the steady-state values for all the remaining variables in the system. Using them together with Eq.(A.2) yields the steady-state level of capital:

$$\bar{K} = \left[\bar{A}^{\gamma}\Lambda\left(\frac{\bar{X}}{1-\gamma}\right)^{1-\gamma}\right]^{\frac{1}{1-\alpha\gamma}} \tag{A.28}$$

The steady-state value of net worth is obtained using Eq.(A.11):

$$\bar{N} = \{\beta(1+\bar{\rho})\}^{\frac{1}{\mu}}\left[\bar{A}\Lambda^{1+\alpha(1-\gamma)}\left(\frac{\bar{X}}{1-\gamma}\right)^{\alpha(1-\gamma)}\right]^{\frac{1}{1-\alpha\gamma}} \tag{A.29}$$

The steady-state level of debt is obtained using Eq.(A.10). In particular, :

$$\bar{D} = \left[1 - \{\beta(1+\bar{\rho})\}^{\frac{1}{\mu}}\right]\left(\frac{\Lambda\bar{X}}{1-\gamma}\right) \tag{A.30}$$

Overall the 13 steady-state variables are determined by the following equations: (A.5), (A.7), (A.15), (A.17), (A.19), (A.21), (A.26), (A.27), (A.28), (A.29), (A.30). Observe that the level of consumption and real wages are given by (A.20).

B. Log-Linearized Version of the Model

This appendix presents the log-linearized version of the model around the symmetric steady-state. For notational purposes, define $\widehat{z}_t \equiv \frac{z_t - \bar{z}}{\bar{z}} \cong \ln\left(\frac{z_t}{\bar{z}}\right)$ as the percentage deviation from the steady state value, $\bar{Z}$.

B.1. Firms' Behavior

The linearized Cobb-Douglas production function implies that:

$$\hat{y}_t = \hat{A}_t + \alpha\hat{k}_t + (1-\alpha)\,\hat{l}_t \tag{B.1}$$

The first-order condition for capital and labor demand yield, respectively:

$$\hat{r}_t = \hat{y}_t - \hat{k}_t + (\gamma - 1)\,\hat{e}_t + \frac{\hat{e}_t^Y}{\bar{\theta} - 1} \tag{B.2}$$

$$\hat{w}_t = \hat{y}_t - \hat{l}_t + (\gamma - 1)\,\hat{e}_t + \frac{\hat{e}_t^Y}{\bar{\theta} - 1} \tag{B.3}$$

where the output demand elasticity augmented with adjustment cost is[41]:

$$\hat{e}_t^Y = \psi_p\bar{\pi}^2\hat{f}_t^p - \beta\psi_p\bar{\pi}^3E_t\hat{f}_{t+1}^p + \hat{\theta}_t \tag{B.4}$$

The technology shock A_t result in:

$$\hat{A}_t = \zeta_A\hat{A}_{t-1} + \varepsilon_{At} \tag{B.5}$$

and the mark-up or cost-push shock of price over the marginal cost:

$$\hat{\theta}_t = \zeta_\theta\hat{\theta}_{t-1} + \varepsilon_{\theta t} \tag{B.6}$$

[41] Notice that in the absence of price adjustment costs, $\psi_p = 0$, the elasticity of output demand equals the elasticity of substitution between different varieties of domestic goods. In such case, the firms' FOC yields the standard condition that in a symmetric monopolistic competition model equilibrium prices are set so that there is a mark-up over marginal costs.

B.2. Households' Behavior

The overall domestic consumer price index:

$$\hat{\pi}_t = \gamma \hat{f}_t^p + (1-\gamma)\,\hat{f}_t^s \tag{B.7}$$

and the definition of the real exchange rate:

$$\hat{e}_t - \hat{e}_{t-1} = \hat{f}_t^s - \hat{f}_t^p \tag{B.8}$$

The consumers' budget constraint results in:

$$\hat{c}_t = \hat{w}_t + \hat{l}_t - \left(\frac{\bar{e}^\gamma}{\bar{C}}\right)\left[dB_t^* - \frac{1}{\beta}dB_{t-1}^*\right] \tag{B.9}$$

The Euler equations for consumption can be expressed as:

$$\hat{c}_t = E_t\hat{c}_{t+1} - E_t\hat{a}_{t+1} - (\hat{\imath}_t - E_t\hat{\pi}_{t+1}) + \hat{a}_t \tag{B.10}$$

$$\hat{c}_t = E_t\hat{c}_{t+1} - E_t\hat{a}_{t+1} - \left(\hat{\imath}_t^* + E_t\hat{f}_{t+1}^s - E_t\hat{\pi}_{t+1}\right) + \hat{a}_t \tag{B.11}$$

where $\hat{\imath}_t \equiv \ln(1+i_t) - \ln(1+\bar{\imath})$ and $\hat{\imath}_t^* \equiv \ln(1+i_t^*) - \ln(1+\bar{\imath}^*)$. The domestic Euler equation simply states that consumption depends inversely on the ex-ante real interest rate and via expectations on the expected future short real rates. Combining the two Euler equations imply that the uncovered interest parity holds up to linearization:

$$\hat{\imath}_t = \hat{\imath}_t^* + E_t\hat{f}_{t+1}^s \tag{B.12}$$

At this point is worth introducing a definitional condition relating international bond interest rates and the risk premium which is required to close the model. This is formally done by setting:

$$\hat{\imath}_t^* = \hat{\rho}_t + \hat{\eta}_t \tag{B.13}$$

where $\hat{\eta}_t \equiv \ln(1+\eta_t) - \ln(1+\bar{\eta})$ is the risk premium, and $\hat{\rho}_t \equiv \ln(1+\rho_t) - \ln(1+\bar{\rho})$is the international risk free interest rate. This interest rate is assumed to follow a first-order autoregressive process:

$$\hat{\rho}_t = \zeta_\rho \hat{\rho}_{t-1} + \varepsilon_{\rho t} \tag{B.14}$$

where $-1 < \zeta_p < 1$ and $\varepsilon_{\rho t} \sim N\left(0, \sigma_\rho^2\right)$is serially uncorrelated.

The optimal condition for labor supply results in:

$$(\nu - 1)\,\hat{l}_t = \hat{w}_t - \hat{c}_t + \left(\frac{1}{\sigma - 1}\right)\hat{e}_t^L \tag{B.15}$$

where $\nu > 1$ is the elasticity of labor supply. Also notice that as in the firms' problem the elasticity of substitution between different types of labor interacts with terms associated to the wage adjustment cost. As a result the labor demand elasticity augmented with adjustment costs is given by:

$$\hat{e}_t^L = \psi_w \bar{\pi}^2 \left(\hat{\Omega}_t + \hat{\pi}_t\right) - \beta \psi_w \bar{\pi}^2 E_t \left(\hat{\Omega}_{t+1} + \hat{\pi}_{t+1}\right) \tag{B.16}$$

where

$$\hat{\Omega}_t = \hat{w}_t - \hat{w}_{t-1} \tag{B.17}$$

The preference shock yields:

$$\hat{a}_t = \zeta_a \hat{a}_{t-1} + \varepsilon_{at} \tag{B.18}$$

B.3. Entrepreneur's Behavior

The entrepreneurs' budget constraint yields:

$$\hat{k}_{t+1} = \left(\frac{1}{1+\psi}\right) \hat{n}_t + \left(\frac{\psi}{1+\psi}\right) \hat{d}_{t+1} + \left(\gamma - \frac{1}{1+\psi}\right) \hat{e}_t \tag{B.19}$$

where $\psi \equiv \frac{\bar{e}\bar{D}}{\bar{N}}$, that is the steady-state ratio of foreign debt to net worth and $\hat{e}_t$ is the real exchange rate.

The risk premium in turn results in the following expression:

$$\hat{\eta}_t = \mu \left[(1-\gamma)\, \hat{e}_t + \hat{k}_{t+1} - \hat{n}_t\right] \tag{B.20}$$

The arbitrage condition between the cost of capital and its expected marginal return gives:

$$\hat{\rho}_t + \hat{\eta}_t = E_t \hat{r}_{t+1} + E_t \hat{\pi}_{t+1} - E_t \hat{f}_{t+1}^s \tag{B.21}$$

This linearized condition together with Eqs. (B.12) and (B.13) is key as it provides the link between the nominal interest rate and the ex-ante real return on capital, in other words we obtain a Fisher Equation.

The entrepreneur's net worth becomes:

$$\hat{n}_t = \{(1-\gamma)\left[1-(1+\psi)\,\phi\right] - \gamma\psi\}\, \hat{e}_t + \phi\,(1+\psi)\,\hat{y}_t + (1-\phi)\,(1+\psi)\left(\hat{w}_t + \hat{l}_t\right) - \psi \hat{d}_t \tag{B.22}$$

where $\phi \equiv \left[1-(1-\alpha)\left(1-\frac{1}{\bar{\theta}}\right)\right]^{-1}$. This expression is conveniently simplified substituting Eq. (B.3) to replace $\hat{w}_t + \hat{l}_t$:

$$\hat{n}_t = (1+\psi)\,\hat{y}_t - \psi \hat{e}_t - \psi \hat{d}_t + (1+\psi)\,(1-\phi)\,\frac{\hat{e}_t^Y}{\bar{\theta}-1} \tag{B.23}$$

B.4. Monetary Policy

The log-linearized version of the interest rate rule is summarized by:

$$\hat{\imath}_t = \omega_i \hat{\imath}_{t-1} + \tilde{\omega}_\pi E_t \hat{\pi}_{t+1} + \tilde{\omega}_y \hat{y}_t + \tilde{\omega}_s \hat{s}_t + \tilde{\omega}_s \hat{\chi}_t \tag{B.24}$$

where $\tilde{\omega}_\pi \equiv (1-\omega_i)\,\omega_\pi$, $\tilde{\omega}_y \equiv (1-\omega_i)\,\omega_y$ and $\tilde{\omega}_s \equiv (1-\omega_i)\,\frac{\omega_s}{1-\omega_s}$.

The devaluationary policy shock becomes[42]:

$$\hat{\chi}_t = \zeta_\chi \hat{\chi}_{t-1} + \varepsilon_{\chi t} \tag{B.25}$$

B.5. Market Clearing

The log-linearized market clearing condition for home goods can be written as:

$$\tau \hat{y}_t = \lambda \tau \hat{k}_{t+1} + [1 + (1-\lambda-\gamma)\,\tau]\,\hat{e}_t + (\tau - 1)\,\hat{c}_t + (1-\lambda\tau)\,\hat{x}_t \tag{B.26}$$

where $\tau \equiv \left[1 - \gamma(1-\alpha)\left(1-\frac{1}{\theta}\right)\right]^{-1}$ and $\lambda = \gamma\alpha\beta\left(1-\frac{1}{\theta}\right)$.

The export demand shock, $\hat{x}_t$ is expressed as:

$$\hat{x}_t = \zeta_x \hat{x}_{t-1} + \varepsilon_{xt} \tag{B.27}$$

C. Kalman Filter

The Kalman filter is an algorithm for calculating the sequence $\left\{\hat{h}_{t|t-1}\right\}_{t=1}^{T}$ and $\left\{\Sigma_{t|t-1}\right\}_{t=1}^{T}$. To apply the Kalman filter define:

$$\tilde{w}_t = \tilde{y}_t - \hat{y}_{t|t-1} = \tilde{y}_t - \Gamma_Z \hat{h}_{t|t-1} = \Gamma_Z\left(\tilde{h}_t - \hat{h}_{t|t-1}\right) \tag{C.1}$$

It then follows that its conditional variance is:

$$E\left\{\left(\tilde{y}_t - \hat{y}_{t|t-1}\right)\left(\tilde{y}_t - \hat{y}_{t|t-1}\right)'\right\} = \Gamma_Z E\left\{\left(\tilde{h}_t - \hat{h}_{t|t-1}\right)\left(\tilde{h}_t - \hat{h}_{t|t-1}\right)'\right\}\Gamma_Z' = \Gamma_Z \Sigma_{t|t-1} \Gamma_Z' \tag{C.2}$$

and the conditional covariance between $\tilde{w}_t$ and the error in forecasting the state vector:

$$E\left\{\left(\tilde{y}_t - \hat{y}_{t|t-1}\right)\left(\tilde{h}_t - \hat{h}_{t|t-1}\right)'\right\} = \Gamma_Z E\left\{\left(\tilde{h}_t - \hat{h}_{t|t-1}\right)\left(\tilde{h}_t - \hat{h}_{t|t-1}\right)'\right\} = \Gamma_Z \Sigma_{t|t-1} \tag{C.3}$$

It follows that the distribution of the vector $\left(\tilde{y}_t', \tilde{h}_t'\right)'$ conditional on $\aleph_t$ is:

$$\begin{bmatrix} \tilde{y}_t|\aleph_{t-1} \\ \tilde{h}_t|\aleph_{t-1} \end{bmatrix} \sim N\left(\begin{bmatrix} \Gamma_Z \hat{h}_{t|t-1} \\ \hat{h}_{t|t-1} \end{bmatrix}, \begin{bmatrix} \Gamma_Z \Sigma_{t|t-1} \Gamma_Z' & \Gamma_Z \Sigma_{t|t-1} \\ \Sigma_{t|t-1}' \Gamma_Z' & \Sigma_{t|t-1} \end{bmatrix}\right) \tag{C.4}$$

[42] For operational purposes the shock enters in a multiplicative form in the interest rule. Therefore a devaluation will be captured by a negative shock on $\varepsilon_{\chi t}$.

