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Abstract

This paper presents an open economy model with tradeable and non-tradeable sectors in which individuals cannot supply labour in both sectors at the same time. In this economy, the Frisch elasticity of labour supply is infinite. I analyse how the infinite labour supply elasticity interacts with the Producer Currency Pricing (PCP) and Local Currency Pricing (LCP) assumptions, and I find that it does not significantly alter the empirical performance of the model with respect to a broad range of statistics.

JEL classification: E24; E32; F41.

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1 Introduction

This paper studies the performance of a two-country dynamic, stochastic, general equilibrium (DSGE) model with tradeable and nontradeable sectors in which individuals cannot supply their labour services in both sectors at the same time. Accounting for the non-convexity arising from this restriction is important for two reasons. First, in real life most people do not or cannot hold two jobs at the same time. Secondly, macroeconomists have developed models with non-convexities which reconcile low individual labour supply elasticities with the observed large fluctuations of aggregate hours over the business cycle. I show that the non-convexity induced by not being able to work in two sectors at the same time implies that the aggregate labour supply has infinite elasticity, as in a classic indivisible labour model. Moreover, I show that the infinite elasticity does not significantly alter the empirical performance of the open economy model with respect to a broad range of statistics.

This paper aims to contribute to the literature by examining the implications of a non-standard assumption regarding the allocation of hours worked between sectors. Many open economy models have two sectors, one producing internationally traded goods and one producing nontradeable goods, so they must also specify how individuals choose to allocate their labour time between the two sectors. The standard assumption is that only the sum of hours worked enters the utility function. As a result, the representative agent is completely indifferent between, say, working 20 hours a week in a tradeable sector firm plus 20 hours in a nontradeable sector firm, and working 40 hours a week in only one of the two firms. Instead I consider an economy in which individual choices are restricted, either work in one sector or the other, so the consumption possibilities set is non-convex. This environment was first introduced by Rogerson (1988b). Like him, I assume employment lotteries with complete markets and derive a stand-in household, whose utility function features both the intensive (hours) and the extensive (participation rates) margins of labour supply. I then show that all the adjustment in the labour supply occurs through the extensive, not the intensive, margin, and the Frisch elasticity of labour supply is infinite.

Since the Frisch elasticity of labour supply cannot be calibrated freely, I investigate whether the assumption that individuals cannot supply their labour services in both sectors at the same time weakens the empirical performance of the model. I find that the infinite intertemporal elasticity has several consequences. First, as expected, employment becomes more sensitive to shocks and more volatile. Moreover, since the labour supply curve becomes flatter, wages become less sensitive to shocks. But because wages affect marginal costs, which in turn affect prices, the smaller is the response of wages, the smaller is the response of prices after a shock. Therefore, the infinite labour supply elasticity dampens the response of prices to exogenous shocks, and in this way it affects the persistence of the model-generated series. The higher is the labour supply elasticity, the lesser is the price adjustment, and the higher is the persistence of the series. Additionally, through its impact on the co-movement of the variables at longer horizons, the labour supply elasticity affects some cross correlations.

As mentioned before, this paper is closely related to Rogerson (1988b), and more generally to the literature on how non-convexities associated with the individual labour supply affect the aggregate economy. As it is well known, the observed large fluctuations in aggregate hours imply that the aggregate labour supply elasticity must be large (Prescott 2005). Moreover, a large labour supply elasticity is important for monetary shocks to have persistent effects on output (Chari, Kehoe and McGrattan 2000). However, estimated intertemporal elasticities from microeconometric studies are well below the calibrated values in macroeconomic models. Seminal work by Hansen (1985) and Rogerson (1988a) showed that these opposing facts can be reconciled by assuming that individual agents are only allowed to make the choice as to whether to be employed or not, but cannot choose their hours of work. In this environment, the elasticity of labour supply of the stand-in aggregate household is infinite. Critics of Rogerson's aggregation theory consider it to be at odds with microeconomic observations, because it relies on employment lotteries with complete markets. However, recently Ljungqvist and Sargent (2005, 2011), and Rogerson and Wallenius (2009) have explored an alternative 'time-averaging' aggregation theory, according to which individuals face a $\{0, 1\}$ employment choice and choose what fraction of their lifetime to work, smoothing consumption across periods by trading in a risk-free asset. Notably, this evolving area of research is absent from the open economy literature, despite the fact that a special kind of labour indivisibility arises quite naturally in economies with sectors (Rogerson 1988b).

The model I develop is related to the New Open Economy Macroeconomics (NOEM) literature. Since the seminal work of Obstfeld and Rogoff (1995), this class of models has been considerably extended. An important issue in this literature is the choice of currency of invoicing. This choice is important because in a two-country, two-currency world it is possible to model price rigidity in different ways. One way, for example, is to assume that the law of one price holds and that prices are sticky in the currency of the producer (producer currency pricing or PCP). This assumption is made, among others, by Obstfeld and Rogoff (1995, 2000, 2007), Corsetti and Pesenti (2001), Galí and Monacelli (2005), and Benigno (2009). Another possibility is to assume that prices are sticky in the currency of the destination market (local currency pricing or LCP). This assumption is made, for example, by Betts and Devereux (1996, 2000), Kollmann (2001), Chari, Kehoe and McGrattan (2002), Benigno and Thoenissen (2003), and Sutherland (2005). To date, the choice of pricing assumption and the degree of exchange rate pass-through (ERPT) into import prices are still open questions in the literature. One of the contributions of this paper is to analyse how the labour supply elasticity interacts with the PCP and LCP assumptions. I follow the approach of Corsetti and Pesenti (2005) and I allow the pass-through elasticity to be either one or zero. I show that the infinite Frisch elasticity increases the volatility of the terms of trade in the PCP scenario, but decreases it in the LCP scenario. I also show that a finite and relatively low labour supply elasticity is key to generate countercyclical net exports as in the data, but this only happens in the LCP case. All in all, if we consider the overall performance with respect to a broad set of moments, under both LCP and PCP, then the assumption that individuals cannot work in two sectors at the same time does not worsen, or improve significantly, the ability of the model to match the data.

The remainder of the paper is as follows. Section 2 illustrate the model, and Section 3 the alternative assumption that individuals supply labour contemporaneously in both sectors. The calibration of the model is described in Section 4. Sections 5 and 6 explain the findings, and Section 7 concludes.

2 The model

The model includes features such as Calvo-style price rigidity, nontradeable goods and home bias in consumption. The elasticity of exchange rate pass-through is a free parameter of the model, which nests both PCP and LCP as special cases.

The world economy consists of two countries, Home and Foreign. Both countries have two sectors, and in each sector there exists a continuum of monopolistic firms, each of them producing a single differentiated product, or brand. The notation I use is as follows. 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. All Foreign variables and indexes are denoted with stars. Prices of individual varieties are denoted with lower cases, aggregate prices with upper cases. Steady state variables have a zero time index.

