The Volatility of the Tradeable and Nontradeable Sectors: Theory and Evidence

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Abstract

This paper investigates the business cycle fluctuations of the tradeable and nontradeable sectors of the US economy. Then, it evaluates whether a "New Open Economy" model having prices sticky in the producer's currency can reproduce the observed fluctuations qualitatively. The answer is positive: the model-implied standard deviations are consistent with the pattern in the data. In particular, tradeable output is more volatile than nontradeable output. A key role in generating this result is played by the greater responsiveness of tradeable output to monetary shocks. Parameter estimates are obtained by Generalised Method of Moments.

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1 Introduction

In the field of international macroeconomics there are now many models that explicitly consider two sectors, one producing tradeable and the other producing nontradeable goods. The explicit modelling of the tradeable and nontradeable sectors has often been done solely in order to explain certain features of the aggregate economy (for example, the observed deviations from purchasing power parity), rather than to understand the properties of the sectors themselves.

However, the strategy of adding a tradeable and a nontradeable sector to an open economy model is not exempt from its own challenges. For example, it is interesting to see whether the implications of these models for the two sectors are matched by real-world observations.

The purpose of this paper is to develop an open economy model with tradeables and nontradeables, estimate it by the Generalised Method of Moments (GMM), and then check whether its implications for the tradeable and nontradeable sectors are reflected in the US data. The model presented in this paper follows the "New Open Economy Macroeconomics" (NOEM) paradigm (with sticky prices in the producer's currency), and the comparison between the data and the model is restricted to second-order moments. The NOEM paradigm is chosen because of its importance in the literature. The decision to restrict the comparison to second-order moments is motivated by the existence of measurement problems,[1] and by the relatively stylised nature of the model.

From the point of view of the empirical researcher, large-scale estimated models, such as, for example, Smets and Wouters (2003), are clearly superior. On the other hand, the more complexity is added into a model, the more it becomes difficult to isolate (among shocks, ad-hoc frictions and theoretical underpinnings) the exact causes of certain facts. The choice made in this paper is to include, whenever possible, many modelling assumptions already present in the NOEM literature, but with the aim of offering a comprehensive yet parsimonious framework,[2] rather than searching for an *ad hoc* specification

[1] This approach in dealing with measurement problems originates from Kydland and Prescott (1982).

[2] The closest model to the one presented in this paper is Benigno and Thoenissen (2003). They construct a comprehensive framework, encompassing several modelling assumptions that had been analysed individually in the previous literature. The model presented in this paper is different from their model because it includes government expenditure shocks, it specifies monetary policy in terms of the growth rate of money rather than an interest rate

that fits the data.

Several authors have already estimated NOEM models, for example (and without any claim to provide an exhaustive list) Bergin (2003), Ghironi (2000), and Lubik and Schorfheide (2005). This paper differs from these contributions not just because of the estimation methodology,[3] but because of the goal of the investigation, which is to compare the properties of the tradeable and nontradeable sectors in the model and in the US data. To this purpose, the paper also derives a system of three equations in three unknowns that illustrates why the shocks in the NOEM affect the two sectors differently. In this way it is possible isolate the exact causes of the model's implications.

Earlier on, it was hinted that this sort of analysis is hampered by a measurement problem. In a nutshell, the properties of the tradeable and nontradeable sectors can only be imperfectly measured, since virtually all sectors (as measured in the official statistics) have both tradeable and nontradeable goods. The strategy adopted here to deal with this problem is to find robust features of the data by comparing the statistics among several sectors, and to restrict ourselves to qualitative, rather than quantitative, comparisons.

In spite of this measurement problem in the data, there is sufficient evidence to suggest that in the US economy output fluctuations are more pronounced in the tradeable than in the nontradeable sector. When the NOEM model is fed with the estimated values, it is successful in reproducing a higher standard deviation of tradeable output. This occurs because tradeable output is more responsive than nontradeable output to domestic monetary shocks, which cause changes in the nominal exchange rate and the terms of trade (the price of imports relative to exports). In the estimated model, tradeable output is more sensitive to terms of trade changes than nontradeable output.[4]

The outline of the remaining of the paper is as follows. Section 2 considers

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feedback rule, and it does not restrict the elasticities of substitution (between tradeables and nontradeables, and between Home and Foreign tradeables) to being equal to one.

[3] Ghironi estimates a NOEM by nonlinear least squares at the single-equation level and FIML system-wide regressions. Bergin uses maximum likelihood techniques, and Lubik and Schorfheide put forward a Bayesian approach.

[4] In the model, nominal exchange rate changes are reflected into terms of trade changes because of the assumption of full pass-through. However, the response of output in each sector depends on the elasticities of substitution. Given that the estimated elasticity of substitution between Home and Foreign tradeables is sensibly lower than one, the expenditure-switching effect (see Tille 2001) is not very large in the model. Consequently, one would not expect monetary shocks to generate large changes in imports and exports. However, simulation exercises show that tradeable output is still more sensitive than nontradeable output to terms of trade changes.

the measurement problem and presents some statistics for several sectors of the US economy. Section 3 explains the model and its numerical solution. Section 4 puts forward a system of log-linearised equations that illustrate why the shocks have different effects in the two sectors. The estimation and calibration of the model is explained in Section 5. Using the equations of Section 4, we can understand the model-implied statistics, which are presented in Section 6. By checking whether the results are sensitive to some of the parametrized values, we can further investigate the properties of the NOEM model. These sensitivity checks are discussed in Section 7. Finally, Section 8 concludes.

2 The evidence

It is often problematic to find data series disaggregated by sector, for example, the US' Bureau of Economic Analysis produces only annual, not quarterly, estimates of its GDP-by-industry accounts. Moreover, it is difficult to isolate in the data the tradeable and the nontradeable sectors explicitly, since virtually in any sector there are goods that are actually traded and goods that are not traded.[5] However, the proportion of output that is traded is not the same in all sectors, so it is possible to decide an approximation, in order to translate the abstract notion of tradability into an operational concept, but only at the cost of accepting a measurement error.

With these considerations in mind, we can start to investigate the cyclical properties of the tradeable and nontradeable sectors by looking at the standard deviation of output and inflation in all US industries, and see whether we can identify any visible pattern. The industry classification is the one adopted by the Bureau of Economic Analysis. As noted above, this data is at the annual frequency and unfortunately there is no data on employment, imports and exports in the same industries. To facilitate the analysis, the industries in Table 1 are divided into two groups, tradeables and nontradeables, following a common classification in the literature.[6] In order to establish some proportions and facilitate the analysis, the industries in Table 1 are listed by their contribution to total GDP, with the largest contributors coming first.

TABLE 1 HERE

[5] Conceptually it is possible to divide goods into tradeables and nontradeables, but disaggregated macroeconomic data, if available, is only for sectors as defined in the statistics.

[6] See, among others, Betts and Kehoe (2006). Agriculture, mining and manufacturing are commonly classified as tradeable, and services, utilities, and construction as nontradeable.

By looking at Table 1, it is evident that, overall, the tradeable sector is characterised by more volatility than the nontradeable sector. As far as output is concerned, only one nontradeable industry, construction, has more volatile output than manufacturing, the largest tradeable industry. But construction only accounts for 4.4% of US GDP, and all the three larger nontradeable industries (Finance, Government and Professional services), much bigger in size than construction, have less volatile output than manufacturing.[7]

As far as inflation is concerned, the evidence is somehow less strong, but it still points to more volatility in the tradeable sector. As much as 5 nontradeable industries (Utilities, Wholesale trade, Transportation and warehousing, Retail trade and Construction) have more volatile inflation rates than manufacturing. However, overall these 5 industries contribute to total GDP by significantly less than the three larger nontradeable industries, which all have less volatile inflation than manufacturing.

Additional evidence, obtained from quarterly data on manufacturing and services only, will be presented in Section 6, but Table 1 remains useful for comparison purposes. By comparing the data at different frequencies and sectoral classifications, we can identify which findings are not robust, and therefore may have been induced by the choice of tradeable-nontradeable approximation.

3 The model

The building blocks of the model are illustrated in this section. Most of the assumptions and the choice of functional forms are standard in the NOEM literature, so as to facilitate comparisons.

However, the model also possesses two features that are nonstandard, compared to the previous literature. The first one is the assumption that individuals cannot contemporaneously supply their labour to the production of both tradeable and nontradeable goods, but they can work only in one sector at a time. This assumption is often true in practice, and, from a modelling point of view, it is also sufficient to ensure that all the labour adjustment takes place along the extensive margin.[8] This result facilitates the estimation of the model, since it is possible to find quarterly data on persons employed,

[7] Moreover, the two other tradeable industries, agriculture and mining, have even more volatile output than manufacturing.

[8] This will be clarified on page 12.

but not on hours worked, in each sector.

The second less standard feature is the assumption of decreasing returns to labour.[9] This assumption ensures that the relative supply curve (the supply of tradeable output relative to nontradeable output, for any given relative price of tradeables to nontradeables) becomes upward-sloping, and in this way monetary and government expenditure shocks are allowed to have an effect on the relative price of tradeables to nontradeables.

3.1 Building blocks of the model

The world economy consists of two countries of equal size, named Home and Foreign, that engage in the production and trade of differentiated goods (or differentiated brands of the same good) for final consumption. Each country has two sectors, one producing a continuum of tradeables and the other a continuum of nontradeables.

In each country and in each sector there exists a continuum of monopolistic firms, each of them producing a single differentiated product, or brand. The firms and the goods they produce are indexed by $f_{TH} \in [0, 1]$ for the Home tradeable sector and $f_N \in [0, 1]$ for the Home nontradeable sector. In the Foreign country, they are indexed by $f^*_{TF} \in [0, 1]$ and $f^*_N \in [0, 1]$ respectively. Foreign variables and indexes are denoted with stars. Moreover, both the Home and the Foreign countries are populated by a continuum of identical individuals of measure one.

3.1.1 Individual preferences and budget constraints

Individuals can move costlessly from one sector to the other within each country. As in Burnside, Eichenbaum and Rebelo (1993), any individual who works incurs a fixed participation cost, measured in units of foregone leisure.

Labour services cannot be contemporaneously supplied to both the tradeable and nontradeable goods sector, but since sectors could pay different wages, this restriction introduces individual heterogeneity in the model.

Nonetheless, this problem can be easily dealt with by applying Rogerson's (1988) result for sectoral economies. Under complete domestic markets, if utility is separable and individuals can choose the probabilities of working

[9] However, Galí, Gertler and Lopez-Salido (2001) use this assumption in their specification of the Phillips curve.

in sectors, then consumption levels must be equal for all individuals in each period. As a result, ex-ante identical individuals will be also identical ex-post.

Following Rogerson, the probabilities of working in each sector are added to the individual maximization problem, and individuals are allowed to vary their labour supply along both the extensive and the intensive margins. That is, the utility of a representative individual in the Home country is written as follows:

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[\begin{array}{c} \frac{C_t^{1-\sigma}-1}{1-\sigma} + \frac{\chi}{1-\varepsilon}\left(\frac{M_t}{P_t}\right)^{1-\varepsilon} + n_{TH,t} \cdot \kappa\left(\Gamma - \psi - \mathbf{h}_{TH,t}\right) \\ + n_{N,t} \cdot \kappa\left(\Gamma - \psi - \mathbf{h}_{N,t}\right) \\ + \left(1 - n_{TH,t} - n_{N,t}\right) \cdot \kappa\left(\tau\right) \end{array} \right], \tag{1}$$

where C is the aggregate consumption index, $\frac{M}{P}$ are real money balances, n_{TH}, n_N are the probabilities of working in the tradeable and nontradeable sector respectively, ψ is a fixed cost of participation,[10] and $\mathbf{h}_{TH} = \int_0^1 h_{TH}\left(f_{TH}\right) df_{TH}$ and $\mathbf{h}_N = \int_0^1 h_N\left(f_N\right) df_N$ are the hours that the individual supplies to the sectors TH and N respectively. Foreign preferences are similarly written, with the same parameters σ, χ, ε, Γ, τ and ψ and functional form κ.

At the international level, markets are incomplete: individuals trade in a one-period non-contingent real bond, denominated in units of the Home tradeable goods consumption index. Similarly to Benigno (2001), individuals must pay a small cost in order to undertake a position in the international asset market.[11] This cost is assumed to be a payment in exchange for intermediation services, offered by financial firms located in both the Home and the Foreign country. Individuals pay this cost only to firms located in their own country.

The period-t budget constraint of the representative individual in the Home country is as follows:

[10] Total time available is different for the employed (Γ) and the unemployed (τ). By assuming that τ is sufficiently small, it is possible to ensure that the unemployed do not enjoy greater utility ex-post than the employed.

[11] This assumption ensures stationarity of the model and a well-defined steady state, as demonstrated by Schmitt-Grohe and Uribe (2003).

$$B_tP_{T,t}+\frac{\nu}{C_0}B_t^2P_{T,t}+M_t\leq(1+r_{t-1})\,B_{t-1}P_{T,t}+M_{t-1}$$
$$+TR_t-P_tC_t+n_{TH,t}W_{TH,t}\mathbf{h}_{TH,t}+n_{N,t}W_{N,t}\mathbf{h}_{N,t}$$
$$+\int_0^1\Pi_{TH,t}\left(f_{TH}\right)df_{TH}+\int_0^1\Pi_{N,t}\left(f_N\right)df_N+R_t\ , \tag{2}$$

where B is the internationally traded bond, $\frac{\nu}{C_0}B$ is the cost of holding one unit of the bond,[12] which depends on the positive parameter ν, M are nominal money balances, r is the real interest rate, TR are government transfers, W_{TH} and W_N are the wages paid in the tradeable and nontradeable sector respectively, $\Pi_{TH}(f_{TH})$ and $\Pi_N(f_N)$ are the profits that the individual receives from firms f_{TH} in the tradeable sector and f_N in the nontradeable sector, and R represents the rents generated by the financial intermediaries.

The Foreign budget constraint is entirely similar, with the same parameter ν. The internationally traded bond B is in zero net supply worldwide.

3.1.2 Government budget constraint and money supply

The Home and Foreign governments purchase only nontradeable goods[13] produced in their own country. As in Chari, Kehoe and McGrattan's (2002) model, money growth rates follow AR(1) processes, having zero unconditional mean. The budget constraint of the Home government at date t is given by:

$$M_t-M_{t-1}=P_{N,t}G_t+TR_t\ , \tag{3}$$

where G is a public expenditure aggregator or production function:

$$G_t=\left[\int_0^1 g_t\left(f_N\right)^{\frac{\eta-1}{\eta}}df_N\right]^{\frac{\eta}{\eta-1}}\ .$$

The Foreign government budget constraint and the public expenditure aggregator are entirely analogous. Government expenditures in both countries

[12] C_0 denotes the steady-state value of consumption.

[13] According to the Bureau of Economic Analysis' "Guide to the National Income and Product Accounts of the United States", government expenditure essentially consists of services provided to the public free of charge. Goods (and services) that are sold by the government are instead classified as personal consumption expenditure (if purchased by individuals), or intermediate inputs (if purchased by businesses).

follow AR(1) processes with zero unconditional mean.

