CPB Memorandum

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Towards a DSGE model for policy analysis in the Netherlands

We present a small-open-economy Dynamic Stochastic General Equilibrium model with distortionary taxation. The model has an overlapping generations structure with fully optimising agents following Blanchard (1985). Firms are monopolistically competitive and are subject to sticky prices. We also include capital and foreign bond adjustment costs.

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1 Introduction

In recent years, there has been much progess in building Dynamic Stochastic General Equilibrium (DSGE) models that can account for observed properties of macroeconomic data. Models such as those of Christiano et al. (2005), Smets and Wouters (2003) and Smets and Wouters (2007) display time series properties similar to real world data and produce impulse responses similar to ‘atheoretic’ VAR models.

Until recently the major focus of DSGE modelling was on monetary policy. However, especially within policy institutions more focus has been placed on building a DSGE framework for fiscal policy analysis. One of the most notable of models with the ability to analyse fiscal policy are from the GIMF model of the IMF (see Kumhof and Laxton (2007)). This model is an advanced mutli-country model designed for the analysis of both monetary and fiscal policy. Our model contains many basic versions of the design and features of GIMF. The European Commission also has a euro area wide DSGE model called QUEST (see Ratto et al. (2009)). Other notable models are SIGMA, from the Federal Reserve Board (see Erceg et al. (2006)); Aino, Bank of Finland (see Kilponen and Ripatti (2006)); PESSOA, Bank of Portugal (see Mourinho Félix et al. (2008)); LSM, the national statistical institute, Luxembourg (see STATEC (2009)); RAMSES, Bank of Sweden (see Adolfson et al. (2007)).

Furthermore, DSGE models have been used for forecasting the key macroeconomic series, with quite some degree of success. Key examples here are Smets and Wouters (2004) for the euro area and Rubaszek and Skrzypczynski (2008) for the US.

At CPB we currently use a large macro model, SAFFIER, for both policy analysis and forecasting (see Kranendonk and Verbruggen (2007)). Recent advances in DSGE modelling, as described by Negro et al. (2005), make an exploration of DSGE models and their applications interesting for CPB.

In this paper a DSGE model is described. The focus of the current version of the model is to get an idea of the potential of DSGE models for CPB. To that end, the current model is a small-open economy model of an economy with distortionary taxes and nominal rigidities. The remainder of this memo proceeds as follows. Section 2 describes the model. Section 3 presents some model simulations and Section 4 concludes. The complete set of model equations is given in the Appendix.

2 The model

2.1 Overview

Our model is a small open economy with exogenous foreign demand, nominal interest rate and foreign prices. The core of our model consists of fully optimising overlapping generation households who exhibit model consistent expectations. The households face a constant probability of death each period which can have important effects on their reaction to fiscal policy because they might be dead when taxes need to rise to pay for current government borrowing. The government in our model levies distortionary taxes on labour income, consumption and interest income. The government also levies a lump-sum tax. Monetary policy is modelled by imposing a no arbitrage condition on foreign and domestic bond holdings under a fixed one-to-one exchange rate.

The production side of our model is made up of monopolistically competitive firms who compete with both domestic and foreign competitors when setting prices. Our model also has a number of rigidities: price adjustments costs, foreign portfolio adjustment costs and capital adjustment costs. These impart more desirable dynamic properties on the model.

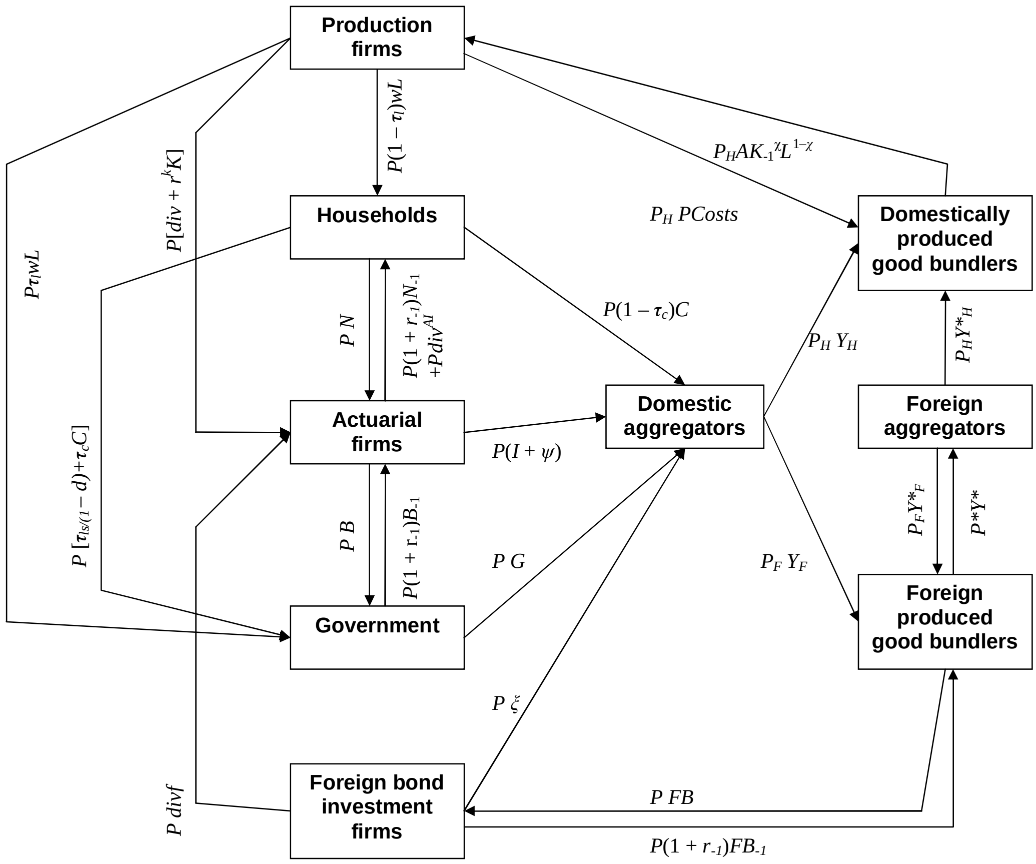
One important characteristic that is absent from our model is unemployment. Much recent research has been done with regards modelling unemployment in an optimising agents framework (see Gertler et al. (2008), for example) although no consensus has been reached on the most useful specification. At present our model is simulated with ad hoc parameterisations. It is not meant to be a representation of the Dutch economy.

Figure 2.1 shows the nominal money flows in the model. The following sections will discuss in more detail the structure and features of the model. For a full derivation of the complete model we refer the reader to the available technical appendix.

2.2 Households

The dominant modelling paradigm for DSGE models is to use an infinitely lived representative agent. However, when it comes to fiscal policy these models produce very limited effects of fiscal policy. In fact, they often display full Ricardian equivalence rendering fiscal policy irrelevant. Consequently, models for fiscal policy analysis often use overlapping generations model based on Blanchard-Yaari households (see Blanchard (1985) and Yaari (1965)), a commonly used model that can be found in many textbooks, for example Frenkel and Razin (1987). We follow this route. An alternative approach is to make extensive use of credit constrained or rule-of-thumb households which do not have access to financial markets. This

Figure 2.1 Nominal payment flows



forces a fraction of households to consume all of their disposable income each period. See Ratto et al. (2009) for an example of such a set-up.

The per-period utility function of a household in period v who was aged a in period zero is:

$$\frac{\left[\left(c^{\varsigma}_{a+v,v}m^{1-\varsigma}_{a+v,v}\right)^{\varphi}(1-l_{a+v,v})^{1-\varphi}\right]^{1-\theta}-1}{1-\theta}$$

where $c_{a+v,v}$ is the consumption of the composite consumption good, $l_{a+v,v}$ is the amount of labour supplied and $m_{a+v,v}$ are the real money holdings of the household in the current period that were chosen last period. Throughout our model our notation refers to start-of-period stocks, as this example with money demonstrates. The key assumption that makes the Blanchard-Yaari model tractable is that households die with probability $(1-d)$ and for which fair actuarial insurance exists. A zero profit condition on the sellers of the insurance ensures that the return on savings is exactly compensated by the probability of death, hence, each household insures their entire financial wealth against death by buying actuarial notes to compensate for the probability of death. This fair actuarial insurance and the particular form of the utility function we have chosen ensures that individual household decisions can be aggregated because the individual household choices are linear in wealth. This is in spite of households taking their finite lives into account when they make their consumption-savings decision. We follow Ascari and Rankin (2007) whereby money is insured just like actuarial notes. Another way of thinking about this is that when a household dies, some mysterious (zero-profit) agency comes to their house and finds all of their cash holdings, which they then distribute across all remaining households in proportion to their current money holdings. The household problem is then to maximise the expected value of (throughout this paper we will leave out the expectations operators that apply to all future variables in order to avoid excessive clutter in the equations)

$$\sum_{v=0}^{\infty} (\beta d)^v \frac{\left[\left(c_{a+v,v}^{\varsigma} m_{a+v,v}^{1-\varsigma}\right)^{\varphi} (1-l_{a+v,v})^{1-\varphi}\right]^{1-\theta} - 1}{1-\theta}$$

with respect to a series of per period budget constraints, which in nominal terms are given by:

$$\begin{aligned} P_v n_{a+v,v} + P_v m_{a+v,v} &= \tfrac{\left(1+i_{v-1}\left(1-\tau_{i,v}\right)\right)}{d} P_{v-1} n_{a+v-1,v-1} + \tfrac{P_{v-1} m_{a+v-1,v-1}}{d} \\ &+ (1-\tau_{l,v}) P_v w_v l_{a+v,v} - (1+\tau_{c,v}) P_v c_{a+v,v} - P_v \tau_{ls,v} + (1-\tau_{i,v}) P_v \tfrac{n_{a+v-1,v-1}}{N_{v-1} d} div_v^{AI} \end{aligned}$$

where $P_v m_{a+v,v}$ are the nominal money holdings. Household savings are held in the form of actuarial notes; $n_{a+v,v}$ are the real value of actuarial notes held by a household aged a in period zero that are taken into the following period, N_{v-1} is the aggregate stock of all actuarial note holdings. The household receieves a real wage, w_v, for their labour effort. As ultimate owners of all firms in the economy, households also receive a direct transfer of the profits of the actuarial insurance firms, div_v^{AI}, whiich is distributed among surviving households in proportion to their holdings of actuarial notes in previous period. The tax on nominal interest income for period t is denoted by $\tau_{i,t}$, on consumption is denoted $\tau_{c,t}$ and on labour income $\tau_{l,t}$. The model also includes a lump-sum tax, $\tau_{ls,t}$. Households choose consumption, labour, real money balances and purchases of actuarial notes. Actuarial notes represent all non-monetary saving for household in the economy. This follows from a simple arbitrage argument whereby households earn a higher return if they delegate ownership of all other asset classes to actuarial insurance firms rather than own them directly. To derive the first order conditions for consumption and saving we use the lifetime budget constraint, which, after using a No Ponzi Game condition on financial wealth, is

$$\begin{aligned} \sum_{i=0}^{\infty} \alpha_i^h (1+\tau_{c,i}) c_{a+i,i} &= fw_{a,0} + \sum_{i=0}^{\infty} \alpha_i^h (1-\tau_{l,i}) w_i l_i - \sum_{i=0}^{\infty} \alpha_i^h \tau_{ls,i} \\ &+ \sum_{i=0}^{\infty} \alpha_i^h (1-\tau_{i,i}) \frac{n_{a+i-1,i-1}}{N_{i-1} d} div_i^{AI} - \sum_{i=0}^{\infty} \alpha_i^h \frac{ni_i}{1+ni_i} m_{a+i,i} \end{aligned}$$

where $fw_{a+v,v}$, total financial wealth including both actuarial notes and real money holdings that a household aged a in period zero takes from period $v-1$ to period v, is given by

$$fw_{a+v,v} = \frac{1}{\pi_v d}\left\{\left[1+i_{v-1}\left(1-\tau_{i,v}\right)\right]n_{a+v-1,v-1}+m_{a+v-1,v-1}\right\}$$

and

$$\alpha_i^h = \prod_{j=1}^{i}\frac{\pi_j d}{1+ni_j} = \prod_{j=1}^{i}\frac{1}{1+r_{j-1}^h},\, \alpha_0 = 1$$

Notice how the lifetime budget constraint contains a money holdings term in addition to the initial financial wealth term. This, the last term on the right hand side, measures the opportunity cost of holding non-interest bearing money. Also, in order to avoid excessive clutter in the equations we have defined the net nominal interest, $ni_t = 1+i_{t-1}\left(1-\tau_{i,t}\right)$.

