Exchange Rates, Sticky Prices and Equilibrium Unemployment[*]

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Abstract

International monetary economists have had difficulty in accounting for the observed persistence and volatility of real exchange rates using dynamic general equilibrium models with nominal rigidities. We develop an open economy model with nominal rigidity in goods markets and matching frictions in labour markets - a framework which has had considerable success as an explanation of the persistence of inflation, output and unemployment in response to a monetary shock in a closed economy context. We find that the exchange rate channel introduced in an open economy context does not mitigate this account of inflation, output and employment persistence. Rather, this combination of real and nominal rigidities generates a plausible explanation of exchange rate persistence and volatility.

KEYWORDS: Exchange rates; sticky prices; equilibrium unemployment.

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1 Introduction.

In recent years, researchers in international monetary economics have developed a number of small-scale dynamic general equilibrium models of open economies. These models focus on the role of nominal rigidities in determininging the open economy's adjustment to monetary policy and other disturbances, see Chari, Kehoe and McGrattan (2002), Gali and Monacelli (2002), Kollman (2001), McCallum and Nelson (1999).[1] They offer insight into the nature of the shocks hitting the economy, the nature of propagation mechanisms at work and have implications for the design of robust and/or optimal policy rules.

The value of these models for policy analysis lies in the ability of the proposed microfoundations to account for observed behaviour. Unfortunately, although models with nominal rigidities outperform flexible-price models in terms of their ability to match quantitative stylised facts for the open economy, they generate puzzles of their own. For instance, a baseline two-country model with nominal rigidities is unable simultaneously to account for both the volatility and persistence of real exchange rates, Chari, Kehoe and McGrattan (2002). In an analagous small open economy model nominal rigidities explain only some 40-50% of historical exchange rate variation of exchange rate data, Kollmann (2001). Moreover, McCallum and Nelson (1999) document the inability of a model with price stickiness to account for the inflation persistence. These problems mirror (and indeed compound) the well-known difficulties, in a closed economy context, of matching the persistence and hump-shaped response of inflation and output in response to monetary innovations. [2] Such difficulties are commonly attributed to the behaviour of the supply side in these models. Inflation responds directly to current marginal costs which, given frictionless labour markets, are proportional to current output, Gali (2002).[3]

This widespread failure to generate realistically persistent responses to shocks is reminiscent

[1] These Dynamic New Keynesian models differ from earlier microfounded open economy models such as Obstfeld and Rogoff (1995), which exhibit only one period price rigidity and thus cannot be said to be realistically dynamic.

[2] For a discussion of the impact of monetary shocks in a closed economy context, see Christiano et al.(1999). Attempts to replicate the response of output and other real variables to monetary shocks require levels of nominal rigidity that appear implausibly long compared with estimates from microeconomic evidence, New Keynesian models assume price rigidity of the order of 9 months as opposed to the 6 months found by Bils and Klenow (2002).

[3] One response, following Fuhrer and Moore (1995) is simply to assume that inflation, rather than the price level is persistent.

of, and possibly related to, the absence of the strong internal propagataion mechanisms in real business cycle models documented by Cogley and Nason (1995). The response within the RBC literature has been to identify stronger internal propagation mechanisms.[4] Cogley and Nason …nd that frictions associated with adjusting labour input increase the strength with which (technology) shocks are propagated.[5] The employment adjustment costs story developed by Cogley and Nason is a somewhat reduced form approach. A more structural approach to capturing frictions in labour market dynamics which has met with notable successes in recent years is the search and matching mediated equilibrium unemployment framework, see Pissarides (2000). Frictions associated with matching jobs and workers improves the account of labour market variables at business cycle frequencies and can generate a strong internal propagation mechanism, Merz (1995), Andolfatto (1996) and Den Haan, Ramey and Watson (1999). In particular, it provides an equilibrium account of unemployment ‡uctuations, see Pissarides (2000). Matching frictions in the labour market also seem to o¤er some insights in an open economy context. Using a small open economy (non-monetary) DSGE model Feve and Langot (1996) …nd that matching frictions can account for the cyclical pattern of (French) labour market variables rather better than can the standard Walrasian approach. While the inclusion of labour market search and matching frictions improves the ability of a two-country business cycle model to match the real ‡uctuations, Hairault (2002).

Returning to monetary economies, a plausible explanation for the persistent response of in‡ation and output to monetary shocks lies in the interaction of real and nominal rigidities (an idea taken up by Ball and Romer (1990)).[6] The strong propagation mechanism implied by matching frictions in labour markets has recently led a number of authors to investigate whether combined with nominal rigidities in the goods market these might help to explain the relationship between in‡ation and unemployment and other features of business cycle ‡uctuations in monetary economies. Maintaining the assumption that prices are perfectly ‡exible while imposing rigidities on (nomi-

[4] For a summary of this research see King and Rebelo (1999).

[5] They also …nd that ‡uctuations in the capital stock add little to the dynamic behaviour at business cycle frequencies (even when capital adjustment costs are incorporated). This, combined with issues of tractability, has led monetary economists to omit capital (and hence investment) in constructing small scale models for policy analysis (Gali, (2002), McCallum and Nelson, (1999).