Firms

Each firm has a fixed probability of changing its prices at date t. All prices are set in the currency of the buyer, thus tradeable goods firms in both countries set two different prices, one for the Home market and one for the Foreign market, denominated in the respective local currencies. However, the degree of ERPT is not necessarily zero, since export prices can adjust to changes in the nominal exchange rate.

More formally, I follow the approach of Corsetti and Pesenti (2005), and assume that the local currency prices of exports of Home and Foreign tradeable varieties f_{TH} and f_{TF}^{*} are given, respectively, by:

$$p_{TH,t}^{*}\left(f_{TH}\right)=\frac{\widetilde{p}_{TH,t}\left(f_{TH}\right)}{e_t^{\zeta}}\ , \qquad p_{TF,t}\left(f_{TF}^{*}\right)=e_t^{\zeta}\widetilde{p}_{TF,t}^{*}\left(f_{TF}^{*}\right)\ ,$$

where e is the nominal exchange rate (price of the Home currency in terms of the Foreign currency), ζ is the pass-through elasticity, constant by assumption, and $\widetilde{p}_{TH}\left(f_{TH}\right)$ and $\widetilde{p}_{TF}^{*}\left(f_{TF}^{*}\right)$ are predetermined components that are not adjusted to variations in the exchange rate during period t. Thus, if ζ is equal to one the ERPT is complete, and if ζ is equal to zero the ERPT is zero.

For example, a Home tradeable sector firm f_{TH} chooses the price $p_{TH,t}\left(f_{TH}\right)$ of domestic sales, and the predetermined component $\widetilde{p}_{TH,t}\left(f_{TH}\right)$ of the export price, by solving the following problem:

$$\begin{array}{ll}
\max & E_t \sum_{j=0}^{\infty} (\varphi\beta)^j\, Q_{t,t+j} \left[\begin{array}{c} \frac{p_{TH,t}(f_{TH})}{P_{t+j}} \cdot y_{TH,t+j|t}\,(f_{TH}) \\ +e_{t+j} \frac{p^*_{TH,t+j}(f_{TH})}{P_{t+j}} y^*_{TH,t+j|t}\,(f_{TH}) \\ -\frac{W_{TH,t+j}}{P_{t+j}} \cdot \widetilde{h}_{TH,t+j|t}\,(f_{TH}) \end{array} \right] , \\
\text{s.t.} & y_{TH,t+j|t}\,(f_{TH}) = \left(\frac{p_{TH,t}(f_{TH})}{P_{TH,t+j}} \right)^{-\eta} C_{TH,t+j}\ , \\
& y^*_{TH,t+j|t}\,(f_{TH}) = \left(\frac{p^*_{TH,t+j|t}(f_{TH})}{P^*_{TH,t+j}} \right)^{-\eta} C^*_{TH,t+j}\ , \\
& p^*_{TH,t+j|t}\,(f_{TH}) = \widetilde{p}_{TH,t}\,(f_{TH})\, e^{-\zeta}_{t+j}\ ,
\end{array}$$

where $Q_{t,t+j} = \frac{u'(C_{t+j})}{u'(C_t)}$, and $(\varphi)^j$ is the probability that $p_{TH,t}\,(f_{TH})$ and $\widetilde{p}_{TH,t}\,(f_{TH})$ still apply at the future date $t+j$. The variables $y_{TH,t+j|t}\,(f_{TH})$ and $y^*_{TH,t+j|t}\,(f_{TH})$ denote the Home and Foreign demands for good f_{TH}, and $\widetilde{h}_{TH,t+j|t}\,(f_{TH})$ denotes the total labour input used by the firm, if the prices decided at t still apply at date $t+j$.

Output sold at Home and abroad is produced using a common plant or production function:

$$y_{TH,t}\,(f_{TH}) + y^*_{TH,t}\,(f_{TH}) = z_{TH,t} \cdot \widetilde{h}_{TH,t}\,(f_{TH})^{\alpha}\ , \tag{1}$$

where the parameter α allows for decreasing returns to labour, and z_{TH} represents technology.

In the Foreign country, the production function and maximization problem of the tradeable sector firms f^*_{TF} are the same as in the Home country.

All parameters are assumed to be the same in both countries and sectors. The pricing behaviour and production functions of nontradeable sector firms f_N and f_N^* are as described in this section, except for the fact that nontradeable firms serve only their own domestic market and do not engage in price discrimination.

Consumption indexes

Preferences over tradeable and nontradeable goods in the Home country are specified as follows:[1]

$$C_t = \left[(1-\gamma)^{\frac{1}{\phi}} \left(C_{T,t} \right)^{\frac{\phi-1}{\phi}} + \gamma^{\frac{1}{\phi}} \left(C_{N,t} \right)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} . \tag{2}$$

The Home aggregator for tradeable goods consumption is:

$$C_{T,t} = \left[(1-\delta)^{\frac{1}{\theta}} \left(C_{TH,t} \right)^{\frac{\theta-1}{\theta}} + \delta^{\frac{1}{\theta}} \left(C_{TF,t} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} . \tag{3}$$

The consumption sub-indices for the individual varieties are CES aggregators, with constant elasticity of substitution η. Price indexes are defined as the minimal expenditures needed to buy one unit of the corresponding consumption aggregators.

Government budget constraint and money supply

The Home and Foreign governments purchase only nontradeable goods produced in their own country. The budget constraint of the Home government

[1] Preferences in the Foreign country are described by the same aggregators.

at date t is given by:[2]

$$M_t - M_{t-1} = P_{N,t} G_t + TR_t \ , \tag{4}$$

where G is a CES aggregator of varieties f_N, with the same elasticity of substitution η.

Individual preferences and labour supply

The Home and Foreign countries are populated by a continuum of identical individuals uniformly distributed on $[0, 1]$. I discuss only the Home maximisation problem, since it is the same in both countries. In each period the individual chooses consumption, real money balances $\frac{M}{P}$ and hours worked in each sector. Let $\mathbf{h}_{TH}$ and $\mathbf{h}_N$ denote total hours supplied to all firms in sectors TH and N. Total time available to an employed individual is normalized to one, and total time available to an unemployed individual is denoted with τ. An individual who works incurs a fixed participation or commuting cost ψ. Because of the restriction that labour cannot be supplied in both sectors simultaneously, the individual's consumption possibilities set $\mathbf{X}$ in any given period is non-convex:

$$\mathbf{X} = \left\{ \left(C, \, \frac{M}{P}, \, \mathbf{h}_{TH}, \, \mathbf{h}_N \right) : C \geq 0, \, \frac{M}{P} \geq 0, \, 0 \leq \mathbf{h}_{TH} \leq 1 - \psi, \, 0 \leq \mathbf{h}_N \leq 1 - \psi, \, \mathbf{h}_{TH} \cdot \mathbf{h}_N = 0 \right\} \ .$$

[2] The Foreign government budget constraint and the public expenditure aggregator are entirely analogous.