3.1.3 Consumption and price indexes

The preferences over tradeable and nontradeable goods in the Home country are specified as follows:

$$C_t = \left[(1-\gamma)^{\frac{1}{\phi}} \left(C_{T,t} \right)^{\frac{\phi-1}{\phi}} + \gamma^{\frac{1}{\phi}} \left(C_{N,t} \right)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} ,$$

where $(1-\gamma)$ and γ are preference weights, and ϕ is the substitution elasticity. Preferences in the Foreign country are described by an equivalent aggregator, with the same parameters γ and ϕ.

The aggregators for tradeable goods consumption in the Home and Foreign countries at date t are, respectively:

$$C_{T,t} = \left[(1-\delta)^{\frac{1}{\theta}} \left(C_{TH,t} \right)^{\frac{\theta-1}{\theta}} + \delta^{\frac{1}{\theta}} \left(C_{TF,t} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} ,$$

$$C^*_{T,t} = \left[(1-\delta^*)^{\frac{1}{\theta}} \left(C^*_{TH,t} \right)^{\frac{\theta-1}{\theta}} + (\delta^*)^{\frac{1}{\theta}} \left(C^*_{TF,t} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} .$$

The elasticity of substitution θ between type-TH and type-TF goods is the same in both countries, but the weights δ and δ^* can differ.

The preferences for the individual goods or varieties are also represented by CES aggregators, for example, in the Home country the preferences for the domestic tradeable varieties are given by:

$$C_{TH,t} = \left[\int_0^1 c_{TH,t} \left(f_{TH} \right)^{\frac{\eta-1}{\eta}} df_{TH} \right]^{\frac{\eta}{\eta-1}} ,$$

The elasticity of substitution η is the same for both the tradeable and nontradeable varieties and for both countries, reflecting the assumption that the degree of monopolistic competition is the same for all firms.

Let us denote the prices of the individual varieties with lower cases, and the price indexes (the prices of the consumption aggregators) with upper cases.[14] The model assumes that the law of one price holds for the individual varieties, so the following equations hold:

[14] The price indexes are defined in the standard way, as the minimal expenditures needed to buy one unit of the corresponding consumption aggregators.

$$p_{TH,t}\left(f_{TH}\right)=e_t\cdot p^{*}_{TH,t}\left(f_{TH}\right), \qquad p_{TF,t}\left(f^{*}_{TF}\right)=e_t\cdot p^{*}_{TF,t}\left(f^{*}_{TF}\right) \ , \tag{4}$$

where $p_{TH,t}\left(f_{TH}\right)$ and $p_{TF,t}\left(f^{*}_{TF}\right)$ ($p^{*}_{TH,t}\left(f_{TH}\right)$ and $p^{*}_{TF,t}\left(f^{*}_{TF}\right)$) are the prices of, respectively, varieties f_{TH} and f^{*}_{TF} in the Home (Foreign) country, and e_t is the nominal exchange rate at date t. As a result, Equations (4) also hold for the tradeable price indexes: $P_{TH,t}=e_t\cdot P^{*}_{TH,t}$ and $P_{TF,t}=e_t\cdot P^{*}_{TF,t}$.

The Home terms of trade is defined as the ratio of the price of imports over the price of exports, expressed in the same currency:

$$T_t\equiv\frac{P_{TF,t}}{P_{TH,t}}=\frac{e_t\cdot P^{*}_{TF,t}}{P_{TH,t}}=\frac{P^{*}_{TF,t}}{P^{*}_{TH,t}} \ . \tag{5}$$

3.1.4 Firms

The production function for the individual firm f_{TH} operating in the Home tradeable goods sector at date t is:

$$y_{TH,t}\left(f_{TH}\right)=z_{TH,t}\cdot\widetilde{h}_{TH,t}\left(f_{TH}\right)^{\alpha} \ , \tag{6}$$

where $\widetilde{h}_{TH}\left(f_{TH}\right)$ represents the aggregate of all labour inputs used by the firm and α is a parameter which allows for decreasing returns to labour. The variable z_{TH} represents technology, and it affects the productivity of labour. Wages are flexible. The aggregate of all labour inputs used by firm f_{TH} is given by:[15]

$$\widetilde{h}_{TH,t}\left(f_{TH}\right)=n_{TH,t}\cdot h_{TH}\left(f_{TH}\right) \ .$$

Following Calvo (1983), nominal rigidities are introduced by assuming that each firm has a fixed probability of changing her price at date t. Hence, firm f_{TH} chooses her price $p_{TH,t}\left(f_{TH}\right)$ by solving the following problem:[16]

[15] The aggregate labour input is given by the number of hours worked in the sector by each individual, times the measure of individuals working in that sector. Because of the law of large numbers, the probabilities chosen at the individual level and the fraction of individuals at the aggregate level that work in a given sector coincide.

[16] In this model firms take into account the demand for their product when maximizing profits, but they take the individuals' allocative choices and supply of hours as given. The assumptions on the functional forms and the requirement that $\alpha\leq 1$ ensure that profits are a concave function of prices.

$$\max \quad E_t \sum_{j=0}^{\infty} (\varphi_{TH}\beta)^j \, Q_{t,t+j} \left[\begin{array}{c} \frac{p_{TH,t}(f_{TH})}{P_{t+j}} \cdot y_{TH,t+j|t}\left(f_{TH}\right) \\ -\frac{W_{TH,t+j}}{P_{t+j}} \cdot \widetilde{h}_{TH,t+j|t}\left(f_{TH}\right) \end{array} \right] ,$$

$$\text{s.t.} \quad y_{TH,t+j|t}\left(f_{TH}\right) = \left(\frac{p_{TH,t}(f_{TH})}{P_{TH,t+j}}\right)^{-\eta} \left(C_{TH,t+j} + C^{*}_{TH,t+j}\right) , \qquad (7)$$

where $Q_{t,t+j} = \frac{u'(C_{t+j})}{u'(C_t)}$, and $(\varphi_{TH})^j$ is the probability that $p_{TH,t}\left(f_{TH}\right)$ still applies at the future date $t+j$. The variables $y_{TH,t+j|t}\left(f_{TH}\right)$ and $\widetilde{h}_{TH,t+j|t}\left(f_{TH}\right)$ denote the total demand for the good,[17] and the total labour input used by the firm, at date $t+j$, if the price $p_{TH,t}\left(f_{TH}\right)$ decided at t still applies.

The production functions and the maximization problems of Home firms f_N and Foreign firms f^{*}_{TF} and f^{*}_{N} are entirely analogous. In each country and sector, the growth rate of technology follows an AR(1) process with zero unconditional mean.

3.2 The solution of the model

The rest of the paper focuses on a symmetric equilibrium, so all firms that can modify their price at date t set the same price.

The model cannot be solved in closed form, and a numerical approximated solution must be found instead. This is obtained by log-linearising the equations around a deterministic equilibrium or steady state in which all the exogenous stochastic processes are set equal to their unconditional means, their variances are set to zero, and net foreign asset positions are normalised at zero.[18] The resulting system is then solved using Uhlig's "Toolkit" algorithm (1999).[19] The shocks to the exogenous stochastic processes are all assumed to be temporary.

Importantly, the steady-state terms of trade is not normalised but it is computed explicitly.[20] A close inspection of the steady-state equations reveals that the steady-state terms of trade depends not only on the preference

[17] This is found by integrating and summing the demand functions of individuals in all countries and of the Home government.

[18] No country is a net borrower or lender in the steady state, but international borrowing and lending occur in the short-run or transitional equilibrium path.

[19] The computer code is available from the author on request.

[20] The method used in the computation of the steady state is adapted from Obstfeld and Rogoff (1995). The calculations are available from the author on request.

parameters but also on real factors, such as the unconditional means of the productivity processes. In particular, three of these unconditional means are free parameters, which are calibrated so as to ensure that the steady state of the model reproduces three facts in the data: the proportions of tradeable to nontradeable employment in the two countries, n_{TH}/n_N and n^*_{TF}/n^*_N , and the ratio of Home to Foreign tradeable output, $P_{TH}Y_{TH}/P_{TF}Y^*_{TF}$. These ratios have been computed using year-2000 data from the Groningen 60-Industry Database.[21]

An important feature of the solution is that hours are always endogenously constant. As a result, all the adjustment in the labour inputs takes place through the extensive margin, i.e. the participation rates or probabilities.[22]

4 The transmission of shocks to the tradeable and nontradeable sectors

The purpose of this section is to present a system of three equations in three unknowns, namely relative output Y_{TH}/Y_N , the relative price P_{TH}/P_N , and relative employment n_{TH}/n_N , and to illustrate how this system can be used to understand the transmission of shocks to the two sectors.[23]

For simplicity, here I assume that firms face the same probability of changing their prices, that is, $\varphi_{TH} = \varphi_N = \varphi$. Moreover, I also assume that in period $t-1$ the economy is at its steady state. All the equations presented in

[21] Groningen Growth and Development Centre, 60-Industry Database, February 2005, http://www.ggdc.net. The database is comparable with the OECD STAN Database. Since the year 2000 is the base year of the Groningen dataset, the data for the year 2000 does not depend on the computation of output deflators.

[22] This happens for the following reason. From the Home individual maximization problem, by combining the first order condition with respect to $\mathbf{h}_{TH,t}$ with the first-order condition with respect to $n_{TH,t}$, we obtain:

$\kappa(\Gamma - \psi - \mathbf{h}_{TH,t}) - \kappa(\tau) = -\kappa'(\Gamma - \psi - \mathbf{h}_{TH,t})\,\mathbf{h}_{TH,t}$

Analogously, by combining the first order condition with respect to $\mathbf{h}_{N,t}$ with the first-order condition with respect to $n_{N,t}$, we obtain:

$\kappa(\Gamma - \psi - \mathbf{h}_{N,t}) - \kappa(\tau) = -\kappa'(\Gamma - \psi - \mathbf{h}_{N,t})\,\mathbf{h}_{N,t}$

It is then immediate to see that both the above two equations are satisfied when hours worked in the two sectors are constant and equal to each other, in the steady state and at each date t.

[23] Since some endogenous variables are included among the explanatory variables, the system provides a "partial equilibrium" analysis, because the equilibrium values for Y_{TH}/Y_N , P_{TH}/P_N and n_{TH}/n_N can all be obtained from the system once a few other endogenous variables (plus the exogenous shocks) are known.

this section describe the short-run equilibrium after a shock occurs at date t.

Deriving a short-run demand and supply for relative output

Since the equations presented here have been obtained from the log-linearised solution of the model, it is necessary to introduce some notation first. For any variable X, let X_0 denote the value of the variable at the deterministic equilibrium or steady state. Let $\widehat{X}_t \equiv \log(X_t/X_0) \simeq (X_t - X_0)/X_0$ denote the approximate short-run log-deviation from the initial steady state, and let $dX_t \equiv (X_t - X_0)/C_0$ denote instead the linear deviation, normalised with respect to steady-state consumption. Let $\pi_{j,t} \equiv \log\left(\frac{P_{j,t}}{P_{j,t-1}}\right)$ denote inflation in sector j.

The supply for relative output describes how firms adjust $Y_{TH,t}/Y_{N,t}$ following changes in the relative price $P_{TH,t}/P_{N,t}$. The demand for relative output describes how Home and Foreign individuals modify their demand for $Y_{TH,t}/Y_{N,t}$, for any given change in $P_{TH,t}/P_{N,t}$.

From the first-order condition of the firm's maximisation problem, described in Section 3.1.4, it is possible to derive an expression describing the evolution of inflation in the Home tradeable sector. By subtracting from that expression its counterpart for the Home nontradeable sector,[24] we obtain the short-run supply for relative output:

$$\widehat{P}_{TH,t} - \widehat{P}_{N,t} = \beta E_t\left(\pi_{TH,t+1} - \pi_{N,t+1}\right) + \left(\frac{1-\varphi\beta}{1+\frac{1-\alpha}{\alpha}\eta}\frac{1-\varphi}{\varphi}\right)\left(\widehat{MC}_{TH,t} - \widehat{MC}_{N,t}\right) . \tag{8}$$

where $MC_{j,t}$ denotes real marginal cost in sector j at time t:

$$\widehat{MC}_{j,t} = \widehat{W}_{j,t} - \widehat{P}_{j,t} - \frac{1}{\alpha}\widehat{z}_{j,t} + \frac{1-\alpha}{\alpha}\widehat{Y}_{j,t} \ ; \quad j = TH,\ N. \tag{9}$$

According to the above equation, short-run movements in $P_{TH,t}/P_{N,t}$ reflect expectations of future inflation and real marginal cost differentials. If expected future inflation rates and changes in real marginal cost in one sector are equal to those in the other sector, then no changes in the relative price $P_{TH,t}/P_{N,t}$ occur.

The slope of the relative supply curve depends on $(1-\alpha)/\alpha$, the coefficient on output in equation (9). In the case of decreasing returns to labour,

[24] Detailed derivations of all the equations are available from the author on request.

$(1-\alpha)/\alpha$ is positive, thus the relative supply curve is upward-sloping: the relative price increases when the supply of relative output increases.[25] This happens because with decreasing returns to labour the marginal productivity falls with production, and firms charge higher prices to compensate for the fall in productivity. On the other hand, with constant returns to labour ($\alpha = 1$) there is no effect of the supply of $Y_{TH,t}/Y_{N,t}$ on the relative price $P_{TH,t}/P_{N,t}$, thus the relative supply relationship is horizontal.

The short-run demand relationship is derived by manipulating the demands for tradeable and nontradeable goods, and the Home and Foreign resource constraints, all log-linearised:

$$\widehat{Y}_{TH,t} - \widehat{Y}_{N,t} = -\phi\left(\widehat{P}_{TH,t} - \widehat{P}_{N,t}\right) + (1-\phi)(1-k_1)\widehat{T}_t + (1-k_1)k_4\left(dB_t - \frac{1}{\beta}dB_{t-1}\right) - k_7 dG_t \ . \tag{10}$$

Equation (10) says that the demand for relative output decreases when the relative price $P_{TH,t}/P_{N,t}$ increases. This relationship is affected by changes in the terms of trade, bond holdings and government expenditures. The coefficients k_1, k_4, and k_7 are computed from the steady state equations, and they are all positive.[26]

The third equation of the system links changes in relative employment to changes in relative output, and it is obtained from a simple manipulation of the production functions in the two sectors:

$$\widehat{n}_{TH,t} - \widehat{n}_{N,t} = \frac{1}{\alpha}\left(\widehat{Y}_{TH,t} - \widehat{Y}_{N,t}\right) - \frac{1}{\alpha}\left(\widehat{z}_{TH,t} - \widehat{z}_{N,t}\right) \ . \tag{11}$$

Equation (11) shows that the changes in relative employment depend only on the changes in relative output and on the productivity shocks.