[6] Jeahne (1998), shows that the addition of real wage rigidity ampli…es the output e¤ects of monetary shocks under nominal rigidity in the goods market, see also Christiano et al, (2001) who consider the interaction of nominal wage and price rigidities (sticky real wages), as well as demand side rigidities such as habit persistence in consumption.. However the allocative implications of such rigidities is unclear, Bils and Chang (2003). Dotsey and King (2002) introduce "real ‡exibilities" such as capital utilisation, to generate output persistence.

nal) portfolio adjustment, Cooley and Quadrini (1999) are able to generate a negative correlation between in‡ation and unemployment. Combining equilibrium unemployment and quadratic costs of price adjustment in a DSGE framework, Cheron and Langot (2000) account for the negative correlation between unemployment and in‡ation (the Phillips curve) and the negative correlation between unemployment and vacancies (the Beveridge curve). Walsh (2003) demonstrates that labour market matching frictions combined with Calvo-style nominal rigidities can account the hump-shaped response of output to monetary shocks, whilst simultaneously reducing the required degree of nominal rigidity to more plausible levels than the 9-12 months typically found in studies using aggregate data.

To date no studies have examined how international linkages a¤ect and are a¤ected by the combination of labour market matching frictions and nominal rigidities in goods markets. This extension is important for two reasons. The above discussion suggests that building real rigidities into monetary models may help to generate realistic dynamics - a pre-requisite for meaningful policy analysis. However the presence of an exchange rate channel in the monetary transmission mechanism can alter the speed with which monetary shocks are transmitted to real variables. The exchange rate can a¤ect the domestic price level directly by altering the domestic currency price of imports (assuming some "exchange rate pass-through"), and can also alter relative prices (when nominal wages or price are sticky), thereby in‡uencing aggregate demand and supply. Loosely speaking openness makes the Phillips curve steeper, see Lane (1997). Thus international linkages may mitigate against the closed-economy evidence that real and nominal rigidities generate output and in‡ation persistetnce. Secondly, if persistence phenomena created by the interaction of nominal and real rigidities do survive the introduction of open economy linkages, they may help to explain some of the exchange rate puzzles uncovered by models that exhibit only nominal rigidities discussed above.

The layout of the paper is as follows. In the next section we outline a small open economy with Calvo-style nominal rigidities in the goods market and matching frcitions in the labour market and characterise the equilibrium. In section three we calibrate the model to U.S. data and investigate the dynamic responses to monetary shocks. Section 4 contains a summary, a conclusion and some suggestions for further work.

2 Model

We extend the price stickiness and labour market search model of Walsh (2003) to the case of a small open economy. The small open economy assumption manifests itself in several ways, which are "standard" within the recent literature, see Gali and Monacelli (2002), McCallum and Nelson (1999). Firstly, domestic exports form a negligible part of rest-of-the-world (RoW) expenditures, so the rest of the world may be regarded as a closed economy for which RoW output equals RoW consumption. Secondly, RoW investors don't hold domestic assets, although domestic investors may hold both domestic and foreign assets.

Within the literature there have been disagreements over how best to model exchange rate linkages. One common, but extreme, assumption is that domestic imports (and exports) are …nal goods, whose prices display nominal rigidity, that the law of one price holds and that goods are priced in terms of producer currency, see Gali and Monacelli (2002) and Clarida, Gali and Gertler (2001). Exchange rate ‡uctuations then impact directly on the relative price of domestic and foreign goods and hence on the price level. This complete exchange rate pass-through speeds up the transmission of monetary shocks and exacerbates the volatility of the exchange rate in the face of nominal shocks. However, this assumption is not consistent with the empirical evidence on exchange rate pass-through - the extent to which shocks exchange rates are passed directly into …nal goods prices - which is close to zero at short-horizons at the …nal goods level, although higher for intermediate goods, see Goldberg and Knetter (1997). Monacelli (2003) therefore analyses the impact of monetary policy in a model in which imports are once again …nal goods, whose prices exhibit nominal rigidity but are priced in local currency - so that the law of one price need not hold. In McCallum and Nelson (1999), goods imported into the domestic economy are used as intermediates in production (not …nal goods) while goods exported from the domestic economy are …nal goods. Their approach can be characterised as providing a simple but incomplete representation of the evidence on incomplete exchange rate pass-through since pass through is complete at the intermediate level but not at the …nal good level.[7] It formalises the idea that at the …nal goods level even imported goods embody a substantial amount of domestic value added.

Below we adapt the McCallum and Nelson (1999) framework to allow for matching frictions in the labour market and nominal rigidities in the goods market. To this end domestic production occurs in two sectors: wholesale and retail. Wholesale goods production combines imports and labour input and can occur only in matched …rm worker pairs.[8] Intermediate goods producers are competitive, but may earn (temporary) rents due to matching frictions in labour markets. The …nal goods / retail sector consists of monopolistically competitive goods producers each of whom costlessly di¤erentiates the homogeneous intermediate good. These monopolistically competitive retailers set the price of their goods intermittently according to a Calvo price adjustment rule. Retail goods are sold both for export and to domestic consumers. This sectoral decomposition of the real rigidity and nominal rigidity follows the approach of Bernanke, Gertler and Gilchrist (1999) treatment of …nancial accelerator features of the business cycle.