The individual's utility function[3] is:

$$U_0 = E_0 \sum\nolimits_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma} - 1}{1-\sigma} + \frac{\chi}{1-\varepsilon} \left(\frac{M_t}{P_t} \right)^{1-\varepsilon} + \upsilon \left(\mathbf{h}_{TH,t},\, \mathbf{h}_{N,t} \right) \right] \ ,$$

where:

$$\upsilon \left(\mathbf{h}_{TH,t},\, \mathbf{h}_{N,t} \right) = \begin{cases} \frac{\kappa}{\omega} \left(1 - \psi - \mathbf{h}_{TH,t} \right)^{\omega} & \text{if } \mathbf{h}_{TH,t} \neq 0 \ , \\ \frac{\kappa}{\omega} \left(1 - \psi - \mathbf{h}_{N,t} \right)^{\omega} & \text{if } \mathbf{h}_{N,t} \neq 0 \ , \\ \frac{\kappa}{\omega} \left(\tau \right)^{\omega} & \text{if } \mathbf{h}_{TH,t} = \mathbf{h}_{N,t} = 0 \ . \end{cases}$$

The consumption set can be convexified by adding lotteries over the choice of working in the two sectors, and with complete markets the decentralized equilibrium reproduces the socially optimal allocation. We can define a stand-in household, having a unit mass of identical individuals, whose chosen allocations equal the aggregate quantities of the economy. The household assigns a fraction of its members to sector TH and another fraction to sector N, pools its members' labour incomes and ensures that each one receives the same level of consumption. The utility function of the stand-in household is obtained by aggregating the utility of its members:

[3] I choose these functional forms because Rogerson's (1988b) aggregation theory requires separable preferences, and because analogous functional forms (but not the non-convexity) can be found in the literature; for example, Obstfeld and Rogoff (1995) or Benigno and Thoenissen (2003).

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[\begin{array}{c} \frac{C_t^{1-\sigma}-1}{1-\sigma} + \frac{\chi}{1-\varepsilon}\left(\frac{M_t}{P_t}\right)^{1-\varepsilon} + n_{TH,t} \cdot \frac{\kappa}{\omega}\left(1-\psi-\mathbf{h}_{TH,t}\right)^{\omega} \\ + n_{N,t} \cdot \frac{\kappa}{\omega}\left(1-\psi-\mathbf{h}_{N,t}\right)^{\omega} \\ + \left(1-n_{TH,t}-n_{N,t}\right) \cdot \frac{\kappa}{\omega}\left(\tau\right)^{\omega} \end{array} \right], \tag{5}$$

where n_{TH} and n_N are the probabilities of working in the tradeable and nontradeable sectors, equal to the fractions of individuals at the aggregate level.

The aggregation theory based on employment lotteries has attracted some objections (Ljungqvist and Sargent 2011), but on the other hand the utility function (5) possesses several advantages. First, it disentangles both margins of labour supply, hours and participation rates. Second, since the probabilities enter linearly, it can be interpreted as average or expected utility. Third, this specification does not impose that sectors pay the same wage.

In order to examine the implications for the labour supply elasticity, it is necessary to specify the budget constraint. Individuals trade in a one-period non-contingent real bond, denominated in units of the Home tradeable goods consumption index, sold at the price P_T. Similarly to Benigno (2001), individuals must pay a small cost in order to undertake a position in the international asset market.[4] 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

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

their own country.

The period-t budget constraint of the stand-in household in the Home country is as follows:

$$B_t P_{T,t} + \frac{\nu}{C_0} B_t^2 P_{T,t} + M_t \leq (1 + r_{t-1}) B_{t-1} P_{T,t} + M_{t-1}$$
$$+TR_t - P_t C_t + n_{TH,t} W_{TH,t} \mathbf{h}_{TH,t} + n_{N,t} W_{N,t} \mathbf{h}_{N,t}$$
$$+ \int_0^1 \Pi_{TH,t} (f_{TH}) \, df_{TH} + \int_0^1 \Pi_{N,t} (f_N) \, df_N + R_t \ , \qquad (6)$$

where B is the internationally traded bond, $\frac{\nu}{C_0} B$ is the cost of holding one unit of the bond, which depends on the positive parameter ν, 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} (tradeable sector) and f_N (nontradeable sector), and R represents the rents generated by the financial intermediaries. The internationally traded bond B is in zero net supply worldwide. Wages are flexible.

When both participation rates and hours worked are choice variables the assumption that preferences are separable has important consequences. By combining a few first order conditions of the maximization problem we obtain:

$$\frac{\kappa}{\omega} (1 - \psi - \mathbf{h}_{TH,t})^{\omega} + \kappa (1 - \psi - \mathbf{h}_{TH,t})^{\omega - 1} \mathbf{h}_{TH,t} = \frac{\kappa}{\omega} (\tau)^{\omega} \ , \qquad (7)$$

$$\frac{\kappa}{\omega}\left(1-\psi-\mathbf{h}_{N,t}\right)^{\omega}+\kappa\left(1-\psi-\mathbf{h}_{N,t}\right)^{\omega-1}\mathbf{h}_{N,t}=\frac{\kappa}{\omega}\left(\tau\right)^{\omega} \quad . \tag{8}$$

Equations (7) and (8) above must have a unique solution, but the solution must be the same in the steady state and in each date t. Therefore, in this model hours worked in the two sectors are always constant and equal to each other.[5] This result in turn implies that the first order conditions with respect to the labour effort reduce to only one equation:

$$\kappa\left(1-\psi-\mathbf{h}_{0}\right)^{\omega-1}C_{t}^{\sigma}=\frac{W_{TH,t}}{P_{t}}=\frac{W_{N,t}}{P_{t}} \ , \tag{9}$$

where $\mathbf{h}_0$ is endogenously constant. Notice that in Hansen's (1985) model $\mathbf{h}_0$ is exogenously given instead. Wages are equalized between sectors, and in this model output demand determines the amount of the labour input. The aggregate labour supply, i.e. the supply of $n_t \equiv n_{TH,t} + n_{N,t}$ holding wealth constant, is infinitely elastic, as is the supply of $n_{TH,t}$ and $n_{N,t}$.