The lifetime budget constraint can be simplified by defining household lifetime wealth as $h_{a,0}$. Then the lifetime budget constraint becomes

$$\sum_{i=0}^{\infty}\alpha_i^h\left(1+\tau_{c,i}\right)c_{a+i,i} = h_{a,0}$$

The optimal consumption decision from the household problem is then given by

$$c_{a+v,v} = \left(1-s_0\right)h_{a,0}\left(\frac{\alpha_v^h}{\left(\beta d\right)^v}\right)^{-\frac{1}{\theta}}$$

where s_0 is given by

$$\left(1-s_0\right) = \left[\begin{array}{c} \left(\varsigma\varphi\right)^{\frac{1}{\theta}}\left(\frac{1-\varphi}{\varsigma\varphi}\right)^{\frac{(1-\varphi)(1-\theta)}{\theta}}\left(\frac{1-\varsigma}{\varsigma}\right)^{\frac{(1-\varsigma)\varphi(1-\theta)}{\theta}} \\ \times\sum_{v=0}^{\infty}\alpha_v^{h\,1-\frac{1}{\theta}}\left(\beta d\right)^{\frac{v}{\theta}}\left[\frac{\left(1+ni_{v+1}\right)^{(1-\varsigma)\varphi}}{ni_{v+1}^{(1-\varsigma)\varphi}\left(1+\tau_{c,v}\right)^{\varsigma\varphi}\left[\left(1-\tau_{l,v}\right)w_v\right]^{1-\varphi}}\right]^{\frac{1-\theta}{\theta}} \end{array}\right]^{-1} X_v$$

and where

$$X_v = \left(\frac{\left(1+\tau_{c,v}\right)}{\varsigma\varphi}\right)^{-\frac{1}{\theta}}\left[\left(1+\tau_{c,v}\right)\frac{\left(1-\varsigma\right)}{\varsigma}\frac{1+ni_{v+1}}{ni_{v+1}}\right]^{\frac{(1-\varsigma)\varphi(1-\theta)}{\theta}}\left(\left(\frac{1+\tau_{c,v}}{1-\tau_{l,v}}\right)\frac{1-\varphi}{\varsigma\varphi w_v}\right)^{\frac{(1-\varphi)(1-\theta)}{\theta}}$$

This tells us that a household spends a linear proportion of the wealth each period. Now that we have optimal consumption per period we can use the per period problem to find optimal labour supply and money demand. The first order conditions are

$$l_{a+v,v} = 1-\frac{\left(1-\varphi\right)}{\varsigma\varphi}\frac{\left(1+\tau_{c,v}\right)}{\left(1-\tau_{l,v}\right)}\frac{c_{a+v,v}}{w_v}$$

and

$$m_{a+v,v} = \left(1+\tau_{c,v}\right)\frac{\left(1-\varsigma\right)}{\varsigma}\frac{1+ni_{v+1}}{ni_{v+1}}c_{a+v,v}$$

Since we have already seen that consumption is linear in wealth it follows that both labour supply and money demand are also linear wealth. This allows us to aggregate across households. After aggregating we arrive at the equations describing the aggregate behaviour of households. See the appendix for the aggregate equations describing household behaviour.

2.3 Actuarial insurance firms

Actuarial insurance firms take households' savings, that is their purchases of actuarial notes, and allocate these among investment in physical capital, government debt and equity shares in domestic production firms and foreign investment firms. Actuarial insurance firms are perfectly competitive and earn zero profits. Production firms rent capital from actuarial firms who own the capital stock. Production firms pay r_t^k to rent capital from actuarial firms. Net investment is defined as

$$I_t = K_t - K_{t-1} + \delta K_{t-1}$$

Investment is subject to adjustment costs which are represented by $\psi\left(\frac{I_t}{K_{t-1}} - \delta\right)$.

Let the constant number of shares in the representative production firm be Z_t, the real share price of production firm shares be q_t and the real dividend paid per share be div_t. The corresponding variables for foreign investment firms are denoted Zf_t, qf_t and $divf_t$. Then the nominal profits of the actuarial firm for period t are

$$\begin{aligned} P_t\Pi_t^{AI} = {} & P_tN_t - (1+i_{t-1})P_{t-1}N_{t-1} - P_tB_t + \left(1+i_{t-1}^g\right)P_{t-1}B_{t-1} - q_tP_tZ_t + (q_t + div_t)P_tZ_{t-1} \\ & - qf_tP_tZf_t + (qf_t + divf_t)P_tZf_{t-1} + r_t^kP_tK_t - \left[1+\psi\left(\frac{I_t}{K_{t-1}} - \delta\right)\right]P_tI_t \end{aligned}$$

Actuarial firms discount future real profits by the expected real return on actuarial notes $1+r_{t-1}$. Implicitly we are assuming that households evaluate risky returns at their expected values. The reason why we use this discount factor rather than the standard stochastic discount factor in representative agent models is that differently aged households have different levels of consumption, so different levels of riskyness across assets held by the actuarial insurance firm would need to be discounted by a different stochastic discount factor for each household, unless we assume certainty equivalence. This is the cost of raising funds from households. This gives the Langrangian

$$\mathscr{L}_v = \sum_{t=v}^{\infty}\alpha_t\left(\begin{array}{l} N_t - (1+r_{t-1})N_{t-1} - B_t + \left(1+r_{t-1}^g\right)B_{t-1} - q_tZ_t + (q_t + div_t)Z_{t-1} \\ -qf_tZf_t + (qf_t + divf_t)Zf_{t-1} + r_t^kK_{t-1} - \left[1+\psi\left(\frac{I_t}{K_{t-1}} - \delta\right)\right]I_t \\ +\Lambda_t\left(I_t + (1-\delta)K_{t-1} - K_t\right) \end{array}\right)$$

where

$$\alpha_t = \frac{1}{\prod_{i=1}^t(1+r_{i-1})}, \alpha_0 = 1$$

A representative actuarial firm is perfectly competitive so it considers the dividend it receives from production firms as fixed when it makes its investment decision. The first order condition with respect to government debt holding is:

$$1+r_t = 1+r_t^g$$

From now on, we will impose this directly. The first order condition for the actuarial insurance firm with respect to production firm share holding is:

$$1+r_t = \frac{q_{t+1}+div_{t+1}}{q_t}$$

with respect to foreign investment firm share holding is:

$$1+r_t = \frac{qf_{t+1}+divf_{t+1}}{qf_t}$$

The first order condition with respect to capital:

$$(1+r_t)\Lambda_t = r_{t+1}^k + \left(\frac{I_{t+1}}{K_t}\right)^2 \psi' \left(\frac{I_{t+1}}{K_t}-\delta\right) + \Lambda_{t+1}(1-\delta)$$

The first order condition with respect to investment is:

$$\Lambda_t = 1+\psi\left(\frac{I_t}{K_{t-1}}-\delta\right) + \frac{I_t}{K_{t-1}}\psi'\left(\frac{I_t}{K_{t-1}}-\delta\right)$$

Since the actuarial firms are perfectly competitive, a zero expected profit condition will also hold, which, when we impose $Z_t = Zf_t = 1$, is:

$$\begin{aligned} 0 = {} & N_{t+1} - (1+r_t)N_t - B_{t+1} + (1+r_t)B_t + div_{t+1} + divf_{t+1} \\ & + r_{t+1}^k K_t - \left[1+\psi\left(\frac{I_{t+1}}{K_t}-\delta\right)\right] I_{t+1} \end{aligned}$$

The equations describing the behaviour of the actuarial insurance firms are repeated in the appendix.

2.4 Foreign investment firms

Foreign investments firms are used to simplify the problem of the actuarial insurance firm. Foreign investment firms take funds from the actuarial insurance firms and buy risk-free foreign bonds denominated in euros. These pay a nominal return of i_t^{fo}. Foreign bond holdings are also subject to adjustment costs. Due to the fixed exchange rate between the domestic economy and the rest of the world, we can use the domestic CPI to price foreign bonds. That is, from the point of view of domestic residents, the real value of their foreign bond holdings is the quantity of the domestic composite good that they can buy. Foreign investment firms pay all of their profits each period as a dividend to their shareholders. The nominal profit of the foreign investment firm, which is paid out as a dividend, is given by:

$$P_t divf_t = \left(1 + i^{fo}_{t-1}\right) P_{t-1} FB_{t-1} - P_t FB_t - P_t \xi\left(\Delta FB_t\right)$$

Note that the foreign investment firm can buy extra foreign bonds by paying a negative dividend. Therefore, the period t real dividend of the foreign investment firms equals

$$divf_t = \left(1 + r^{fo}_{t-1}\right) FB_{t-1} - FB_t - \xi\left(\Delta FB_t\right)$$

where $\xi\left(\Delta FB_t\right)$ denotes adjustment costs and where

$$1 + r^{fo}_t = \frac{1 + i^{fo}_t}{\pi_{t+1}}$$

The foreign investment firm aims to maximise discounted profits. The first order conditions for the time t choice variables FB_t and ΔFB_t:

$$\Lambda f_t = 1 + \xi'\left(\Delta FB_t\right)$$

$$\Lambda f_t = \frac{1}{1 + r_t}\left(r^{fo}_t + \Lambda f_{t+1}\right)$$

2.5 Government and money supply

Whilst the Netherlands doesn't have its own monetary policy, it does share seignorage revenues from the euro area. For completeness and because it may one day be interesting to look at how seignorage revenues affect fiscal policy, we will include a simple model of monetary policy in our model. We will therefore model seignorage revenues as if they were purely domestic given a fixed exchange rate.

2.5.1 Monetary authority

Central banks can inject money into the economy by performing open market operations. That is, they use newly printed money to buy nominal bonds. Since we have a non-Ricardian model we need to model open market operations because they affect the quantity of bonds held by domestic residents. Let us define $P_t B_t$ as the nominal price of a bond in period t, then the budget constraint of the monetary authority is:

$$P_t M_t - P_{t-1} M_{t-1} + i_{t-1} P_{t-1} B^M_{t-1} = P_t B^M_t - P_{t-1} B^M_{t-1} + P_t Transfer_t$$

Here, B^M_t are the real bond holdings of the monetary authority. The left hand side is the nominal income of the monetary authority: the nominal money issued plus the nominal interest received on bond holdings. The right hand side are the outgoings: the increase in nominal bond holdings plus the transfers to the fiscal authority.

2.5.2 Fiscal authority

We now turn to the budget constraint of the fiscal authority. For ease of notation, let us define a term to represent all nominal tax receipts, P_tT_t. We will return to taxation later:

$$P_tT_t = \tau_{i,t}i_{t-1}P_{t-1}N_{t-1} + \tau_{l,t}P_tw_tL_t + \tau_{c,t}P_tC_t + \frac{1}{1-d}P_t\tau_{ls,t} + \tau_{i,t}P_tdiv_t^{AI}$$

the fiscal authority budget constraint is then:

$$P_tG_t + i_{t-1}P_{t-1}B_{t-1}^T = P_tB_t^T - P_{t-1}B_{t-1}^T + P_tT_t + P_tTransfer_t$$

Here, $P_tB_t^T$ are the total of all outstanding nominal bonds. Using the definition:

$$B_t^M + B_t = B_t^T$$

where, B_t, are the real bond holdings of the public, we can combine the two budget constraints to get a single budget constraint for the government as a whole: the consolidated government budget constraint:

$$P_tG_t + i_{t-1}P_{t-1}B_{t-1} = P_tB_t - P_{t-1}B_{t-1} + P_tT_t + P_tM_t - P_{t-1}M_{t-1}$$

If we look at this we can see that there is interaction between fiscal and monetary policy because the seignorage revenues enter into the budget constraint. We can rewrite this as the evolution of real government debt.

$$B_t = G_t + (1+r_{t-1})B_{t-1} - \tau_{r,t}\frac{i_{t-1}}{\pi_t}N_{t-1} + \tau_{i,t}div_t^{AI} - \tau_{l,t}w_tL_t - \tau_{c,t}C_t - \frac{1}{1-d}\tau_{ls,t} - M_t + \frac{M_{t-1}}{\pi_t}$$

So far we have said nothing about government expenditure. We assume that these follow a simple process, namely

$$G_t = G_0 + e_t^g$$

An exogenous monetary policy is already modelled by stipulating that there is a fixed exchange rate. In the steady state, the nominal interest rate on domestic government debt and foreign bonds are equal. This follows from our specific specification of foreign bond adjustment costs. Away from the steady state the nominal interest rates are not necessarily equal due to the costs of adjusting foreign bond holdings. We could make these costs non-zero in steady state to give us a risk premium.

2.5.3 Debt repayment

So far, we have nothing that prevents the government from paying for all government consumption by issuing debt. To prevent this we use a fiscal policy rule that ensures a that a No

Ponzi game condition is met for the path of government debt. The government levies lump-sum and distortionary taxes on consumption, labour income and interest income. How taxes are split among these depends on the fiscal policy rule. The fiscal policy rule describes which tax rate adjusts to ensure that debt does not explode. The following example uses lump-sum taxes to pay off slightly more than the interest burden on outstanding debt:

$$\frac{1}{1-d}\tau_{ls,t} = (1 + r_{t-1} + \tau_{sus})\, B_{t-1}$$

Alternatively we can think of many different rules such as the following that adjusts consumption taxes smoothly to target a specific deficit-to-GDP ratio:

$$\tau_{c,t}C_t = \rho_{ts}\,\tau_{c,t-1}C_{t-1} + \Omega\left[\frac{G_t + (1 + r_{t-1})\,B_{t-1} - T_t - \psi_1 Y_t}{Y_t}\right]$$

Again, the necessary model equations describing government behaviour are repeated in the appendix.