Money is introduced via a cash in advance constraint. so that income generated in period t can not be used to purchase consumption goods until period $t+1$, so the nominal interest rate a¤ects the present discounted value of current production. This gives rise to a cost channel (see Barth and Ramey (2000)) through which nominal interest rate changes may impact on output and employment.[9]

Given this basic outline of the model let us now …ll in some detail by discussing in turn the decision problems of households, wholesale …rms, retail …rms, our assumptions about the actions of the government and …nally characterising the equilibrium for the economy.

2.1 Households

Let us assume that the economy consists of a continuum of households of unit mass indexed by $j \in [0;1]$. Domestic households supply their labour inelastically, own all …rms and carry cash balances to the goods market to purchase consumption goods subject to a cash in advance

7 Note that domestic exports are priced in terms of domestic (producer) currency and so exhibit full exchange rate pass through.

8 Thus an exchange rate appreciation leads wholsesale …rms to increase job destruction, reduce employment and output, and so causes a negative supply shock which raises wholesale prices relative to retail prices and leads to retail price in‡ation.

9 Following Walsh (2003) an increase in the nominal interest rate reduces the present value of production and leads wholesale …rms to raise job destruction, reduce employment and output.

constraint. They can also hold domestic and/or foreign bonds. To avoid the distributional issues that arise because some firms and workers are unmatched, it is assumed that workers pool their income at the end of the period and choose aggregate consumption to maximise the expected utility function of a representative worker [10]

$$U_t = E_t \left[\sum_{s=t} \beta^{s-t} \left[u(C_s) + (1-\chi_s) h - \chi_s a \right] \right] : \tag{1}$$

where β gives the discount factor, h is the utility value of (non-tradable) home production, a is the disutility of work. For any individual household $j \in [0;1]$, χ_s^j is an indicator function taking the value 1 when the agent is employed and zero otherwise. C_s is the composite consumption index consumed by the representative domestic household in period s, this index consists of all differentiated goods sold by the monopolistically competitive retailers. Let us assume that there is a continuum of such firms of unit mass, and define the composite consumption index by the CES aggregator

$$C_s \equiv \left[\int_0^1 c(z)_s^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}} \qquad \varepsilon > 0:$$

Where ε represents the elasticity of demand for product z. The price deflator P for nominal money balances corresponding to this index is the consumption-based money price index. Let p(z) be the price of good z then P is obtained as the index that minimises nominal expenditures $Z = \int_0^1 p(z)\, c(z)\, dz$, associated with the purchase of 1 unit of the consumption index. Hence $P = \left[\int_0^1 p(z')^{1-\varepsilon} dz' \right]^{\frac{1}{1-\varepsilon}}$; and demand for good z is $c(z) = \left(\frac{p(z)}{P} \right)^{-\varepsilon} C$. [11]

Domestic households maximise this objective function (1) subject to a cash in advance (CIA) constraint

$$\int_0^1 p_s(z)\, c_s(z)\, dz = P_s C_s \leq M_{s-1}^j + P_s T_s \tag{2}$$

where M_t^j is household j's holdings of nominal money at the end of period t, and T_t denotes a lump-sum transfer expressed in terms of the consumption index. This implies that a consumer's current income is unavailable for purchasing domestic goods in the current period, and also that

[10] This assumption is a common simplification in the literature on business cycle fluctuations under labour market search, see e.g. Andolfatto (1996), designed to facilitate tractability. There is of course an issue surrounding the incentive compatibility of participation.

[11] Formally P solves

$$\min_{c(z)} \int_0^1 p(z)\, c(z)\, dz + \left[1 - \left(\int_0^1 c(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right)^{\frac{\varepsilon}{\varepsilon-1}} \right] :$$

only the domestic currency required for purchases of domestic retail goods by domestic consumers need be held in advance.

The representative domestic household's budget constraint can be written in units of domestic currency as

$$M_s^i + P_sC_s + P_sB_s + S_sP_s^*B_s^* = P_sY_s^l + P_sD_s + M_{s-1}^i + R_s^nP_sB_{s-1} + R_s^{n*}S_sP_s^*B_s^* + P_sT_s \quad (3)$$

P_sB_s represents expenditure by the representative household on domestic 1-period bonds B_s, acquired at the end of period s. Domestic bonds held between dates $s-1$ and s pay the gross nominal rate of return R_s^n. $S_sP_s^*B_s^*$ represents nominal expenditure in units of domestic currency by the representtaive domestic household on foreign bonds, B_s^*, S_t is the nominal exchange rate. Foreign bonds held between dates $s-1$ and s pay the gross nominal rate of return R_s^{n*}. Y_s^l is the household's real labour income and D_s is its share of real aggregate profits from wholesale and retail firms.