3 If labour is supplied in both sectors simultaneously

The standard assumption in the literature is that individuals can work contemporaneously in both the tradeable and nontradeable sectors. For comparability purposes I keep the same functional forms in both scenarios. The

[5] It is possible to ensure that hours worked in the two sectors are different by specifying a different participation cost ψ in the two sectors.

utility function and budget constraint are as follows:

$$U_0 = E_0 \sum\nolimits_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma} - 1}{1-\sigma} + \frac{\chi}{1-\varepsilon} \left(\frac{M_t}{P_t} \right)^{1-\varepsilon} + \frac{\kappa}{\omega} \left(1 - \psi - \mathbf{h}_{TH,t} - \mathbf{h}_{N,t}\right)^{\omega} \right] , \tag{10}$$

$$\begin{aligned} B_t P_{T,t} + \frac{\nu}{C_0} B_t^2 P_{T,t} + M_t \leq (1 + r_{t-1}) B_{t-1} P_{T,t} + M_{t-1} \\ + TR_t - P_t C_t + W_t \left(\mathbf{h}_{TH,t} + \mathbf{h}_{N,t}\right) \\ + \int_0^1 \Pi_{TH,t} \left(f_{TH}\right) df_{TH} + \int_0^1 \Pi_{N,t} \left(f_N\right) df_N + R_t \ . \end{aligned} \tag{11}$$

Since hours worked enter additively, the individual is indifferent between working in one sector or both, provided the aggregate labour supply $\mathbf{h}_t \equiv \mathbf{h}_{TH,t} + \mathbf{h}_{N,t}$ is the same. Notice that in an interior solution sectors must pay the same wage.

It may be possible to interpret (10) as the utility function of a stand-in household, whose hours of work equal aggregate hours in the economy. There are however some unresolved issues. This specification does not distinguish between the intensive and the extensive margins of labour supply, however, if $\mathbf{h}_{TH,t}$ and $\mathbf{h}_{N,t}$ are to be interpreted as aggregate hours, they must be the outcome of choices made on both margins. If, for example, we define the hours in (10) as the product of participation rates times hours worked per person, then this specification is not the average or expected utility. More generally, it is not possible to see how the intensive and extensive margins determine the aggregate hours in (10) without a formal derivation of the utility of the stand-in household from individual preferences.

To examine the implications of (10) for the labour supply elasticity, consider the first order condition with respect to the labour effort:

$$\kappa \left(1-\psi-\mathbf{h}_t\right)^{\omega-1} C_t^{\sigma} = \frac{W_t}{P_t}\ . \tag{12}$$

The Frisch elasticity of the aggregate labour supply is $\frac{1}{1-\omega}\frac{1-\psi-\mathbf{h}_t}{\mathbf{h}_t}$. Given $\mathbf{h}_0$, the choice of ω determines its steady state value. Therefore, the labour supply (for a given level of wealth) is upward sloping.[6] Firms decide how aggregate hours worked are allocated between the two sectors.

4 Parameterization

The parameterization of the model is shown in Table 1.

The parameter σ is the same as in Chari, Kehoe and McGrattan (2002). Given σ, I choose ϵ so that the consumption elasticity of money demand is equal to one, and I choose κ and ψ so that hours worked in the steady state are equal to 324.8/1369.[7]

The elasticity of substitution between tradeable and nontradeable goods is as in Obstfeld and Rogoff (2005). I choose a value for the elasticity of substitution between domestic and foreign tradeables that is somehow in the

[6] Once the Frisch elasticity is chosen, the actual values of κ and ψ are irrelevant to the dynamics of the log-linearized model. Notice that if $\omega = 1$ the elasticity of labour supply becomes infinite.

[7] These numbers are average hours worked in a year and total hours available, taken from Burnside and Eichenbaum (1996).

middle of the range of values in the literature. The preference weight for nontradeables γ is set between the values suggested by Obstfeld and Rogoff (2007) and Benigno and Thoenissen (2003), and the parametrization of δ, the preference weight for Foreign-produced tradeables, is as in Obstfeld and Rogoff (2004). I calibrate the steady state ratios of exogenous technology so that the ratio of Home to Foreign tradeable output is equal to one, and the Home and Foreign ratios of tradeable to nontradeable output[8] are equal to 0.2.

The intermediation cost parameter ν is chosen so that the spread in the nominal interest rates approximates the value suggested by Benigno (2009). The parameter η implies that the steady state markup is about 1.15, and the probabilities of not changing prices imply an average price duration of about one year. The elasticity of output with respect to hours is calibrated so that, given the mark-up, in the steady state the share of wages in output is equal to 0.7.

The growth rates of technology, the money growth rates and government expenditures are all assumed to be exogenously given by AR(1) processes, with zero unconditional means (except for the technology processes). The calibrated parameters of the exogenous processes are taken from Chari, Kehoe and McGrattan (2002) and Corsetti, Dedola and Leduc (2008), and are the same for both countries. Chari, Kehoe and McGrattan (2002) calibrate the variance of the monetary shocks so that their model reproduces the stan-

[8]The ratio of value added in manufacturing over the value added in services is approximately equal to 0.2 in the US. Source: own calculations based on the Groningen 60-Industry Database, http://www.ggdc.net.

dard deviation of US GDP. This method gives a different calibrated value in each specification of the model. Since I want to keep the volatility of the money shocks constant in all parametrizations, I proceed as follows. I compute the standard deviation of the monetary shocks so as to match the standard deviation of US GDP (given all the other parameters in Table 1), under four different scenarios: finite and infinite elasticity, LCP and PCP. I then set the standard deviation of the monetary shocks equal to the average of these four values.

I solve the model numerically using Uhlig's "Toolkit" algorithm (1999). The numerical solution is obtained by log-linearising the equations around a deterministic equilibrium or steady state. I assume that in the steady state bond holdings are zero.

5 Results

I illustrate the performance of the benchmark model against the data and against the alternative assumption that individuals supply labour contemporaneously in both sectors, in which case the Frisch elasticity of labour supply is finite. I consider two values for the Frisch elasticity[9], 1.5 and 0.75, and I report second-order moments in Tables 2 and 3. I consider both pricing

[9] These are steady state values. I choose these two values because most estimates in the macro literature lie in this range. Raffo (2008) reports that the range of estimates for the Frisch elasticity of labour supply is between 1 and 1.5 at the aggregate level. Based on their survey of the literature, Chetty et al. (2011) recommend calibrating macro models to match a Frisch elasticity of aggregate hours of 0.75.

On the other hand, some authors in the NOEM literature assume that the disutility from labour is linear, so the Frisch labour supply elasticity is infinite (for example, Cooke 2010).

assumptions, LCP and PCP.

An important issue to consider beforehand is the measurement of the aggregate labour input. In the benchmark model, all variation in the labour input is due to variation in the extensive margin, or changes in participation rates, so I measure the aggregate labour input with n_t. On the other hand, if individuals supply labour contemporaneously in both sectors, all variation in the labour input is due variation in the intensive margin, or changes in hours, so the aggregate labour input is $\mathbf{h}_t$. Finally, I choose to measure the aggregate labour input in the data with aggregate hours, which are the product of average weekly hours and employment, and therefore reflect changes along both margins.[10]

The other variables of interest are real aggregate output, which is defined as $Y_t \equiv P_{TH,0}Y_{TH,t} + P^*_{TH,0}Y^*_{TH,t} + P_{N,0}Y_{N,t}$, while total tradeable output is $Y^{Tot}_{TH,t} \equiv Y_{TH,t} + Y^*_{TH,t} = C_{TH,t} + C^*_{TH,t}$. The real exchange rate is the ratio of Foreign to Home aggregate price indexes $RER_t \equiv (e_t P^*_t) / P_t$, and the (Home) terms of trade is the relative price of imports over exports:

$$T_t \equiv \frac{P_{TF,t}}{e_t P^*_{TH,t}} \tag{13}$$

Finally, net exports are measured as the ratio of real net exports to real GDP, $NX_t \equiv \left(P^*_{TH,0}Y^*_{TH,t} - P_{TF,0}Y_{TF,t}\right)/Y_t$.