Now employ the following statistical result that states that if $z_1$and z_2 are normal variables that have a joint normal distribution[43]:

$$\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} \sim N\left(\begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}, \begin{bmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{bmatrix}\right) \tag{C.5}$$

then the distribution of z_2 conditional on z_1 is $N(m, \Delta)$ where:

$$m = \mu_2 + \Delta_{21}\Delta_{11}^{-1}(z_1 - \mu_1) \tag{C.6}$$

$$\Delta = \Delta_{22} - \Delta_{21}\Delta_{11}^{-1}\Delta_{21} \tag{C.7}$$

This result can then be used to obtain the optimal forecast of z_2 conditional on having observed z_1 and its corresponding mean squared error which are given by Eqs. (C.6) and (C.7), respectively. That is, given that $\tilde{h}_t|\aleph_t = \tilde{h}_t|\tilde{y}_t, \aleph_{t-1}$ it follows from the previous result that $\tilde{h}_t|\aleph_t$ is distributed $N\left(\hat{h}_{t|t}, \Sigma_{t|t}\right)$where $\hat{h}_{t|t}$ and $\Sigma_{t|t}$ are given by Eqs. (C.6) and (C.7), respectively. Formally:

$$\hat{h}_{t|t} = \hat{h}_{t|t-1} + \Sigma'_{t|t-1}\Gamma'_Z\left(\Gamma_Z\Sigma_{t|t-1}\Gamma'_Z\right)\left(\tilde{y}_t - \Gamma_Z\hat{h}_t\right) \tag{C.8}$$

$$\Sigma_{t|t} = \Sigma_{t|t-1} - \Sigma_{t|t-1}\Gamma'_Z\left(\Gamma_Z\Sigma_{t|t-1}\Gamma'_Z\right)^{-1}\Gamma_Z\Sigma_{t|t-1} \tag{C.9}$$

Now the final step is to calculate the forecast of $\tilde{h}_{t+1}$ conditional on $\aleph_t$. It is not hard to see that $\tilde{h}_{t+1}|\aleph_t \sim N\left(\hat{h}_{t+1|t}, \Sigma_{t+1|t}\right)$ where:

$$\hat{h}_{t+1|t} = \Gamma_V\hat{h}_{t|t} \tag{C.10}$$

$$\begin{aligned}
\Sigma_{t+1|t} &= E\left\{\left(\tilde{h}_{t+1} - \hat{h}_{t+1|t}\right)\left(\tilde{h}_{t+1} - \hat{h}_{t+1|t}\right)'\right\} \\
&= E\left\{\left(\Gamma_V\left(\tilde{h}_t - \hat{h}_{t|t}\right) + v_{t+1}\right)\left(\Gamma_V\left(\tilde{h}_t - \hat{h}_{t|t}\right) + v_{t+1}\right)'\right\} \\
&= \Gamma_V\Sigma_{t|t}\Gamma'_V + Q
\end{aligned} \tag{C.11}$$

where we have used Eq. (C.10) to replace $\hat{h}_{t+1|t}$ to obtain this last equation.

Combining Eq. (C.8) with Eq. (C.10), and Eq. (C.9) with Eq. (C.11) yields, respectively:

$$\hat{h}_{t+1|t} = \Gamma_V\hat{h}_{t|t-1} + \tilde{K}_t\left(\tilde{y}_t - \Gamma_Z\hat{h}_t\right) \tag{C.12}$$

$$\Sigma_{t+1|t} = \Gamma_V\Sigma_{t|t-1}\Gamma'_V - \tilde{K}_t\Gamma_Z\Sigma_{t|t-1}\Gamma'_V + Q \tag{C.13}$$

where $\tilde{K}_t \equiv \Gamma_V\Sigma'_{t|t-1}\Gamma'_Z\left(\Gamma_Z\Sigma_{t|t-1}\Gamma'_Z\right)$ is "Kalman gain" or "gain matrix".

[43]See Hamilton (1994b, pp.3047).

To start the recursion described by the Kalman filter the values are initialized with the unconditional mean and variance of $\tilde{h}_1$:

$$\hat{h}_{1|0} = 0 \tag{C.14}$$

$$\Sigma_{1|0} = E\left\{\left(\tilde{h}_1 - \hat{h}_{1|0}\right)\left(\tilde{h}_1 - \hat{h}_{1|0}\right)'\right\} \tag{C.15}$$

where $\Sigma_{1|0}$ is calculated using the following formula[44]:

$$vec\left(\Sigma_{1|0}\right) = \left[I_{15^2\times 15^2} - \Gamma_V \otimes \Gamma_V\right] \cdot vecQ \tag{C.16}$$

Given that the expression in brackets is non-singular.

D. Obtaining the Estimated Log-Linearized System of Equations

First, combine Eqs.(B.7) and (B.8) so that the inflation of domestically produced goods can be expressed as:

$$\hat{f}_t^p = \hat{\pi}_t - (1-\gamma)\,\hat{e}_t + (1-\gamma)\,\hat{e}_{t-1} \tag{D.1}$$

This result, allows to eliminate $\hat{f}_t^p$ from the system. In particular, the nominal devaluation rate can be expressed as:

$$\hat{f}_t^s = \hat{\pi}_t + \gamma\hat{e}_t - \gamma\hat{e}_{t-1} \tag{D.2}$$

Using this result it is possible to express the output demand elasticity augmented with adjustment cost, $\hat{e}_t^Y$ in terms in terms of the C.P.I. inflation rate and the real exchange rate only:

$$\begin{aligned}\hat{e}_t^Y &= (1-\gamma)\,\beta\psi_p\bar{\pi}^3 E_t\hat{e}_{t+1} - \beta\psi_p\bar{\pi}^3 E_t\hat{\pi}_{t+1} - (1-\gamma)\,\psi_p\bar{\pi}^2\left(1+\beta\bar{\pi}\right)\hat{e}_t \\ &\quad +\psi_p\bar{\pi}^2\hat{\pi}_t + (1-\gamma)\,\psi_p\bar{\pi}^2\hat{e}_{t-1} + \hat{\theta}_t\end{aligned} \tag{D.3}$$

The next step is to combine Eqs.(B.2) and (B.3) to obtain the capital-labor trade-off equation:

$$\hat{w}_t + \hat{l}_t = \hat{r}_t + \hat{k}_t \tag{D.4}$$

Observe that this equation replaces Eq.(B.3) in the system.

To further simplify, plug Eqs.(D.3) and (B.16) into Eqs. (B.2) and (B.15), respectively to obtain:

$$\begin{aligned}\hat{r}_t + \hat{k}_t &= (1-\gamma)\,\beta\psi_p\bar{\pi}^3 E_t e_{t+1} - \beta\psi_p\bar{\pi}^3 E_t\hat{\pi}_{t+1} - (1-\gamma)\left[1 + \left(1+\beta\bar{\pi}\right)\psi_p\bar{\pi}^2\right]\hat{e}_t \\ &\quad +\hat{y}_t + \psi_p\bar{\pi}^2\hat{\pi}_t + (1-\gamma)\,\psi_p\bar{\pi}^2\hat{e}_{t-1} + \hat{\theta}_t\end{aligned} \tag{D.5}$$

$$\begin{aligned}\nu\,(\sigma-1)\,\hat{l}_t &= -\beta\psi_w\bar{\pi}^2 E_t\hat{\pi}_{t+1} - \beta\psi_w\bar{\pi}^2 E_t\hat{w}_{t+1} + \psi_w\bar{\pi}^2\hat{\pi}_t \\ &\quad +(1+\beta)\,\psi_w\bar{\pi}^2\hat{w}_t + (\sigma-1)\left(\hat{r}_t + \hat{k}_t - \hat{c}_t\right) - \psi_w\bar{\pi}^2\hat{\omega}_{t-1}\end{aligned} \tag{D.6}$$

[44] This is obtained after using the following result: $vec\,(ABC) = (C' \otimes A) \cdot vec\,(B)$.

Notice we have eliminate $\hat{\Omega}_t$ from the system using Eq. (B.17) in this last equation.

Next, combine Eqs.(B.21) together with Eqs. (B.12) and (B.13) to obtain a Fisher type equation:

$$\hat{\imath}_t = E_t\hat{r}_{t+1} + E_t\hat{\pi}_{t+1} \tag{D.7}$$

Now the entrepreneurs problem can be reduced as to eliminate η_t and $\hat{n}_t$ from the system. Take the net worth equation (B.23) and replace it into the risk premium equation (Eq. B.20) and into the entrepreneur's budget constraint to obtain:

$$\hat{\eta}_t = \mu\left[(1-\gamma+\psi)\,\hat{e}_t + \hat{k}_{t+1} - (1+\psi)\,\hat{y}_t + \psi\hat{d}_t - (1+\psi)\,(1-\phi)\,\frac{\hat{e}_t^Y}{\bar{\theta}-1}\right] \tag{D.8}$$

and

$$\hat{k}_{t+1} = \hat{y}_t - (1-\gamma)\,\hat{e}_t + \left(\frac{\psi}{1+\psi}\right)\left(\hat{d}_{t+1} - \hat{d}_t\right) + (1-\phi)\,\frac{\hat{e}_t^Y}{\bar{\theta}-1} \tag{D.9}$$

Now use (D.8) to eliminate η_t from Eq. (B.21). Some algebraic manipulation yields:

$$\begin{aligned}\mu\hat{k}_{t+1} &= E_t\hat{r}_{t+1} + E_t\hat{\pi}_{t+1} - E_t\hat{f}^s_{t+1} + \mu\,(1+\psi)\,\hat{y}_t - \mu\psi\hat{d}_t \\ &\quad -\mu\,(1-\gamma+\psi)\,\hat{e}_t + \mu\,(1+\psi)\,(1-\phi)\,\frac{\hat{e}_t^Y}{\bar{\theta}-1} - \hat{\rho}_t\end{aligned} \tag{D.10}$$

Substituting $\hat{e}_t^Y$ in the last two equations and defining $\Psi = \frac{\psi}{1+\psi} > 0$; $\check{S} = \beta\psi_p\bar{\pi}^3 \geq 0$; $\check{U} = \psi_p\bar{\pi}^2 \geq 0$; $\check{I} = \mu\,(1+\psi)$; $\check{G} = \frac{1-\phi}{\bar{\theta}-1}$; $\check{O} = \check{I}\check{G} \geq 1$; $\check{R} = \check{S}\check{O} \geq 0$; $\check{T} = \check{U}\check{O} \geq 0$; $\check{Z} = (1+\beta\bar{\pi}) > 0$, and $\check{A} = \mu\,(1-\gamma+\psi) + (1-\gamma)\,\check{Z}\check{T}$ yields, respectively:

$$\begin{aligned}\hat{k}_{t+1} &= (1-\gamma)\,\check{S}\check{G}E\hat{e}_{t+1} - \check{S}\check{G}E_t\hat{\pi}_{t+1} + \Psi\left(\hat{d}_{t+1} - \hat{d}_t\right) \\ &\quad - (1-\gamma)\left[1 + \check{Z}\check{U}\check{G}\right]\hat{e}_t + (1-\gamma)\,\check{U}\check{G}\hat{e}_{t-1} + \hat{y}_t + \check{U}\check{G}\hat{\pi}_t + \check{G}\hat{\theta}_t\end{aligned} \tag{D.11}$$

$$\begin{aligned}\mu\hat{k}_{t+1} &= (1-\gamma)\,\check{R}E\hat{e}_{t+1} - \check{A}\hat{e}_t + (1-\gamma)\,\check{T}\hat{e}_{t-1} - \mu\psi\hat{d}_t \\ &\quad + \left(1-\check{R}\right)E_t\hat{\pi}_{t+1} + E_t\hat{r}_{t+1} - E_t\hat{f}^s_{t+1} + \check{T}\hat{\pi}_t + \check{I}\hat{y}_t + \check{O}\hat{\theta}_t - \hat{\rho}_t\end{aligned} \tag{D.12}$$