The representative household chooses a sequence of consumption, money holdings and holdings of foreign and domestic bonds. The first order conditions for the consumer's problem can be reduced to a standard Euler equation, which for the case of CRRA instantaneous utility, $u(C_t) = \frac{C_t^{1-\sigma}}{1-\sigma}$; is:

$$1 = \beta R_t^n E_t\left[\frac{P_t}{P_{t+1}}\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\right] \quad (4)$$

and also an uncovered interest parity condition:

$$E_t\left\{R_{t+1}^n\right\} = E_t\left\{\frac{R_{t+1}^{n*}S_{t+1}}{S_t}\right\}: \quad (5)$$

2.2 Goods and Labour Markets

Business activity occurs in retail (final) and wholesale (intermediate) sectors. Production occurs in the wholesale sector, in firm-worker pairs. These employment relationships are formed through an aggregate matching process. Output produced in the wholesale sector is sold in a competitive market to retail firms, which then costlessly transform the wholesale output into retail goods. Both the domestic market and the export market for domestic retail goods are monopolistically competitive, so retail prices display a markup over wholesale prices. Retail prices are sticky.

2.2.1 The Wholesale sector

Production Production of intermediate goods takes place in the wholesale sector through in matched firm-worker pairs - or, for notational ease, matches. Each match consists of 1 worker and 1 firm, who together engage in production until the employment relationship is severed. Both firms and workers are restricted to a maximum of one employment relationship at any given time. At date t match i can use imported goods, IM_{it} to produce

$$Y_{it}^{w} = Z_t X_{it} IM_{it}^{\alpha}$$

units of wholesale goods, where Z_t and X_{it} represent aggregate and idiosyncratic non-negative productivity disturbances, with common mean of unity. We assume that idiosyncratic productivity disturbances are serially uncorrelated while log aggregate productivity disturbances follow an AR(1) process:

$$z_t = \rho_z z_{t-1} + \varepsilon_{z;t}.$$

Matches act as price takers and sell their wholesale output in a competitive market place at (nominal) price P_t^w. Match i chooses the flexible factor, imports, to maximise the value of current profits.

$$\max_{IM_{it}} \left\{ \frac{P_t^w Z_t X_{it} IM_{it}^{\alpha} - S_t P_t^{*} IM_{it}}{R_t^n P_t} \right\}$$

Here the nominal interest rate term in the denominator arises because the CIA constraint dictates that current profits are only available for consumption next period. This feature introduces a cost channel for monetary policy transmission. The optimal choice of inputs for production unit i at date t is

$$IM_{it} = \left(\frac{\alpha Z_t X_{it}}{\mu_t Q_t} \right)^{\frac{1}{1-\alpha}}$$

where $\mu_t = \frac{P_t}{P_t^w}$ is the markup (of retail prices over wholesale prices) and

$$Q_t = \frac{S_t P_t^{*}}{P_t} \tag{6}$$

is the real exchange rate. Thus the NPV of date t production by match i is

$$(1-\alpha)\, \alpha^{\frac{\alpha}{1-\alpha}} (R_t^n)^{-1} \left[\frac{Z_t X_{it}}{\mu_t Q_t^{\alpha}} \right]^{\frac{1}{1-\alpha}}.$$

Despite the competitive nature of the wholesale goods market, the presence of frictions associated with the formation of matches allows existing production units to earn rents. The expected value of an existing match that produces in date t is the value of current profits, less the utility cost of working, a, plus the continuation value, Γ^J. This continuation value represents the present value of expected future rents associated with being part of an ongoing productive relationship. So the value of an existing match that does produce in period t is

$$(1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}}\left(R_t^n\right)^{-1}\left[\frac{Z_t X_{it}}{\mu_t Q_t^{\alpha}}\right]^{\frac{1}{1-\alpha}} - a + \Gamma_{it}^J$$

which is increasing in X, Z and Γ^J and decreasing in μ, a, Q and R^n. Thus the exchange rate and interest rate affect the value of a match, output and, as I show below, employment decisions.

Separation, Matching and Labour Market Variables A match will break up (separate) endogenously if its value is less than the value of the outside options available to the constituent firm and worker. Any firm can post a vacancy, so free entry ensures that the value of this option, a matched firm's outside option, is zero. By contrast, the value of the worker's opportunities outside the match is the sum of the value of home production, h, and the present value of future worker opportunities (probability weighted value of future employment relationships and future spells of unemployment), denoted as Γ_{it}^U. Define the surplus for match i at date t, SU_{it}, as the difference between the value of a match and the value of the outside options available to the firm and worker:

$$SU_{it} = (1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}}\left(R_t^n\right)^{-1}\left[\frac{Z_t X_{it}}{\mu_t Q_t^{\alpha}}\right]^{\frac{1}{1-\alpha}} - a + \Gamma_{it}^J - \left[h + \Gamma_{it}^U\right] \qquad (7)$$