As it is possible to see from Tables 2 and 3, compared with the assumption

[10] This choice is consistent with many studies, including the indivisible labour literature. For example, Hansen (1985) considers total hours (i.e. aggregate) for persons at work in non-agricultural industries. However, other studies measure $\mathbf{h}_t$ with employment data (for example, Chari, Kehoe and McGrattan 2002).

that individuals are indifferent about their hours allocation, the assumption that individuals cannot work simultaneously in both sectors does not significantly alter the performance of the model. The implications for the Frisch elasticity are dramatically different, but, as far as second-order moments are concerned, the performance is similar along several dimensions.

Under both PCP and LCP, the model-implied standard deviations of consumption, output, employment and the nominal exchange rate are fairly close to the data. The cross-correlations of consumption and hours with output are also fairly close to the data. On the other hand, both the benchmark model and the same model modified to accommodate the assumption that individuals supply labour contemporaneously in both sectors do not match the data along several dimensions. They do not generate enough volatility in the real exchange rate and generate too much volatility in the terms of trade. The standard deviation of net exports is well above or well below the data, in the PCP and LCP scenarios, respectively. They generate cross-correlations of the terms of trade, real and nominal exchange rate that are well away from the data. Finally, the model-generated series are not as persistent as the data.

The only significant advantage of having a finite Frisch elasticity is that it allows to replicate countercyclical net exports, but this is only possible in the LCP case. The other most significant effect of the Frisch elasticity is its impact on the standard deviation of the terms of trade in the PCP case, but even with a relatively low value of 0.75 this moment remains well above the value in the data.

Given the focus of this paper on the tradeable and nontradeable sectors, I also report sectoral statistics in Tables 2 and 3. In the data, the tradeable sector is represented by manufacturing, and the nontradeable sector by the service sector. Under both LCP and PCP, the sectoral statistics generated by the benchmark model are similar to the ones obtained with a finite Frisch elasticity. However, only in the PCP scenario the model and its finite-elasticity variant are able to generate more volatile employment and output in the tradeable sector than in the nontradeable sector.[11]

All in all, if we consider the overall performance with respect to a broad set of moments, under both LCP and PCP, then there is no reason to argue that the assumption that individuals cannot work in two sectors at the same time significantly improves, or worsens, the ability of the model to match the data.[12] Naturally, we can ask why the benchmark model and its alternatives in Tables 2 and 3 do not generate exactly the same statistics. I provide an explanation in the paragraphs that follow.

The Frisch elasticity is the elasticity of the labour supply curve, holding wealth constant. Therefore, the larger is this elasticity and the more pronounced is the response of employment after a shock. This intuition is con-

[11] Devereux and Hnatkovska (2012) document the properties of sectoral shares. Notice that, since some manufacturing output is nontradeable, and some services are actually traded internationally, the data is an imprecise measure of the *theoretical* tradeable and nontradeable output levels. To some extent, this is true for all sectoral classifications of the data. Therefore, it is more sensible to investigate the ability of the model to reproduce the same qualitative pattern as in the data (higher volatilities in the tradeable sector), rather than its ability to replicate the data moments quantitatively. I discuss this measurement error in Povoledo (2012).

[12] This is true also when comparing second-order moments obtained under other parametrizations of the model. These are available on request.

firmed by Tables 2 and 3: both sectoral and aggregate employment are more volatile when the Frisch elasticity is higher. But notice that the larger is the Frisch elasticity and the flatter is the labour supply curve, so not only the response of employment is magnified, but also the response of wages is reduced. Since wages affect marginal costs, the lower is the response of wages, the lower is the response of prices after a shock, because firms optimally choose not to raise their prices much if wages do not rise much. Therefore, the higher is the Frisch elasticity, the less responsive are prices.

Since the Frisch elasticity controls the responses of prices after a shock, it fundamentally affects the response of output, at the sectoral as well as the aggregate level. To understand how output is affected by the Frisch elasticity, it is essential to distinguish between supply-type and demand-type shocks.[13] After a positive demand-type shock, such as a positive monetary or government expenditure shock, labour demand increases, putting upward pressure on wages and prices. But the smallest is the increase in prices, the bigger is the effect of the demand shock on output. Therefore, a comparatively high Frisch elasticity amplifies the effect of demand-type shocks on output. On the other hand, after a positive supply-type shock, such as a positive technology shock, labour demand falls, putting downward pressure on wages and therefore prices. The strongest is the fall in prices, the bigger is the effect of the supply-type shock on output. Therefore, a relatively high Frisch elasticity reduces the effect of supply-type shocks on output. In conclusion, the impact

[13] In explaining how output is affected by the Frisch elasticity, for simplicity I only consider shocks originating in the same country and sector.

of the Frisch elasticity on output volatility depends on which shocks are the main source of business cycle fluctuations. Tables 2 and 3 show that the infinite Frisch elasticity causes output to become more volatile: this fact suggests that in the model demand-type shocks are the main cause of business cycles. This intuition is confirmed by a formal variance decomposition exercise that I present in Section 6.

The Frisch elasticity of labour supply also affects the persistence of the model-generated series. Except for the persistence of the shocks, the only other mechanism ensuring persistence is the Calvo price stickiness. If prices were fully flexible the adjustment towards the steady state would be very rapid. As explained above, if the Frisch elasticity of labour supply is relatively high, wages, and therefore marginal costs, do not change much after a shock. As a result, the firms that are allowed to change their price after a shock will optimally choose a small adjustment, and ultimately a small price adjustment gives persistence. Tables 2 and 3 confirm this intuition.[14]

Moreover, since the Frisch elasticity of labour supply affects the persistence, it can also affect the cross correlation between variables. For example, consider any two variables which move together in the same direction, after any shock and at all horizons. If the Frisch elasticity is relatively high, as explained above the adjustment towards the steady state is slower, so the two variables in this example will stay positively correlated at longer horizons. As a result, their correlation coefficient will increase. Of course, not all variables

[14] The only exception is the autocorrelation of the terms of trade, which actually goes down if the Frisch elasticity increases.

move in the same direction at all horizons and after all shocks. This example merely serves to illustrate why the Frisch elasticity matters for some cross correlation coefficients, as shown by Tables 2 and 3, but its impact on any given coefficient cannot be generalised, instead, it must be investigated on a case-by-case basis.