Analysing the transmission of shocks to the two sectors

Both the supply and the demand for relative output $Y_{TH,t}/Y_{N,t}$ are illustrated in Figure 1.

[25] Notice that both $\widehat{P}_{TH,t}$ and $\widehat{P}_{N,t}$ appear both on the left and on the right-hand side of equation (8), since they affect the two marginal costs. It is possible to fully solve equation (8) for the change in the relative price $P_{TH,t}/P_{N,t}$, but the slope would remain positive.

[26] The coefficient $1-k_1$ is equal to the steady-state import share in total tradeable consumption.

FIGURE 1 HERE

A positive Home monetary shock (a temporary increase in the growth rate of money) affects bond holdings and causes an increase in the terms of trade,[27] thus inducing a change in the right-hand side of Equation (10) and a shift in the demand curve in Figure 1. Let us call the changes in the relative output demand (10) brought about by changes in the terms of trade and bond holdings the "terms of trade" and "wealth" effects respectively.[28] These terms of trade and wealth effects explain why the responsiveness of output to monetary shocks is different in the two sectors. An increase in the terms of trade induces an increase (decrease) in relative output if the substitution elasticity ϕ is lower (higher) than one. An increase in bond holdings relative to period $t-1$ always induces an increase in relative output $Y_{TH,t}/Y_{N,t}$.

Positive productivity shocks lower real marginal costs for firms, and induce them to lower their prices. Because of price rigidity, the effect on expected future inflation is of lower magnitude than the effect on current marginal cost, therefore, by looking at the right-hand side of Equation (8), it is easy to predict the direction of the shift of the supply relationship. Specifically, a positive productivity shock in the TH sector shifts the short-run relative supply relationship down, and a positive productivity shock in the N sector shifts the relationship up. As a result, under a positive productivity shock in the TH sector the relative price $P_{TH,t}/P_{N,t}$ falls and relative output $Y_{TH,t}/Y_{N,t}$ increases, while the opposite happens under a positive productivity shock in the N sector.[29]

Government expenditure shocks directly affect the demand for relative output (10), thus the effects of Home government expenditure shocks are also easy to predict. After an increase in government expenditure, the relative output $Y_{TH,t}/Y_{N,t}$ decreases, and, if the slope of the relative supply curve is positive, the relative price $P_{TH,t}/P_{N,t}$ decreases.

Finally, Foreign shocks induce changes in bond holdings and the terms of trade, and in this way they bring on changes in $Y_{TH,t}/Y_{N,t}$ and $P_{TH,t}/P_{N,t}$,

[27] Under all parametrisations, a positive monetary shock causes a depreciation of the Home currency. Since prices are rigid, this always results in an increase in the terms of trade T_t , and in an increase in the price of tradeables $P_{T,t}$.

[28] These definitions will be used in Sections 6 and 7.

[29] Productivity shocks induce changes in bond holdings and the terms of trade, thus they also shift the short-run demand for relative output. However, under most parametrisations the shift of the relative demand relationship will be less pronounced than the shift of the relative supply relationship.

as suggested by Equations (10) and (8). Thus the terms of trade and wealth effects are important not only for the transmission of monetary shocks, but also of Foreign shocks, and they explain why the volatility of output may be different in the two sectors.

5 Estimation

This section begins with some background information on the sample period and presents some applied choices.[30] Then, it illustrates some parameter choices prior to the GMM estimation, describes the choice of moment conditions, and finally concludes with a brief comment on the estimated parameters values.

The sample period is 1981:1 to 2004:3. The Home country is represented by the US, and the Foreign country by an aggregate of its major trading partners. The latter is comprised by Canada, France, Germany,[31] Japan, Mexico and the UK, which together represented 50.1% of the US total trade in goods in September 2004.[32] The combined GDP of these six countries was 105% of the US GDP in the third quarter of 2004.

The tradeable sector is represented by manufacturing, and the nontradeable sector by services. This approximation is advantageous because quarterly observations on output, prices and employment levels are available, and it is consistent with the standard classification in the literature.

Not all of the model parameters could be estimated by GMM, as in some cases identification problems occurred during estimation. Table 2 shows the parameters that have not been estimated by GMM but instead have been chosen according to suggestions made in the literature.[33]

TABLE 2 HERE

The discount rate β and the degree of monopolistic competition η are parameterized according to Rotemberg and Woodford (1998). The preference

[30] Detailed appendices illustrating the construction of the data variables and the derivation of the moment conditions are available from the author on request.

[31] Germany is West Germany up until 1990:4.

[32] Source: US Census Bureau website. China has recently emerged as another top US trading partner, but it was not included in the aggregate of Foreign countries because of the limited availability of data on the Chinese economy.

[33] In doing so, I do not take into account parameter uncertainty in the GMM estimation of the other parameters.

weights γ and δ are calibrated so that the steady-state import and service shares in consumption are consistent with the US data, while δ^* is set equal to $1 - \delta$ for symmetry.[34] The intermediation cost parameter ν is chosen so that the spread in the nominal interest rates approximates the benchmark value suggested by Benigno (2001). Finally, the probabilities of not changing prices are set equal in all countries and sectors, and the parametrized value is taken from Galí (2003).[35]

Since the parametrized values of β and η enter the moment conditions, they might affect the GMM estimates. I have found that if β is in the range $[0.97, 0.99]$ and η is in the range $[6, 12]$, the parameter estimates of Table 3 are not very much affected.[36]

The estimated parameters and the moment conditions are presented in Tables 3 and 4 respectively. The choice of an exactly identified system is motivated by the small size of the sample. The optimal weighting matrix is computed using the Newey and West (1987) estimator with a Bartlett kernel.[37]

TABLE 3 HERE
TABLE 4 HERE

The first moment condition is obtained from the steady-state equation that relates the parameter α to the labour share in total GDP.[38] The GMM procedure simultaneously estimates α and the parameters of the log-linearised technology processes.

The remaining moment conditions are derived from the log-linearised solution (as in Ghironi 2000), and have been estimated using logged, seasonally adjusted and Hodrick-Prescott (HP) filtered data,[39] with $\lambda = 1,600$.

The second and third moment conditions are obtained by combining the Home and Foreign consumption Euler equations, the first-order conditions

[34] These values for γ, δ and δ^* are broadly consistent with the literature: see, among others, Benigno and Thoenissen (2003), and Obstfeld and Rogoff (2004).

[35] The specification of the functional form κ and the calibration of the parameters χ, Γ, τ and ψ are irrelevant for the solution.

[36] All sensitivity checks are available on request.

[37] I have also verified that the estimates are not significantly affected by the choice of kernel or lag length.

[38] A Dickey-Fuller test rejects the hypothesis of nonstationarity of the ratio of compensation of employees over GDP in the US.

[39] Variables must be detrended because they enter the log-linearised equations as percentage deviations from the steady state. In Ghironi (2000), the steady state is a constant trend, while in the real business cycle literature it is common to detrend the variables using the HP filter instead. I prefer to use the HP filter to allow for nonlinear trends in the data.

for money balances and the definitions of the nominal interest rates, using contemporaneous real money balances and consumption differentials as instruments.[40]

The fourth and fifth moment conditions are obtained from log-linearised expenditure shares, using contemporaneous price ratios as instruments.

Finally, the remaining moment conditions result from the properties of the exogenous stochastic processes $\widehat{x}_j$. In order to reduce the computational cost, I do not estimate all the covariances among shocks. Instead, I proceed as follows. First, I run a separate GMM estimate having the full variance-covariance matrix, and compute all the correlation coefficients. Then, I keep in the final system only the covariances associated with correlation coefficients higher than 0.2, and I fix all the other covariances at zero.

On the whole, the estimated parameter values agree with the suggestions made in the literature. Obstfeld and Rogoff (2005) noted that the elasticities of substitution between tradeables and nontradeables, and between Home and Foreign tradeables, were both found to be lower than one in some empirical studies. The estimated risk aversion for consumption σ is close to the value suggested by Chari, Kehoe and McGrattan (2002). Finally, a quick calculation shows that the estimated standard deviation of US tradeable productivity shocks is equal to 0.78%, which is quite a familiar value in the real business cycle literature.

6 Results

6.1 Identifying the properties of the data

In order to take into account the measurement problem in the comparison of the model with the data,[41] this paper adopts a specific approach, outlined as follows. First, only second-order moments are considered, obtained from the same data set that was used to estimate the model. These data moments are

[40] Chari, Kehoe and McGrattan (2002) estimate the utility parameters from a single-country money demand equation, estimated using US data. I prefer to use a relative money demand equation in order to make use of both US and Foreign data (the model restricts ε and σ to be the same in the two countries), with a parsimonious instrument set.

[41] The measurement problem affects also the GMM estimates, since these were based on the approximation of tradeables with manufacturing, and nontradeables with services. But it does not affect equally all the estimated values, for example, it does not affect the variance of the monetary shocks. This consideration confirms that the comparison between the data and the model-generated statistics cannot be strictly quantitative.

presented in Table 5, and they are chosen so as to characterise the cyclical properties of the US tradeable and nontradeable sectors.

TABLE 5 HERE

Secondly, wherever possible the findings of Table 5 are validated by seeing whether they are also reproduced in Table 1, which includes more sectors.[42] Finally, the comparison between the data and the model's statistics is qualitative in nature rather than quantitative.

We can now concentrate on the properties of the data as illustrated by Table 5. We will first check whether they are compatible with the findings of Section 2, and then we will turn our attention to the model-generated statistics.

Once again, according to Table 5, the most significant difference between the tradeable and the nontradeable sectors is in the volatility. The standard deviation of inflation is slightly higher in the nontradeable sector, and both output and employment levels fluctuate remarkably more in the tradeable than in the nontradeable sector. But not all of these findings can be validated by Table 1. Although Table 1 certainly confirms that tradeable output is more volatile than nontradeable output, it is silent on employment levels and it does not show that the standard deviation of inflation is higher in the nontradeable than in the tradeable sector, but rather the opposite.

From the combined evidence of Tables 1 and 5, we can now select a set of qualitative findings for the purpose of comparing the model with the data. The first one is that tradeable output is more volatile than nontradeable output. The second finding is that tradeable employment is more volatile than nontradeable employment. This second finding is shown only in Table 5, however, if we postulate that tradeable output is more volatile than nontradeable output, then it is reasonable to assume that the labour input is more volatile too. The evidence on inflation is not conclusive in a way or another, but both Table 5 and Table 1 suggest that the gap in the volatility of the inflation rates in the two sectors is not very large, that is, not as large as the gap in the standard deviations of the two sectoral output levels. This will be our third qualitative finding.

[42] The actual numbers cannot be compared since Table 5 is based on quarterly data and Table 1 on annual data.

6.2 The model-implied statistics

The statistics obtained from the estimated model are presented in Table 6, while the impulse responses to all shocks are presented in Figures 2 to 4.

TABLE 6 HERE
FIGURES 2 TO 4 HERE

The impulse responses are ordered according to the estimated standard deviation of the shocks, with the responses to the shocks having the higher standard deviation coming first. There exist a clear demarcation among shocks, since the standard deviation of the first four is considerably higher than the standard deviation of the last four shocks.

Overall, the estimated model generates standard deviations that are compatible with the three qualitative findings listed at the end of the previous section. There is not a large gap in the standard deviations of inflation rates in the two sectors. The standard deviations of output and employment are sensibly higher in the tradeable sector than in the nontradeable sector. Moreover, the cross correlations are all positive, as in Table 5.

The results of Table 6 are mainly generated by the responses to the domestic monetary shocks. The other shocks have a lesser influence, either because they induce a lower response in the variables,[43] or because their estimated standard deviation is lower.[44]

How can Section 4's equations be used to explain the higher volatility of output in the tradeable sector in the US? First of all, a domestic positive monetary shock causes an increase in inflation, output and employment levels. This is a standard result, common to many NOEM models, not least Obstfeld and Rogoff's (1995). However, the responses are not the same in the two sectors; in particular, tradeable output reacts more to a US monetary shock

[43] However, the US tradeable technology shock (one of the four with the higher estimated variance) causes a relatively large response of US tradeable employment.

[44] A simple exercise confirms this intutition. If the model is simulated with only domestic monetary shock, the resulting standard deviations of tradeable (nontradeable) inflation, output and employment are equal to .31 (.30), .92 (.65), 1.40 (.98) respectively. With only domestic tradeable technology shocks, the same model-implied standard deviations are instead equal to .09 (.00), .17 (.03), and 1.38 (.05) respectively. Thus, while US tradeable productivity shocks play the role of contributing factors, all in all it is the sensitivity or responsiveness of tradeable output to US monetary shocks the main reason why it is more volatile than nontradeable output.

than nontradeable output.[45] Then, for this to occur, it must be true that the monetary shock affects the right-hand side of Equation (10), causing $\widehat{Y}_{TH,t} - \widehat{Y}_{N,t}$ to become positive. This happens because the domestic monetary shock induces a terms of trade effect and a wealth effect, both of them temporary. But the terms of trade effect is the most important quantitatively, since bond holdings are a stock variable that adjusts only slowly.

The terms of trade effect can be explained as follows. The depreciation of the US (Home) currency after a positive monetary shock causes an increase of the terms of trade, thus, since ϕ is lower than one, the relative demand curve (10) shifts to the right. This shift to the right has the following economic motivation. The terms of trade depreciation makes Foreign tradeables more expensive, therefore the output of US tradeables increases, so as to generate the resources to pay for the costly imports. US consumption switches from Foreign tradeables towards domestically-produced goods, both tradeable and nontradeable. But since ϕ is lower than one, there is little substitution towards nontradeable goods,[46] so the positive monetary shock actually benefits the US tradeable sector more than the nontradeable sector.

In addition to the terms of trade effect, there is also a temporary wealth effect. The latter arises because the positive monetary shock makes the tradeable bundle C_T more expensive,[47] so Home individuals prefer to substitute away from tradeable goods. As a result, tradeable consumption increases[48] less than tradeable output, so dB_t increases relative to the previous period. The wealth effect influences the relative demand (10) alongside the terms of trade effect.

The terms of trade and bond holdings are affected not only by domestic monetary shocks, but by Foreign shocks as well. Thus, these two open economy effects "amplify" also the responses of tradeable output to the Foreign

[45] This result is true in the estimated model but it is not at all general. Under certain parametrisations tradeable output would respond less than nontradeable output to domestic monetary shocks.

[46] Given that both elasticities of substitution, ϕ and θ, are lower than one, we can infer that the data favours only modest expenditure-switching effects.

[47] The terms of trade depreciation makes Foreign tradeables more expensive, thus both the tradeable goods price index P_T and the overall price index P increase. However, since tradeable goods constitute only a fraction of all the goods consumed in the Home country, P_T increases proportionately more than P, so the relative price of tradeables goes up.

[48] The lower is σ, and the higher is the increase in overall consumption C after a monetary shock. Since the estimated risk aversion parameter is quite high, the impact increase in consumption is relatively modest.

shocks, a fact that can be easily verified by looking at Figure 3.