D.1. The Reduced System

Overall the system can the be summarized by 13 equations in 13 unknowns ($\hat{k}$, $\hat{e}$, $\hat{s}$, $d\hat{b}^*$, $\hat{w}$, $\hat{d}$, $\hat{\imath}$, π, $\hat{y}$, $\hat{l}$, $\hat{r}$, $\hat{c}$, $\hat{f}^s$):

$$0 = \alpha \hat{k}_t - \hat{y}_t + (1-\alpha)\,\hat{l}_t + \hat{A}_t \tag{D.13}$$

$$0 = -\hat{w}_t + \hat{k}_t - l_t + \hat{r}_t \tag{D.14}$$

$$0 = \gamma \hat{e}_t - \gamma \hat{e}_{t-1} + \hat{\pi}_t - \hat{f}^s_t \tag{D.15}$$

$$0 = \left(\frac{\bar{e}^\gamma}{\bar{C}}\right) dB^*_t - \hat{k}_t - \frac{1}{\beta}\left(\frac{\bar{e}^\gamma}{\bar{C}}\right) dB^*_{t-1} - \hat{r}_t + \hat{c}_t \tag{D.16}$$

$$0 = \lambda\tau \hat{k}_{t+1} + [1 + (1-\lambda-\gamma)\,\tau]\,\hat{e}_t - \tau \hat{y}_t + (\tau - 1)\,\hat{c}_t + (1-\lambda\tau)\,\hat{x}_t \tag{D.17}$$

$$0 = \hat{s}_t - \hat{s}_{t-1} - \hat{f}^s_t \tag{D.18}$$

$$\begin{aligned} 0 \;\; = \;\; & (1-\gamma)\,\check{S} E_t e_{t+1} - (1-\gamma)\left[\bar{\theta} - 1 + \check{Z}\check{U}\right]\hat{e}_t - (\bar{\theta}-1)\hat{k}_t \\ & + (1-\gamma)\,\check{U}\hat{e}_{t-1} - \check{S}E_t\hat{\pi}_{t+1} + \check{U}\hat{\pi}_t + \left(\bar{\theta} - 1\right)(\hat{y}_t - \hat{r}_t) + \hat{\theta}_t \end{aligned} \tag{D.19}$$

$$0 = \hat{\imath}_t - E_t\hat{\pi}_{t+1} - E_t\hat{c}_{t+1} + \hat{c}_t + E_t\hat{a}_{t+1} - \hat{a}_t \tag{D.20}$$

$$0 = \hat{\imath}_t - E_t\hat{\pi}_{t+1} - E_t\hat{r}_{t+1} \tag{D.21}$$

$$\begin{aligned} 0 \;\; = \;\; & -\beta E_t \hat{w}_{t+1} + (1+\beta)\,\hat{w}_t - (1-\sigma)\,\check{D}\hat{k}_t - \hat{w}_{t-1} \\ & -\beta E_t\hat{\pi}_{t+1} + \hat{\pi}_t + (1-\sigma)\,\check{D}\left(\nu\hat{l}_t - \hat{r}_t + \hat{c}_t\right) \end{aligned} \tag{D.22}$$

$$\begin{aligned} 0 \;\; = \;\; & (1-\gamma)\,\check{R}E\hat{e}_{t+1} - \mu\hat{k}_{t+1} - \check{A}\hat{e}_t + (1-\gamma)\,\check{T}\hat{e}_{t-1} - \mu\psi\hat{d}_t \\ & + \left(1 - \check{R}\right) E_t\hat{\pi}_{t+1} + E_t\hat{r}_{t+1} - E_t\hat{f}^s_{t+1} + \check{T}\hat{\pi}_t + \check{I}\hat{y}_t + \check{O}\hat{\theta}_t - \hat{\rho}_t \end{aligned} \tag{D.23}$$

$$\begin{aligned} 0 \;\; = \;\; & (1-\gamma)\,\check{S}\check{G}E\hat{e}_{t+1} - \hat{k}_{t+1} - (1-\gamma)\left[1 + \check{Z}\check{U}\check{G}\right]\hat{e}_t + \Psi\hat{d}_{t+1} \\ & + (1-\gamma)\,\check{U}\check{G}\hat{e}_{t-1} - \Psi\hat{d}_t - \check{S}\check{G}E_t\hat{\pi}_{t+1} + \check{U}\check{G}\hat{\pi}_t + \hat{y}_t + \check{G}\hat{\theta}_t \end{aligned} \tag{D.24}$$

$$0 = \tilde{\omega}_s\hat{s}_t - \hat{\imath}_t + \omega_i\hat{\imath}_{t-1} + \tilde{\omega}_\pi E_t\hat{\pi}_{t+1} + \tilde{\omega}_y\hat{y}_t + \tilde{\omega}_s\hat{\chi}_t \tag{D.25}$$

where $\check{D} = \frac{1}{\psi_w \bar{\pi}^2} > 0$.

E. Solution Representation

As discussed in the text, the model cannot be solved for analytically.. To solve it numerically, Uhlig's (1997) method of undetermined coefficients is used. To apply his method we write the system in the following matrix form. Let $\tilde{x} = \left[\hat{k}\ \hat{e}\ \hat{w}\ \hat{d}\ dB^*\ \hat{\imath}\ \hat{s}\right]'$, $\tilde{y} = \left[\hat{\pi}\ \hat{y}\ \hat{l}\ \hat{r}\ \hat{c}\ \hat{f}^s\ \hat{\imath}\ \hat{\varrho}\right]'$, and $\tilde{z} = \left[\hat{\rho}\ \hat{x}\ \hat{A}\ \hat{\theta}\ \hat{\chi}\ \hat{a}\right]'$. Then the equilibrium relationships between the endogenous state vector $\tilde{x}_t$ 7×1, the other endogenous variables $\tilde{y}_t$ 8×1 and the exogenous stochastic processes $\tilde{z}_t$ $k\times1$ can be written as:

$$0 = \Gamma_A \tilde{x}_t + \Gamma_B \tilde{x}_{t-1} + \Gamma_C \tilde{y}_t + \Gamma_D \tilde{z}_t \tag{E.1}$$

$$0 = E_t[\Gamma_F \tilde{x}_{t+1} + \Gamma_G \tilde{x}_t + \Gamma_H \tilde{x}_{t-1} + \Gamma_J \tilde{y}_{t+1} + \Gamma_K \tilde{y}_t + \Gamma_L \tilde{z}_{t+1} + \Gamma_M \tilde{z}_t] \tag{E.2}$$

$$\tilde{z}_{t+1} = \Gamma_N \tilde{z}_t + \tilde{\varepsilon}_{t+1} \tag{E.3}$$

$$E_t\left[\tilde{\varepsilon}_{t+1}\right] = 0 \tag{E.4}$$

where

$$\Gamma_A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & \gamma & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{\bar{e}\gamma}{\bar{C}} & 0 \\ \lambda\tau & 1+(1-\lambda-\gamma)\tau & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Gamma_B = \begin{bmatrix} \alpha & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\gamma & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & -\frac{\bar{e}\gamma}{\beta\bar{C}} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Gamma_C = \begin{bmatrix} 0 & -1 & 1-\alpha & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 \\ 0 & -\tau & 0 & 0 & \tau-1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\Gamma_D = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1-\lambda\tau \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Gamma_F = \begin{bmatrix} 0 & (1-\gamma)\check{S} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\beta & 0 & 0 & 0 \\ 0 & (1-\gamma)\check{R} & 0 & 0 & 0 & 0 & 0 \\ 0 & (1-\gamma)\check{S}\breve{G} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Gamma_G = \begin{bmatrix} 0 & -(1-\gamma)\left[\theta - 1 + \check{Z}\breve{U}\right] & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1+\beta & 0 & 0 & 0 \\ -\mu & -\breve{A} & 0 & 0 & 0 & 0 & 0 \\ -1 & -(1-\gamma)\left[1 + \check{Z}\breve{U}\breve{G}\right] & 0 & 0 & \Psi & 0 & 0 \\ 0 & 0 & \tilde{\omega}_s & 0 & 0 & 0 & -1 \end{bmatrix}$$

$$\Gamma_H = \begin{bmatrix} 1-\bar{\theta} & (1-\gamma)\breve{U} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ (\sigma-1)\check{D} & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & (1-\gamma)\check{T} & 0 & 0 & -\mu\psi & 0 & 0 \\ 0 & (1-\gamma)\breve{U}\breve{G} & 0 & 0 & -\Psi & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \omega_i \end{bmatrix}$$

$$\Gamma_J = \begin{bmatrix} -\check{S} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ -\beta & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1-\check{R} & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ -\check{S}\breve{G} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \tilde{\omega}_\pi & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Gamma_K = \begin{bmatrix} \breve{U} & \bar{\theta}-1 & 0 & 1-\bar{\theta} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & \nu(1-\sigma)\breve{D} & (\sigma-1)\breve{D} & (1-\sigma)\breve{D} & 0 & 0 & 0 \\ \breve{T} & \breve{I} & 0 & 0 & 0 & 0 & 0 & 0 \\ \breve{U}\breve{G} & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \tilde{\omega}_y & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Gamma_L = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \Gamma_M = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \breve{O} & 0 & 0 & -1 & 0 \\ 0 & \breve{G} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \tilde{\omega}_s & 0 & 0 \end{bmatrix}$$

F. Maximum Likelihood Estimation and Standard Error Calculations

To ensure that the numerical search always satisfy the theoretical restrictions imposed on the parameters the likelihood function was re-parameterized. As suggested by Hamilton (1994, Ch. 5) a vector λ for which $\Theta = \mathrm{g}(\lambda)$, where the function g:$R^a \rightarrow R^a$ incorporates the desired restrictions. Therefore, given the data and initial value for the transformed vector of parameters λ, it is possible to set $\Theta = \mathrm{g}(\lambda)$ and calculate $L(\Theta)$.Once the value of $\hat{\lambda}$ that maximizes the likelihood function is found, it is possible to obtain $\hat{\Theta} = \mathrm{g}\left(\hat{\lambda}\right)$. For estimation purposes the following transformations are used. For parameter values λ_i the original parameters are recovered as follows[45]. For $\theta_i \in (0,1)$ then $\theta_i = \frac{\lambda_i^2}{1+\lambda_i^2}$; For parameter values such that $\theta_i \geq 0$ then $\theta_i = |\lambda_i|$ and for $\theta_i > 1$ then $\theta_i = 1 + |\lambda_i|$.

To calculate the standard errors rely on the fact that for a large sample size, the distribution of the maximum likelihood estimate $\hat{\Theta}$ can be well approximated by:

$$\hat{\Theta} \approx N\left(\Theta_o, T^{-1}\vartheta^{-1}\right) \tag{F.1}$$

where Θ_o denotes the true parameter vector and ϑ is the information matrix. The information matrix is estimated using the second-derivative of the information matrix:

$$\hat{\vartheta} = -T^{-1} \left.\frac{\partial^2 L(\Theta)}{\partial\Theta\partial\Theta'}\right|_{\Theta=\hat{\Theta}} \tag{F.2}$$

With these two equations it is possible to approximate the variance-covariance matrix of

[45] With some abuse of notation, in this appendix θ_i represents an element of Θ. Therefore, θ should not be confused with the model's mark-up parameter.