2.6 Aggregators

Composite domestic and foreign bundles

We largely follow Galí and Monacelli (2005) and Faia and Monacelli (2008) when modelling the interaction of monopolistically competitive domestic producers and their foreign competitors. Aggregate consumption, government expenditure, investment and the associated real adjustment costs must be made from the same composite good, Υ_t. The composite good is made up of foreign and domestically produced goods, $\Upsilon_{F,t}$ and $\Upsilon_{H,t}$ respectively, from the following CES aggregator:

$$\Upsilon_t \equiv \left[(1-(1-n)\,\alpha)^{\eta}\,\Upsilon_{H,t}^{1-\eta} + ((1-n)\,\alpha)^{\eta}\,\Upsilon_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

Here, η is the degree of substitutability between domestic and foreign goods, α measures the degree of home bias with $\alpha = 1$ indicating no home bias and n gives the size of the domestic economy relative to the rest of the world. Given that the domestically produced good has price P_H and the foreign good price P_F, cost minimisation gives us the price of the composite good as well as the demand for each of the two components.

$$P_t = \left[(1-(1-n)\,\alpha)\,P_{H,t}^{\frac{\eta-1}{\eta}} + (1-n)\,\alpha P_{F,t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$$

$$\Upsilon_{H,t} = (1-(1-n)\alpha)\left(\frac{P_t}{P_{H,t}}\right)^{\frac{1}{\eta}}\Upsilon_t$$

$$\Upsilon_{F,t} = (1-n)\alpha\left(\frac{P_t}{P_{F,t}}\right)^{\frac{1}{\eta}}\Upsilon_t$$

Assuming symmetric home bias at home and abroad, we get the following price and demands in the rest of the world

$$P_t^* = \left[n\alpha P_{H,t}^{\frac{\eta-1}{\eta}} + (1-n\alpha)P_{F,t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$$

$$\Upsilon_{H,t}^* = n\alpha\left(\frac{P_t^*}{P_{H,t}}\right)^{\frac{1}{\eta}}\Upsilon_t^*$$

$$\Upsilon_{F,t}^* = (1-n\alpha)\left(\frac{P_t^*}{P_{F,t}}\right)^{\frac{1}{\eta}}\Upsilon_t^*$$

Note that due to home bias the home and foreign composite goods will contain different proportions of the two underlying goods and will therefore not necessarily have the same price. The price level can be non-stationary, so we define everything in terms of relative prices. This directly gives us the terms of trade and the CPI-PPI ratios in the home and foreign countries.

$$S_t = \frac{P_{F,t}}{P_{H,t}}$$

$$g(S_t) = \left[(1-(1-n)\alpha) + (1-n)\alpha S_t^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} = \frac{P_t}{P_{H,t}}$$

$$g^*(S_t) = \left[(1-n\alpha) + n\alpha S_t^{\frac{1-\eta}{\eta}}\right]^{\frac{\eta}{\eta-1}} = \frac{P_t^*}{P_{F,t}}$$

The terms of trade is still defined in terms of the indivdual levels but we can redefine it as a difference equation:

$$\frac{S_t}{S_{t-1}} = \frac{\pi_{F,t}}{\pi_{H,t}}$$

We can use the above to derive an expression for the trade balance:

$$P_t NX_t = P_{H,t}\Upsilon_{H,t}^* - P_{F,t}\Upsilon_{F,t}$$

Or in real terms

$$NX_t = \frac{1}{g(S_t)} n\alpha\left(g^*(S_t)S_t\right)^{\frac{1}{\eta}}\Upsilon_t^* - (1-n)\alpha\left(\frac{g(S_t)}{S_t}\right)^{\frac{1-\eta}{\eta}}\Upsilon_t$$

We can also use the above definitions to derive the following expression for domestic CPI inflation:

$$\pi_t = \frac{g(S_t)}{g(S_{t-1})}\pi_{H,t}$$

Within domestic bundles

The domestic good that makes up the domestic share of the aggregate composite good is itself a composite of a continuum of domestically produced goods. The consumption bundle $\Upsilon_{H,t}$ represents the domestic consumption of the continuum of domestic varieties on the interval $[0,n]$. The bundle $\Upsilon^*_{H,t}$ represents the foreign consumption of the continuum of domestic varieties on the interval $[0,n]$. Similarly, the consumption bundle $\Upsilon_{F,t}$ equals domestic consumption of the continuum of the foreign varieties which are on the interval $[n,1]$. The foreign consumption $\Upsilon^*_{F,t}$ of such varieties is defined analogously. Stated formally we define:

$$\Upsilon_{H,t} \equiv \left[\int_0^n \left(\frac{1}{n}\right)^{\varepsilon} \Upsilon_{H,t}(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$$

$$\Upsilon_{F,t} \equiv \left[\int_n^1 \left(\frac{1}{1-n}\right)^{\varepsilon} \Upsilon_{F,t}(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$$

$$\Upsilon^*_{H,t} \equiv \left[\int_0^n \left(\frac{1}{n}\right)^{\varepsilon} \Upsilon^*_{H,t}(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$$

$$\Upsilon^*_{F,t} \equiv \left[\int_n^1 \left(\frac{1}{1-n}\right)^{\varepsilon} \Upsilon^*_{F,t}(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$$

where i represents a particular variety and $0 \leq \varepsilon \leq 1$ represents the inverse of the substitution elasticity of the domestic varieties as well as the foreign varieties. This implies the cost minimising choice of domestic variety of an individual in the domestic economy $0 \leq j \leq n$, ie. individual demand for variety j is:

$$\Upsilon_{H,t}(j) = \frac{1}{n}\left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\frac{1}{\varepsilon}} \Upsilon_{H,t}$$

A similar expression can be derived for a foreign individual's demand for a given domestic variety:

$$\Upsilon^*_{H,t}(j) = \frac{1}{n}\left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\frac{1}{\varepsilon}} \Upsilon^*_{H,t}$$

These expressions are the demand curves faced by each monopolistically competitive domestic production firm, which are repeated in the appendix allong with the other model equations derived from the aggregators.

2.7 Production firms

Production firms are monopolistically competitive in their product markets. Therefore they are able to set a different price than their competitors. They are competitive in the input markets.

The demand for each intermediate good is given by summing the demand from domestic aggregators and from exports. Due to the constant returns to scale production function, we can rewrite the total cost of production as the product of the marginal cost and the quantity produced. We will use this result to express the firm's optimisation problem in those terms, which we will do here without deriving an expression for marginal cost just yet. The production function of the firm is given by:

$$Y_t = A_t K_{t-1}^{\chi} L_t^{1-\chi}$$

We follow Faia and Monacelli (2008) who use Rotemberg (1982) sticky prices. That is, changing prices has a real cost given by

$$\frac{\vartheta}{2}\left(\frac{\bar{P}_{H,t}}{P_{H,t-1}}-1\right)^2$$

That is, if the firm wants to change its price it must go and buy some of the domestic composite good to cover the costs. So the problem for the firm is to choose a price that will maximise expected profits using a discount factor from their owner. In the Faia and Monacelli paper the household owns the firm and there are complete contingent markets, so the discount factor is the price in period zero of a certain claim on one unit of domestic currency in period t. Whereas for us, the actuarial insurance firms own the firms. We will still call this $Q_{t,t+k}$ since we can put in whatever discount rate we like at a later date. This gives us an expression for the expected nominal profit:

$$E_t \sum_{k=0}^{\infty} Q_{t,t+k}\left[Y_{t+k}(j)\left(\bar{P}_{H,t+k} - MC_{t+k}^n\right) - \frac{\vartheta}{2}\left(\frac{\bar{P}_{H,t+k}}{P_{H,t+k-1}}-1\right)^2 P_{H,t+k}\right]$$

The firm chooses a price to maximise this subject to the demand curve it faces. They set prices rather than quantities. This is made up by summing the demand from the domestic aggregators and export demand where domestic demand for domestically produced goods is given by

$$\Upsilon_{H,t} = (1-(1-n)\alpha)\left(\frac{P_t}{P_{H,t}}\right)^{\frac{1}{\eta}}\Upsilon_t$$

and foreign demand for domestically produced goods is given by

$$\Upsilon_{H,t}^* = n\alpha\left(\frac{P_t^*}{P_{H,t}}\right)^{\frac{1}{\eta}}\Upsilon_t^*$$

where Υ_t is total domestic demand for the composite good

$$\Upsilon_t = C_t + I_t + G_t + \Psi\left(\frac{I_t}{K_{t-1}} - \delta\right) I_t + \xi\left(\Delta FB_t\right)$$

Since the firm is small they can take total consumption of all domestically produced goods as given when solving their pricing problem. We can also adjust the definition introduced in the aggregators section to simplify our analysis. We adjust the definition to take into account aggregate price adjustment costs, which are exogenous to the firm under consideration so setting demand equal to supply gives

$$Y_{t+k}(j) = \Upsilon_{D,t+k}(j) = \frac{1}{n}\left(\frac{\overline{P}_{H,t+k}}{P_{H,t+k}}\right)^{-\frac{1}{\varepsilon}} \Upsilon_{D,t+k}$$

where

$$\Upsilon_{D,t} = (1-(1-n)\alpha)\left(\frac{P_t}{P_{H,t}}\right)^{\frac{1}{\eta}} \Upsilon_t + n\alpha\left(\frac{P_t^*}{P_{H,t}}\right)^{\frac{1}{\eta}} \Upsilon_t^* + \frac{\vartheta}{2}\left(\pi_{H,t} - 1\right)^2$$

gives the total demand for the domestically produced good. Demand for the domestic good is a proportion of total domestic demand plus a proportion of total foreign demand, plus the price adjustment costs of domestic production firms. Therefore, the firm's problem is to maximise

$$E_t \sum_{k=0}^{\infty} Q_{t,t+k}\left[\frac{1}{n}\Upsilon_{D,t+k}\left(\frac{\overline{P}_{H,t+k}}{P_{H,t+k}}\right)^{-\frac{1}{\varepsilon}}\left(\overline{P}_{H,t+k} - MC_{t+k}^n\right) - \frac{\vartheta}{2}\left(\frac{\overline{P}_{H,t+k}}{P_{H,t+k-1}} - 1\right)^2 P_{H,t+k}\right]$$

After imposing a symmetric equilibrium, $\overline{P}_{H,t} = P_{H,t}$ and substituting in the discount factor from the actuarial insurance firms we arive at the optimal price for domestic firms:

$$\varepsilon\vartheta\pi_{H,t}\left(\pi_{H,t} - 1\right) = \frac{1}{n}\Upsilon_{D,t}\left(MC_t^r - 1 + \varepsilon\right) + \frac{\varepsilon\vartheta}{1+r_t}\frac{g(S_t)}{g(S_{t+1})}\pi_{H,t+1}\left(\pi_{H,t+1} - 1\right)$$

This is an exact non-linear New Keynesian Phillips Curve. The pricing equation is already assuming optimal behaviour in factor markets. So what is that behaviour? Remember the firm has set the price, not the quantity. So whatever is demanded at the current price the firm must supply. Once the firm has set the price there will be a unique quantity of capital and labour that will minimise the cost of matching demand and maximise profits. This is given by the cost minimisation problem:

$$\min_{K,L}\left\{g(S_t)\, w_t L_t + g(S_t)\, r_t^k K_{t-1}\right\}$$

subject to

$$\Upsilon_t = A_t K_{t-1}^{\chi} L_t^{1-\chi} \geq \overline{\Upsilon}$$

The first order condition for capital gives capital demand:

$$g(S_t)\, r_t^k = MC_t^r \chi A_t \left(\frac{K_{t-1}}{L_t}\right)^{\chi-1}$$

The first order condition for labour gives labour demand:

$$g(S_t)\, w_t = MC_t^r\, (1-\chi)\, A_t \left(\frac{K_{t-1}}{L_t}\right)^{\chi}$$

In order to keep track of all resource flows we also need an expression for the total profit of production firms per period. This is paid as a dividend directly to households. The real dividend per period is (using the definitions of the real wage, real rental rate for capital and real dividend as defined in the household problem and the actuarial firm problem, respectively)

$$div_t = \frac{Y_t}{g(S_t)} - w_t L_t - r_t^k K_t - \frac{\vartheta}{2}\left(\pi_{H,t} - 1\right)^2 \frac{1}{g(S_t)}$$

Once again, the relevant equations are repeated in the appendix.

2.8 Digression on superflous equations

The model presented here contains superflous equations and institutions. For example, an equivalent model could be written where households invest directly in all available assets, given that they purchase actuarial insurance on their asset holdings. This would do away with actuarial insurance firms and foreign investment firms, thus reducing significantly the number of equations required to decribe the model. However, we have chosen to write the model in the expanded form because we have one eye on future developments of the model, which may be aided considerably by having separate institutions and superflous equations as starting points. For example, if we want to build a banking sector in our model, we already have the actuarial insurance firms as a financial intermediate explicitly written in the current set-up. Conceivably this will reduce the conceptual difficulty of introducing institutions at a later date to perform this role, both in the derivations and in the relevant model code.