Given that tradeable output responds more to the domestic monetary shocks, then the firms' demand for the labour input has to respond more too. This explains why there is higher volatility of employment in the tradeable sector than in the nontradeable sector. Moreover, the productivity shocks, which affect firms' labour demand, are more volatile for tradeables rather than nontradeables.

Why do tradeable and nontradeable inflation rates have a similar standard deviation in the model? Let us again consider a positive monetary shock, which causes positive inflation in both sectors. Equation (8) shows that the relative price change $\widehat{P}_{TH,t} - \widehat{P}_{N,t}$ depends on both expected future inflation rates and current marginal costs differentials.[49] But the coefficient on marginal costs differentials is quantitatively small, moreover, under the assumption that the two sectors have the same degree of price stickiness, expected future inflation rates will be very similar for tradeable and nontradeable firms. As a result, inflation rates in the two sectors will respond similarly to the monetary shock.

Finally, the cross-correlations in the model are all positive because of the importance of the estimated US monetary shocks, which cause US inflation rates, output and employment in the two sectors to move all in the same direction, and thereby induce a positive correlation among these variables.

7 Sensitivity analysis

The parameter values of Table 2 were not estimated but were instead taken from the literature. However, for these parameters the range of acceptable values is rather limited in practice, so, provided that the parametrized values stay in that range,[50] the qualitative findings of the previous Section cannot change; in fact, they do not change.[51] Therefore, only the most interesting

[49] Since we assume that the economy is at the steady state in period $t-1$ (before the shock occurs), then the impact changes in prices give the inflation rates: $\pi_{TH,t} = \widehat{P}_{TH,t}$ and $\pi_{N,t} = \widehat{P}_{N,t}$.

[50] For example, an acceptable range for the parameter γ is $[.5, .9]$, for δ maybe $[.2, .4]$, and so on.

[51] I have also experimented with linear detrending instead of HP-filtering, with single-country money demand equations, with lagged instruments and.with single-equation estimates. In all these cases the NOEM model generates standard deviations that are compatible, from a qualitative point of view, with the pattern in the data.

sensitivity checks are reported here.

TABLE 7 HERE

One way to control the responsiveness of output to changes in the terms of trade is by changing the preference weights. This is because an increase in the amount of Foreign-produced goods in tradeable consumption (caused, for example, by the ongoing process of trade integration) affects the US' vulnerability to shocks occurring abroad.

If US and Foreign households increase the share assigned to each other's goods in the tradeable consumption basket, then both tradeable and nontradeable output become more volatile, as shown by the second column of Table 7. The reason why output levels become more volatile is as follows. An increase in the terms of trade increases the price that US households pay for Foreign imports. Thus if the terms of trade increases, the US will produce more tradeable output, so as to generate more resources to pay for its tradeable consumption. If δ is higher, then imports constitute a higher proportion of US tradeable consumption, so US tradeable output will be more responsive to changes in the terms of trade and more volatile, as shown by Table 7. Additionally, through the increase in the price paid for Foreign goods, a rise in the terms of trade increases the tradeable price index P_T and encourages US households to consume more nontradeables. If δ is higher, this effect will be stronger, so nontradeable output will also be more responsive to changes in the terms of trade and more volatile, as shown by Table 7.

The third column of Table 7 shows the model-implied standard deviations under a lower value for φ_N , the degree of price stickiness in the nontradeable sector. Under this scenario, nontradeable sector firms are allowed to adjust their prices more frequently, thus the standard deviation of nontradeable inflation increases. Because changes in demand are curbed by stronger price responses, the standard deviation of nontradeable output falls.[52] But a larger gap between φ_N and φ_{TH} would imply a larger divergence in the standard deviations of the two inflation rates, a fact that is not supported by the data.

8 Conclusion

This paper has developed and estimated by GMM a new open economy model, having prices sticky in the producer's currency, with the purpose of analysing

[52] The same would happen if the price mark-up in the nontradeable sector was higher.

the fluctuations of the tradeable and nontradeable sectors. The estimated model generates standard deviations that are compatible, from a qualitative point of view, with the pattern observed in the data. The data suggests that the standard deviations of output and employment are higher in the tradeable sector than in the nontradeable sector. Both facts are reproduced by the model. The evidence on inflation rates is not as conclusive, but at a minimum it suggests that the gap in the standard deviation of inflation rates in the two sectors is not as large as the gap in the two standard deviations of output. This fact is also reproduced by the estimated model.

The model-implied responses of tradeable and nontradeable output levels to monetary shocks are broadly consistent with the VAR-based investigation of Ganley and Salmon (1997). These authors have found that, in the UK, manufacturing is more responsive to monetary shocks than the service sector.

The assumption that prices are set in the producer's currency simplifies the estimation and preserves analytical tractability, thus allowing the derivation of the system of equations in Section 4. However, it would be interesting to see whether the larger response of tradeable output to monetary shocks is maintained also under other price-setting assumptions. For example, if a proportion of tradeable goods firms set their prices in the buyer's currency, then the output produced by those firms would not be sensitive to changes in the terms of trade induced by monetary shocks. But on the other hand, since in this situation the response of the nominal exchange rate after a monetary shock would be magnified,[53] so the response of tradeable output produced by the firms which set prices in their own currency would probably continue to be different from the response of nontradeable output.

[53] Betts and Devereux (2000).

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Table 1: Sectoral statistics

Sectors	% Std deviation		% value
	inflation	output	added
Tradeable:			
Manufacturing	2.04	4.80	14.5
Mining	11.57	4.00	1.2
Agriculture, forestry	10.11	6.07	1.0
Nontradeable:			
Finance, insurance	1.06	1.10	19.7
Government	1.14	2.67	12.3
Professional and business services	1.36	2.95	11.6
Educational services, health care	1.91	1.49	6.9
Retail trade	2.36	3.00	6.7
Wholesale trade	3.13	3.01	6.0
Information	1.39	2.53	4.7
Construction	2.36	5.27	4.4
Arts, entertainment, recreation	1.73	2.09	3.6
Transportation and warehousing	2.49	3.77	3.1
Other services, except gov.	1.21	2.33	2.3
Utilities	3.61	4.58	1.9

Notes: Calculations based on chain-type price and quantity indexes for value added by industry. Source: Bureau of Economic Analysis. The last column reports the value added by the sector as a percentage of aggregate GDP. Statistics were computed using logged and HP-filtered annual data. The sample is 1947 to 2005.

Table 2: Parametrization

	Description	*Value*
β	Discount factor	0.99
γ	Weight of nontradeable goods in total consumption	0.67
δ	Weight of Foreign goods in Home tradeable consumption	0.34
δ^*	Weight of Foreign goods in Foreign tradeable consumption	0.66
η	Elasticity of substitution among differentiated goods	7.88
ν	Intermediation cost	0.0005
φ_j , φ_j^*	Probabilities of not changing prices	0.75

Table 3: GMM estimates

	Description	*Estimate*[a]
α	Returns to labour	0.6594 (0.0021)
ε	Elasticity of marginal utility of real money balances	1.6428 (0.9442)
σ	Risk aversion for consumption	4.0617 (2.9609)
ϕ	Elasticity of substitution tradeable-nontradeables	0.6967 (0.1274)
θ	Elasticity of substitution Home-Foreign tradeables	0.7851 (0.0956)
Exogenous processes: $\widehat{x}_{j,t} = \rho_j \cdot \widehat{x}_{j,t-1} + \epsilon_j$		
ρ_j	AR coefficient Home nominal money growth	0.5043 (0.0852)
	AR coefficient Home tradeable technology	0.8840 (0.0479)
	AR coefficient Home nontradeable technology	0.6789 (0.0705)
	AR coefficient Home government expenditure	0.6378 (0.0802)
	AR coefficient Foreign nominal money growth	0.3799 (0.0886)
	AR coefficient Foreign tradeable technology	0.8902 (0.0420)
	AR coefficient Foreign nontradeable technology	0.5494 (0.0965)
	AR coefficient Foreign government expenditure	0.2576 (0.1218)
$Var(\epsilon_j)$	Variance Home nominal money growth	$8.43 \cdot 10^{-5}$ $(1.36 \cdot 10^{-5})$
	Variance Home tradeable technology	$6.06 \cdot 10^{-5}$ $(1.14 \cdot 10^{-5})$
	Variance Home nontradeable technology	$2.72 \cdot 10^{-6}$ $(5.88 \cdot 10^{-7})$
	Variance Home government expenditure	$1.55 \cdot 10^{-6}$ $(2.64 \cdot 10^{-7})$
	Variance Foreign nominal money growth	$7.09 \cdot 10^{-5}$ $(1.85 \cdot 10^{-5})$
	Variance Foreign tradeable technology	$1.01 \cdot 10^{-4}$ $(1.60 \cdot 10^{-5})$
	Variance Foreign nontradeable technology	$4.17 \cdot 10^{-6}$ $(7.29 \cdot 10^{-7})$
	Variance Foreign government expenditure	$6.69 \cdot 10^{-6}$ $(9.97 \cdot 10^{-7})$

Table 3 (continues): GMM estimates

	Description	*Estimate*[a]
$Cov\left(\epsilon_j, \epsilon'_j\right)$	Cov(Home nom. money growth, Home nontrad. prod.)	$3.75 \cdot 10^{-6}$ $\left(1.45 \cdot 10^{-6}\right)$
	Cov(Home nom. money growth, Home gov. exp.)	$2.97 \cdot 10^{-6}$ $\left(1.14 \cdot 10^{-6}\right)$
	Cov(Home nom. money growth, Foreign trad. prod.)	$-3.76 \cdot 10^{-5}$ $\left(8.02 \cdot 10^{-6}\right)$
	Cov(Home trad. prod., Foreign trad. prod.)	$3.21 \cdot 10^{-5}$ $\left(8.03 \cdot 10^{-6}\right)$
	Cov(Home nontrad. prod., Home gov. exp.)	$1.04 \cdot 10^{-6}$ $\left(2.35 \cdot 10^{-7}\right)$
	Cov(Home gov. exp., Foreign gov. exp.)	$3.28 \cdot 10^{-7}$ $\left(4.29 \cdot 10^{-7}\right)$
	Cov(Foreign trad. prod., Foreign nontrad. prod.)	$5.71 \cdot 10^{-6}$ $\left(1.59 \cdot 10^{-6}\right)$

[a] Numbers in parenthesis are standard errors.

Table 4: List of moment conditions

(1):	$E\left[\frac{Comp_t}{Y_t} - \alpha\frac{\eta-1}{\eta}\right] = 0$
(2):	$E\left\{\left[\begin{array}{c}\varepsilon\left(\widehat{M}_t - \widehat{P}_t - \widehat{M}_t^* + \widehat{P}_t^*\right)\\ -\sigma\left(\widehat{C}_t - \widehat{C}_t^*\right) + \beta\left(\widehat{i}_t - \widehat{i}_t^*\right)\end{array}\right] \cdot \left[\widehat{M}_t - \widehat{P}_t - \widehat{M}_t^* + \widehat{P}_t^*\right]\right\} = 0$
(3):	$E\left\{\left[\begin{array}{c}\varepsilon\left(\widehat{M}_t - \widehat{P}_t - \widehat{M}_t^* + \widehat{P}_t^*\right)\\ -\sigma\left(\widehat{C}_t - \widehat{C}_t^*\right) + \beta\left(\widehat{i}_t - \widehat{i}_t^*\right)\end{array}\right] \cdot \left[\widehat{C}_t - \widehat{C}_t^*\right]\right\} = 0$
(4):	$E\left\{\left[\widehat{\frac{P_{N,t}C_{N,t}}{P_tC_t}} - (1-\phi)\left(\widehat{P}_{N,t} - \widehat{P}_t\right)\right] \cdot \left[\widehat{P}_{N,t} - \widehat{P}_t\right]\right\} = 0$
(5):	$E\left\{\left[\widehat{\frac{P_{TF,t}C_{TF,t}}{P_{T,t}C_{T,t}}} - (1-\theta)\left(\widehat{P}_{TF,t}^* + \widehat{e}_t - \widehat{P}_{T,t}\right)\right] \cdot \left[\widehat{P}_{TF,t}^* + \widehat{e}_t - \widehat{P}_{T,t}\right]\right\} = 0$
(6) to (13):	$E\left[\widehat{x}_{j,t} \cdot \widehat{x}_{j,t-1} - \rho_j \cdot \widehat{x}_{j,t-1}^2\right] = 0$
(14) to (21):	$E\left[\left(\widehat{x}_{j,t} - \rho_j \cdot \widehat{x}_{j,t-1}\right)^2 - Var\left(\epsilon_j\right)\right] = 0$
(22) to (28):	$E\left[\left(\widehat{x}_{j,t} - \rho_j \cdot \widehat{x}_{j,t-1}\right)\left(\widehat{x}'_{j,t} - \rho'_j \cdot \widehat{x}'_{j,t-1}\right) - Cov\left(\epsilon_j, \epsilon'_j\right)\right] = 0$

Note: the estimated exogenous processes $\widehat{x}_j$ in the Home country are defined as follows: $\mu =$ nominal money growth rate; $\widehat{z}_{TH} = \widehat{Y}_{TH} - \alpha\widehat{n}_{TH}$ tradeable technology; $\widehat{z}_N = \widehat{Y}_N - \alpha\widehat{n}_N =$ nontradeable technology; $dG =$ government expenditure. The estimated exogenous processes in the Foreign country are similarly defined.

Table 5: Data moments

	% st dev	1-st AC	Correlogram π_{TH}	π_N	$\widehat{Y}_{TH}$	$\widehat{Y}_N$	$\widehat{n}_{TH}$	$\widehat{n}_N$
π_{TH} - Home tradeable inflation	0.33	0.19	1.00					
π_N - Home nontradeable inflation	0.38	0.54	0.06	1.00				
$\widehat{Y}_{TH}$ - Home tradeable output	2.64	0.91	0.35	0.36	1.00			
$\widehat{Y}_N$ - Home nontradeable output	0.23	0.81	0.13	0.05	0.38	1.00		
$\widehat{n}_{TH}$ - Home tradeable employment	1.98	0.92	0.21	0.56	0.86	0.31	1.00	
$\widehat{n}_N$ - Home nontradeable employment	0.27	0.71	0.34	0.27	0.66	0.41	0.63	1.00

Notes: Data sources and definitions are given in Appendices 1 and 2. Statistics were computed using logged and HP-filtered prices, output and employment levels.