$\hat{\Theta}$ by:

$$E\left(\hat{\Theta}-\Theta_o\right)\left(\hat{\Theta}-\Theta_o\right)\cong\left[-\left.\frac{\partial^2 L(\Theta)}{\partial\Theta\partial\Theta'}\right|_{\Theta=\hat{\Theta}}\right]^{-1} \quad \text{(F.3)}$$

where the term inside the brackets is calculated numerically as:[46]

$$\hat{D}_T=\left(\frac{1}{T}\right)\sum_{t=1}^{T}\left.\frac{\partial^2 \log f\left(\tilde{y}_t|\aleph_{t-1},\Theta\right)}{\partial\Theta\partial\Theta'}\right|_{\Theta=\hat{\Theta}} \quad \text{(F.4)}$$

It is important to notice that standard errors cannot be calculated directly for $\hat{\Theta}$ using the re-parameterization discussed above. To obtain the standard errors for $\hat{\Theta}$, first the likelihood function must is parameterized in terms of λ to find the MLE, and then the MLE is re-parameterized in terms of Θ to calculate the matrix of second derivatives evaluated at $\hat{\Theta}$.

Finally, to calculate the standard errors it is necessary to evaluate numerically the matrix of second derivatives of the log-likelihood function and then invert that full matrix. These two steps can introduce significant approximation errors into the statistics. As a result it is important to interpret these statistics with caution.

[46] See Hamilton (1994, Ch. 14).

G. FIGURES

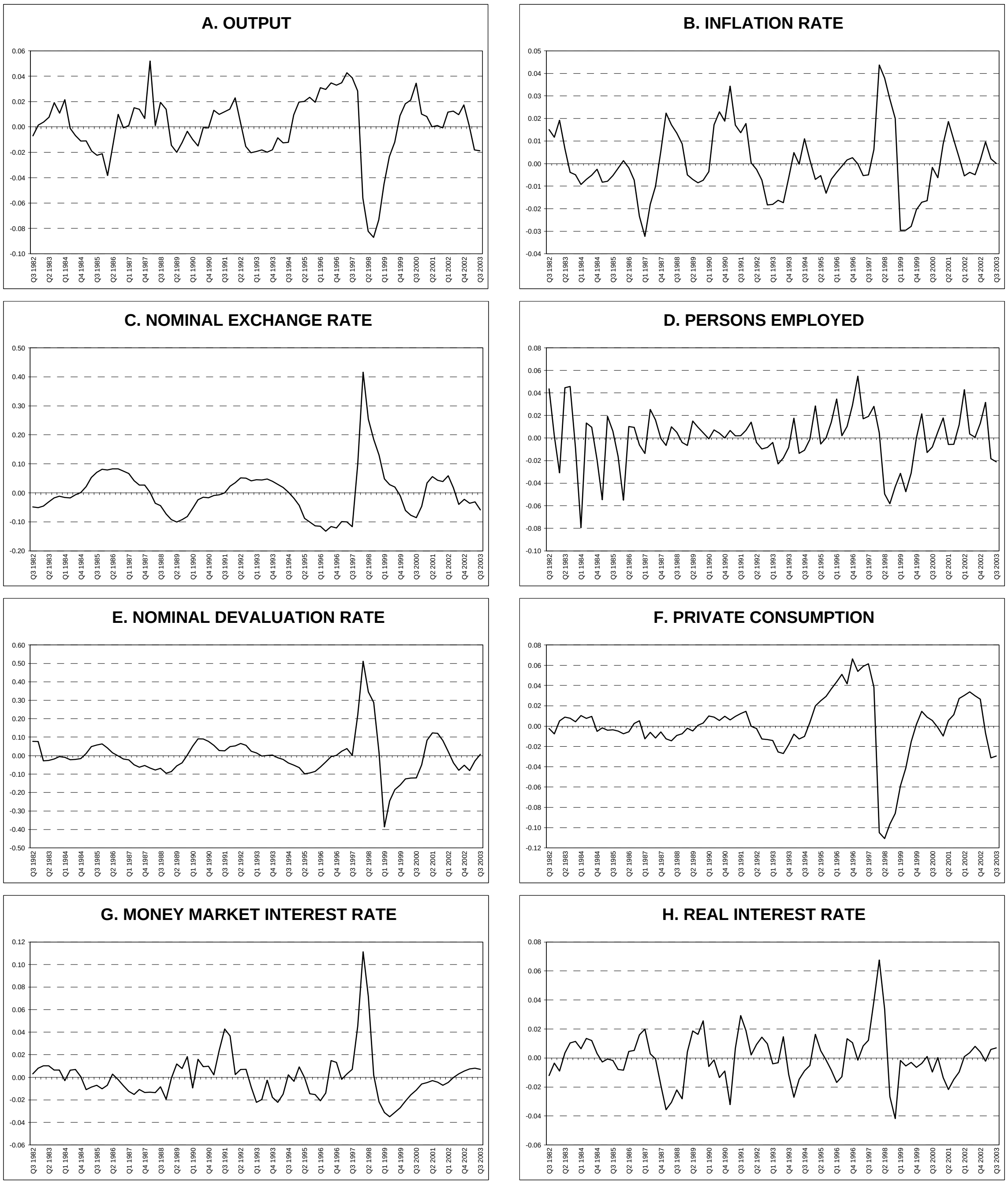

Figure G.1: South Korea 1982:3 to 2003:3. Main economic variables in logs and HP filtered.

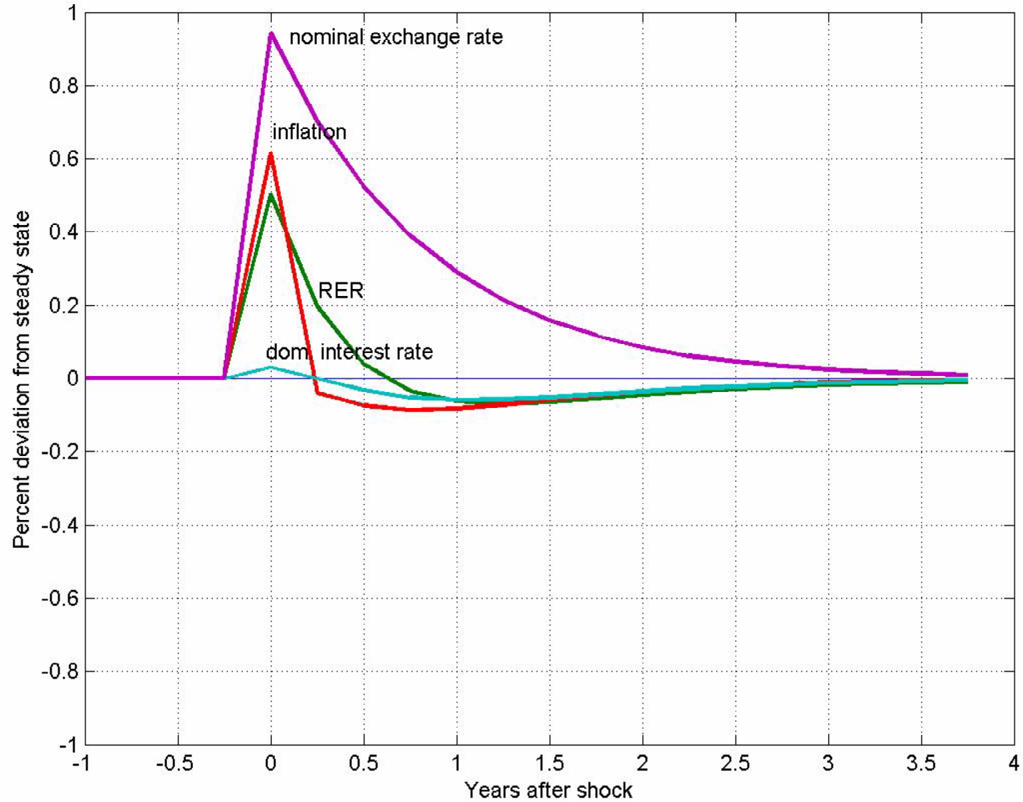

Figure G.2: Impulse response to a one percent devaluationary shock.

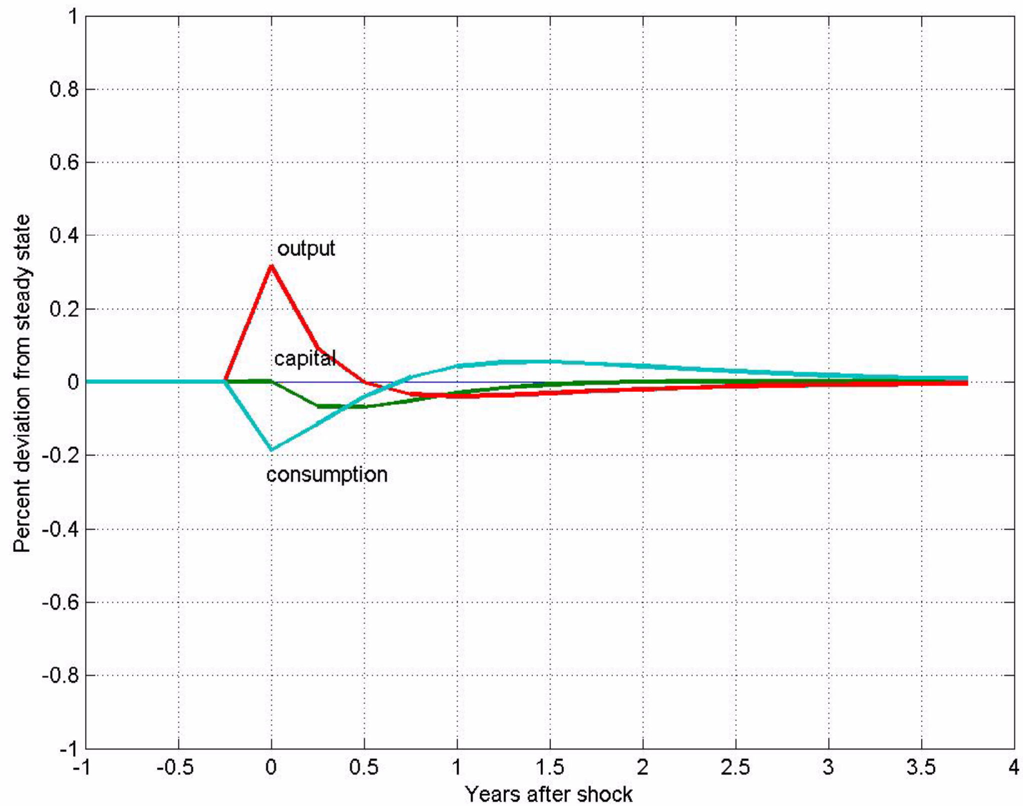

Figure G.3: Impulse response to a one percent devaluationary shock.

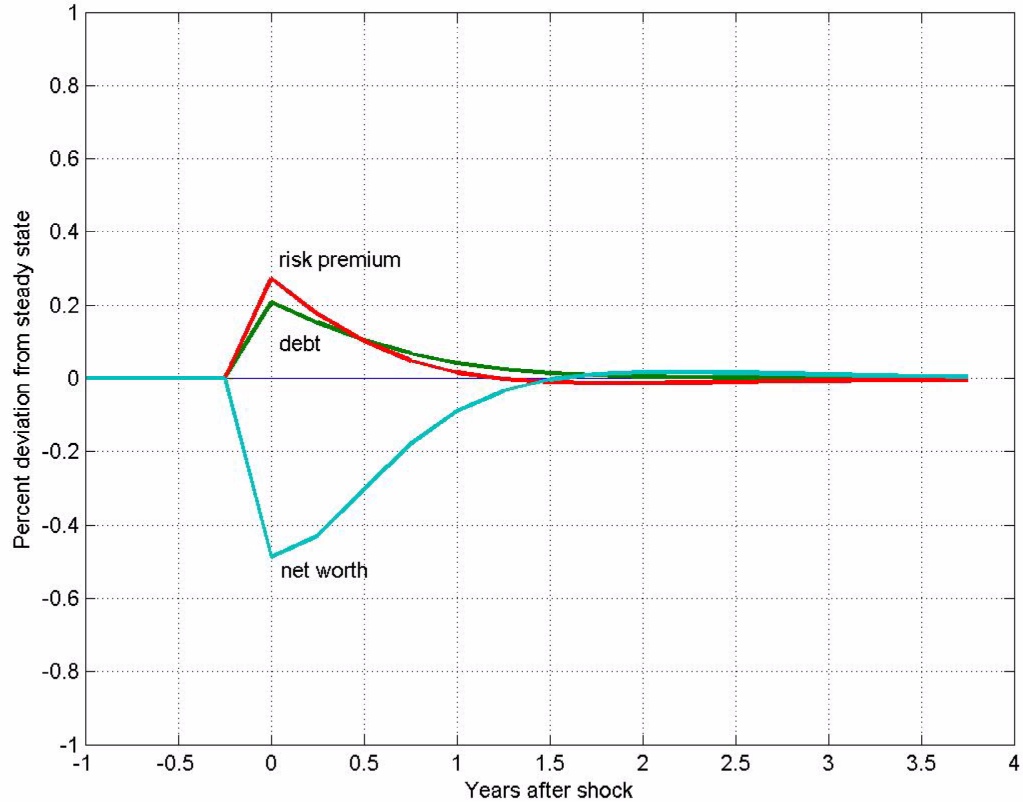

Figure G.4: Impulse response to a one percent devaluationary shock.