Endogenous separation occurs when $SU_{it} \le 0$. This enables us to define a threshold value of idosyncratic productivity, $\bar{X}_{it}$, such that separation occurs if

$$X_{it}^{\frac{1}{1-\alpha}} \le \bar{X}_{it}^{\frac{1}{1-\alpha}} = \frac{\left(\mu_t Q_t^{\alpha}\right) R_t^n}{(1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}} Z_t^{1/(1-\alpha)}}\left[h + \Gamma_{it}^U + a - \Gamma_{it}^J\right]$$

Finally note that the temporal independence of the idiosyncratic shock allows the i subscript to be dropped from the terms $\bar{X}_t = \bar{X}_{it}$, $\Gamma_t^U = \Gamma_{it}^U$, $\Gamma_t^J = \Gamma_{it}^J$, so the threshold value for idiosyncratic productivity can be rewritten

$$X_{it}^{\frac{1}{1-\alpha}} \le \bar{X}_t^{\frac{1}{1-\alpha}} = \frac{\left(\mu_t Q_t^{\alpha}\right) R_t^n}{(1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}} Z_t^{1/(1-\alpha)}}\left[h + \Gamma_t^U + a - \Gamma_t^J\right] \qquad (8)$$

Having described efficient endogenous separation we are in position to describe the timing of employment and separation decisions. Let us define the number of matches at the beginning of period t as $N_t \in [0,1]$. We assume that quits are exogenous and capture this by allowing a fraction, ρ^x, of matches to separate exogenously prior to the realisation of period t (productivity) shocks. Subsequently, idiosyncratic and aggregate productivity disturbances are realised, and a match may choose to break up if the value of the match surplus is negative. Endogenous separation occurs with probability ρ^n_{it} where

$$\rho^n_{it} = \rho^n_t = \int_{-\infty}^{\tilde{X}_t} f(X)\,dX \tag{9}$$

and $f(\cdot)$ is the probability density function over X_{it}.[12] The overall separation rate in period t is

$$\rho_{it} = \rho^x + (1-\rho^x)\rho^n_t. \tag{10}$$

If the match does not sever then date t production occurs. Aggregate output of wholesale goods, Y_t^w, is therefore

$$Y_t^w = (1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}}(1-\rho^x)N_t\left(\frac{Z_t}{\mu_t}\right)^{\frac{1}{1-\alpha}} Q_t^{\frac{-\alpha}{1-\alpha}} \cdot \int_{\tilde{X}_t}^{\infty} X^{\frac{1}{1-\alpha}} f(X)\,dX \tag{11}$$

while aggregate imports are

$$IM_t = \alpha^{\frac{1}{1-\alpha}}(1-\rho^x)N_t\left(\frac{Z_t}{\mu_t Q_t}\right)^{\frac{1}{1-\alpha}} \cdot \int_{\tilde{X}_t}^{\infty} X^{\frac{1}{1-\alpha}} f(X)\,dX. \tag{12}$$

Next we turn to the matching frictions that are at the heart of the model. We model this rigidity using an aggregate matching function. Matching occurs at the same time as production. It is assumed that there is a continuum of potential firms, with infinite mass, and a continuum of workers of unit mass. Unmatched firms choose whether or not to post a vacancy given that it costs C per period to post a vacancy. Free entry of firms determines the size of the vacancy pool. Define the mass of firms posting vacancies to be V_t. Let the mass of searchers, i.e. unmatched workers, be U_t. All unmatched workers may enter the matching market in period t - even if their match dissolved at the start of period t. So

$$U_t = 1 - (1-\rho_t)N_t \tag{13}$$

[12] Note that this endogenous separation rate represents the probability that a match severs given i) the date t realisations of the productivity shocks and ii) that the match has not separated exogenously during period t. It is an increasing function of $\tilde{X}_t$.

New matches in date t begin production in date t + 1, while unmatched workers remain in the worker matching pool. The flow of successful matches created in period t is given by

$$M_t = mU_t^{\gamma}V_t^{1-\gamma}; \tag{14}$$

where $\gamma \in (0;1)$ and $m > 0$. Thus the number of employment relationships at the start of period t + 1 is

$$N_{t+1} = (1-\rho_t)\,N_t + M_t \tag{15}$$

Denote the probability that a vacancy is filled in date t as

$$\kappa_t^f = \frac{M_t}{V_t} \tag{16}$$

and the probability that an unemployed worker enters employment in period t as

$$\kappa_t^w = \frac{M_t}{U_t}; \tag{17}$$

Gross job destruction equals the employment relationships that separate less exogenous separations that rematch within period

$$DES_t = \frac{\left[\rho^x + (1-\rho^x)F\left(\bar{X}_t\right)\right]N_t - \kappa_t^f\rho^x N_t}{N_t} = \rho^x + (1-\rho^x)F\left(\bar{X}_t\right) - \kappa_t^f\rho^x \tag{18}$$

Gross job creation equals the flow of new matches (as a fraction of existing employment) less matches due to firms that filling vacancies that resulted from exogenous separations

$$CRE_t = \frac{M_t - \kappa_t^f\rho^x N_t}{N_t} = \frac{M_t}{N_t} - \kappa_t^f\rho^x \tag{19}$$