Table 6: Model moments

	% st dev	1-st AC	Correlogram π_{TH}	π_N	$\widehat{Y}_{TH}$	$\widehat{Y}_N$	$\widehat{n}_{TH}$	$\widehat{n}_N$
π_{TH} - Home tradeable inflation	0.31	0.64	1.00					
π_N - Home nontradeable inflation	0.28	0.65	0.96	1.00				
$\widehat{Y}_{TH}$ - Home tradeable output	0.94	0.65	0.90	0.94	1.00			
$\widehat{Y}_N$ - Home nontradeable output	0.68	0.62	0.93	0.96	0.94	1.00		
$\widehat{n}_{TH}$ - Home tradeable employment	1.94	0.62	0.85	0.68	0.66	0.69	1.00	
$\widehat{n}_N$ - Home nontradeable employment	0.98	0.64	0.92	0.96	0.93	0.96	0.69	1.00

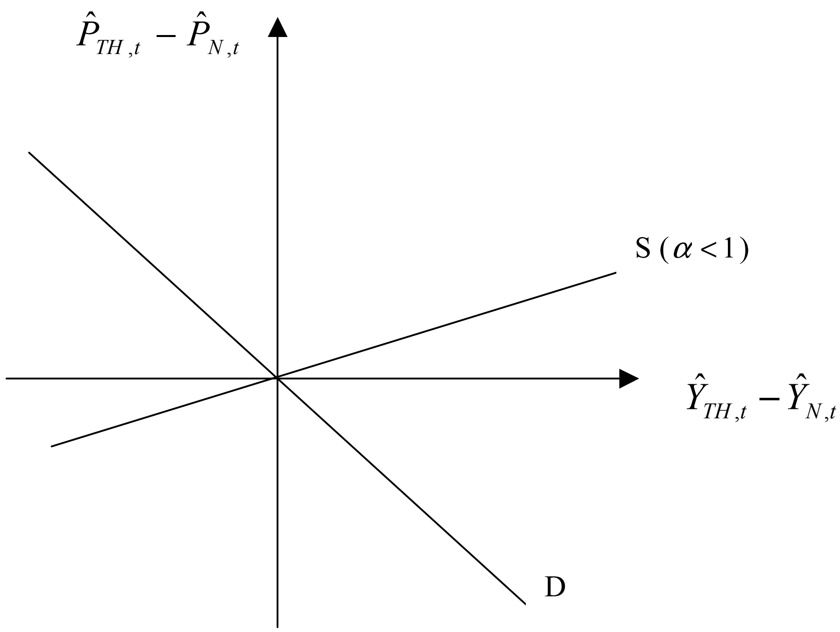
Notes: Statistics are averages over 100 simulations, each of length 93, after the first 1,000 observations were discarded. Statistics were computed using logged and HP-filtered variables. The calibration of the model is consistent with the values of Tables 2 and 3.

Table 7: Sensitivity analysis

	Percent standard deviations	
	$\delta = 0.42$ & $\delta^{*} = 0.58$	$\varphi_N = 0.67$
π_{TH} - Home tradeable inflation	0.31	0.31
π_N - Home nontradeable inflation	0.29	0.38
$\widehat{Y}_{TH}$ - Home tradeable output	1.02	0.97
$\widehat{Y}_N$ - Home nontradeable output	0.73	0.63
$\widehat{n}_{TH}$ - Home tradeable employment	2.04	1.97
$\widehat{n}_N$ - Home nontradeable employment	1.05	0.89

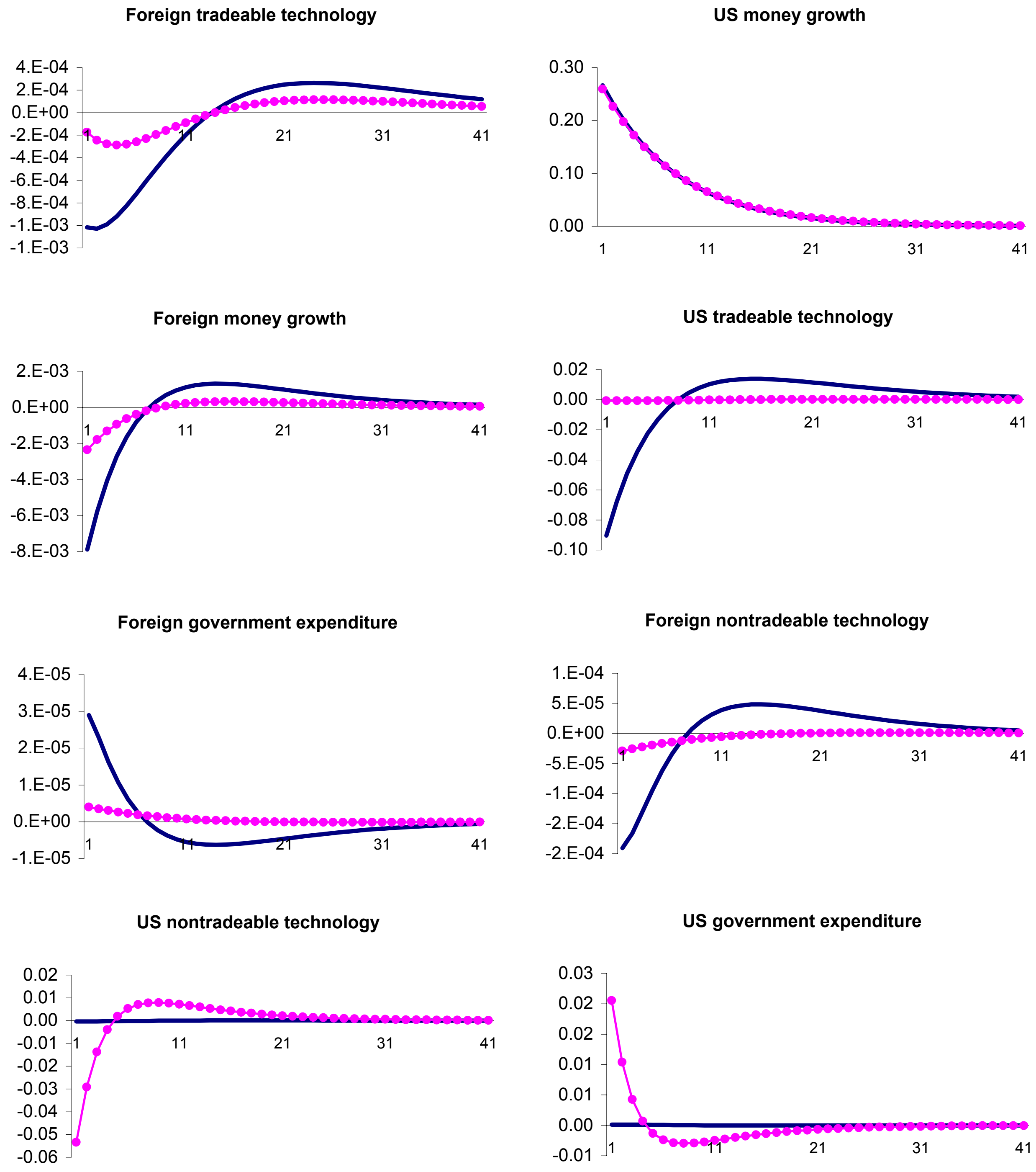
Notes: The calibration of the model differs from Table 6 only with respect to the parameters indicated at the top of each column. Statistics are computed as averages over simulations.

Figure 1: The short-run demand and supply for relative output



The supply (S) and demand (D) schedules are given by equations (8) and (10). The supply schedule is upward-sloping if $\alpha < 1$; in the particular case of constant returns to labour, $\alpha = 1$, the supply relationship is horizontal.

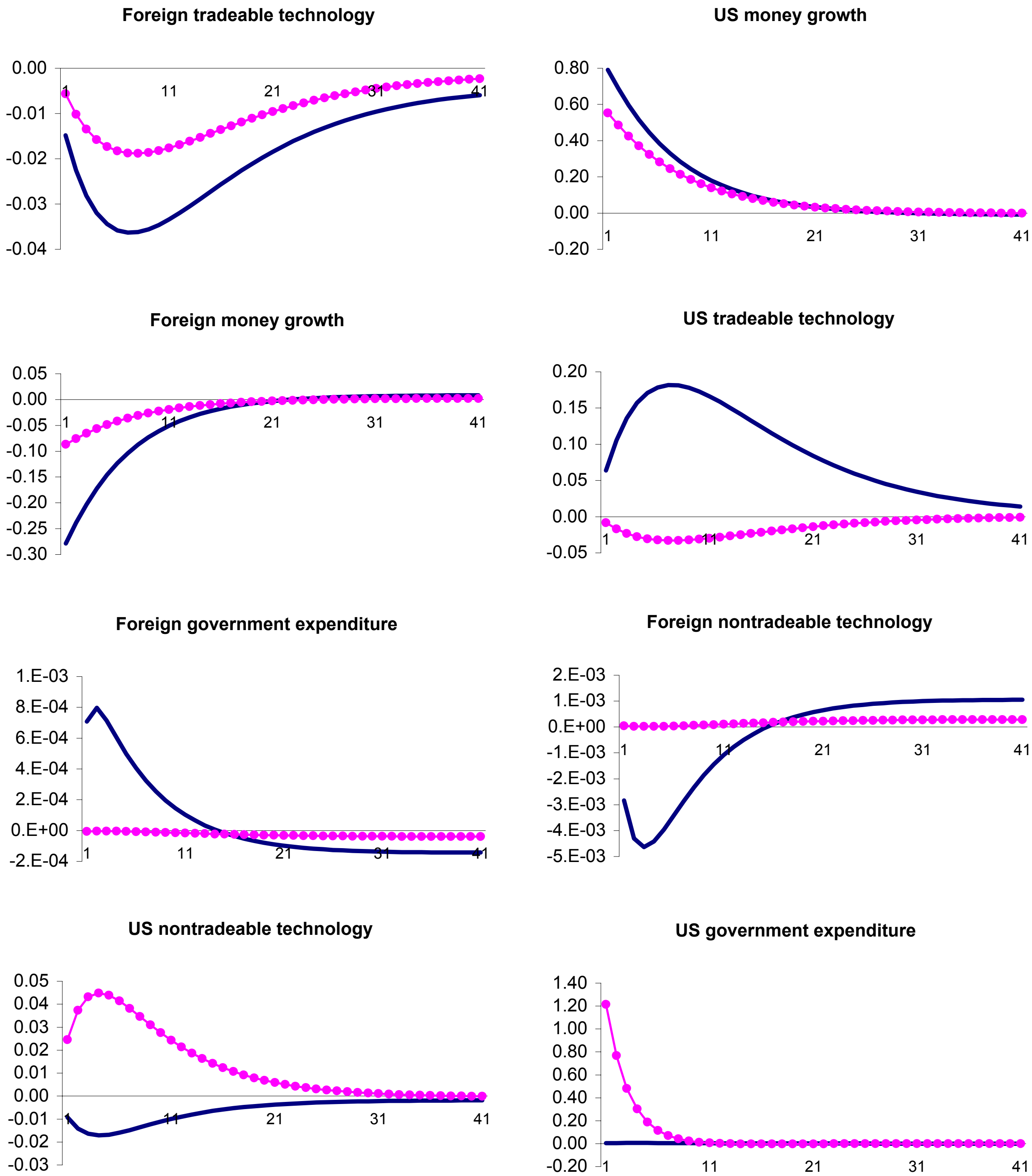
Figure 2: Impulse responses of inflation rates



The solid line indicates tradeable inflation, the dotted line nontradeable inflation. Time is in quarters.

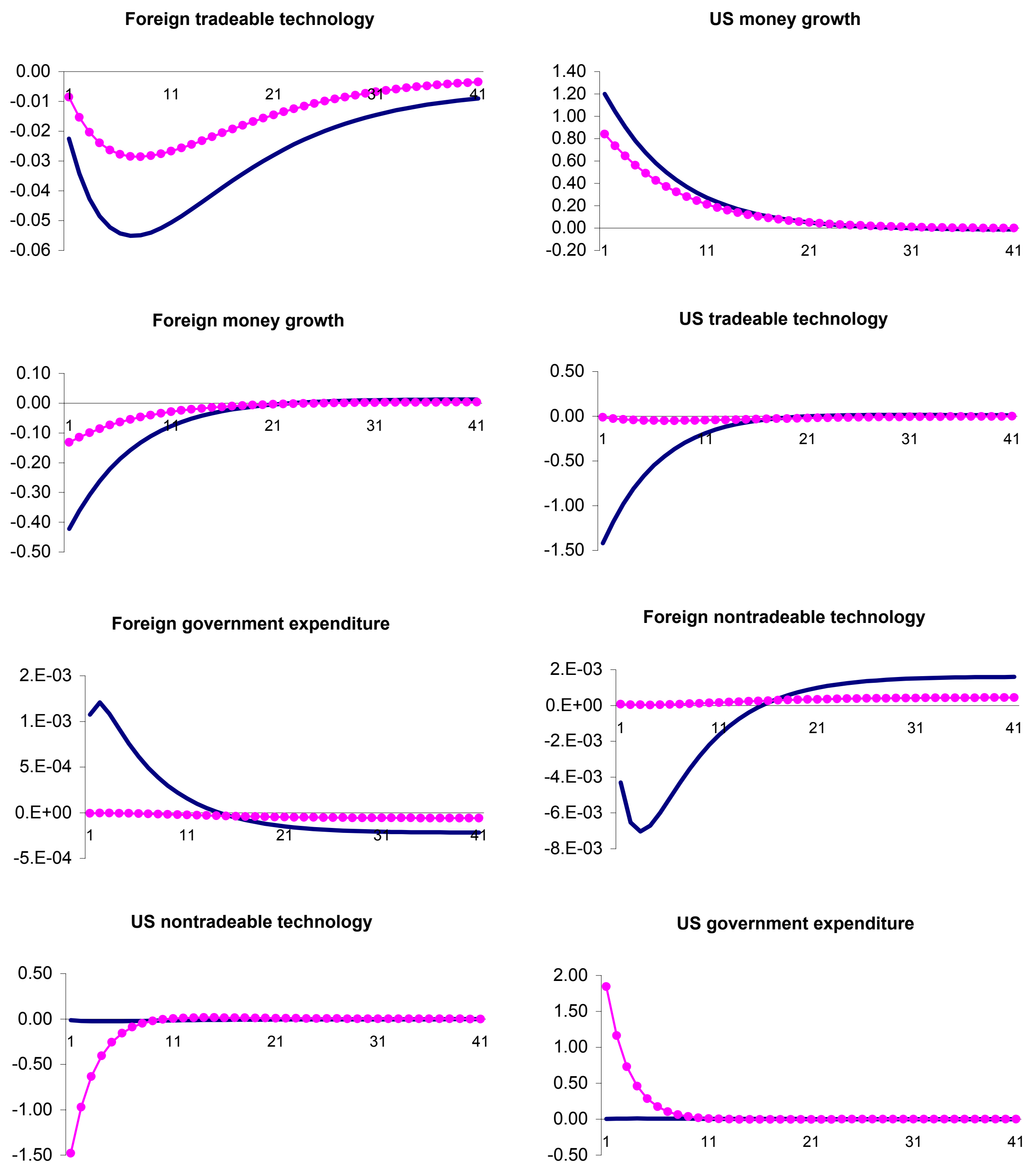
Estimated standard deviations (percent): Foreign tradeable productivity 1.00, US money growth 0.92, Foreign money growth 0.84, US tradeable productivity 0.78, Foreign gov. expenditure 0.26, Foreign nontradeable productivity 0.20, US nontradeable productivity 0.17, US gov. expenditure 0.12.