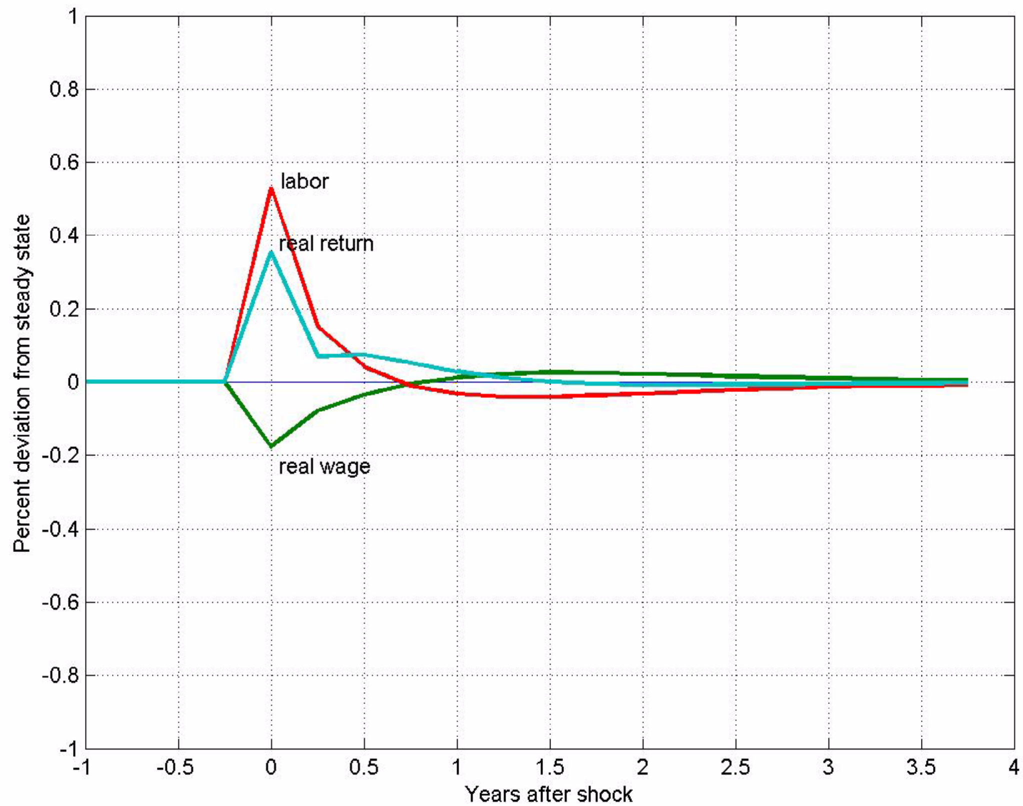

Figure G.5: Impulse response to a one percent devaluationary shock.

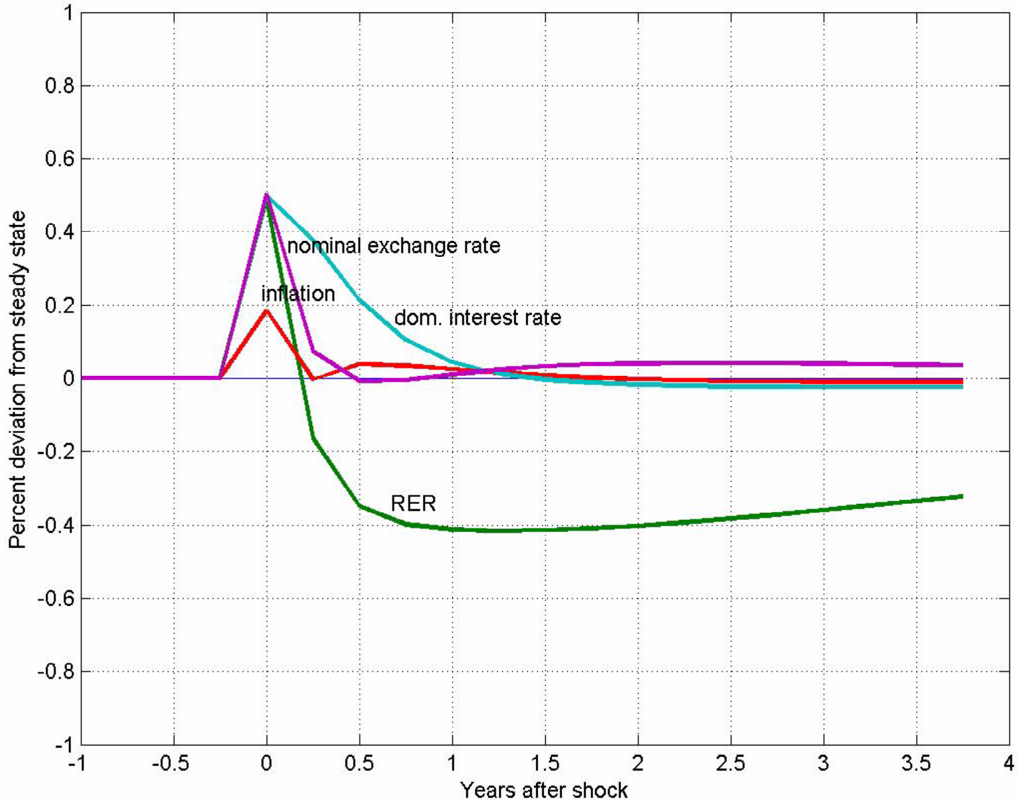

Figure G.6: Impulse response to a one percent increase in the international risk free interest rate.

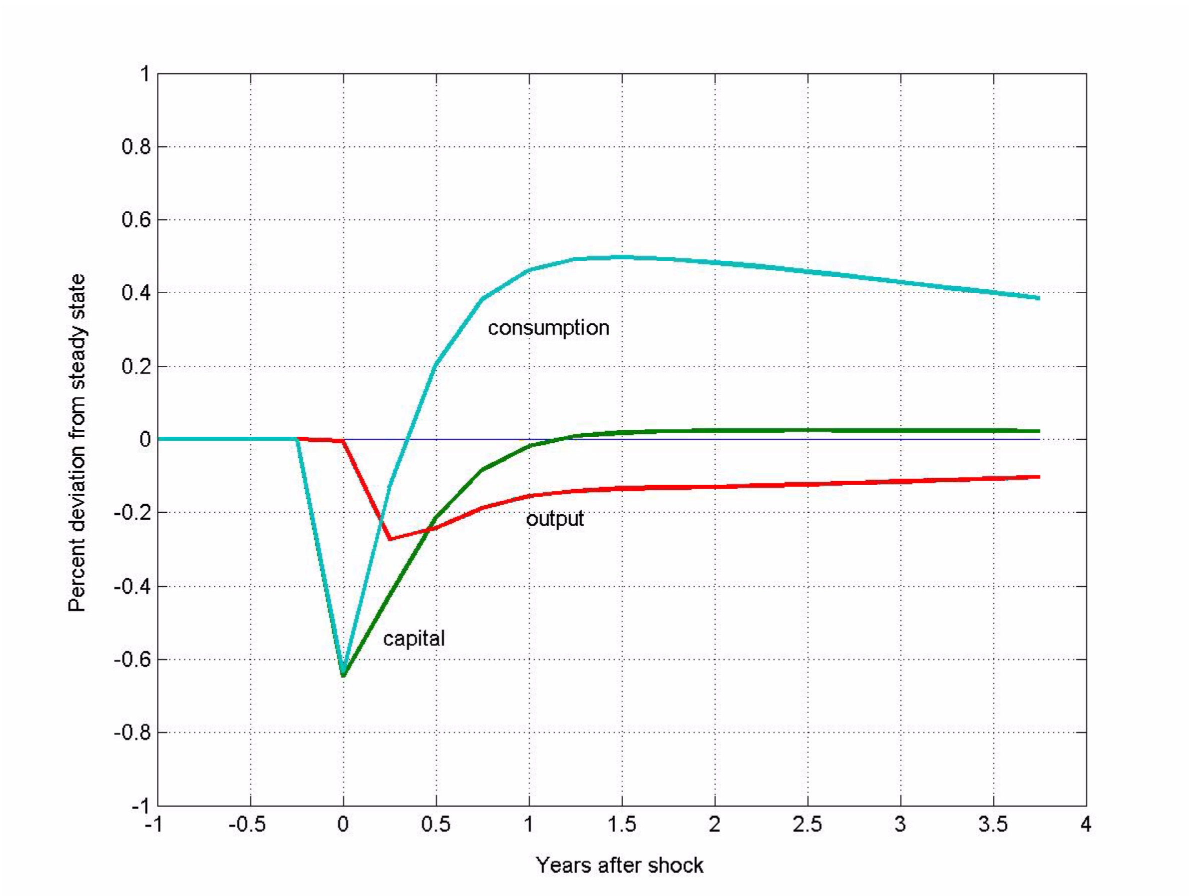

Figure G.7: Impulse response to a one percent increase in the international risk free interest rate.

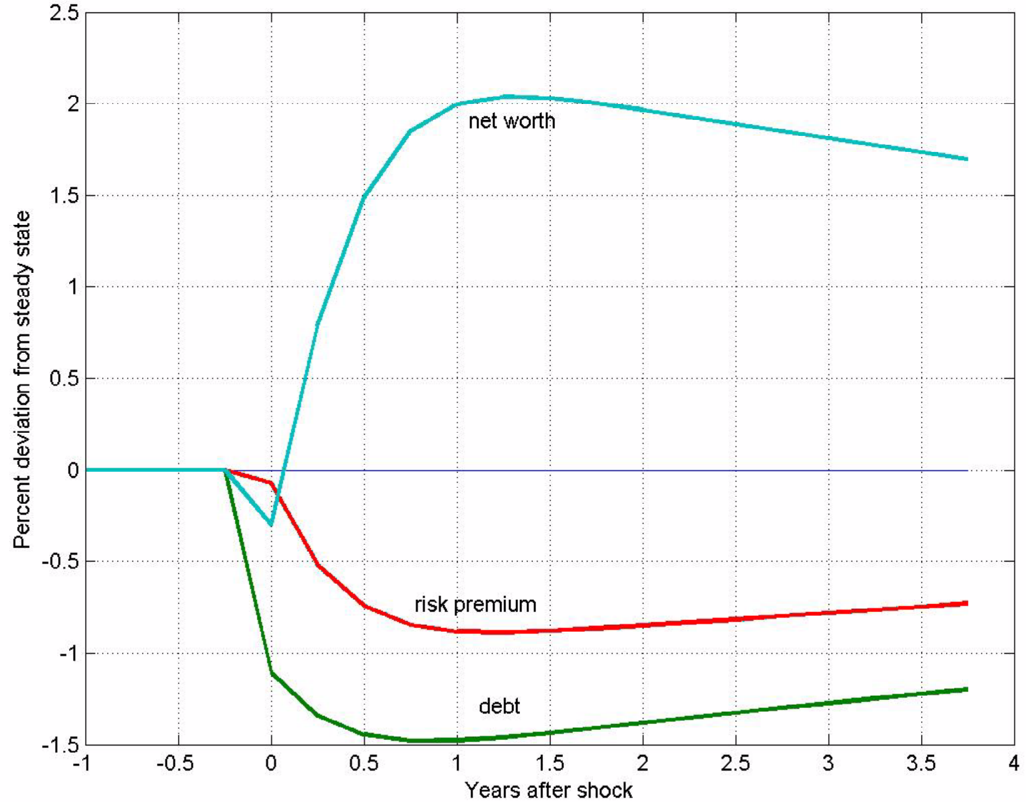

Figure G.8: Impulse response to a one percent increase in the international risk free interest rate.