6 Discussion

To further understand the results of Tables 2 and 3 it is important to ascertain which shocks are the main sources of business cycle fluctuations, and how the macroeconomic variables respond to them. The former task can be achieved by performing a variance decomposition exercise, and the latter by inspecting the impulse responses. The variance decompositions are shown in Table 4. For most variables, Home and Foreign money shocks are the main cause of fluctuations, but the impact of technology and government expenditure shocks on aggregate and sectoral employment and output is significant. Since nontradeables make up the largest component of aggregate output, government spending shocks, which affect nontradeables, explain a large proportion of the variance of aggregate output. However, the sum of Home and Foreign money shocks always explains the largest share of the variance of most variables, even of those that are significantly affected by technology and government expenditure shocks.[15] Therefore, for the sake of concision, I only present the responses of the benchmark model variables to domestic money shocks, under

[15] Thus demand-type shocks are the main cause of business cycles.

both PCP and LCP.[16]

Figure 1 shows the responses of consumption, the terms of trade and the real and nominal exchange rates. A positive Home monetary shock causes a nominal depreciation of the Home currency, which is more pronounced in the LCP scenario. Because of price rigidity, the nominal depreciation is accompanied by a real depreciation. Under PCP, the exchange rate pass-through into import prices is full, so the currency depreciation causes an increase in Home import prices plus a fall in export prices, and as a result the terms of trade increases. On the other hand, under LCP there is no exchange rate pass-through, thus the nominal depreciation causes the terms of trade to fall.[17]

As noted in Section 5, the benchmark model and its variant with finite labour supply elasticity have very different implications for the volatility of the terms of trade. I will now provide an explanation of this fact, focusing on monetary shocks only as these explain almost 90% of the variance of the terms of trade. Consider LCP first. After a positive Home monetary shock, the nominal depreciation raises the denominator of Equation 13. Home prices also increase, so the denominator of Equation 13 increases also because of the increase in the predetermined component of export prices. As explained in Section 5, the response of prices depends on the Frisch elasticity. The lower is the Frisch elasticity, the larger is the increase in the predetermined component of export prices, so the more pronounced is the fall in the terms of

[16] I only show the responses of aggregate variables. The responses of sectoral variables and the responses to the other shocks are available on request.

[17] See also Obstfeld and Rogoff (2000) for an analysis of the implications of the PCP and LCP assumptions for the terms of trade.

trade. Therefore, under LCP the terms of trade is more volatile if the Frisch elasticity is relatively low. This intuition is confirmed by Table 2.

Next, consider a positive Home monetary shock under PCP. In this case, a nominal depreciation does not affect the denominator of Equation 13, instead it raises the numerator proportionally.[18] But because the predetermined component of export prices always affects the denominator, the rise in Home prices now dampens the terms of trade increase, so a lower Frisch elasticity lessens the responsiveness of the terms of trade to monetary shocks. As a result, under PCP the terms of trade is less volatile if the Frisch elasticity is relatively low, which is confirmed by Table 3.

Finally, Figure 2 shows the responses of aggregate employment, aggregate output and net exports. The responses of these variables to a Home monetary shock are different under the two scenarios. Under PCP, Home employment, output and net exports all benefit from expenditure-switching (the shift of foreign and domestic demand towards Home tradeable goods). On the other hand, under LCP nominal exchange rate movements are not passed onto international prices, so there is no expenditure-switching. As a result, after a positive Home monetary shock, output and employment increase considerably less and net exports become negative instead. Therefore, the absence of expenditure-switching is crucial for net exports to be counter-cyclical, as in the data. However, notice that, at longer horizons, the responses of net exports and output have the same sign. So the slower is the adjustment towards the steady state, the less negative is the correlation. Hence, in order to ensure

[18] Obstfeld and Rogoff (2000), p. 120.

that the correlation between net exports and output stays negative, one must select a comparatively low Frisch elasticity (see Table 2) because it helps to speed up the adjustment towards the steady state.

7 Conclusion

I consider an open economy with sectors in which labour supply choices are restricted, as individuals can work either in one sector or the other. I introduce a stand-in household that uses employment lotteries to convexify the individual consumption set. The household assigns a fraction of its members to each sector and insures each member's consumption against the income risk. An advantage of this approach is that it shows that labour supply is the outcome of choices made on the extensive and intensive margins, as it has been recognised in microeconometric studies.

In this environment, the Frisch elasticity of the aggregate labour supply is infinite. As a result, employment becomes more sensitive to shocks and more volatile. Moreover, since the labour supply curve becomes flat, wages respond less after a shock. However, wages affect marginal costs, so if wages do not change much after a shock, firms will find it optimal not to adjust their prices much. Consequently, the infinite labour supply elasticity increases the persistence of the model-generated series, although not as much as in the data.

In conclusion, the Frisch elasticity of labour supply controls the response of prices after a shock and its impact on the second-order moments ranges from modest to substantial. However, if we consider the overall performance with respect to a broad set of moments, then the assumption that individuals cannot work in two sectors at the same time does not significantly alter the ability of the model to match the data.

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Appendix

Data sources and calculations

Alias	*Description*	*Source*[a]
	Exports of goods and services; Imports of goods and services (chained volume estimates)	OECD QNA
	Exports deflator; Imports deflator	OECD QNA
	Dollar exchange rates	IMF IFS
C	Private final consumption expenditure	OECD QNA
$\mathbf{Y}$	Gross Domestic Product	OECD QNA
$\mathbf{n}$	Aggregate weekly hours index, total private industries (quarterly averages of monthly data)	FRED
NX	Exports - Imports of goods and services /GDP	
T	Exports deflator / Imports deflator	
e	Geometric GDP-weighted average of France, Germany, Canada, Japan, Mexico and UK dollar exchange rates	
P	Consumer Price Index for all items	OECD MEI
P^*	Geometric GDP-weighted average of Canada, France, Germany, Japan, Mexico and UK CPI indexes	
RER	$= eP^*/P$	
Y_{TH}^{Tot}	Index of production in total manufacturing	OECD MEI
Y_N	Index of real Gross Domestic Product of services	BEA NIPA
n_{TH}	Employees in manufacturing	OECD MEI
n_N	Employees of service-providing industries (quarterly averages of monthly data)	BLS

[a] Legend: BEA NIPA = Bureau of Economic Analysis, National Income and Product Accounts; BLS = Bureau of Labor Statistics; FRED = Federal Reserve Economic Data; IMF IFS = IMF International Financial Statistics; OECD MEI = OECD Main Economic Indicators; OECD QNA = OECD Quarterly National Accounts.