Figure 3: Impulse responses of output



The solid line indicates tradeable output, the dotted line nontradeable output. Time is in quarters.

Figure 4: Impulse responses of employment



The solid line indicates tradeable employment, the dotted line nontradeable employment. Time is in quarters.

1 Appendices

These appendices describe the data used in the estimation, and explain the derivation of the equations presented in the paper.

A brief overview is as follows:

1.1 Appendix A: Description of data used in the estimation

Several statistical sources have been used in the construction of the dataset. Table A.1 provides a list of all the raw data series and their respective sources, and Table A.2 illustrates the construction of the data variables. Foreign variables are obtained as either geometric or arithmetic weighted averages of individual country variables. The weights are time-varying, and are given by each country's share of total real GDP, measured in a common currency. For consistency, all aggregates are constructed using the same GDP weights. Moreover, real variables are obtained using constant 2000 prices and nominal exchange rates.

One problem encountered in the estimation of the model is the lack of data on tradeable goods consumed in the country of production and tradeable goods consumed abroad. Therefore, a satisfactory approximation has to be found. I assume that Foreign tradeables consumed in the Home country, C_{TF}, are represented by US imports, while the price of Foreign tradeables P^*_{TF} is represented by the producer-based manufacturing price index. The aggregate tradeable price index P_T (which contains both US and Foreign–produced goods) is represented by the consumer-based US commodity price index, while total (domestic and foreign) consumption of tradeables in the Home country, C_T, is represented by the total US consumption of durable and nondurable goods.[1]

[1] These variables are all logged and detrended, therefore, "levels" do not matter.

Table A.1: Raw data

Alias	*Description*	*Source*[a]
$Comp$	Compensation of employees *(US only)*	OECD QNA
$Cons$	Private final consumption expenditure	OECD QNA
$Cons_N$	Expenditure on services, National Income and Product Accounts *(US only)*	BEA
$Cons_T$	Imports from Canada, France, Germany, Japan, Mexico UK *(US only)*	BEA
CPI	Consumer Price Index for all items	OECD MEI
CPI_N	Consumer Price Index for services *(US only)*	BLS
CPI_T	Consumer Price Index for commodities *(US only)*	BLS
$EmpMan$	Employees in manufacturing; except France: Employees in market industries; and UK: Employee jobs in manufacturing	OECD MEI all except UK: ONS
$EmpSer$	Civilian employment in Services. Not including Mexico	OECD QLFS
ER	Market exchange rate; except Mexico: Principal rate. US Dollar per national currency	IMF IFS
Exp	Personal consumption expenditure, National Income and Product Accounts *(US only)*	BEA
Exp_T	Sum of expenditure on durable and nondurable goods, NIPA *(US only)*	BEA
GDP	Gross Domestic Product *(US only)*	OECD QNA
$GExp$	Government final consumption expenditure	OECD QNA
$GFCF$	Gross fixed capital formation *(US only)*	OECD QNA
GNP	Gross National Product *(US only)*	OECD QNA
Inv	Changes in private inventories *(US only)*	OECD QNA
IR	Short-term nominal interest rates - US: 3-month Treasury bill rate, bond equivalent - Canada: 3-month Treasury bill rate - France: 3-month Treasury Bill Rate - Germany: Call money rate - Japan: Call money rate - Mexico: rate on 91-day treasury certificates - UK: 3-month Treasury bill rate, bond equivalent	IMF IFS all except Mexico: OECD MEI
Mon	Monetary aggregate M1; except UK: M2	OECD MEI & IMF IFS
$PrMan$	Index of prod. in total manufacturing, base year 2000	OECD MEI
$PrSer$	Service's Production; except Japan: Index of Production in total services sectors	OECD QNA US: BEA Jap: OECD MEI
PPI_M	Producer Price Index in manufacturing; except Mexico: Export prices index	OECD MEI Mexico: INEGI

[a] Legend: BEA = Bureau of Economic Analysis, US; BLS = Bureau of Labor Statistics, US; ESRI = Economic and Social Research Institute, Japan; ILO = International Labour Organization; IMF IFS = IMF International Financial Statistics; INEGI = Instituto Nacional de Estadística Geografía e Informática, Mexico; OECD MEI = OECD Main Economic Indicators; OECD QNA = OECD Quarterly National Accounts; OECD QLFS = OECD Quarterly Labour Force Statistics; ONS = Office for National Statistics, UK.

Table A.2: Constructed data variables

Series	*Description*
C	Home consumption: $C_t = Cons_t^{US}$
C^*	Foreign consumption: $C_t^* = \sum_j Cons_t^j \cdot ER_0^j$
CA	Home current account as a percentage of consumption in 2000: $CA_t = \frac{GNP_t^{US} - \left(Cons_t^{US} + GFCF_t^{US} + Inv_t^{US} + GExp_t^{US}\right)}{Cons_0^{US}}$
e	Nominal exchange rate: $e_t = \prod_j \left(ER_t^j\right)^{w_t^j}$
G	Home government expenditure relative to consumption: $G_t = \frac{GExp_t^{US}}{Cons_0^{US}}$
G^*	Foreign government exp. relative to consumption: $G_t = \prod_j \left(\frac{GExp_t^j}{Cons_0^j}\right)^{w_t^j}$
i	Home nominal interest rate: $i_t = IR_t^{US}$
i^*	Foreign nominal interest rate: $i_t^* = \sum_j w_t^j \cdot IR_t^j$
μ	Home nominal money growth rate: $\mu_t = \frac{Mon_t^{US} - Mon_{t-1}^{US}}{Mon_{t-1}^{US}}$
μ^*	Foreign nominal money growth rate: $\mu_t^* = \sum_j w_t^j \cdot \frac{Mon_t^j - Mon_{t-1}^j}{Mon_{t-1}^j}$ From 1999:1, the nominal money growth rates for France and Germany are equal to the euro-area money growth rate
M	Home nominal money balances: $M_t = Mon_t^{US}$
M^*	Foreign nominal money balances: $M_t^* = M_{t-1}^* \cdot (1 + \mu_t^*)$
n_N	Employment Home nontradeable sector: $n_{N,t} = EmpSer_t^{US}$
n_N^*	Employment Foreign nontrad. sector: $n_{N,t}^* = \sum_j EmpSer_t^j$ The series are initially normalised to ensure that $n_{N,0}^*$ is equal to the number of persons engaged in the Foreign service sector in 2000 according to the Groningen 60-Industry Database
n_{TH}	Employment in the Home tradeable sector: $n_{TH,t} = EmpMan_t^{US}$
n_{TF}^*	Employment in the Foreign tradeable sector: $n_{TF,t}^* = \sum_j EmpMan_t^j$ The series are initially normalised to ensure that $n_{TF,0}^*$ is equal to the number of persons engaged in Foreign manufacturing in 2000 according to the Groningen 60-Industry Database
P	Home price level: $P_t = CPI_t^{US}$
P^*	Foreign price level: $P_t^* = \prod_j \left(CPI_t^j\right)^{w_t^j}$
P_N	Home nontradeable prices: $P_{N,t} = CPI_{N,t}$
P_T	Home tradeable prices: $P_{T,t} = CPI_{T,t}$
P_{TH}	Price of Home tradeable goods: $P_{TH,t} = PPI_{M,t}^{US}$
P_{TF}^*	Price of Foreign tradeable goods: $P_{TF,t}^* = \prod_j \left(PPI_{M,t}^j\right)^{w_t^j}$
$\frac{P_N \cdot C_N}{P \cdot C}$	Home nontradeable expenditure share: $\frac{P_{N,t} \cdot C_{N,t}}{P_t \cdot C_t} = \frac{Cons_{N,t}}{Exp_t}$
$\frac{P_{TF} \cdot C_{TF}}{P_T \cdot C_T}$	Home import share: $\frac{P_{TF,t} \cdot C_{TF,t}}{P_{T,t} \cdot C_{T,t}} = \frac{Cons_{T,t}}{Exp_{T,t}}$
w^j	Country weights: $w_t^j = \frac{GDP_t^j \cdot ER_0^j}{Y_t^*}$

Table A.2 (continues): Constructed data variables

Series	*Description*
Y	Home output: $Y_t = GDP_t^{US}$
Y_N	Home nontradeable output: $Y_{N,t} = PrSer_t^{US}$
Y_N^*	Foreign nontr. output: $\widehat{Y}_{N,t}^* = \sum_j PrSer_t^j \cdot ER_0^j$ The series are initially normalised to ensure that $Y_{TF,0}^*$ is equal to the value of Foreign manufacturing output in 2000 according to the Groningen 60-Industry Database
Y_{TH}	Home tradeable output: $Y_{TH,t} = PrMan_t^{US}$
Y_{TF}^*	Foreign Tradeable output $Y_{TF,t}^* = \sum_j PrMan_t^j \cdot ER_0^j$ The series are initially normalised to ensure that $Y_{TF,0}^*$ is equal to the value of Foreign manufacturing output in 2000 according to the Groningen 60-Industry Database

Notes: Data variables were constructed with seasonally adjusted data, converted to constant (2000) prices and quarterly frequency. Superscripts are used to denote the country: US denotes the United States, j any of the 6 countries that constitute the Foreign aggregate. Subscripts are used to denote time, with 0 denoting the year 2000. The Groningen 60-Industry Database is constructed by the Groningen Growth and Development Centre.

1.2 Appendix B: Deriving the equations of Section 4

In this Section I describe the derivation of the equations presented in Section 4. Variables with a 'hat' denote percentage or log-deviations from the steady state, while the operator 'd' denotes linear deviations, calculated in proportion to the steady state level of consumption. That is, for any variable X, let X_0 denote the value of the variable at the steady state. Then, $\widehat{X}_t \equiv \frac{X_t - X_0}{X_0} \simeq \log\left(\frac{X_t}{X_0}\right)$, while $dX_t \equiv \frac{X_t}{C_0}$. Money growth rates, government expenditures and bond holdings are all normalised at zero in the steady state.

1.2.1 The short-run supply for relative output

The maximisation problem faced by firm f_{TH} in the Home tradeable sector changing her price at time t is:

$$\begin{array}{ll} \max & E_t \sum_{j=0}^{\infty} (\varphi_{TH}\beta)^j Q_{t,t+j} \left[\begin{array}{c} \frac{p_{TH,t}(f_{TH})}{P_{t+j}} \cdot y_{TH,t+j|t}(f_{TH}) \\ -\frac{W_{TH,t+j}}{P_{t+j}} \cdot \widetilde{h}_{TH,t+j|t}(f_{TH}) \end{array} \right] \\ \text{s.t.} & y_{TH,t+j|t}(f_{TH}) = \left(\frac{p_{TH,t}(f_{TH})}{P_{TH,t+j}}\right)^{-\eta} Y_{TH,t+j} \quad , \end{array}$$

where Y_{TH} is the demand for aggregate Home tradeable output:

$$Y_{TH,t} = C_{TH,t} + C^*_{TH,t} \ .$$

The first-order condition describing optimal price setting is as follows:

$$E_t \sum_{j=0}^{\infty} (\varphi_{TH}\beta)^j Q_{t,t+j} \left[\begin{array}{c} \frac{1}{P_{t+j}} \cdot y_{TH,t+j|t}(f_{TH})(1-\eta) \\ +\eta \cdot \frac{W_{TH,t+j}}{P_{t+j}} \cdot \frac{\vartheta \widetilde{h}_{TH,t+j|t}(f_{TH})}{\vartheta y_{TH,t+j|t}(f_{TH})} \cdot \frac{y_{TH,t+j|t}(f_{TH})}{p_{TH,t}(f_{TH})} \end{array} \right] = 0 \ .$$

Given the sequences $\{C_t\}$, $\{P_t\}$, $\{W_{TH,t}\}$, $\{P_{TH,t}\}$ and $\{Y_{TH,t}\}$, the sequences of shocks and the initial conditions, each producer that chooses a new price in period t will choose the same price $p_{TH,t}(f_{TH})$ and the same level of output $y_{TH,t+j|t}(f_{TH})$. Then the optimal paths of prices $\{p_{TH,t}(f_{TH}), P_{TH,t}\}$ satisfy the above first-order condition and the following law of motion:

$$P_{TH,t} = \left[\varphi_{TH} P_{TH,t-1}^{1-\eta} + (1-\varphi_{TH})\, p_{TH,t}(f_{TH})^{1-\eta}\right]^{\frac{1}{1-\eta}} \ .$$

By log-linearising the law of motion above we get:

$$\widehat{X}_t = \frac{\varphi_{TH}}{1-\varphi_{TH}} \pi_{TH,t} \ ,$$

where $X_t \equiv \frac{p_{TH,t}(f_{TH})}{P_{TH,t}}$, and $\pi_{TH,t} \equiv \log \frac{P_{TH,t}}{P_{TH,t-1}}$ is the inflation rate in the Home tradeable goods sector. Notice that:

$$\widehat{X}_{t+j}=\widehat{X}_t-\sum_{s=1}^{j}\pi_{TH,t+s}=\frac{\varphi_{TH}}{1-\varphi_{TH}}\pi_{TH,t}-\sum_{s=1}^{j}\pi_{TH,t+s}\ ,$$

where $X_{t+j}\equiv\frac{p_{TH,t}(f_{TH})}{P_{TH,t+j}}$. From the individual firm's production function:

$$y_{TH,t}\left(f_{TH}\right)=z_{TH,t}\cdot\widetilde{h}_{TH,t}\left(f_{TH}\right)^{\alpha}\ ,$$

we obtain:

$$\frac{\vartheta\widetilde{h}_{TH,t+j|t}\left(f_{TH}\right)}{\vartheta y_{TH,t+j|t}\left(f_{TH}\right)}=\frac{1}{\alpha}\cdot\left(z_{TH,t+j}\right)^{-\frac{1}{\alpha}}\cdot\left(y_{TH,t+j|t}\left(f_{TH}\right)\right)^{\frac{1}{\alpha}-1}\ .$$

Substituting the above expression into the first-order condition and multiplying by $p_{TH,t}\left(f_{TH}\right)$ we obtain:

$$E_t\sum_{j=0}^{\infty}\left(\varphi_{TH}\beta\right)^j Q_{t,t+j}\left[\begin{array}{c}\frac{p_{TH,t}(f_{TH})}{P_{TH,t+j}}\cdot\frac{P_{TH,t+j}}{P_{t+j}}\cdot y_{TH,t+j|t}\left(f_{TH}\right)\left(1-\eta\right)\\+\frac{\eta}{\alpha}\cdot\left(z_{TH,t+j}\right)^{-\frac{1}{\alpha}}\cdot\frac{W_{TH,t+j}}{P_{t+j}}\cdot\left(y_{TH,t+j|t}\left(f_{TH}\right)\right)^{\frac{1}{\alpha}}\end{array}\right]=0\ .$$