State transitions and the value of Γ_t^J and Γ_t^U Suppose that firms and workers obtain fixed shares of any non-negative match surplus, S_t; where η is the worker's share. To determine the equilibrium values of Γ_t^U and Γ_t^J we need to consider the possible period t + 1 outcomes for unmatched firms, unmatched workers and ongoing firm-worker pairs. First note that the value of the surplus for match i from production in period t + 1, is

$$S_{it+1} = (1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}}\left(R_{t+1}^n\right)^{-1}\left[\frac{Z_{t+1}X_{it+1}}{\mu_{t+1}Q_{t+1}^{\alpha}}\right]^{\frac{1}{1-\alpha}} - a + \Gamma_{t+1}^J - \left(h + \Gamma_{t+1}^U\right)$$

Now consider a worker in the unemployment pool at date t. Her future payoff is $h + \Gamma_{t+1}^U$ either if the worker is unsuccessful in the matching market at date t, or if she successfully matches at date t, but severs (exogenously or endogenously) prior to production at date t + 1. On the other hand if she successfully matches in date t and the relationship survives to date t + 1, then she obtains $\eta S_{t+1} + h + \Gamma_{t+1}^{U}$. Appropriately discounted, the date t value of the unemployed worker's expected future payoffs is therefore

$$\Gamma_t^U = E_t\left[\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\phi}\left[\kappa_t^w(1-\rho^x)\int_{\tilde{X}_{t+1}}^{\infty}\eta S_{it+1} f(X)\,dX + h + \Gamma_{t+1}^U\right]\right] \tag{20}$$

where κ_t^w is the probability that she successfully matches in period t. The worker obtains ηS_{t+1} with probability $\kappa_t^w(1-\rho^x)\left(1-\rho_{t+1}^n\right)$, reflecting the probability that she matches in period t and that the match survives to t + 1.

Due to free entry, the value of a firm in the period t vacancy pool must be 0, so

$$0 = -C + \kappa_t^f E_t\left[\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\phi}(1-\rho^x)\int_{\tilde{X}_{t+1}}^{\infty}(1-\eta)S_{it+1} f(X)\,dX\right] \tag{21}$$

where κ_t^f represents the probability that the firm matches in in period t.

Finally, the present value, Γ_t^J, of the expected future joint returns to an ongoing employment relationship which produces both at date t and date t + 1 is

$$\Gamma_t^J = E_t\left[\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\phi}\left[(1-\rho^x)\int_{\tilde{X}_{t+1}}^{\infty}S_{it+1} f(X)\,dX + h + \Gamma_{t+1}^U\right]\right] \tag{22}$$

2.2.2 Retail Sector

There is a continuum of retailers, with unit mass. Retail firm z acquires the wholesale good at price P_t^w and costlessly transform it into the divisible retail good z which is then either sold directly to households or exported to the rest of the world. The market for retail goods is characterised by monopolistic competition. The aggregate demand for good z in period t is

$$\begin{aligned} Y_t(z) &= c_t(z) + ex_t(z) = \left(\frac{p_t(z)}{P_t}\right)^{-\varepsilon} C_t + \left(\frac{p_t(z)}{P_t}\right)^{-\varepsilon} EX_t \\ &= \left(\frac{p_t(z)}{P_t}\right)^{-\varepsilon}[C_t + EX_t] \end{aligned}$$

where C_t denotes the composite (domestic) consumption index and EX_t denotes aggregate exports and we have assumed that the elasticity of substitution between heterogeneous domestic final goods is identical in the domestic economy and in the rest of the world.[13] Aggregation across goods, z,

[13] Note that the exchange rate does not appear in the export demand term because it cancels from both the numerator and the denominator.

gives an expression for aggregate demand

$$Y_t = C_t + EX_t. \tag{23}$$

We assume that aggregate exports are an increasing function of the real exchange rate and (exogenous) rest-of-world income Y_t^*:

$$EX_t = Q_t^{a} Y_t^{*b} \qquad a, b > 0. \tag{24}$$

Suppose output of final good z is demand determined and that final goods prices exhibit nominal rigidities and follow a Calvo style adjustment scheme in which a (time-invariant) fraction of firms adjust their prices optimally in any given period so as to maximise their expected profits subject to the demand curve it faces. Let the probability that a firm adjusts its price in a given period be $1-\omega$, and define the price of retail good z at date t be $p_t(z)$. All firms setting price at date t face the same expected future demand and cost conditions and so choose the same price independent of z. In recognition of this we write the price set by firms which adjust (price) in date t as p_t^*. Then the retail firm's price-setting problem can be written as

$$\min_{p_t^*} E_t \sum_{s=t}^{\infty} \omega^{s-t} \prod_{j=t}^{s} \frac{1}{R_j} \left[\frac{p_t^* Y_s(z) - P_s^w Y_s(z)}{P_s} \right].$$