3 Model simulations

In this section we show a number of model simulations using the model described in section 2. These simulations were performed using Dynare (see Juillard (1996)). These simulations are meant to show the range of questions that such a model can provide answers for. We calibrate the model parameters as shown in Table 3.1. The adjustment costs parameters in our model have no directly observable counterparts in the real world, so it is hard to talk about whether they are high or low. In terms of their effects on the sluggishness of model responses, the adjustment costs for capital, characterized by cp, and for foreign bonds, cpf, are relatively low. With regards prices, the classification is more difficult because the firms in the domestic economy set their prices relative to those in the rest of the world. This is what Woodford (2003) calls *strategic complementarity in pricing*. This real rigidity is very powerful in our model. Even if there is no price stickyness, domestic firms do not choose to deviate much from their foreign competitors. Nonetheless, setting $\vartheta = 100\ 000$ significantly reduces the spikyness of price movements.[1]

Table 3.1 Parameter Values

Parameter	**value**
β	0.97
χ	0.3
cp	0.1
cpf	0.001
d	0.96
δ	0.05
φ	0.4
α	0.5
ε	0.1
η	0.1
n	0.1
ϑ	100 000

The values assigned to exogenous variables are presented in Table 3.2. The government raises revenue from the following taxes: labour tax, consumption tax, lump sum tax and interest rate tax. We consider the exercise that labour tax is endogenous, whereas both the consumption, lump sum and interest rate are exogenous, and set at reasonable rates for the Netherlands. However, we set the interest rate tax equal to zero. The lump sum tax has been set to 0.2. This

[1] It is also possible to linearise our New Keynesian Phillips Curve and compare our linearised equation with those in the literaure that follow the more common Calvo (1983) sticky prices approach. However, evaluation of the degree of stickyness would be complicated by our rather simple treatment of foreign prices, which are at present unrelated to the other foreign variables.

allows the endogenous tax rate to be at a rate appropriate for the Netherlands. G, government expenditure is entirely wasteful in our model.

Where approriate in the figures, green lines in the figures give the original steady state whilst the red lines give the new steady state after the policy experiment,

Table 3.2 Exogenous Variables

Exogenous variable	value
A	5
G	50
π_f	1
i^{fo}	π_f -1 + 0.045
τ_c	0.19
τ_{ls}	0.2
τ_r	0
Υ^*	2000

3.1 Simulation 1: Increased government expenditure

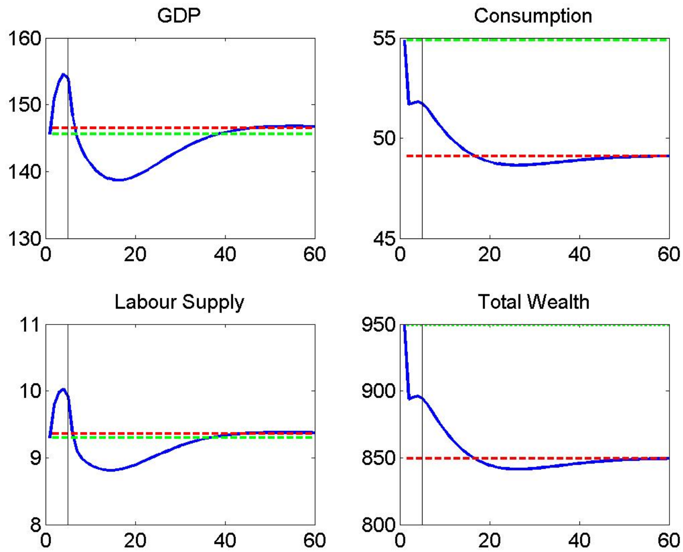
We present simulation results for the exercise that government expenditure increases permanently in period 5 by 10%. That is, they increase from 50 to 55. These expenses are funded by an increase in the *labour income tax* that ensures a balanced budget. These changes are perfectly foreseen by all agents in the model. It is also worth remembering that government expenditure comes from exactly the same composite good as consumption and investment. This has important consequences for the responses of consumption to changes in government expenditure. It also means that the same proportion of government expenditure is sourced from imported goods – there is no extra home bias for government expenditure.

Households

For households the higher labour tax increases the amount of leisure that must be given up for 1 extra unit of consumption after period 5. Therefore, immediately after the rise in labour income tax labour supply falls. In the long-run there is an opposite effect that dominates. There is a link between total lifetime wealth and labour supply – less wealthy households supply more labour. As can be seen in figure 3.1 the latter income effect is slightly bigger than the substitution effect. Before period 5, however, households are relatively rich compared to what will happen after period 5. Therefore, they can increase lifetime utility by working hard before period 5 and saving for the future. Because households are working harder, aggregrate production goes up. It is also instructive to note the linear relationship between consumption and total lifetime wealth.

One common finding in models of fiscal policy is that increased government expenditure, whilst it may increase GDP, is associated with lower levels of private consumption. Our model is no different. The empirical literature often describes the opposite relationship – increasing government expenditure boosts private consumption.

Figure 3.1 Increased government expenditure from period 5**.**



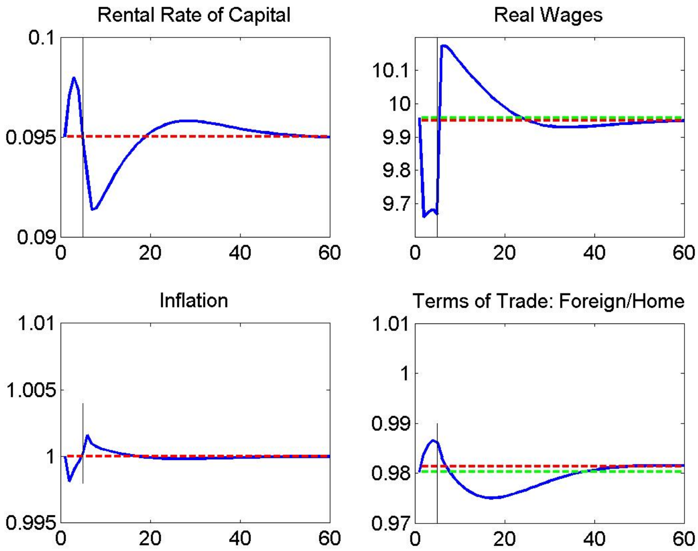
Production Firms

Before period 5 the production firms face a rising labour supply; each unit of capital is used by more labour so the marginal productivity of capital increases. This increases the demand for capital and, due to the capital adjustment costs, drives up the rental rate of capital. Since both inputs to the production process have increased, more is produced. Therefore, prices of domestically produced goods will fall (relative to foreign prices too) to clear the extra quantity produced. Hence, inflation falls as well, see figure 3.2.

Afterwards, labour supply falls reversing the process. In the long-run, the terms of trade mirror the relative GDPs. Foreign GDP stays the same, whilst domestic GDP rises slightly due to the increased labour supply. Finally, we remark that in the long-run, inflation is anchored by foreign inflation, which is equal to 1.[2]

[2] We define inflation as $\frac{P_t}{P_{t-1}}$, so inflation equal to 1 gives no change in prices.

Figure 3.2 Increased government expenditure from period 5 (cont'd).



Actuarial Insurance Firms

Prior to period 5 households are trying to save more. Since households are saving more and the demand for capital has increased, the actuarial firms allocate more funds to the capital stock and pay back foreign debt, see figure 3.3.

At period 5, households shift from saving to dissaving. GDP remains high due to built up capital even though investment falls dramatically, so foreign bonds do not immediately start to fall back towards their new steady state. Interestingly, net foreign debt increases in the long-run because domestic private saving decreases whilst investment is virtually unchanged.

Alternative parameterisations

Changing the model parameters changes the responses. Here we show the effect of reducing the disutility of labour and increasing capital adjustment costs on the key series.

Reduced disutility of labour

In figure 3.4 we can see the effects of decreasing the disutility of labour. In this case, we increase the parameter φ from 0.4 to 0.6. Again, no attempt at interpretating what 0.6 means, just to note that it affects the responses. The steady state level of GDP is dramatically increased, since housholds supply approximately 50% more labour compared to under the old parameter value. However, absolute movements around the steady states are much reduced since households value leisure less, so their labour supply responds less to the higher labour income tax in period 5.

Figure 3.3 Increased government expenditure from period 5 (cont'd).

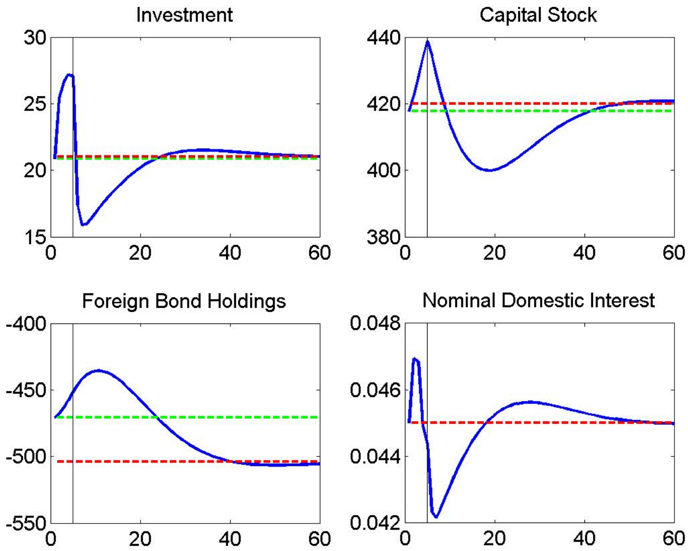
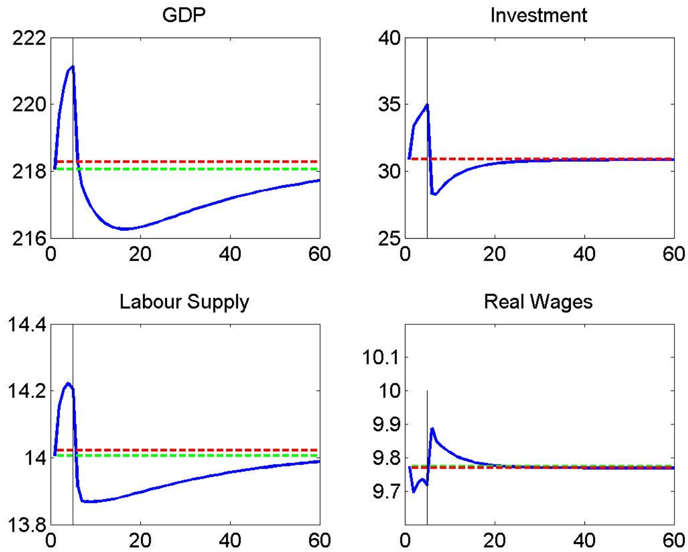


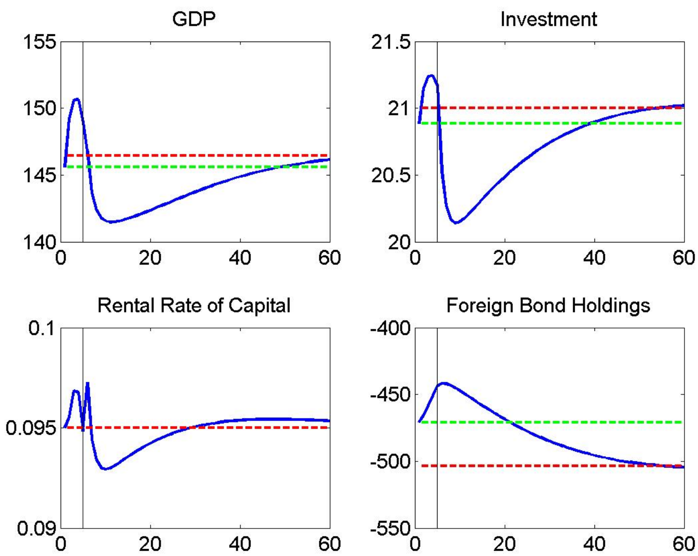
Figure 3.4 Increased government expenditure from period 5 with lower disutility of labour.



Higher capital adjustment costs

In figure 3.5 we can see the effects of increasing the adjustment costs of capital. In this case, we increase adjsutment costs from 0.1 to 100. Again, no attempt at interpretation is made. Increased capital adjustment costs reduces the magnitude of the GDP response without affecting the steady state. The investment response is now more asymmetric, the downswing is more pronounced than the upswing because capital adjustment costs are quadratic. In fact the reduced demand for capital induces a change in the capital stock such that the adjustment costs cause the rental rate to increase despite reduced demand for capital.

Figure 3.5 Increased government expenditure from period 5 with high capital adjustment costs.



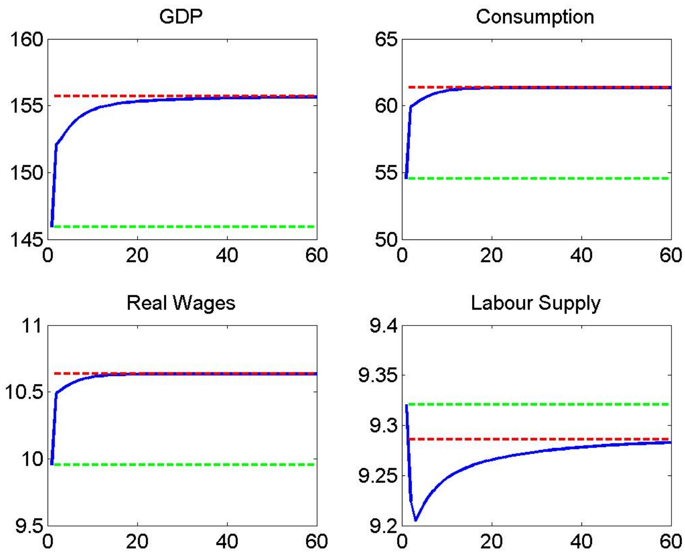
3.2 Simulation 2: Increase in technology

In this exercise the level of technology permanently increases by 5% in period zero. The endogenous tax is on consumption. The labour income tax is set at 40%.