Now we log-linearise around a deterministic equilibrium or steady state in which all the exogenous stochastic processes are set equal to their unconditional means, their variances are set to zero, the individuals hold no internationally traded bond. In this deterministic equilibrium $p_{TH,t}\left(f_{TH}\right)=P_{TH,t+j}$. We obtain:

$$E_t\sum_{j=0}^{\infty}\left(\varphi_{TH}\beta\right)^j\left[\begin{array}{c}\widehat{X}_{t+j}+\widehat{P}_{TH,t+j}-\widehat{P}_{t+j}+\widehat{y}_{TH,t+j|t}\left(f_{TH}\right)\\-\left(-\frac{1}{\alpha}\cdot\widehat{z}_{TH,t+j}+\widehat{W}_{TH,t+j}-\widehat{P}_{t+j}+\frac{1}{\alpha}\cdot\widehat{y}_{TH,t+j|t}\left(f_{TH}\right)\right)\end{array}\right]=0\ .$$

Log-linearising output demand:

$$y_{TH,t+j|t}\left(f_{TH}\right)=\left(\frac{p_{TH,t}\left(f_{TH}\right)}{P_{TH,t+j}}\right)^{-\eta}\left(C_{TH,t+j}+C^{*}_{TH,t+j}\right)\ ,$$

we obtain:

$$\widehat{y}_{TH,t+j|t}\left(f_{TH}\right)=-\eta\cdot\widehat{X}_{t+j}+\widehat{Y}_{TH,t}\ .$$

We can substitute into the log-linearised first-order condition the expressions for $\widehat{X}_{t+j}$ and $\widehat{y}_{TH,t+j|t}\left(f_{TH}\right)$, and after some simplifications we obtain:

$$E_t\sum_{j=0}^{\infty}\left(\varphi_{TH}\beta\right)^j\left[\begin{array}{c}\left(1+\frac{1-\alpha}{\alpha}\eta\right)\frac{\varphi_{TH}}{1-\varphi_{TH}}\pi_{TH,t}-\left(1+\frac{1-\alpha}{\alpha}\eta\right)\sum_{s=1}^{j}\pi_{TH,t+s}\\+\widehat{P}_{TH,t+j}-\widehat{W}_{TH,t+j}+\frac{1}{\alpha}\widehat{z}_{TH,t+j}-\frac{1-\alpha}{\alpha}\widehat{Y}_{TH,t}\end{array}\right]=0\ ,$$

which can be further simplified as follows:

$$
\begin{aligned}
&\frac{1}{1-\varphi_{TH}\beta}\frac{\varphi_{TH}}{1-\varphi_{TH}}\left(1+\frac{1-\alpha}{\alpha}\eta\right)\pi_{TH,t} = \\
&\frac{1}{1-\varphi_{TH}\beta}\left(1+\frac{1-\alpha}{\alpha}\eta\right)E_t\sum\nolimits_{j=1}^{\infty}\left(\varphi_{TH}\beta\right)^j\pi_{TH,t+j} \\
&-E_t\sum\nolimits_{j=0}^{\infty}\left(\varphi_{TH}\beta\right)^j\left[\widehat{P}_{TH,t+j}-\widehat{W}_{TH,t+j}+\frac{1}{\alpha}\widehat{z}_{TH,t+j}-\frac{1-\alpha}{\alpha}\widehat{Y}_{TH,t}\right] .
\end{aligned}
$$

Finally, simplifying and using the law of iterated expectations, we can write the forward-looking equation for inflation in the Home tradeable goods sector:

$$
\pi_{TH,t} = \beta E_t\pi_{TH,t+1} + \left(\frac{1-\varphi_{TH}\beta}{1+\frac{1-\alpha}{\alpha}\eta}\frac{1-\varphi_{TH}}{\varphi_{TH}}\right)\left(\widehat{W}_{TH,t}-\widehat{P}_{TH,t}-\frac{1}{\alpha}\widehat{z}_{TH,t}+\frac{1-\alpha}{\alpha}\widehat{Y}_{TH,t}\right) .
$$

The forward-looking equation links current inflation to expected future inflation and real marginal costs, since:

$$
\widehat{MC}_{TH,t} = \widehat{W}_{TH,t}-\widehat{P}_{TH,t}-\frac{1}{\alpha}\widehat{z}_{TH,t}+\frac{1-\alpha}{\alpha}\widehat{Y}_{TH,t} ,
$$

where MC_{TH} is real marginal cost in sector TH. In the particular case of constant returns to labour ($\alpha = 1$), the level of output does not affect real marginal costs, and the equation becomes more standard:

$$
\pi_{TH,t} = \beta E_t\pi_{TH,t+1} + \left(1-\varphi_{TH}\beta\right)\frac{1-\varphi_{TH}}{\varphi_{TH}}\left(\widehat{W}_{TH,t}-\widehat{P}_{TH,t}-\widehat{z}_{TH,t}\right) .
$$

In the Home nontradeable sector, the forward-looking equation for inflation is:

$$
\pi_{N,t} = \beta E_t\pi_{N,t+1} + \left(\frac{1-\varphi_{N}\beta}{1+\frac{1-\alpha}{\alpha}\eta}\frac{1-\varphi_{N}}{\varphi_{N}}\right)\left(\widehat{W}_{N,t}-\widehat{P}_{N,t}-\frac{1}{\alpha}\widehat{z}_{N,t}+\frac{1-\alpha}{\alpha}\widehat{Y}_{N,t}\right) .
$$

If we make use of the simplifying assumption $\varphi_{TH} = \varphi_N = \varphi$ then the following relationship holds:

$$
\begin{aligned}
&\pi_{TH,t}-\pi_{N,t} = \beta E_t\left(\pi_{TH,t+1}-\pi_{N,t+1}\right) \\
&+\left(\frac{1-\varphi\beta}{1+\frac{1-\alpha}{\alpha}\eta}\frac{1-\varphi}{\varphi}\right)\left[\begin{array}{c}\left(\widehat{W}_{TH,t}-\widehat{P}_{TH,t}-\frac{1}{\alpha}\widehat{z}_{TH,t}+\frac{1-\alpha}{\alpha}\widehat{Y}_{TH,t}\right)\\ -\left(\widehat{W}_{N,t}-\widehat{P}_{N,t}-\frac{1}{\alpha}\widehat{z}_{N,t}+\frac{1-\alpha}{\alpha}\widehat{Y}_{N,t}\right)\end{array}\right] .
\end{aligned}
$$

Moreover, if we assume that the economy is at the steady state in period $t-1$, then $\pi_{TH,t} = \widehat{P}_{TH,t}$ and $\pi_{N,t} = \widehat{P}_{N,t}$, therefore we can write:

$$\widehat{P}_{TH,t} - \widehat{P}_{N,t} = \beta E_t\left(\pi_{TH,t+1} - \pi_{N,t+1}\right) +$$
$$+\left(\frac{1-\varphi\beta}{1+\frac{1-\alpha}{\alpha}\eta}\frac{1-\varphi}{\varphi}\right)\left[\begin{array}{c}\left(\widehat{W}_{TH,t} - \widehat{P}_{TH,t} - \frac{1}{\alpha}\widehat{z}_{TH,t} + \frac{1-\alpha}{\alpha}\widehat{Y}_{TH,t}\right) \\ -\left(\widehat{W}_{N,t} - \widehat{P}_{N,t} - \frac{1}{\alpha}\widehat{z}_{N,t} + \frac{1-\alpha}{\alpha}\widehat{Y}_{N,t}\right)\end{array}\right] .$$

1.2.2 The short-run demand for relative output

The derivation is divided into the following steps:

1. First, find the expressions for the aggregate Home tradeable and non-tradeable output demands.
2. Find the log-linearised demands for aggregate Home tradeable and nontradeable output and for Foreign tradeable output.
3. Using the Home and Foreign aggregate resource constraints, substitute out from the demand for Y_{TH} the share that comes from the Foreign country.
4. Using the formulas for the CES aggregators, substitute out the consumption indexes, then find the short-run demand for relative output.

Step 1
The demand for the output produced by the individual firm f_{TH} is:

$$y_{TH,t}\left(f_{TH}\right) = \left(\frac{p_{TH,t}\left(f_{TH}\right)}{P_{TH,t}}\right)^{-\eta}\left[C_{TH,t} + C^*_{TH,t}\right] .$$

The aggregate price index for Home tradeable goods is:

$$P_{TH} = \left(\int_0^1 p_{TH}\left(f_{TH}\right)^{1-\eta} df_{TH}\right)^{\frac{1}{1-\eta}} .$$

Aggregate tradeable output is defined by the following equation:

$$Y_{TH,t} \equiv \left[\int_0^1 y_{TH,t}\left(f_{TH}\right)^{\frac{\eta-1}{\eta}} df_{TH}\right]^{\frac{\eta}{\eta-1}} .$$

Therefore, the demand for aggregate Home tradeable output is given by:

$$Y_{TH,t} = C_{TH,t} + C^*_{TH,t} , \tag{1}$$

and the expression for aggregate Home nontradeable output is similarl, but it includes government expenditure:

$$Y_{N,t} = C_{N,t} + G_t .$$

Step 2

Substituting into the demand for aggregate Home nontradeable output (1) the following expressions:

$$C_{TH,t} = (1-\delta)\left(\frac{P_{TH,t}}{P_{T,t}}\right)^{-\theta} C_{T,t}\ ,$$

$$C^*_{TH,t} = (1-\delta^*)\left(\frac{P^*_{TH,t}}{P^*_{T,t}}\right)^{-\theta} C^*_{T,t}\ ,$$

$$\left(\frac{P_{TH,t}}{P_{T,t}}\right)^{-\theta} = \left[(1-\delta)+\delta\,(T_t)^{1-\theta}\right]^{\frac{\theta}{1-\theta}}\ ,$$

$$\left(\frac{P^*_{TH,t}}{P^*_{T,t}}\right)^{-\theta} = \left[(1-\delta^*)+\delta^*\,(T_t)^{1-\theta}\right]^{\frac{\theta}{1-\theta}}\ ,$$

and log-linearising, we get:

$$\widehat{Y}_{TH,t} = k_1\widehat{C}_{T,t} + (1-k_1)\,\widehat{C}^*_{T,t} + \theta\,(1-k_1)\,(1+k_1-k_1^*)\,\widehat{T}_t\ , \tag{2}$$

where $k_1 = \frac{C_{TH0}}{Y_{TH0}} = (1-\delta)\left(\frac{P_{TH0}}{P_{T0}}\right)^{1-\theta}$, $k_1^* = \frac{C_{TF0}}{Y^*_{TF0}} = (1-\delta^*)\left(\frac{P^*_{TH0}}{P^*_{T0}}\right)^{1-\theta}$ and $k_6 = \frac{C_0}{C_{TH,0}+C^*_{TH,0}}$ are coefficients that can be computed from the steady state equations. Using the same procedure for Home nontradeable output and Foreign tradeable output we get:

$$\widehat{Y}_{N,t} = \widehat{C}_{N,t} + k_7 dG_t\ , \tag{3}$$

$$\widehat{Y}^*_{TF,t} = k_1^*\widehat{C}_{T,t} + (1-k_1^*)\,\widehat{C}^*_{T,t} - \theta k_1^*\,(1+k_1-k_1^*)\,\widehat{T}_t\ , \tag{4}$$

where $k_7 = \frac{C_0}{C_{N,0}}$ and $k_6^* = \frac{C_0^*}{Y^*_{TF0}}$ are coefficients from the steady state.

Step 3

Equations (2) and (4) together imply:

$$\widehat{Y}_{TH,t} - \widehat{Y}^*_{TF,t} = (k_1-k_1^*)\left(\widehat{C}_{T,t} - \widehat{C}^*_{T,t}\right) + \theta\,(1+k_1-k_1^*)\,(1-k_1+k_1^*)\,\widehat{T}_t\ . \tag{5}$$

Equation (5) is the log-linearised demand for $\frac{Y_{TH0}}{Y^*_{TF0}}$ obtained from the individual demand equations. The Home and Foreign aggregate resource constraints are:

$$B_tP_{T,t} = (1+r_{t-1})\,B_{t-1}P_{T,t} + P_{TH,t}\cdot Y_{TH,t} - P_{T,t}C_{T,t}\ ,$$

$$B_t^*\frac{P_{T,t}}{e_t} = (1+r_{t-1})\,B^*_{t-1}\frac{P_{T,t}}{e_t} + P^*_{TF,t}\cdot Y^*_{TF,t} - P^*_{T,t}\cdot C^*_{T,t}\ .$$

After log-linearising around a steady state with $B_0 = 0$ and government expenditures equal to zero, and substituting prices out, we obtain:

$$dB_t = \frac{1}{\beta} dB_{t-1} - (1 - k_1) k_2 k_3 \widehat{T}_t + k_2 k_3 \widehat{Y}_{TH,t} - k_2 k_3 \widehat{C}_{T,t} \ ,$$

$$\frac{C_0}{C_0^*} \frac{P_{T0}}{e_0 P_{T0}^*} dB_t^* = \frac{C_0}{C_0^*} \frac{P_{T0}}{e_0 P_{T0}^*} \frac{1}{\beta} dB_{t-1}^* + k_1^* k_2^* k_3^* \widehat{T}_t + k_2^* k_3^* \widehat{Y}_{TF,t}^* - k_2^* k_3^* \widehat{C}_{T,t}^* \ ,$$

where $k_2 = \frac{P_{TH0} Y_{TH0}}{P_0 C_0} = \frac{P_{T0} C_{T0}}{P_0 C_0} = (1 - \gamma) \left(\frac{P_{T0}}{P_0} \right)^{1-\phi}$, $k_2^* = \frac{P_{TF0}^* Y_{TF0}^*}{P_0^* C_0^*} = \frac{P_{T0}^* C_{T0}^*}{P_0^* C_0^*} = (1 - \gamma) \left(\frac{P_{T0}^*}{P_0^*} \right)^{1-\phi}$, $k_3 = \frac{P_0}{P_{T0}}$ and $k_3^* = \frac{P_0^*}{P_{T0}^*}$ are coefficients from the steady state. Since $dB_t^* = dB_t$, we obtain:

$$\widehat{Y}_{TH,t} = \frac{1}{k_2 k_3} \left(dB_t - \frac{1}{\beta} dB_{t-1} \right) + (1 - k_1) \widehat{T}_t + \widehat{C}_{T,t} \ ,$$

$$\widehat{Y}_{TF,t}^* = - \frac{1}{k_2^* k_3^*} \frac{P_{T0}}{e_0 P_{T0}^*} \frac{C_0}{C_0^*} \left(dB_t - \frac{1}{\beta} dB_{t-1} \right) - k_1^* \widehat{T}_t + \widehat{C}_{T,t}^* \ .$$