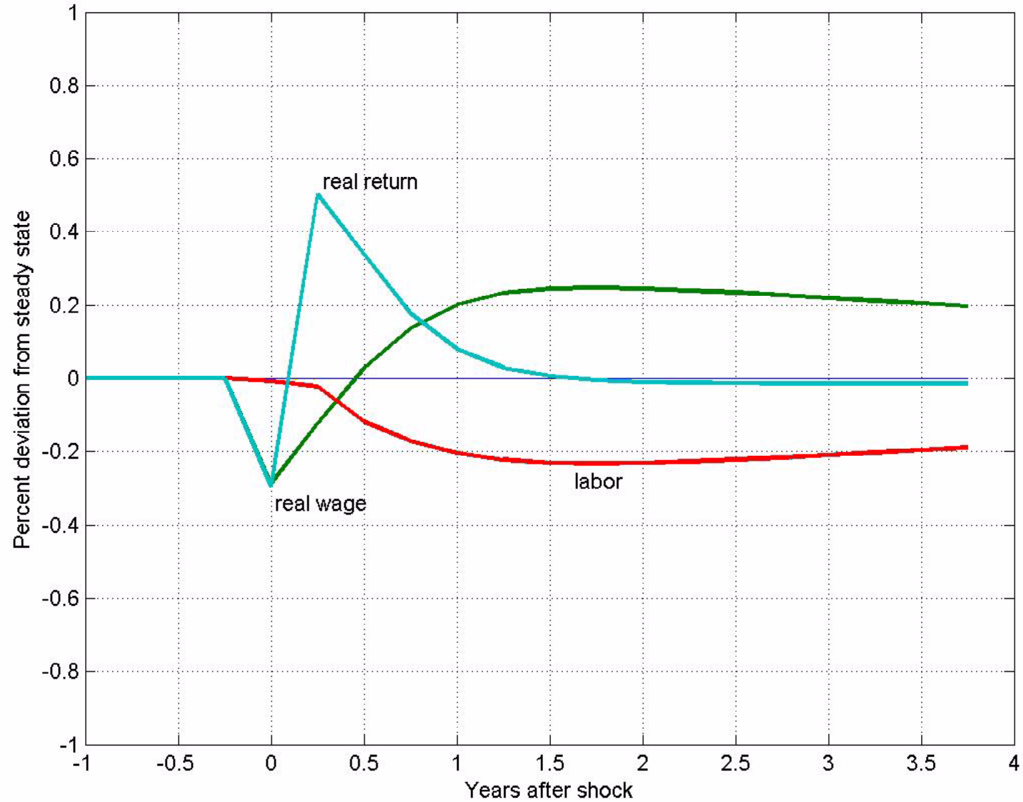

Figure G.9: Impulse response to a one percent increase in the international risk free interest rate.

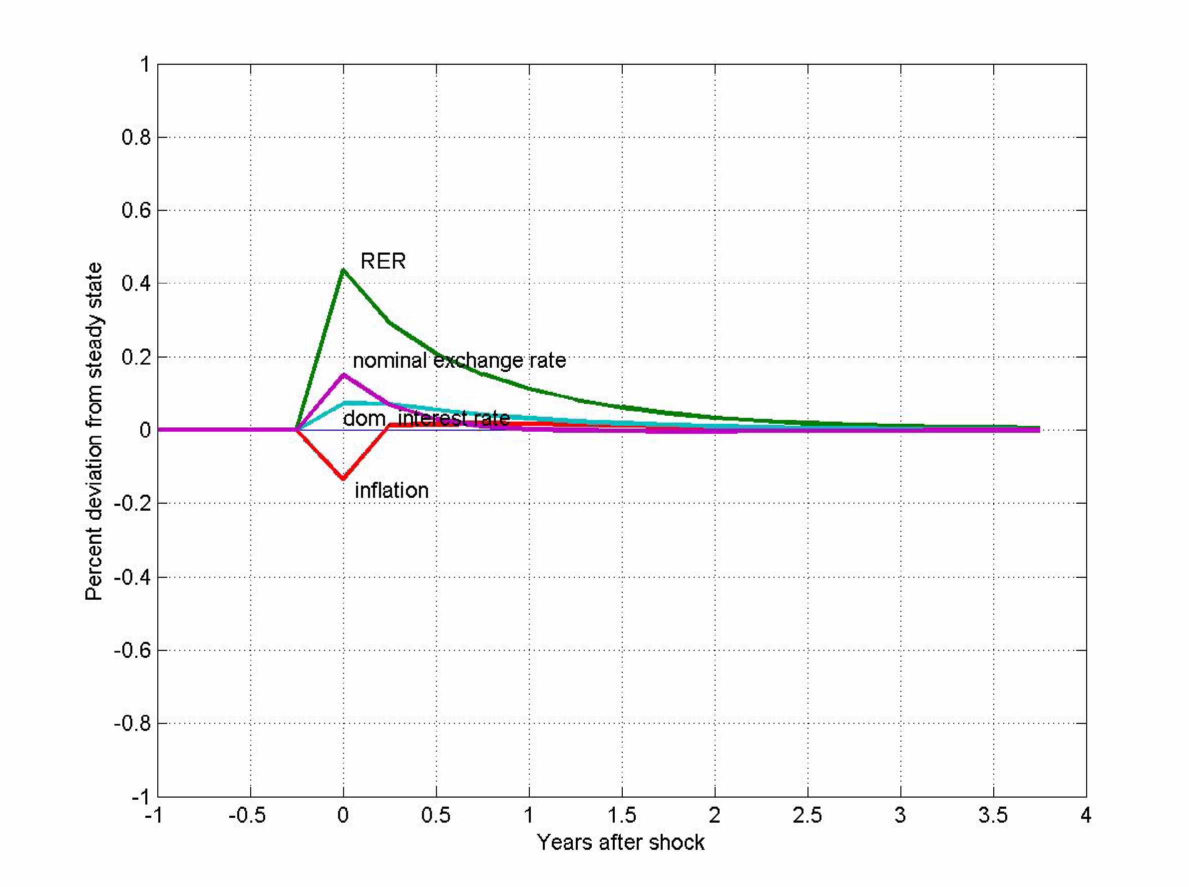

Figure G.10: Impulse response to a one percent adverse export demand shock.

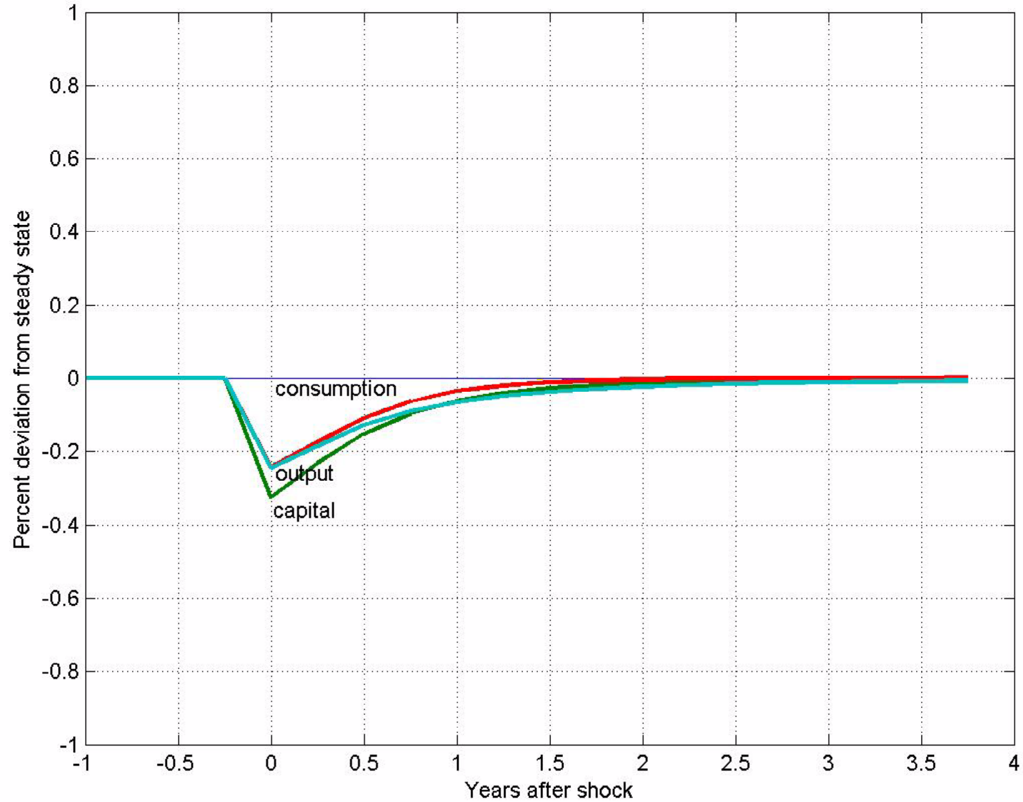

Figure G.11: Impulse response to a one percent adverse export demand shock.

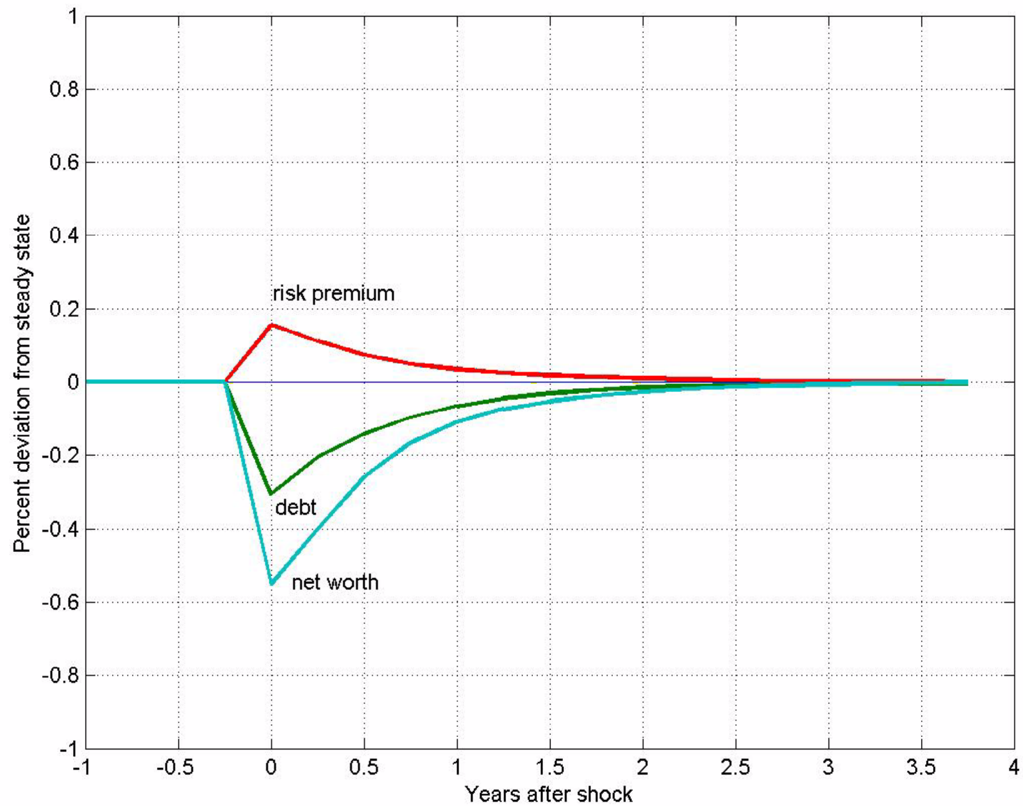

Figure G.12: Impulse response to a one percent adverse export demand shock.