Households

The immediate effects of increased technology are increased output and increased marginal productivity of labour, hence higher labour demand and real wages (see figure 3.6). Since the effects are permanent, total lifetime wealth is also increased and consumption follows. However, these series do not immediately jump to their new steady states as the capital stock needs to be built up. Once again, we also see that steady state labour supply falls as households become richer. Labour supply overshoots before rising back to the new steady state because consumption taxes fall gradually as increasing consumption generates higher tax revenues than are needed to balance the budget. The falling consumption tax works on the consumption-leisure margin, making it relatively attractive to substitute leisure for increased consumption. In other words, the real wage in terms of consumption goods that households can buy increases as consumption taxes fall.

Figure 3.6 Technology shock.



Production Firms

Firms are immediately much more productive. Since they produce more, the prices of the products have to be reduced to clear the market. If wages and the rental rate of capital stay the same, the profits of the production firms will rise. So, firms increase the scale of production to take advantage of increased profitability. The need for capital goes up, and thus the rental rate of capital jumps up to cover the adjustment costs (see figure 3.7), as do wages.

Actuarial Insurance Firms

The increased demand for capital stimulates actuarial insurance firms to invest in the capital stock. In order to do this they borrow from abroad. Furthermore, net exports fall since a share of the investment goods are made abroad.

Figure 3.7 Technology shock (cont'd).

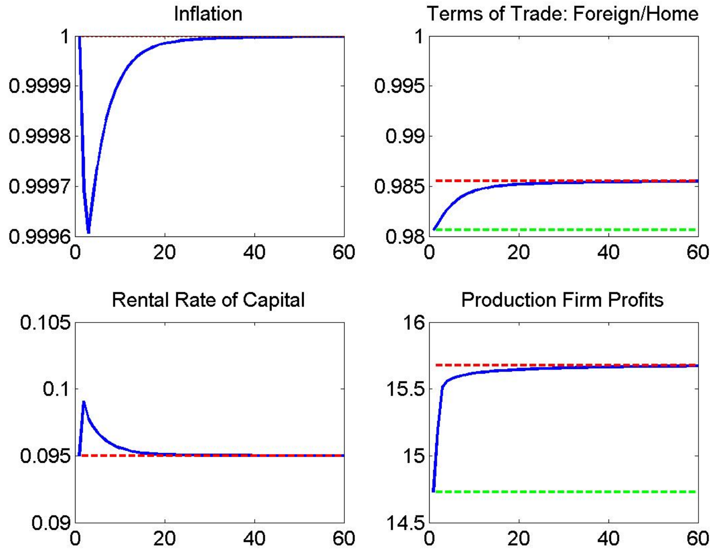
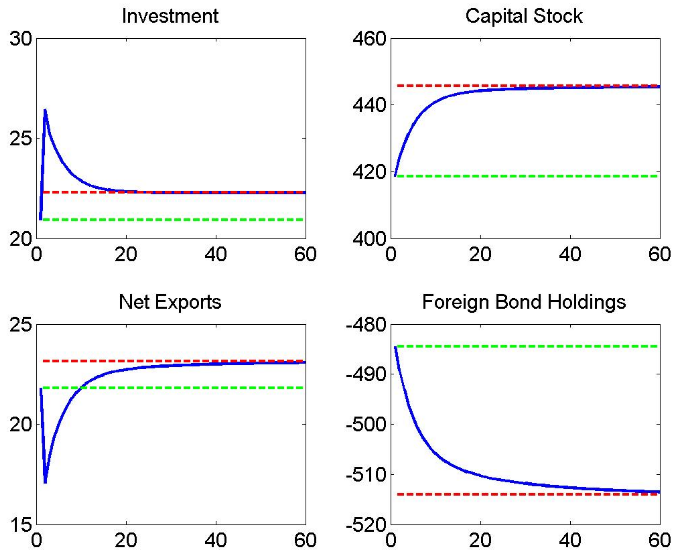


Figure 3.8 Technology shock (cont'd).



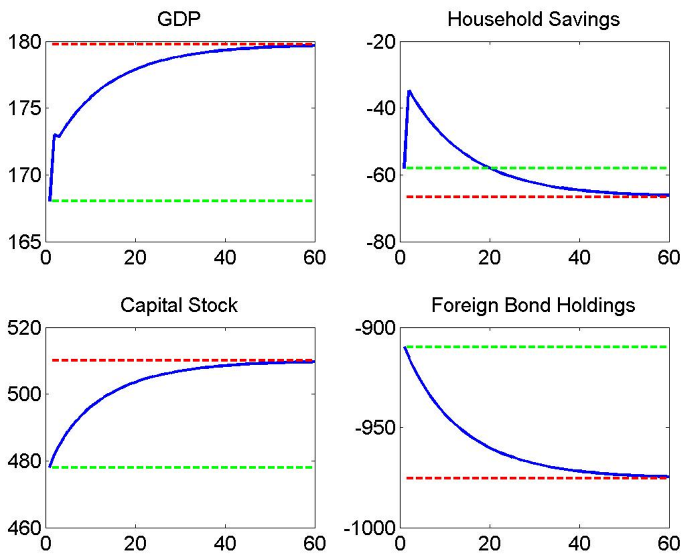
Alternative parameterisations

Changing the model parameters changes the responses. Here we show the effect of reducing the intertemporal elasticity of substitution and increasing home bias on the key series.

Decreased intertemporal elasticity of substitution

Increasing the parameter θ from 1 to 1.1 makes households less patient. It makes them less willing to substitute consumption from today to tomorrow. Also, moving away from $\theta = 1$ means that simulations affect the marginal propensity to save out of lifetime wealth, in this case they are less patient and less willing to save. figure 3.9 shows this clearly since household saving is negative in the steady state. This was not the case under the baseline parameterisation. The key effect, which can be seen in figure 3.9, is to raise steady state GDP. This is because households save less and are therefore poorer (see how they borrow more from abroad); they therefore supply more labour. Higher GDP is required to pay the interest due on foreign debt. It takes longer for GDP to reach its new level because of the adjustment costs built into both investment and the foreign borrowing required to fund the extra investment.

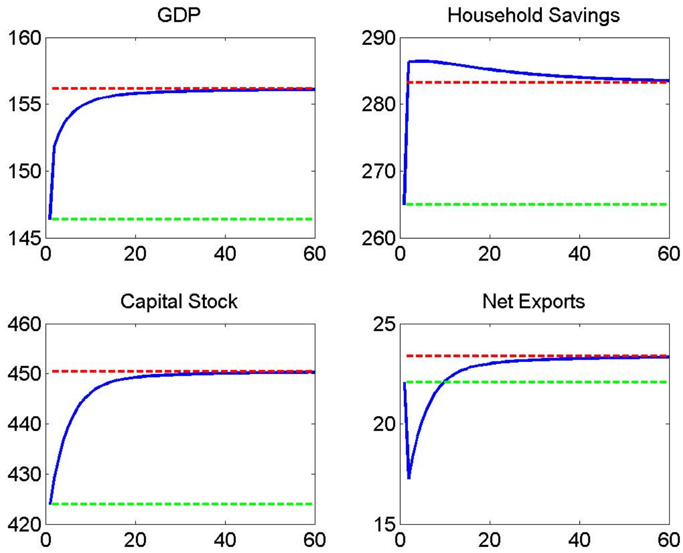
Figure 3.9 Technology shock with less patient households.



Lower home bias

Reducing home bias spreads demand more evenly over all varieties. This is achieved by increasing α from 0.5 to 0.7. Since home bias is symmetric across both home and foreign demand, this reduces the pricing power of firms and increases the quantity produced towards what would be observed under perfect competition. This can be seen in figure 3.10. The qualitative effects of the technology shock remain the same.

Figure 3.10 Technology shock with lower home bias.



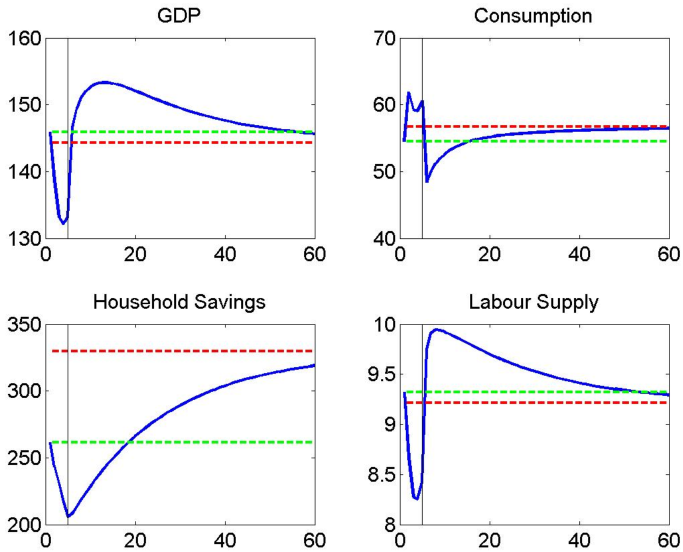
3.3 Simulation 3: Switching taxes from labour to consumption

In this simulation the tax burden on labour is reduced in period 5 from a 40% tax to a 25% tax. Since the consumption tax is the endogenous tax, the effect of this simulation is to switch the tax burden from labour to consumption. As with simulation 1, this switch is perfectly anticipated by all agents in the economy.

Households

Once the policy is anounced, households know that the current rewards to work are lower than they will be after the switch. So they reduce labour supply with the intention of working hard later to make up for the lower labour income today, as can be seen in figure 3.11. In a similar vein, consumption goods today are relatively cheap compared to what they will be after the switch. Therefore households consume more today. The next effect of these two responses is that households run down their savings to pay for extra consumption and leisure today. Since the optimal capital-labour ratio is approximately fixed (only approximately due to the capital adjustment costs) by the exogenous foreign real interest rate, GDP follows the labour supply response. In the long-run, real after-tax labour income increases, so total lifetime wealth increases leading to lower labour supply and more savings. Since households are richer they consume more.

Figure 3.11 Switch in taxes from labour taxes to consumption taxes.



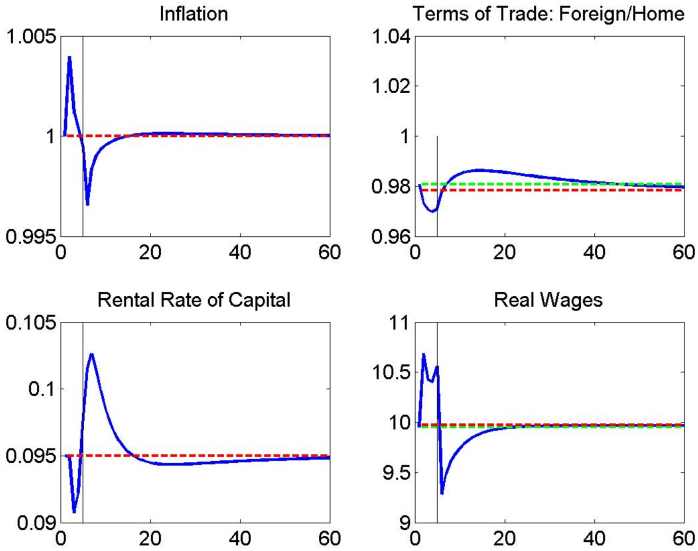
Production Firms

Faced with the decision to reduce labour supply by households, the marginal productivity of labour has risen so the real wage that firms offer increases, as in figure 3.12. Since the optimal capital-labour is approximately fixed, the rental rate of capital is a mirror of the labour supply response with the addition of an upward shift to account for the capital adjustment costs. Since firms produce less with less labour and less capital, the market for domestically produced goods will clear at a higher price. Since there is a long-run GDP effect there will also be a long-run effect on the terms of trade.

Actuarial Insurance Firms

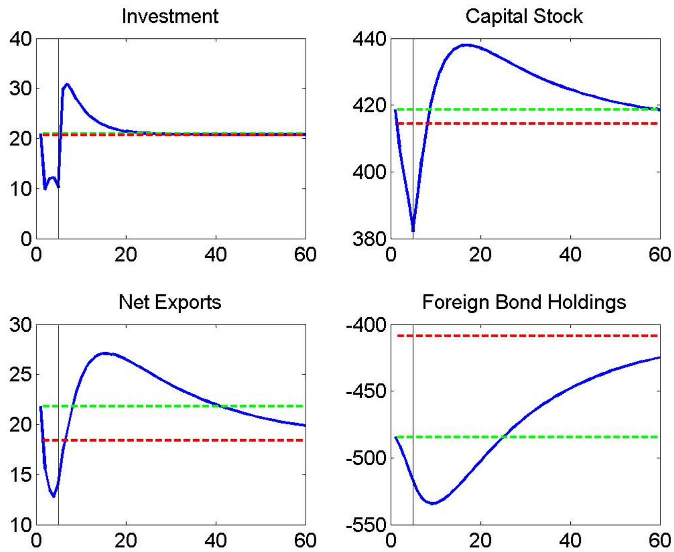
The decisions made by households and production firms clearly play out in how resources are allocated by the actuarial insurance firms in figure 3.13. The capital stock follows labour supply to keep the capital-labour ratio approximately constant. In order to fund the initial burst of consumption and the necessary levels of investment, we can see that foreign borrowing must increase. Then we see households become richer and reduce their level of reliance on foreign

Figure 3.12 Switch in taxes from labour taxes to consumption taxes (cont'd).



borrowing. Since the magnitudes of the initial responses of consumption and investment are similar, given that GDP falls, it must be the case that net exports also falls. That is, taken together, the sum of consumption and investment stays the same but less is produced - the difference must be imported.