Therefore:

$$\begin{aligned} \widehat{Y}_{TH,t} - \widehat{Y}_{TF,t}^* = & - (1 - k_1 + k_1^*) k_4 \left(\frac{1}{\beta} dB_{t-1} - dB_t \right) \\ & + (1 - k_1 + k_1^*) \widehat{T}_t + \widehat{C}_{T,t} - \widehat{C}_{T,t}^* \ , \end{aligned} \tag{6}$$

where $k_4 = \frac{1}{1 - k_1 + k_1^*} \left(\frac{1}{k_2 k_3} + \frac{P_{T0}}{e_0 P_{T0}^*} \frac{C_0}{C_0^*} \frac{1}{k_2^* k_3^*} \right)$. Equation (6) is the log-linearised demand for $\frac{Y_{TH0}}{Y_{TF0}^*}$ obtained from the Home and Foreign aggregate resource constraints. Equations (5) and (6) together imply:

$$\widehat{C}_{T,t}^* = \widehat{C}_{T,t} - [\theta (1 + k_1 - k_1^*) - 1] \widehat{T}_t - k_4 \left(\frac{1}{\beta} dB_{t-1} - dB_t \right) \ . \tag{7}$$

Substituting (7) into (2) we obtain:

$$\widehat{Y}_{TH,t} = \widehat{C}_{T,t} + (1 - k_1) \widehat{T}_t - (1 - k_1) k_4 \left(\frac{1}{\beta} dB_{t-1} - dB_t \right) \ . \tag{8}$$

Step 4

From the equations:

$$C_{T,t} = (1 - \gamma) \left(\frac{P_{T,t}}{P_t} \right)^{-\phi} C_t \ ,$$

$$C_{N,t} = \gamma \left(\frac{P_{N,t}}{P_t} \right)^{-\phi} C_t \ ,$$

and substituting out the price indexes, we get the log-linearised demand for C_T and :

$$\widehat{C}_{T,t} = -\phi(1-k_1)(1-k_2)\widehat{T}_t - \phi(1-k_2)\left(\widehat{P}_{TH,t} - \widehat{P}_{N,t}\right) + \widehat{C}_t \ , \qquad (9)$$

$$\widehat{C}_{N,t} = \phi(1-k_1)k_2\widehat{T}_t - \phi k_2\left(\widehat{P}_{N,t} - \widehat{P}_{TH,t}\right) + \widehat{C}_t \ . \qquad (10)$$

By substituting (9) into (8) we obtain:

$$\widehat{Y}_{TH,t} = -\left[\phi(1-k_2)-1\right](1-k_1)\widehat{T}_t - \phi(1-k_2)\left(\widehat{P}_{TH,t} - \widehat{P}_{N,t}\right) + \widehat{C}_t - (1-k_1)k_4\left(\frac{1}{\beta}dB_{t-1} - dB_t\right) \ . \qquad (11)$$

And by substituting (10) into (3) we obtain:

$$\widehat{Y}_{N,t} = \phi(1-k_1)k_2\widehat{T}_t + \phi k_2\left(\widehat{P}_{TH,t} - \widehat{P}_{N,t}\right) + \widehat{C}_t + k_7 dG_t \ . \qquad (12)$$

Finally, subtracting (12) from (11) we obtain the short-run demand for relative output:

$$\widehat{Y}_{TH,t} - \widehat{Y}_{N,t} = (1-\phi)(1-k_1)\widehat{T}_t - \phi\left(\widehat{P}_{TH,t} - \widehat{P}_{N,t}\right) + (1-k_1)k_4\left(dB_t - \frac{1}{\beta}dB_{t-1}\right) - k_7 dG_t \ .$$

1.3 Appendix C: Derivation of the moment conditions

In this Section I clarify the derivation of the moment conditions presented in Table 4.

Moment condition # 1:

The steady state of the model coincides with the flexible price equilibrium, hence prices are a markup over marginal costs. Moreover, $p_{TH,0}(f_{TH}) = P_{TH,0}$. Therefore, the following equations are satisfied:

$P_{TH,0} = \frac{\eta}{\eta-1} \cdot W_{TH,0} \cdot \frac{1}{\alpha} \cdot \frac{1}{z_{TH,0}} \cdot \widetilde{h}_{TH,0}(f_{TH})^{1-\alpha}$

$P_{N,0} = \frac{\eta}{\eta-1} \cdot W_{N,0} \cdot \frac{1}{\alpha} \cdot \frac{1}{z_{N,0}} \cdot \widetilde{h}_{N,0}(f_N)^{1-\alpha}$

$P_{TH,0}Y_{TH,0} = \frac{1}{\alpha}\frac{\eta}{\eta-1} \cdot W_{TH,0}\widetilde{h}_{TH,0}$

$P_{N,0}Y_{N,0} = \frac{1}{\alpha}\frac{\eta}{\eta-1} \cdot W_{N,0} \cdot \widetilde{h}_{N,0}$

$P_{TH,0}Y_{TH,0} + P_{N,0}Y_{N,0} = \frac{1}{\alpha}\frac{\eta}{\eta-1} \cdot W_{TH,0}\widetilde{h}_{TH,0} + \frac{1}{\alpha}\frac{\eta}{\eta-1} \cdot W_{N,0}\widetilde{h}_{N,0}$

$$\frac{W_{TH,0}\widetilde{h}_{TH,0} + W_{N,0}\widetilde{h}_{N,0}}{P_{TH,0}Y_{TH,0} + P_{N,0}Y_{N,0}} = \alpha\frac{\eta-1}{\eta}$$

The right-hand side of the above equation is equal to Total Wages / GDP. The parameter α also affect the estimation of the technology processes.

Moment conditions # 2 and 3:

The Home and Foreign Euler equations for consumption are given by:

$C_t^{-\sigma}\left\{1+\frac{\nu}{C_0}B_t\right\}\frac{P_{T,t}}{P_t}=\beta E_t\left[\left(1+r_t\right)C_{t+1}^{-\sigma}\frac{P_{T,t+1}}{P_{t+1}}\right]$

$\left(C_t^*\right)^{-\sigma}\left[1+\frac{\nu}{C_0}B_t^*\right]\frac{P_{T,t}}{e_tP_t^*}=\beta E_t\left[\left(1+r_t\right)\left(C_{t+1}^*\right)^{-\sigma}\frac{P_{T,t+1}}{e_{t+1}P_{t+1}^*}\right]$

The cost parameter ν is the same for the Home and Foreign countries and $B_t+B_t^*=0$ at any date t. Log-linearising and linearising around the steady state and substituting out $dB_t^*=-dB_t$:

$$\sigma E_t\widehat{C}_{t+1}-\sigma\widehat{C}_t+\nu dB_t=\left(1-\beta\right)\widehat{r}_t+E_t\widehat{P}_{T,t+1}-\widehat{P}_{T,t}-E_t\widehat{P}_{t+1}+\widehat{P}_t \quad (13)$$

$$\sigma E_t\widehat{C}_{t+1}^*-\sigma\widehat{C}_t^*-\nu dB_t=\left(1-\beta\right)\widehat{r}_t+E_t\widehat{P}_{T,t+1}-E_t\widehat{e}_{t+1}-\widehat{P}_{T,t}+\widehat{e}_t-E_t\widehat{P}_{t+1}^*+\widehat{P}_t^* \quad (14)$$

If we define the nominal interest rate as the opportunity cost of holding money with respect to bonds, then we need to adjust the standard Fisher parity condition, to adapt it to the presence of the adjustment cost on bonds.

Home:

$\left(1+i_t\right)\left(1+\frac{\nu}{C_0}B_t\right)=\left(1+r_t\right)E_t\left[\frac{P_{T,t+1}}{P_{T,t}}\right]$

Foreign:

$\left(1+i_t^*\right)\left(1-\frac{\nu}{C_0}B_t\right)=\left(1+r_t\right)E_t\left[\frac{P_{T,t+1}}{P_{T,t}}\frac{e_t}{e_{t+1}}\right]$

Log-linearisation:[2]

$$\widehat{i}_t=\left(\frac{1}{1-\beta}\right)\left(E_t\widehat{P}_{T,t+1}-\widehat{P}_{T,t}\right)+\widehat{r}_t-\frac{1}{1-\beta}\nu dB_t \quad (15)$$

$$\widehat{i}_t^*=\left(\frac{1}{1-\beta}\right)\left(E_t\widehat{P}_{T,t+1}-E_t\widehat{e}_{t+1}\right)-\left(\frac{1}{1-\beta}\right)\left(\widehat{P}_{T,t}-\widehat{e}_t\right)+\widehat{r}_t+\frac{1}{1-\beta}\nu dB_t \quad (16)$$

Finally, the Home and Foreign first-order conditions with respect to money holdings are given by:

$\chi\left(\frac{M_t}{P_t}\right)^{-\varepsilon}=C_t^{-\sigma}-\beta E_t\left[C_{t+1}^{-\sigma}\frac{P_t}{P_{t+1}}\right]$

$\chi\left(\frac{M_t^*}{P_t^*}\right)^{-\varepsilon}=\left(C_t^*\right)^{-\sigma}-\beta E_t\left[\left(C_{t+1}^*\right)^{-\sigma}\frac{P_t^*}{P_{t+1}^*}\right]$

Log-linearising:

$$-\varepsilon\widehat{M}_t+\varepsilon\widehat{P}_t=\frac{1}{1-\beta}\left[-\sigma\widehat{C}_t+\sigma\beta E_t\widehat{C}_{t+1}-\beta\widehat{P}_t+\beta E_t\widehat{P}_{t+1}\right] \quad (17)$$

[2] As in Benigno (2001), uncovered interest parity does not hold. The spread in the nominal interest rates rates reflects a premium on top of the expected exchange rate depreciation:

$$\widehat{i}_t-\widehat{i^*}_t=\left(\frac{1}{1-\beta}\right)\left(E_t\widehat{e}_{t+1}-\widehat{e}_t\right)-2\frac{\nu C_0}{1-\beta}dB_t$$

$$-\varepsilon\widehat{M}_t^* + \varepsilon\widehat{P}_t^* = \frac{1}{1-\beta}\left[-\sigma\widehat{C}_t^* + \sigma\beta E_t\widehat{C}_{t+1}^* - \beta\widehat{P}_t^* + \beta E_t\widehat{P}_{t+1}^*\right] \tag{18}$$

Chari, Kehoe and McGrattan (Review of Economic Studies 2002, page 547), estimate the utility parameters from the US money demand equation with consumption and interest rates. An analogous money demand equation is obtained by using (13) to substitute out $\widehat{C}_{t+1}$ from Equation (17):

$$-\varepsilon\widehat{M}_t+\varepsilon\widehat{P}_t = \tfrac{1}{1-\beta}\begin{bmatrix} -\sigma\widehat{C}_t - \beta\widehat{P}_t + \beta E_t\widehat{P}_{t+1} \\ +\beta\left((1-\beta)\widehat{r}_t + E_t\widehat{P}_{T,t+1} - \widehat{P}_{T,t} - E_t\widehat{P}_{t+1} + \widehat{P}_t + \sigma\widehat{C}_t - \nu dB_t\right)\end{bmatrix}$$

$$-\varepsilon\widehat{M}_t + \varepsilon\widehat{P}_t = \tfrac{1}{1-\beta}\begin{bmatrix} -(1-\beta)\sigma\widehat{C}_t \\ +\beta(1-\beta)\widehat{r}_t + \beta\left(E_t\widehat{P}_{T,t+1} - \widehat{P}_{T,t}\right) - \beta\nu dB_t\end{bmatrix}$$

$$-\varepsilon\widehat{M}_t + \varepsilon\widehat{P}_t = -\sigma\widehat{C}_t + \beta\widehat{r}_t - \tfrac{\beta}{1-\beta}\nu dB_t + \tfrac{\beta}{1-\beta}\left(E_t\widehat{P}_{T,t+1} - \widehat{P}_{T,t}\right)$$

However, the problem with estimating the equation above is the need to have observations on the real interest rate and bond holdings, which may be imperfectly measured. Therefore, I use Equation (15) to substitute out $\widehat{r}_t$:

$$-\varepsilon\widehat{M}_t + \varepsilon\widehat{P}_t = -\sigma\widehat{C}_t + \beta\left[\widehat{i}_t - \left(\tfrac{1}{1-\beta}\right)\left(E_t\widehat{P}_{T,t+1} - \widehat{P}_{T,t}\right) + \tfrac{1}{1-\beta}\nu dB_t\right] - \tfrac{\beta}{1-\beta}\nu dB_t + \tfrac{\beta}{1-\beta}\left(E_t\widehat{P}_{T,t+1} - \widehat{P}_{T,t}\right)$$

Thus, in my setup the money demand equation in the Home country is given by:

$$\varepsilon\left(\widehat{M}_t - \widehat{P}_t\right) - \sigma\widehat{C}_t + \beta\widehat{i}_t = 0$$

and in the Foreign country:

$$\varepsilon\left(\widehat{M}_t^* - \widehat{P}_t^*\right) - \sigma\widehat{C}_t^* + \beta\widehat{i}_t^* = 0$$

Instead of estimating σ and ε from either the Home or the Foreign money demands, I prefer to use a linear combination of the two:

$$\varepsilon\left[\widehat{M}_t - \widehat{P}_t - \left(\widehat{M}_t^* - \widehat{P}_t^*\right)\right] - \sigma\left(\widehat{C}_t - \widehat{C}_t^*\right) + \beta\left(\widehat{i}_t - \widehat{i}_t^*\right) = 0 \tag{19}$$

Equation (19) enables me to use both US and Foreign data with a parsimonious instrument set. It is a "relative" money demand equation, linking changes in $\frac{M/P}{M^*/P^*}$ to: a) changes in relative consumption, and b) changes the interest rate differential.

Moment condition # 4:

The demand for Home nontradeables is given by:

$C_{N,t} = \gamma\left(\frac{P_{N,t}}{P_t}\right)^{-\phi} C_t$

Therefore:

$\frac{P_{N,t}C_{N,t}}{P_tC_t} = \gamma\left(\frac{P_{N,t}}{P_t}\right)^{1-\phi}$

Log-linearising:

$$\widehat{\frac{P_{N,t}C_{N,t}}{P_tC_t}} - (1-\phi)\left(\widehat{P}_{N,t} - \widehat{P}_t\right) = 0$$

Moment condition # 5:
The Home demand for Foreign tradeables is given by:
$C_{TF,t} = \delta \left(\frac{P_{TF,t}}{P_{T,t}} \right)^{-\theta} C_{T,t}$
Therefore, since $P_{TF,t} = e_t \cdot P^*_{TF,t}$:
$\frac{P_{TF,t} C_{TF,t}}{P_{T,t} C_{T,t}} = \delta \left(\frac{P_{TF,t}}{P_{T,t}} \right)^{1-\theta}$
Log-linearising:

$$\frac{\widehat{P_{TF,t} C_{TF,t}}}{P_{T,t} C_{T,t}} - (1-\theta) \left(\widehat{P}^*_{TF,t} + \widehat{e}_t - \widehat{P}_{T,t} \right) = 0$$

Finally, the remaining moment conditions **# 6 to 28** result from the properties of the exogenous stochastic processes $\widehat{x}_i$. The technology processes are thus estimated simultaneously with α.

End