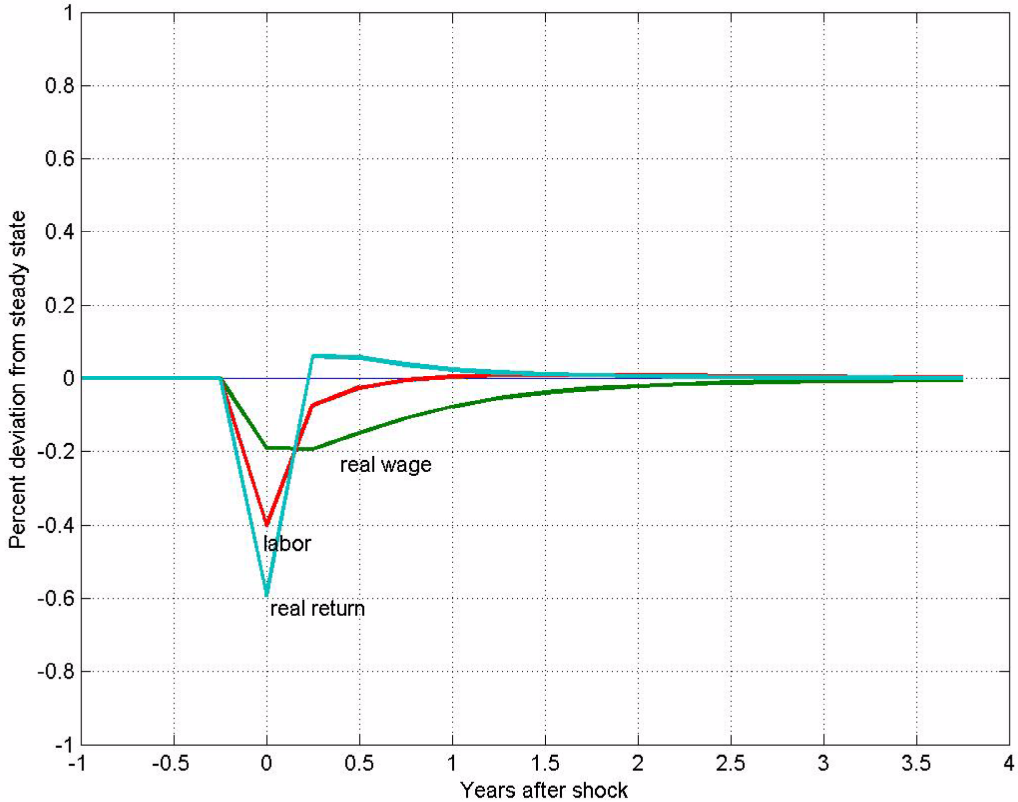

Figure G.13: Impulse response to a one percent adverse export demand shock.

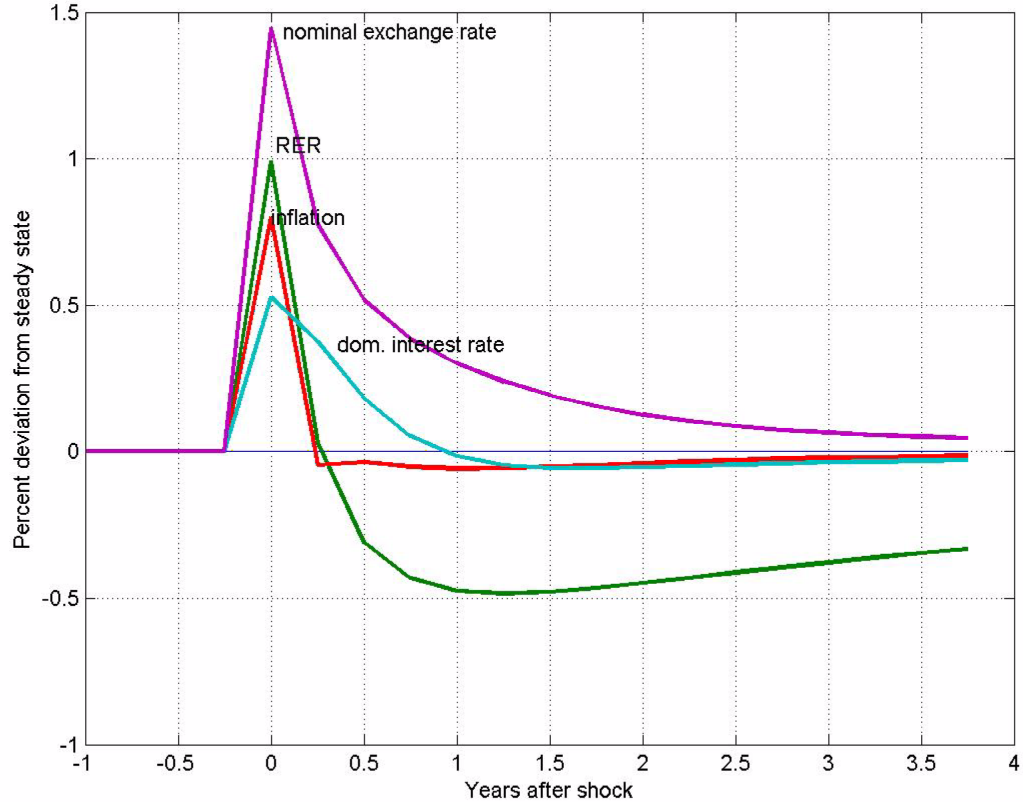

Figure G.14: Impulse response to a one percent devaluation and international interest rate shock.

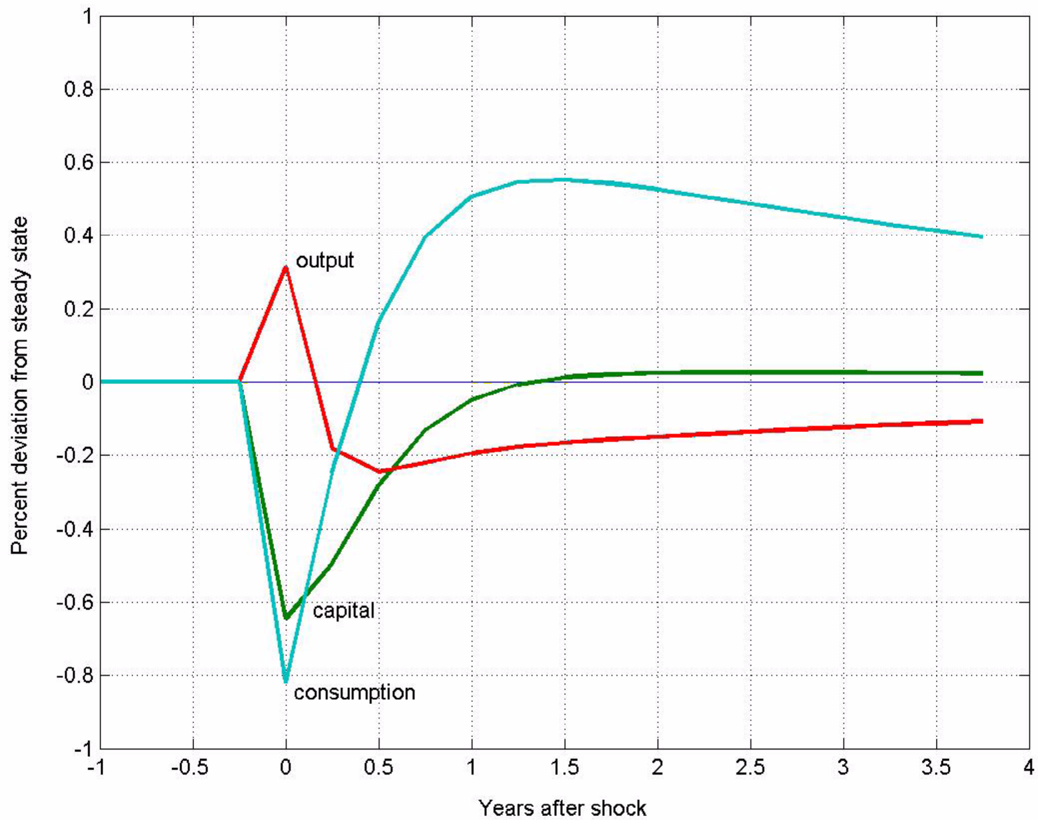

Figure G.15: Impulse response to a one percent devaluation and international interest rate shock.

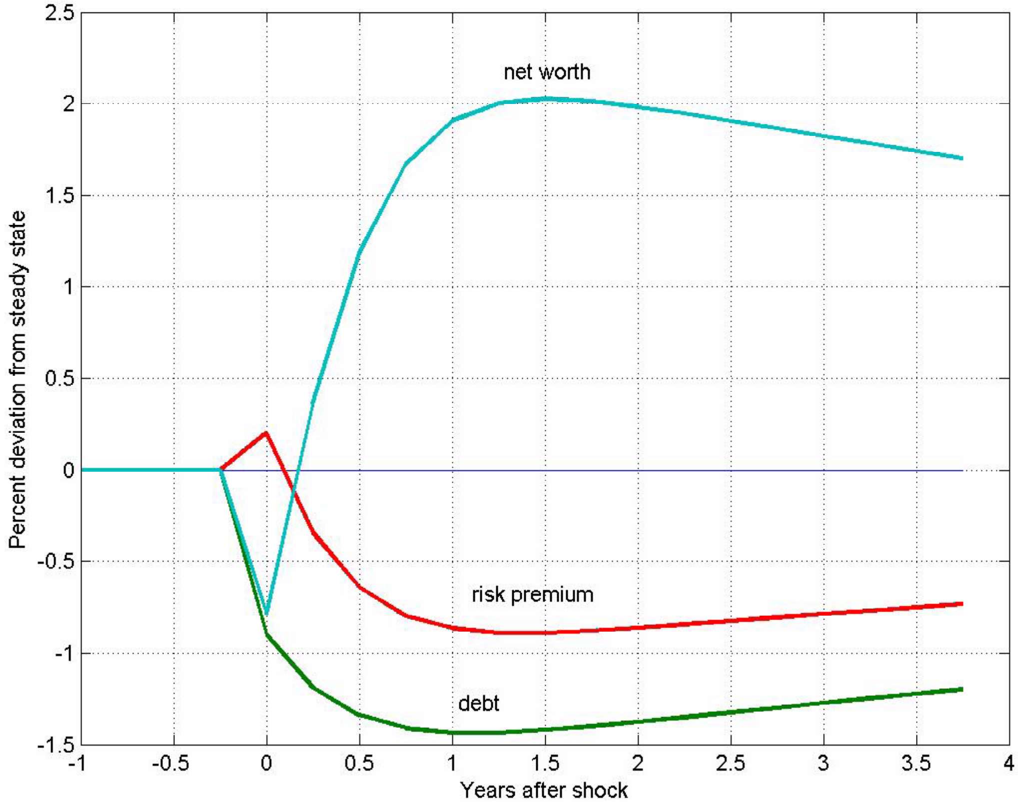

Figure G.16: Impulse response to a one percent devaluation and international interest rate shock.

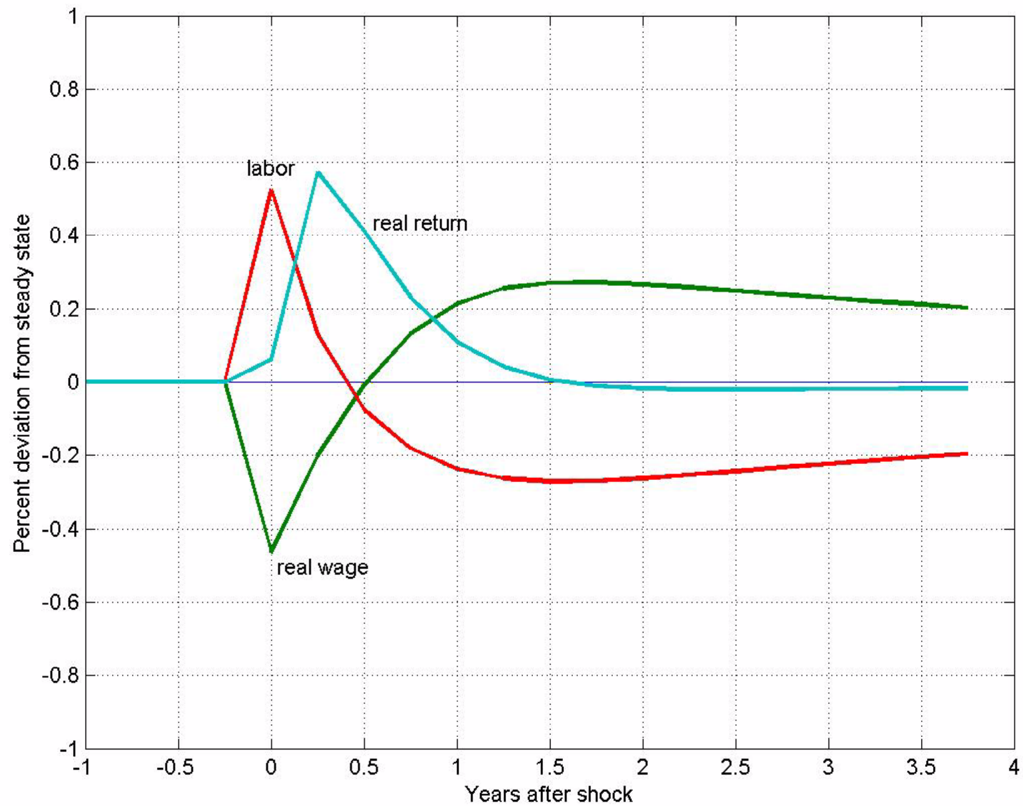

Figure G.17: Impulse response to a one percent devaluation and international interest rate shock.