Figure 3.13 Switch in taxes from labour taxes to consumption taxes (cont'd).

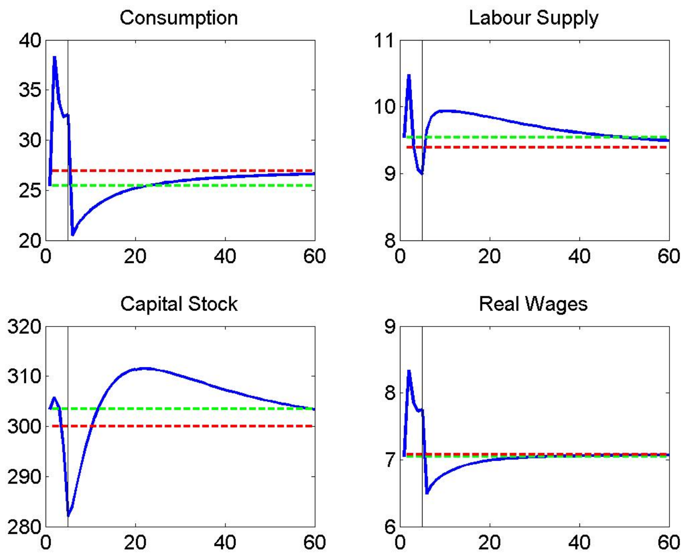


Alternative parameterisations

Less competitive markets

Less competitive markets are implemented by increasing ε and η from 0.1 to 0.3. This increases the pricing power of the monopolistically competitive firms in relation to both their domestic and foreign competitors. The steady state is characterised by lower production, consumption and capital stock as firms use their market power to reduce quantities and increase prices, as can be seen in figure 3.14. The product market competition parameters feed through into lower real wages in the labour market - if less output is required the demand for inputs is lower. Importantly, with more pricing power, production firms can profit from the increased initial consumption by raising prices and production. This leads to an initial increase in employment and capital stock that was not seen under the baseline parameterisation.

Figure 3.14 Switch in taxes from labour taxes to consumption taxes with less competitive markets.



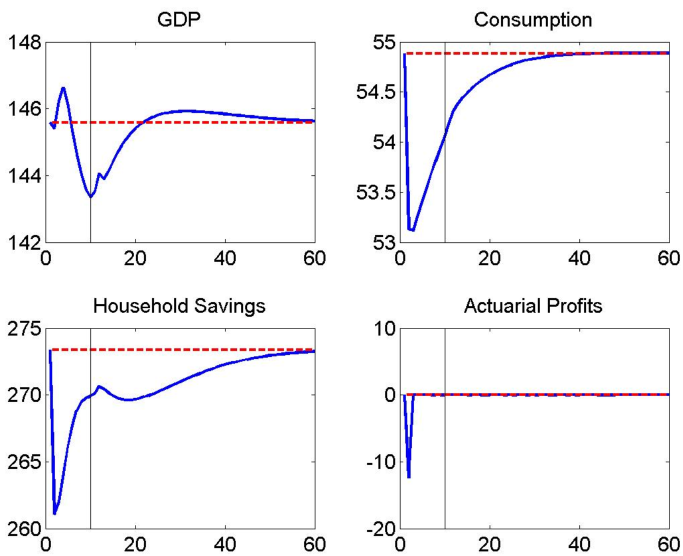
3.4 Simulation 4: Increased foreign interest rate

In this simulation the foreign nominal interest rate is increased from 4.5% to 5% from periods 1 to 9. Period zero is the initial steady state used to set predetermined variables such as the capital stock. The initial increase is a surprise to agents since it occurs in the first period. However, all agents know that the interest rate will be lowered to 4.5% in period 10. It is also important to note that all other foreign variables remain unchanged for this simulation. That is, the foreign interest rate does not have any effect on foreign GDP or inflation. For this simulation the endogenous tax rate is that on labour income.

Households

Households are made immediately poorer by the surprise increase in foreign interest rates. This is because the actuarial insurance firms make a loss since demand for capital falls relative to the interest rates agreed previously for houshold saving, as is shown in figure 3.15. Since households are poorer they consume less and their stock of savings falls due to the equity injection they must give actuarial insurance firms. Since they are poorer they also supply more labour and GDP rises.

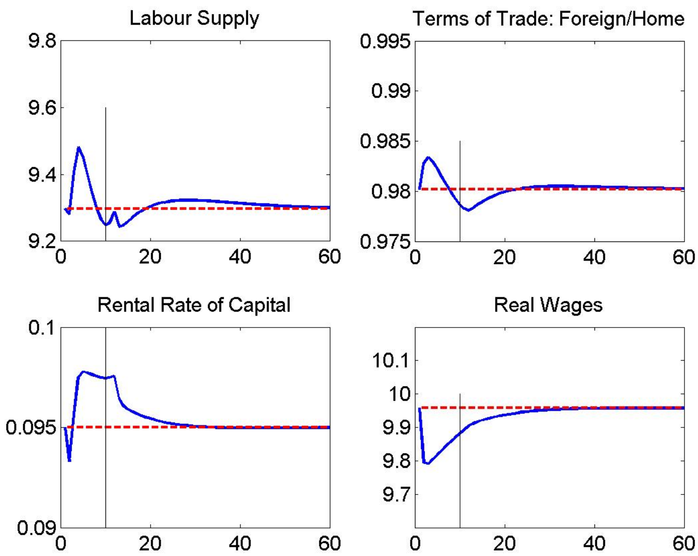
Figure 3.15 Temporary increase in the foreign nominal interest rate.



Production Firms

Production firms face lower demand from domestic consumers and rising labour supply. Therefore the real wage falls as can be seen in figure 3.16. Even so, we have already seen that more is produced so this must be sold to foreign agents; therefore prices of domestically produced goods fall and the terms of trade adjusts to clear the market. Since actuarial insurance firms can now earn a higher return on foreign bonds they increase the price of renting capital and the demand for capital falls accordingly. In essence, the increased foreign interest rate changes the optimal capital-labour ratio in the domestic economy. The reduction of the capital stock soon offsets the rise in the labour supply and GDP falls.

Figure 3.16 Temporary increase in the foreign nominal interest rate (cont'd).



Actuarial Insurance Firms

As can be seen in figure 3.17, actuarial insurance firms shift their portfolio of assets away from capital to foreign bonds, which offer a higher rate of return. Under our baseline parameterisation that means paying back some foreign debt. Since production has risen and investment and consumption have fallen, net exports must be the channel through which the extra production is cleared.

Alternative parameterisations

Lower disutility of work

In this simulation the parameter φ has been increased from 0.4 to 0.6. The main effect of this change is on the steady state values, see figure 3.18. More labour is supplied and more output produced. Everyone is richer so consumes more. In terms of the dynamic response to the simulation the change makes labour supply less sensitive. Therefore the initial increase in labour supply and GDP is less pronounced under the alternative parameterisation.

3.5 Simulation 5: Decreased foreign demand

In this simulation, foreign demand is decreased from period 1 to period 9, returning to normal in period 10. This is achieved by reducing foreign GDP from 2000 to 1950, or by 2.5%. The endogenous tax is the labour income tax.

Figure 3.17 Temporary increase in the foreign nominal interest rate (cont'd).

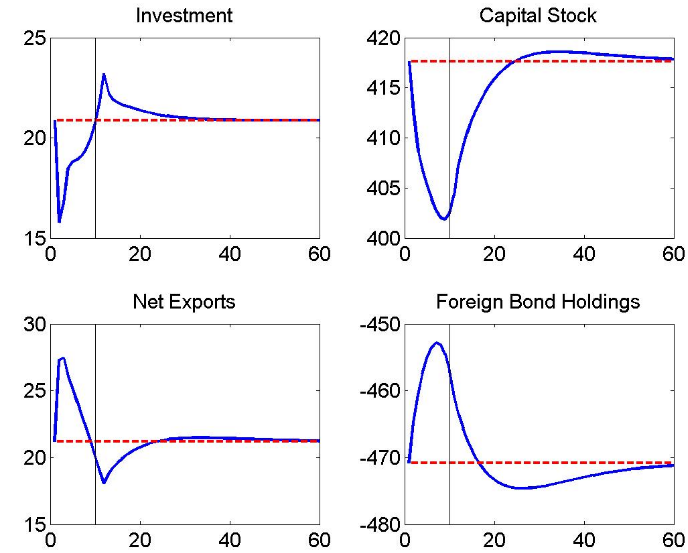
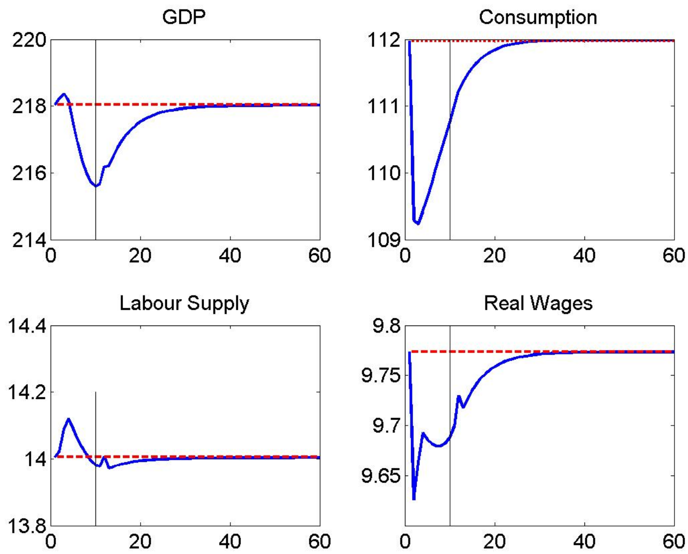


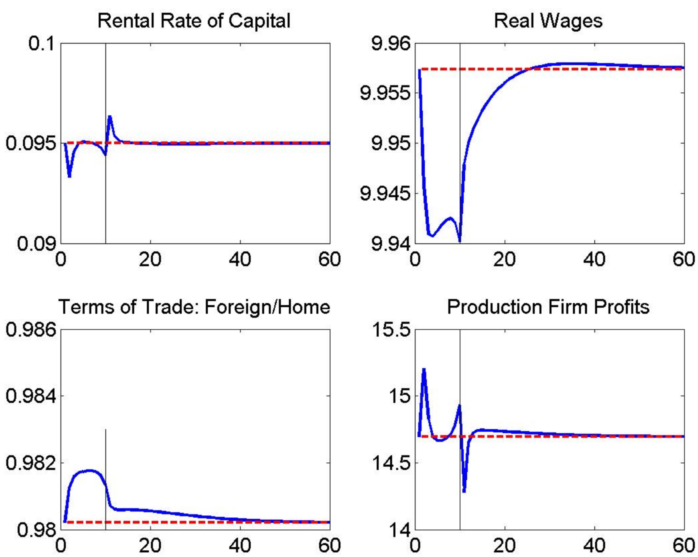
Figure 3.18 Temporary increase in the foreign nominal interest rate with lower disutility of work.



Production Firms

The total demand faced by each firm has fallen so firms reduce their prices in response, see figure 3.19. The fall in demand for final goods is also passed on to falling demand for the factors of production: both the rental rate of capital and real wages fall. With the baseline parameterisation, where goods prices are sticky and factor prices not, the fall in demand leads to temporarily higher profits for production firms. The intuition behind this result is that a monopolist would always choose lower output and higher prices than our monopolistically competitive firms – if all firms could coordinate they could make higher profits by charging higher prices. However, this does not happen in the steady state because of the competition with the other firms. The reason profits rise following the fall in demand is that each firm knows that all of the other firms also have price adjustment costs, and are also reluctant to lower prices. This allows the aggregate producer price to stay higher than would have been the case without price adjustment costs, thus temporarily raising profits. In simulation with lower price adjustment costs profits fall rather than rise after the shock.