Table 1: Parameter values

Utility	$\beta = 0.99$, $\sigma = \varepsilon = 5$, $\mathbf{h}_0 = 0.24$
Consumption indexes	$\phi = 1$, $\theta = 1$, $\gamma = 0.70$, $\delta = 0.30$
Asset market	$\nu = 0.005$
Firms	$\varphi = 0.75$, $\eta = 7.88$, $\alpha = 0.8$ $\zeta = 0$ (LCP) or $\zeta = 1$ (PCP)
Exogenous processes: $\widehat{x}_{j,t} = \overline{x}_j + \rho_j \cdot \widehat{x}_{j,t-1} + \epsilon_j$	
Money growth	$\rho = 0.68$, $\mathrm{var}(\epsilon) = \mathrm{var}(\epsilon^*) = (0.0151)^2$, $\mathrm{corr}(\epsilon, \epsilon^*) = 0.50$
Tradeable technology	$\rho = 0.95$, $\mathrm{var}(\epsilon) = \mathrm{var}(\epsilon^*) = (0.007)^2$, $\mathrm{corr}(\epsilon, \epsilon^*) = 0.25$
Nontradeable technology	$\rho = 0.95$, $\mathrm{var}(\epsilon) = \mathrm{var}(\epsilon^*) = (0.007)^2$, $\mathrm{corr}(\epsilon, \epsilon^*) = 0.25$
Government expenditure:	$\rho = 0.97$, $\mathrm{var}(\epsilon) = \mathrm{var}(\epsilon^*) = (0.01)^2$, $\mathrm{corr}(\epsilon, \epsilon^*) = 0$

Table 2: Business cycle statistics under LCP

Standard deviations	C	Y	n	NX	T	RER	e	
US data	0.97	1.26	1.78	0.36	2.23	6.12	6.01	
Benchmark model	1.08	1.17	1.64	0.07	3.78	4.55	5.86	
Frisch = 1.5	1.05	1.11	1.56	0.06	3.91	4.49	5.84	
Frisch = 0.75	1.03	1.08	1.49	0.07	3.94	4.42	5.82	
Autocorrelations	C	Y	n	NX	T	RER	e	
US data	0.84	0.85	0.91	0.86	0.83	0.82	0.82	
Benchmark model	0.66	0.68	0.68	0.68	0.57	0.65	0.72	
Frisch = 1.5	0.66	0.67	0.67	0.50	0.59	0.65	0.72	
Frisch = 0.75	0.65	0.66	0.66	0.55	0.59	0.64	0.72	
Cross-correlations	C, Y	Y, Y	n, Y	NX, Y	T, Y	RER, Y	e, Y	
US data	0.81	1.00	0.80	-0.39	0.09	0.11	0.09	
Benchmark model	0.91	1.00	0.85	-0.03	-0.40	0.43	0.39	
Frisch = 1.5	0.91	1.00	0.83	-0.23	-0.41	0.42	0.37	
Frisch = 0.75	0.90	1.00	0.82	-0.26	-0.41	0.41	0.36	
Sectoral standard deviations & cross-correlations	Y_{TH}^{Tot}	Y_N	n_{TH}	n_N	Y_{TH}^{Tot}, Y	Y_N, Y	n_{TH}, Y	n_N, Y
US data	2.50	0.50	1.98	0.89	0.90	0.49	0.82	0.74
Benchmark model	1.03	1.32	1.55	1.90	0.84	0.98	0.68	0.81
Frisch = 1.5	0.99	1.27	1.50	1.82	0.82	0.98	0.65	0.79
Frisch = 0.75	0.97	1.23	1.46	1.76	0.81	0.98	0.62	0.77

NOTE: The data moments have been computed using quarterly series for the period 1980:1 to 2007:4. Data sources and calculations are explained in the Appendix. All moments have been computed from logged and H-P-filtered series, except net exports, which are HP-filtered but not logged.

Table 3: Business cycle statistics under PCP

Standard deviations	C	Y	n	NX	T	RER	e	
US data	0.97	1.26	1.78	0.36	2.23	6.12	6.01	
Benchmark model	1.04	1.54	2.07	0.69	4.68	3.87	5.86	
Frisch = 1.5	1.03	1.42	1.90	0.55	3.18	3.95	5.85	
Frisch = 0.75	1.00	1.37	1.82	0.53	3.10	3.80	5.83	
Autocorrelations	C	Y	n	NX	T	RER	e	
US data	0.84	0.85	0.91	0.86	0.83	0.82	0.82	
Benchmark model	0.67	0.67	0.67	0.66	0.66	0.67	0.73	
Frisch = 1.5	0.66	0.64	0.65	0.58	0.51	0.67	0.73	
Frisch = 0.75	0.66	0.63	0.64	0.57	0.50	0.66	0.73	
Cross-correlations	C, Y	Y, Y	n, Y	NX, Y	T, Y	RER, Y	e, Y	
US data	0.81	1.00	0.80	-0.39	0.09	0.11	0.09	
Benchmark model	0.86	1.00	0.91	0.73	0.73	0.73	0.64	
Frisch = 1.5	0.88	1.00	0.89	0.69	0.66	0.69	0.58	
Frisch = 0.75	0.87	1.00	0.88	0.69	0.66	0.69	0.57	
Sectoral standard deviations & cross-correlations	Y_{TH}^{Tot}	Y_N	n_{TH}	n_N	Y_{TH}^{Tot}, Y	Y_N, Y	n_{TH}, Y	n_N, Y
US data	2.50	0.50	1.98	0.89	0.90	0.49	0.82	0.74
Benchmark model	2.00	1.45	2.65	2.04	0.92	0.97	0.86	0.83
Frisch = 1.5	1.88	1.33	2.49	1.89	0.91	0.97	0.84	0.80
Frisch = 0.75	1.82	1.29	2.41	1.83	0.90	0.97	0.83	0.79