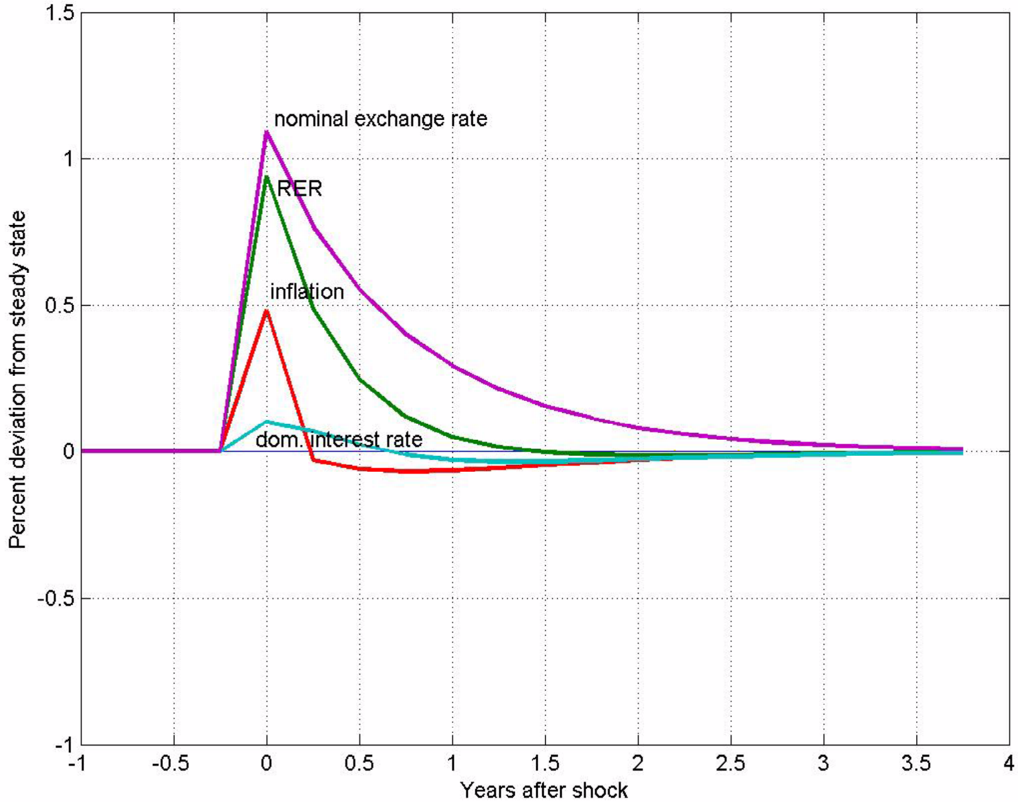

Figure G.18: Impulse response to a one percent devaluation and adverse export demand shock.

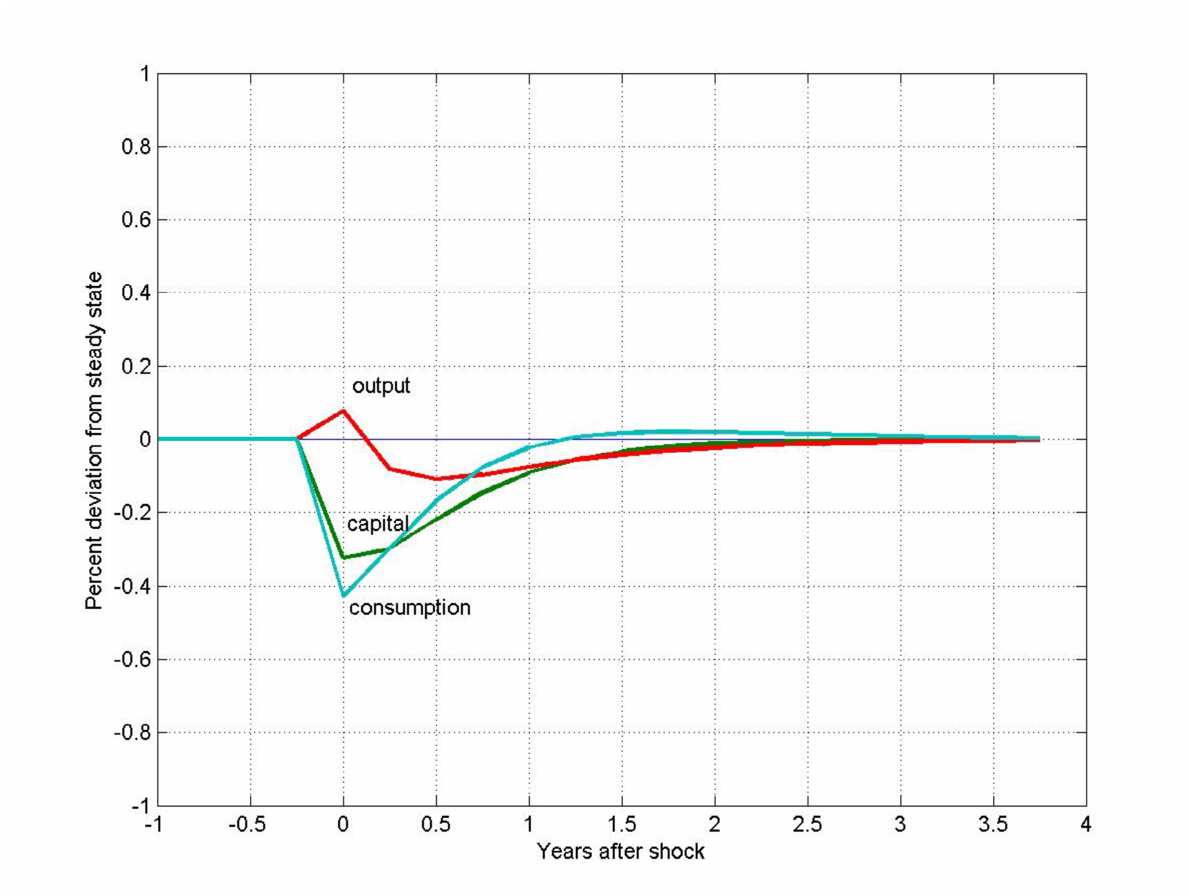

Figure G.19: Impulse response to a one percent devaluation and adverse export demand shock.

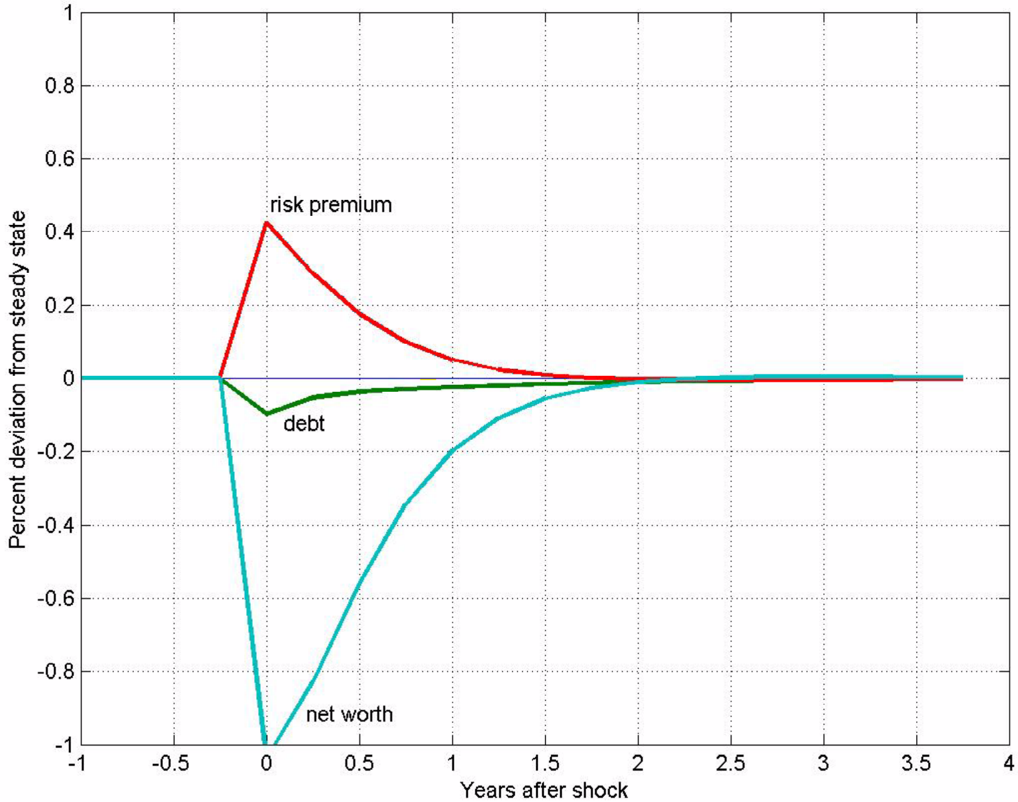

Figure G.20: Impulse response to a one percent devaluation and adverse export demand shock.

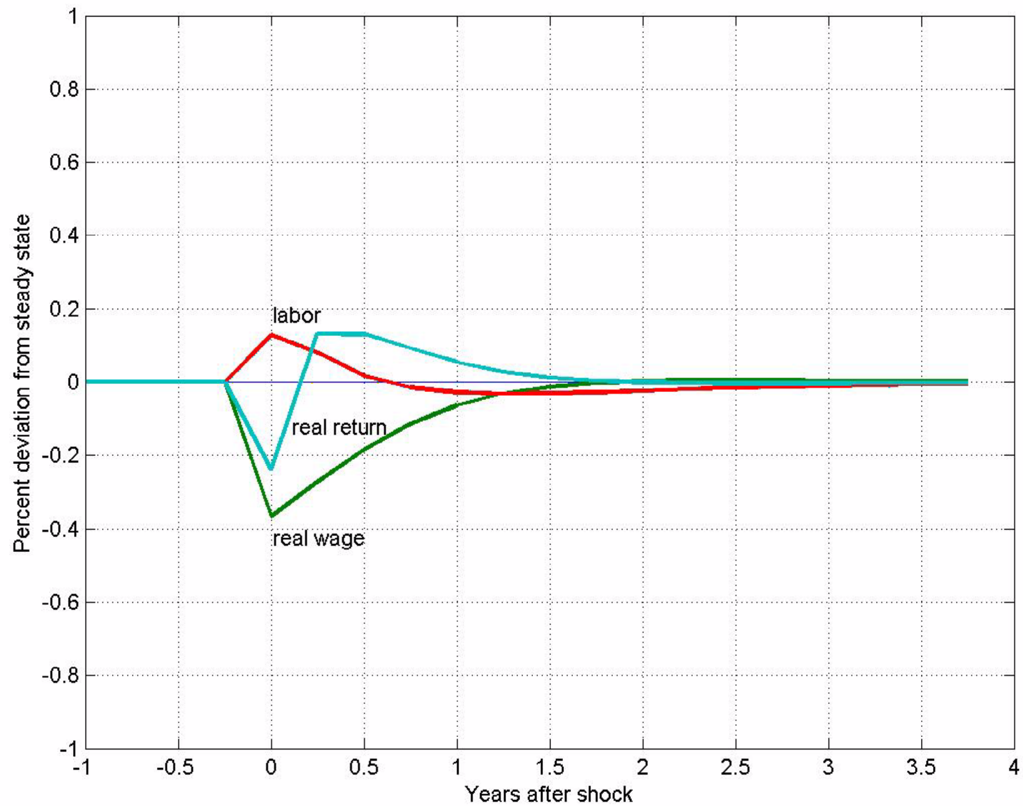

Figure G.21: Impulse response to a one percent devaluation and adverse export demand shock.