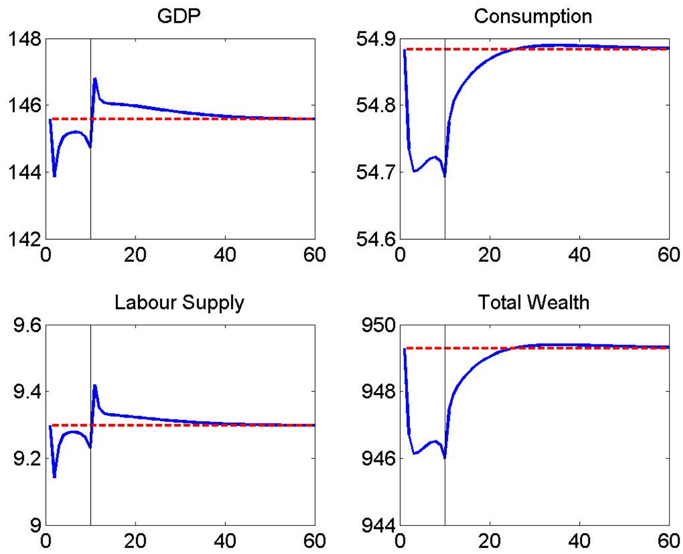
Figure 3.19 Temporary decrease in the foreign demand.



Households

The reduction in foreign demand reduces production in the domestic economy. Since wages fall in response to lower demand for labour, households are poorer, see figure 3.20. This feeds through to consumption. In the previous simulations we found that lower wealth lead to higher labour supply. In this simulation labour supplied falls because labour demand has been reduced by the fall in foreign GDP. That is, the reduction in the demand for labour is greater than households extra willingness to work that follows from the fall in their lifetime wealth.

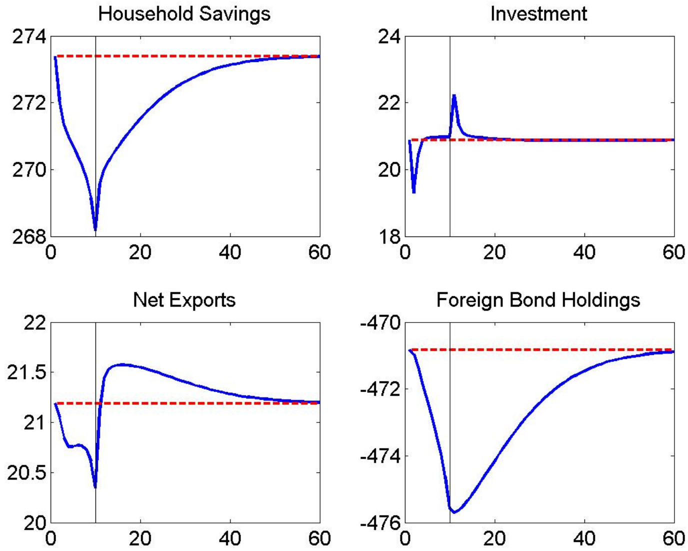
Figure 3.20 Temporary decrease in the foreign demand (cont'd).



Actuarial Insurance Firms

In order to smooth their consumption, households run down their stock of savings, as can be seen in figure 3.21. In order for actuarial insurance firms to fund their investments in the capital stock and, through the production firms and foreign investment firms, the costs associated with changing prices and portfolios, the actuarial insurance firms turn to the foreign investment firms to borrow on their behalf. This increasing pace of foreign borrowing immediately prior to foreign GDP returning to its original level drives up the foreign portfolio adjustment costs leading to a falling rental rate of capital. That is, because of increasing costs of changing the foreign portfolio, there is a wedge between the domestic real interest rate and the foreign real interest rate. The fall in the rental rate occurs despite investment being flat. Investment jumps once again with the restoration of foreign demand in period 10.

Figure 3.21 Temporary decrease in the foreign demand (cont'd).

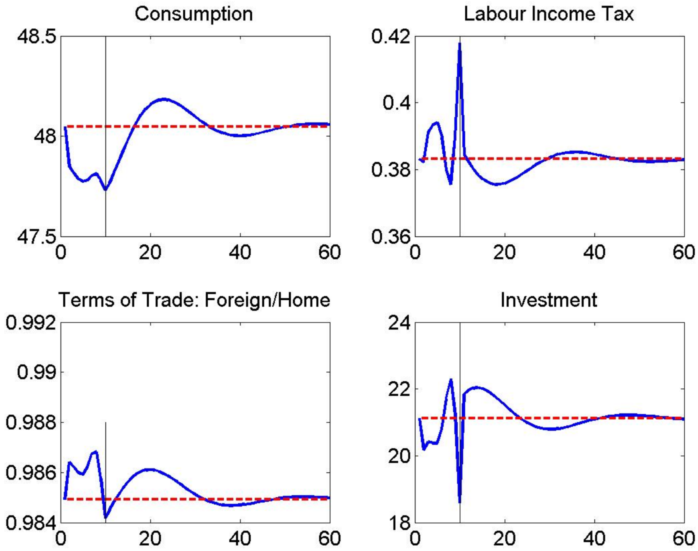


Alternative parameterisations

Valued real money

In this simulation the parameter governing households' demand for real money balances, ς, has been lowered from 1 to 0.9. This has the effect of making steady state real money balances positive. Since the steady state inflation rate is zero there is no direct effect on the government budget constraint in steady state since seignorage revenues are zero. However, the steady state level of consumption is lower, as can be seen by comparing figure 3.20 and figure 3.22. This is because households give up some consumption each period in order to compensate for the opportunity cost of money holding. Since households pay this cost each period, their steady state wealth is lower and labour supply and GDP are higher. Much of the DSGE literature concludes that real money has no effect on the dynamic responses of the other variables. This is not the case in our model. This is because of the interaction between fiscal and monetary policy. If prices fall the government enjoys negative seignorage revenues, which must be compensated for by higher labour income taxes to balance the budget. The spike in the labour income tax rate if figure 3.22 is clearly visible.

Figure 3.22 Temporary decrease in the foreign demand with valued real money.



3.6 Simulation 5: Increased government expenditure with debt financed fiscal policy

The simulation presented here is similar to that in simulation 1. The difference here is that the endogenous labour income tax adjusts to pay off a proportion of debt each time rather than balance the budget. Specifically, instead of balancing the budget each period the fiscal authority follows the following fiscal policy rule:

$$\tau_{l,t} w_t L_t = (1 + r_{t-1} + \tau_{sus}) B_{t-1}$$

This has the effect of adjusting the labour income tax rate so that a fraction of last period's debt is paid off each period. We set the parameter that determines whether the debt is sustainable or not, τ_{sus}, to -0.1. Some key differences are noticeable between the steady states for balanced budget fiscal policy in figures 3.1, 3.2 and 3.3, and for debt financed policy in figures 3.23 and 3.24. These all come about because of the extra labour income tax needed to service the debt. The extra labour income tax reduces labour supply and therefore GDP. Lower wealth also lowers steady state consumption. As for the dynamics, there is not so much difference between the balanced budget and debt financed. The differences that do occur are related to the way that labour income taxes do not jump up immediately when government expenditure increases. Thereafter is also an interplay between debt levels and the tax rate. One place where this can be readily seen is in the inflation responses in figures 3.2 and 3.24. Under debt financed fiscal policy inflation persists for longer. This is because labour supply falls more under debt financed fiscal policy. The reduction in labour supply and the increased labour income tax pushes up the gross wages that firms must pay for longer. This extended increase in real marginal cost causes firms to keep inflation higher for longer.

Figure 3.23 Increased government expenditure with debt funded fiscal policy.

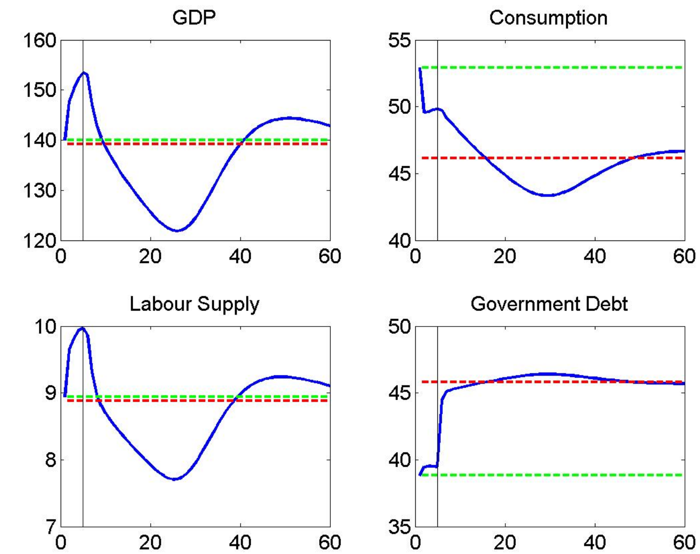
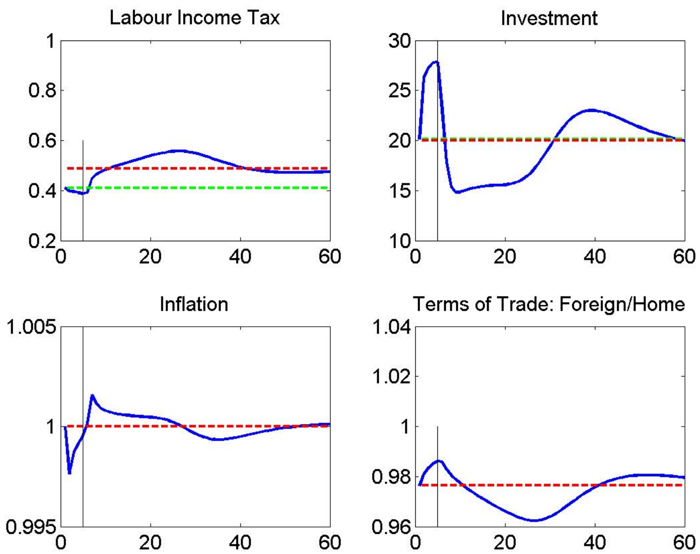


Figure 3.24 Increased government expenditure with debt funded fiscal policy (cont'd).



Alternative parameterisations

Taxes held constant for 10 periods

Suppose now, that a fiscal policy is anounced and the current goverment is unconcerned with sustainability – they leave current tax rates unchanged until a point in the future, which we may want to think of as after the next election. The constant tax rate for the endogenous tax was achieved by adding shocks to the endogenous tax such that it didn't react as the fiscal policy rule dictated. The tax rates are set according to the fiscal policy rule above from period 11 onwards. The key difference between the two debt financed simulations is again caused by labour supply in figure 3.25 and the labour income tax in figure 3.26. Since income taxes do not rise when government expenditure rises, the increase in labour supply keeps going longer, since labour is relatively well rewarded up to period 11 when taxes start rising. When taxes do start adjusting, the necessary adjustment is much stronger because government debt has grown to a higher level. This spike in income taxes causes a more severe contraction in labour supplied.

Figure 3.25 Increased government expenditure with debt funded fiscal policy. Taxes held constant for 10 periods.

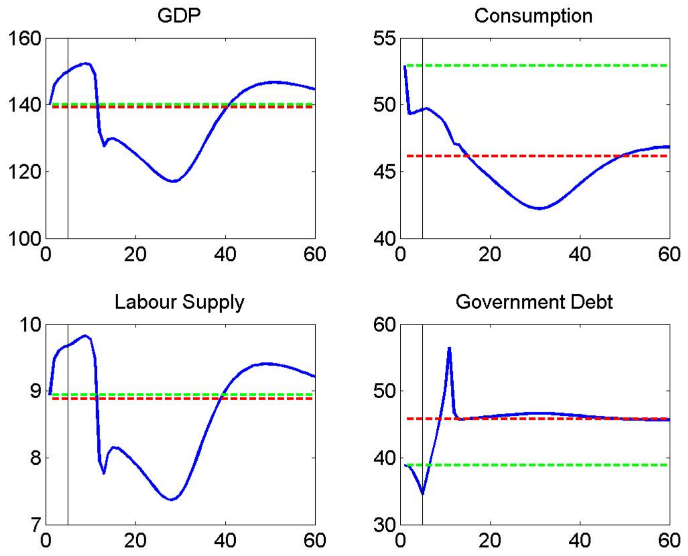


Figure 3.26 Increased government expenditure with debt funded fiscal policy. Taxes held constant for 10 periods (cont'd).

4 Conclusions

We have developed a DSGE model with optimising agents and distortionary taxes. The current version of the model has a number of desirable features as well as a number of less desirable ones. One of the nicest features of the model is the range of questions that can be asked; it is also nice that agents anticipate anounced policy changes and we have shown in this document some simulations of this type. On the negative side, there is no unemployment in our model and the model responses are ‘too spiky’.

Ongoing research is focused on incorporating unemployment into the model and in reducing the spikyness of the responses. For reducing the spikyness we are incorporating features found to be important in the literature, namely capital capacity utilisation and habit formation in consumption. A related question is whether our responses really are too spiky. To answer this we plan to undertake a number of empirical studies, especially attempting to estimate the model with Bayesian methods. Many other adjustments are also on the drawing board, including a more realistic description of government behaviour with regards debt, a more realistic specification of foreign variables and the interaction between them, and distinct modelling of specific sectors, especially government expenditure which likely exhibits more home bias and a greater reliance on labour in the production function.