Now we substitute for $Y_s(z)$ (exploiting the structure of demand for good z), R_s using the Fisher equation $R_s = \frac{R_s^n P_{s-1}}{P_s}$ and the Euler equation. Then the retailer's problem may be re-expressed as

$$\min_{p_t^*} E_t \sum_{s=t}^{\infty} (\beta\omega)^{s-t} \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \left[\left(\frac{p_t^*}{P_s} \right)^{1-\theta} - \mu_s^{-1} \left(\frac{p_t^*}{P_s} \right)^{-\theta} \right] Y_s.$$

The first order condition for this problem is for the Calvo-price setting firm is to choose the real retail price:

$$\left(\frac{p_t^*}{P_t} \right) = \frac{\theta}{\theta - 1} \frac{E_t \sum_{s=t}^{\infty} (\beta\omega)^{s-t} \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \left[\mu_s^{-1} \left(\frac{P_s}{P_t} \right)^{\theta} \right] Y_s}{E_t \sum_{s=t}^{\infty} (\beta\omega)^{s-t} \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \left(\frac{P_s}{P_t} \right)^{\theta - 1} Y_s} \tag{25}$$

The aggreate retail price index evolves according to

$$P_t^{1-\theta} = (1-\omega)(p_t^*)^{1-\theta} + \omega P_{t-1}^{1-\theta}. \tag{26}$$

2.3 Monetary and Fiscal Policy

It is assumed that the government undertakes no spending and maintains a balanced budget so that all seigniorage revenues are rebated to the households in the form of transfers. The government budget constraint is thus

$$P_s T_s = M_s - M_{s-1}$$

where M_s is the aggregate money stock. Money supply growth rate is assumed to evolve according to the AR(1) process

$$\mu_t = \rho_\mu \mu_{t-1} + \varepsilon_{\mu,t}. \tag{27}$$

2.4 Equilibrium

In equilibrium $M_t^j = M_t$, and the government budget constraint holds so $P_t T_t = M_t - M_{t-1}$ and the cash in advance constraint becomes

$$C_t = \frac{M_t}{P_t}. \tag{28}$$

In equilibrium aggregate demand, $Y_t = EX_t + C_t$, equals aggregate wholesale output less expenditures on vacancies

$$Y_t = Y_t^w - CV_t$$

Combining this information

$$C_t + EX_t = Y_t^w - CV_t \tag{29}$$

Thus the system of equations governing equilibrium in the economy consists of the numbered equations (4) through to equation (29).

3 Simulations

Here we use the widely adopted practice of log-linearising the model about its (zero-inflation, zero growth) steady state and use impulse response analysis and dynamic simulations to tease out the dynamic structure of the economy. Parameter values are chosen to match U.S. data and are taken from previous studies.

3.1 Steady State & Calibration

Model calibration involves choice of several sets of parameters governing steady state values of labour market variables; wholesale production; resource constraints; international linkages; household preferences; retail sector variables and nominal price rigidity. We also calibrate the processes governing the evolution of aggregate and idiosyncratic productivity processes and money supply growth. Where feasible, in order to facilitate comparison, we follow the parameterisations used by Walsh (2003) and for open economy parameters McCallum and Nelson (1999). These authors choose values to match the behaviour of the US economy. The parameter values are summarised in Table 1, the following sections contain some discussion of the rationale for and origins of these choices.

3.1.1 Labour Markets, Matching and Separation

We specify the following labour market parameters ρ, N, CRE, γ, κ^f, and η.

In steady state the probability of separation, ρ, can be written as $\rho = \rho^x + (1-\rho^x)F\left(\bar{X}\right)$. Substituting into equation (13) the steady state value of the number of workers searching for work in any given period is

$$U = 1 - (1-\rho)N$$

This can be rearranged to obtain an expression for the ratio of searchers to employment U/N as

$$\frac{U}{N} = \frac{1}{N} - (1-\rho). \qquad (30)$$

Den Haan, Ramey and Watson (2000), suggest that, for the US economy around 10% of employment relationships separate each quarter: $\rho = 0.1$ and assume that the fraction of workers in employment (in steady state) is set as $N = 0.94$, (so steady state unemployment is 6%). Therefore the ratio of workers searching for jobs to employed workers, U/N, is 0.154.

Another aspect of steady-state is that the rate of job creation (19) equals the rate of job destruction (18)

$$CRE = DES = \rho - \rho^x\kappa^f.$$

Based on US data Den Haan et al. (2000) set steady state job creation, CRE equal 5.2%, and the average probability of filling a vacancy, κ^f, at 0.7, so that the probability of exogenous separation, $\rho^x = 0.068$. In steady state, the average probability of filling a vacancy depends on the ratio of workers engaged in search to posted vacancies. In steady state equation (16) becomes

$$\kappa^f = \frac{mU^{\gamma}V^{1-\gamma}}{V} = m\left(\frac{U}{N}\right)^{\gamma}\left(\frac{V}{N}\right)^{-\gamma}. \tag{31}$$

The steady state condition for the employment evolution equation (15) is

$$\rho = m\left(\frac{U}{N}\right)^{\gamma}\left(\frac{V}{N}\right)^{1-\gamma}.$$

so using equation (31) and re-arranging we determine the ratio of vacancies to employment as

$$\frac{V}{N} = \frac{\rho}{\kappa^f}.$$

For our simulation work we compute $\frac{V}{N} = \frac{1}{7}$. We assume, following Petrongolo and Pissarides (2001) that the parameter γ in the matching function takes the value 0.6. Then $m = 0.68$.