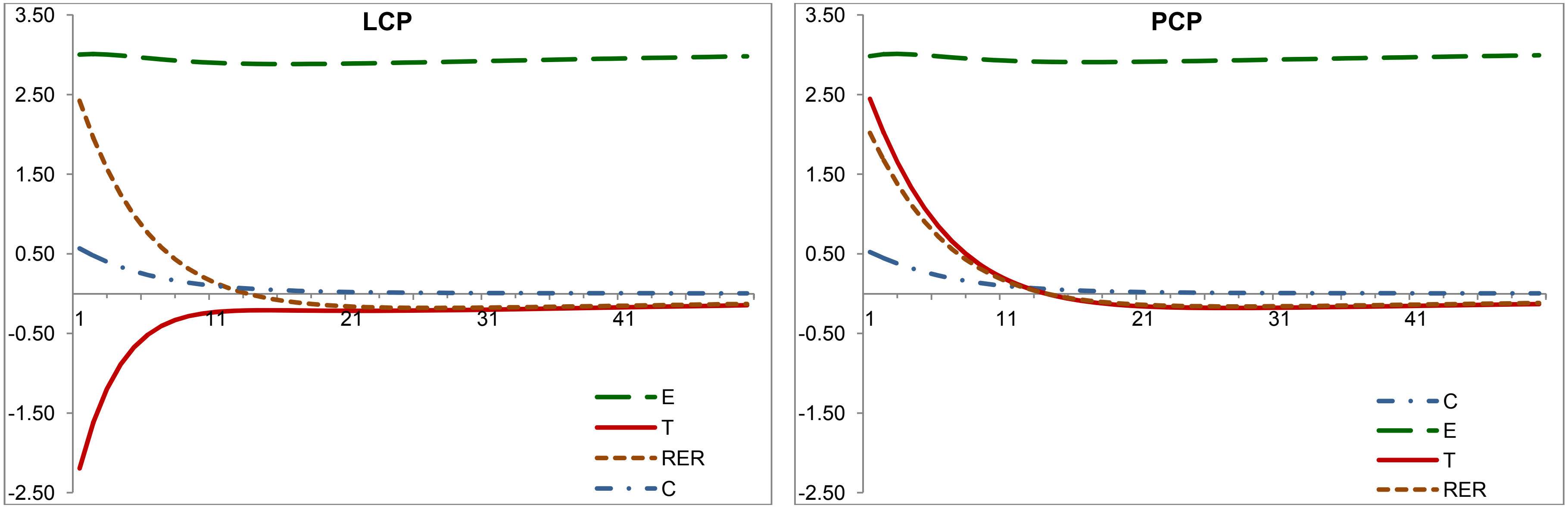
NOTE: See Table 2.

Table 4: Variance decompositions, benchmark model

Variables:	C	Y	n	NX	T	RER	e	Y_{TH}^{Tot}	Y_N	n_{TH}	n_N
Shocks:						LCP					
H money growth	82.93	45.11	32.71	37.85	43.40	48.77	49.99	28.29	34.91	31.09	27.78
F money growth	13.00	8.85	6.42	37.85	43.40	48.77	49.99	20.87	3.96	22.94	3.15
H tradeable technology	0.33	0.97	3.37	8.40	5.01	0.03	0.00	35.50	0.97	28.23	0.77
F tradeable technology	0.09	0.14	0.42	8.40	5.01	0.03	0.00	0.65	0.25	1.60	0.20
H nontradeable technology	3.41	1.72	25.01	3.52	1.48	1.15	0.01	13.07	7.22	14.36	25.71
F nontradeable technology	0.08	0.16	0.85	3.52	1.48	1.15	0.01	0.92	0.36	1.01	0.76
H government expenditure	0.16	43.05	31.22	0.22	0.11	0.05	0.00	0.68	52.31	0.75	41.62
F government expenditure	0.00	0.01	0.00	0.22	0.11	0.05	0.00	0.02	0.00	0.02	0.00
						PCP					
H money growth	80.32	62.11	49.08	47.78	45.24	48.40	49.99	64.86	40.66	67.86	32.92
F money growth	15.40	5.38	4.25	47.78	45.24	48.40	49.99	10.62	3.21	11.11	2.60
H tradeable technology	0.35	0.68	2.59	1.52	3.62	0.04	0.00	17.15	0.89	12.90	0.72
F tradeable technology	0.09	0.10	0.33	1.52	3.62	0.04	0.00	0.31	0.23	0.75	0.19
H nontradeable technology	3.58	1.24	19.09	0.66	1.05	1.49	0.01	6.25	6.65	6.54	23.97
F nontradeable technology	0.09	0.12	0.67	0.66	1.05	1.49	0.01	0.47	0.33	0.49	0.72
H government expenditure	0.17	30.36	23.99	0.04	0.08	0.06	0.00	0.33	48.03	0.34	38.89
F government expenditure	0.00	0.00	0.00	0.04	0.08	0.06	0.00	0.01	0.00	0.01	0.00

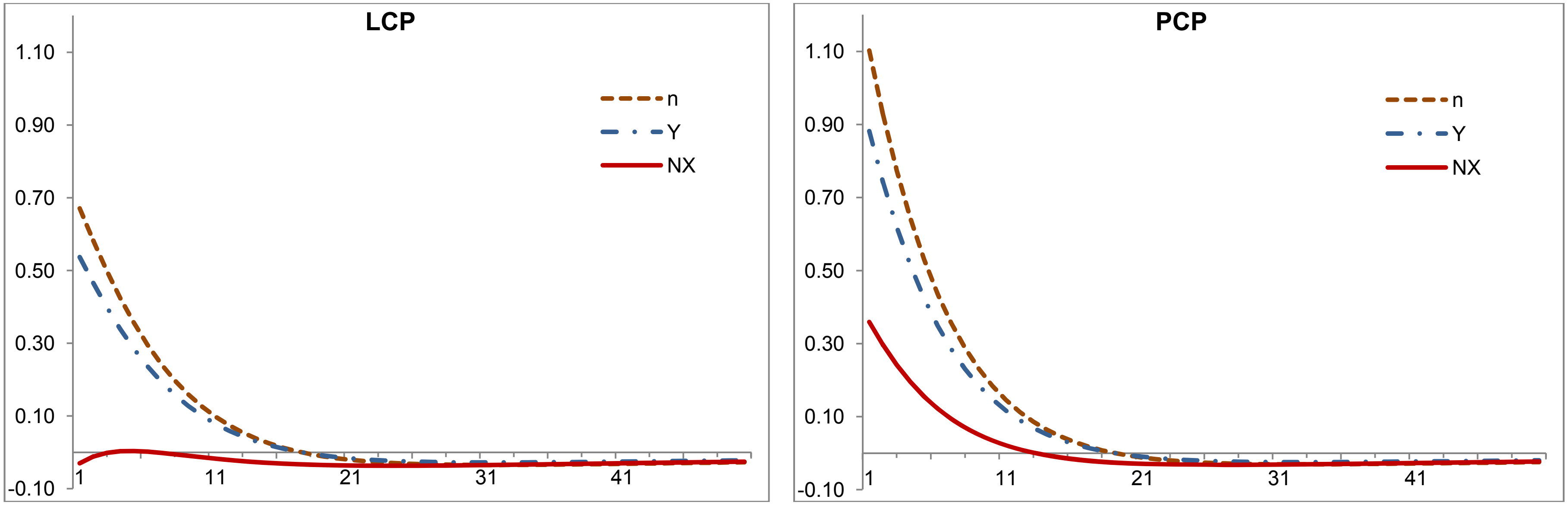
NOTE: Shocks are orthogonalised using the Cholesky method, and the horizon is set at 200 quarters. Each column reports, for each variable, the share of the total variance explained by every shock, measured in per cent. The numbers are averages across all possible variance decompositions, given by the number of different orderings of the 8 shocks (40,320).

Figure 1: Impulse responses to a 1% Home monetary shock, benchmark economy



Note: Time is in quarters.

Figure 2: Impulse responses to a 1% Home monetary shock, benchmark economy



Note: Time is in quarters.