Appendix A Model equations

Household block

Optimal consumption

$$C_t = (1 - s_t) H_t \tag{A.1}$$

Total wealth

$$H_t = HW_t + FW_t \tag{A.2}$$

Human wealth

$$HW_t = (1 - \tau_{l,t}) w_t L_t - \frac{1}{1-d} \tau_{ls,t} - \frac{ni_t}{1+ni_t} M_t + (1 - \tau_{i,t}) div_t^{AI} + \frac{d\pi_{t+1}}{1+ni_{t+1}} HW_{t+1} \tag{A.3}$$

Financial wealth

$$FW_t = \frac{1}{\pi_t d} \left\{ [1 + ni_t] N_{t-1} + M_{t-1} \right\} \tag{A.4}$$

Marginal propensity to consume

$$(1 - s_t)^{-1} = Z_t X_t + \frac{Z_t}{Z_{t+1}} (\beta d)^{\frac{1}{\theta}} \left(1 + r_t^h\right)^{\frac{1}{\theta} - 1} (1 - s_{t+1})^{-1} \tag{A.5}$$

where

$$X_t = \left[\frac{(1 + ni_{t+1})^{(1-\varsigma)\varphi}}{ni_{t+1}^{(1-\varsigma)\varphi} (1 + \tau_{c,t})^{\varsigma\varphi} \left[(1 - \tau_{l,t}) w_t\right]^{1-\varphi}} \right]^{\frac{1-\theta}{\theta}} \tag{A.6}$$

and

$$Z_t = (1 + \tau_{c,t})^{\frac{1}{\theta}} \left[(1 + \tau_{c,t}) \frac{1 + ni_{t+1}}{ni_{t+1}} \right]^{-\frac{(1-\varsigma)\varphi(1-\theta)}{\theta}} \left(\frac{(1 + \tau_{c,t})}{(1 - \tau_{l,t})} \frac{1}{w_t} \right)^{-\frac{(1-\varphi)(1-\theta)}{\theta}} \tag{A.7}$$

Labour supply

$$L_t = \frac{1}{1-d} - \frac{(1-\varphi)}{\varsigma\varphi} \frac{(1 + \tau_{c,t})}{(1 - \tau_{l,t})} \frac{(1 - s_t)}{w_t} H_t \tag{A.8}$$

Money demand

$$M_t = (1 + \tau_{c,t}) \frac{(1-\varsigma)}{\varsigma} \frac{1 + ni_{t+1}}{ni_{t+1}} (1 - s_t) H_t \tag{A.9}$$

Actuarial firms block

Demand for production shares

$$1 + r_t = \frac{q_{t+1} + div_{t+1}}{q_t} \tag{A.10}$$

Demand for foreign investment firm shares

$$1+r_t = \frac{qf_{t+1} + divf_{t+1}}{qf_t} \tag{A.11}$$

Optimal investment (1)

$$\Lambda_t = 1+\Psi\left(\frac{I_t}{K_{t-1}} - \delta\right) + \frac{I_t}{K_{t-1}}\Psi'\left(\frac{I_t}{K_{t-1}} - \delta\right) \tag{A.12}$$

Optimal investment (2)

$$\Lambda_t = \frac{1}{1+r_t}\left[r^k_{t+1} + \left(\frac{I_{t+1}}{K_t}\right)^2 \Psi'\left(\frac{I_{t+1}}{K_t} - \delta\right) + \Lambda_{t+1}(1-\delta)\right] \tag{A.13}$$

Per period dividend

$$\begin{aligned} div^{AI}_t &= N_t - (1+r_{t-1})N_{t-1} - B_t + (1+r_{t-1})B_{t-1} + div_t + divf_t \\ &\quad + r^k_t K_{t-1} - \left[1+\psi\left(\tfrac{I_t}{K_{t-1}} - \delta\right)\right] I_t \end{aligned} \tag{A.14}$$

Zero expected profit condition:

$$\begin{aligned} 0 &= N_{t+1} - (1+r_t)N_t - B_{t+1} + (1+r_t)B_t + div_{t+1} + divf_{t+1} \\ &\quad + r^k_{t+1} K_t - \left[1+\psi\left(\tfrac{I_{t+1}}{K_t} - \delta\right)\right] I_{t+1} \end{aligned} \tag{A.15}$$

Definition of investment

$$I_t = K_t - (1-\delta)K_{t-1} \tag{A.16}$$

Adjustment cost function

$$\Psi\left(\frac{I_t}{K_{t-1}}\right) = cp \times \left(\frac{I_t}{K_{t-1}} - \delta\right)^2 \tag{A.17}$$

Foreign investment firms block

Optimal foreign bond holding (1)

$$\Lambda f_t = 1 + \xi'(\Delta FB_t) \tag{A.18}$$

Optimal foreign bond holding (2)

$$\Lambda f_t = \frac{1}{1+r_t}\left(r^{fo}_t + \Lambda f_{t+1}\right) \tag{A.19}$$

Definition of real dividend

$$divf_t = r^{fo}_{t-1} FB_{t-1} - \Delta FB_t - \xi(\Delta FB_t) \tag{A.20}$$

Definition of foreign bond adjustment

$$\Delta FB_t = FB_t - FB_{t-1} \tag{A.21}$$

Adjustment cost function

$$\xi\left(\Delta FB_t\right) = cpf \times \left(\Delta FB_t\right)^2 \tag{A.22}$$

Real net exports definition: Capital account

$$NX_t = FB_t - \left(1 + r_{t-1}^{fo}\right) FB_{t-1} \tag{A.23}$$

Government block

Government spending

$$G_t = G_0 + e_t^g \tag{A.24}$$

Government budget constraint

$$B_t = G_t + (1 + r_{t-1}) B_{t-1} - \tau_{r,t} \frac{i_{t-1}}{\pi_t} N_{t-1} + \tau_{i,t} div_t^{AI} - \tau_{l,t} w_t L_t - \tau_{c,t} C_t - \frac{1}{1-d} \tau_{ls,t} - M_t + \frac{M_{t-1}}{\pi_t} \tag{A.25}$$

Fiscal policy rule

$$\frac{1}{1-d} \tau_{ls,t} = \left(1 + r_{t-1} + \tau_{sus}\right) B_{t-1} \tag{A.26}$$

Aggregators block

Evolution of terms of trade

$$\frac{S_t}{S_{t-1}} = \frac{\pi_{F,t}}{\pi_{H,t}} \tag{A.27}$$

The domestic CPI to PPI ratio

$$g\left(S_t\right) = \left[\left(1 - (1-n)\,\alpha\right) + (1-n)\,\alpha S_t^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{A.28}$$

The foreign CPI to PPI ratio

$$g^*\left(S_t\right) = \left[\left(1 - n\alpha\right) + n\alpha S_t^{\frac{1-\eta}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{A.29}$$

Real net exports definition: Current account

$$NX_t = \frac{1}{g(S_t)} n\alpha \left(g^*\left(S_t\right) S_t\right)^{\frac{1}{\eta}} \Upsilon_t^* - (1-n)\alpha \left(\frac{g(S_t)}{S_t}\right)^{\frac{1-\eta}{\eta}} \Upsilon_t \tag{A.30}$$

Domestic CPI definition

$$\pi_t = \frac{g\left(S_t\right)}{g\left(S_{t-1}\right)} \pi_{H,t} \tag{A.31}$$

Production firms block

Real output

$$Y_t = A_t K_{t-1}^{\chi} L_t^{1-\chi} \tag{A.32}$$

Labour demand

$$MC_t^r (1-\chi) A_t K_{t-1}^{\chi} L_t^{-\chi} = g(S_t) w_t \tag{A.33}$$

Capital demand

$$MC_t^r \chi A_t K_{t-1}^{\chi-1} L_t^{1-\chi} = g(S_t) r_t^k \tag{A.34}$$

Definition of real dividend

$$div_t = \frac{Y_t}{g(S_t)} - w_t L_t - r_t^k K_{t-1} - \frac{PCosts_t}{g(S_t)} \tag{A.35}$$

Price adjustment costs

$$PCosts_t = \frac{\vartheta}{2} (\pi_{H,t} - 1)^2 \tag{A.36}$$

Optimal price

$$\varepsilon \vartheta \pi_{H,t} (\pi_{H,t} - 1) = \frac{1}{n} \Upsilon_{D,t} (MC_t^r - (1-\varepsilon)) + \frac{\varepsilon \vartheta}{1+r_t} \frac{g(S_t)}{g(S_{t+1})} \pi_{H,t+1} (\pi_{H,t+1} - 1) \tag{A.37}$$

Definition of total demand

$$\Upsilon_{D,t} = (1-(1-n)\alpha) \left(\frac{P_t}{P_{H,t}} \right)^{\frac{1}{\eta}} \Upsilon_t + n\alpha \left(\frac{P_t^*}{P_{H,t}} \right)^{\frac{1}{\eta}} \Upsilon_t^* + \frac{\vartheta}{2} (\pi_{H,t} - 1)^2 \tag{A.38}$$

Domestic demand

$$\Upsilon_t = C_t + I_t + G_t + \Psi \left(\frac{I_t}{K_{t-1}} - \delta \right) I_t + \xi (\Delta FB_t) \tag{A.39}$$

Technology and definitions

Technology

$$A_t = A_0 + e_t \tag{A.40}$$

Aggregrate resource constraint

$$Y_t = g(S_t)(\Upsilon_t + NX_t) + PCosts_t \tag{A.41}$$

Net interest definition

$$ni_t = (1 - \tau_{i,t}) i_{t-1} \tag{A.42}$$

Household real interest definition

$$1+r_t^h = \frac{1+ni_{t+1}}{\pi_{t+1}d} \tag{A.43}$$

Real interest definition

$$1+r_t = \frac{1+i_t}{\pi_{t+1}} \tag{A.44}$$

Real foreign interest definition

$$1+r_t^{fo} = \frac{1+i_t^{fo}}{\pi_{t+1}} \tag{A.45}$$

Appendix B Model variables and parameters

Table B.1 Model variables

	name[a]	type[b]
Endogenous variables		
Technology	A	4
Government bonds	B	2
Consumption	C	2
Price factor after consumption tax	$1+\tau_c$	4
Increase in foreign bonds	ΔFB	2
Production firm dividend	div	2
Actuarial insurance firm dividend	div_t^{AI}	2
Foreign dividend	$divf$	2
Foreign bonds	FB	2
Financial wealth	FW	2
Government	G	2
CPI / PPI (= P/P_H)	$g(S)$	5
CPI* / PPI* (= P^*/P_F)	$g^*(S)$	5
Total wealth	H	2
Human wealth	HW	2
Interest	i	1
Inflation	π	1
Inflation domestically produced goods	π_H	1
Interest rate tax	$1-\tau_i$	4
Investments	I	2
Capital	K	2
Labour	L	4
Labour tax	$1-\tau_l$	4
Lagrangian optimal investment	Λ	2
Lagrangian optimal foreign bond holding	Λ_f	2
Lump sum tax	τ_{ls}	2
Money	M	2
Actuarial notes	N	2
Net interest	ni	1
Net exports	NX	2
Price adjustment costs	$PCosts$	3

Table B.2 Model variables, continued

	name[a]	type[b]
Endogenous variables		
Capital adjustment cost	Ψ	4
Firm value	q	2
Foreign investment firm value	qf	2
Real interest rate	r	2
Real rate of households	r^h	2
Real rental rate of capital	r^k	2
Real marginal cost	MC^r	3
Foreign real interest rate	r^{fo}	2
Marginal propensity to save	s	4
Terms of trade (= P_F/P_H)	S	5
Lump sum tax	τ_{ls}	2
Domestic demand for goods	Υ	2
Demand for domestically aggregated goods	Υ_D	3
Wage	w	2
Auxiliary variable for s	X	6
Bonds adjustment cost	ξ	2
Real output	Y	3
Auxiliary variable for s	Z	6
Exogenous variables		
Technology shock	e	4
Domestic government spending shock	e^g	2
Foreign producer price inflation	π_F	1
Foreign nominal interest rate	i^{fo}	1
Consumption tax rate	τ_c	4
Labour income tax rate	τ_l	4
Interest income tax	τ_i	4
Foreign demand for composite good	Υ^*	2

[a] Time subscripts are omitted for brevity.
[b] 1: nominal, 2: real in CPI terms 3: real in PPI terms 4: scalar 5: price converter 6: auxiliary variable

Table B.3 Model parameters

		Domain	Specification
Home-bias	α	$[0,1]$	0 = maximal and 1 = no homebias
Steady state technology level	A_0	>0	
Time discount rate	β	$[0,1]$	1 = no time preference
Capital share	χ	$[0,1]$	
Labour income tax rate	cp	≥ 0	0 = no adjustment costs
Interest income tax	cpf	≥ 0	0 = no adjustment costs
Probability of still being alive next period	d	$[0,1]$	
Depreciation rate of capital	δ	$[0,1]$	0 = no and 1 = full depreciation
Inverse demand elasticity production firms	ε	≥ 0	0 = perfect competition
Inverse demand elasticity domestic and foreign produced goods	η	≥ 0	0 = perfect elasticity
Steady state government spending	G_0	>0	
Steady state relative size of domestic economy	n	$[0,1]$	0 = no economy, 1 = world economy
Utility parameter substitutability consumption/money and leisure	φ	$[0,1]$	1 = leisure not valued
Utility parameter for curvature	θ	≥ 0	0 = linear utility, 1 = log utility
Price adjustment costs parameter	ϑ	≥ 0	0 = flexible prices
Utility parameter substitutability consumption and money	ς	$[0,1]$	1 = money not valued

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