The steady state value of the separation threshold can be determined from equations (9) and (10). The steady state endogenous probability of separation $\rho^n = 0.036$ is pinned down by this information. By specifying the disctribution of idiosyncratic productivity shocks (see below) the value of $\tilde{X}$ is determined.

The share of any match surplus obtained by workers is set, following the literature, at $\eta = 0.5$. Then the steady state of equation (21) can be used to determine the cost of posting a vacancy, C. To do this we also need to know the value of the elasticity of output with respect to imports, α. We will return to this after discussing price setting and preferences.

3.1.2 Price Rigidity & Price Setting

Calibration of nominal rigidities and price setting by retailers involves specification of ω, P and ε.

The extent of nominal rigidity in the goods market is completely determined by ω, which captures the fraction of retailers each period that do not adjust their price. Empirical evidence from studies using aggregate data suggests that prices rigidities of the order of 9 months to1 year are common place. This would suggest values of ω between 2/3 and 3/4. The former value is taken as the baseline value in the simulation work described below. [14]

[14] Studies using microeconomic data suggest that the estimates from aggregate data are implausibly high - Bils and Klenow (2002) indicates that the average time between price changes is of the order of 6 months, consistent with $\omega = \frac{1}{2}$.

In steady state, from equation (26), price-setting firms set price, p^*, equal to the aggregate price level, P,

$$p^* = P.$$

For simplicity we normalise the aggregate price level to unity. Combining this with steady state optimal price setting behaviour (from equation (25)) determines the steady state mark up as

$$\mu = \frac{\varepsilon}{(\varepsilon - 1)}.$$

We assume that, ε, the elasticity of demand equals 11, therefore the steady state value of the markup is $\mu = 1.1$.

3.1.3 Preferences

Following Walsh (2003), the preferences of the representative household are characterised by the parameters σ, β and h.

In steady state, the Euler equation (4) collapses to

$$1 = \beta R^n. \tag{32}$$

The discount factor reflecting the subjective rate of time preference is standard in DSGE models. Under the assumption that 1 period represents 1 quarter we set $\beta = 0.989$. This determines R^n. We assume a constant relative risk aversion form for the instantaneous utility function $u(C_t) = \frac{C_t^{1-\sigma}}{1-\sigma}$, and set $\sigma = 2$.

The value of home production, h, is normalised to zero. Given assumptions about the probability of separation, the import elasticity of output α, and the parameters of the distribution of idiosyncratic shocks, this will determine the disutility of work, a, from the steady state of equation (8), the condition which defines the endogenous separation threshold.

3.1.4 Intenational Linkages

International linkages involve choice of steady state values for Q, S; and P^*, and $\frac{IM}{Y}$ and parameters b_{Y^*} and b_q.

The steady state version of the uncovered interest parity condition (5) requires the domestic and rest of world nominal interest rates be tied together.

$$R^n = R^{n*}. \tag{33}$$

Normalising the price and real exchange rate indices in equation (6) pins down the steady state value of the nominal exchange rate, S, as

$$Q = \frac{SP^*}{P}. \tag{34}$$

For simplicity the steady state values of the real exchange rate, Q, the nominal exchange rate S, the foreign price level, P^* are set equal to 1.

The assumption that imports are used only as factors of production follows directly from McCallum and Nelson (1999). They assume that output is a general CES function of imports and labour inputs, but assume that both inputs can be adjusted costlessly. To retain a reasonably simple characterisation given our more complex labour market frictions we specialise further to a Cobb Douglas production function. Based on US data McCallum and Nelson assume the steady state share of imports as a fraction of domestic GDP, $\frac{IM}{Y}$ is 0.11. This implies a value of α of 0.1. So we can compute a and C as siscussed in previous paragraphs.

The steady state version of the economy wide resource constraint (29) is $Y \equiv C + EX = Y^w - CV$. Under the assumption that $CV \ll Y^w$, $Y \approx Y^w$, the import:output ratio $IM/Y \approx IM/Y^w$.[15] Dividing (12) by (11), and proceding to the steady state gives

$$\frac{IM}{Y} \approx \frac{\alpha}{1-\alpha}. \tag{35}$$

Steady state also requires that

$$IM = EX.$$

The aggregate export equation (24) takes the same form as in McCallum and Nelson (1999). Parameters, b_{Y^*} and b_Q governing the elasticity of domestic exports with respect to the real exchange rate and foreign output are set equal to 1.

15 Under plausible calibrations, such as ours, this is a reasonable assumption.

Parameter / Variable	Value
½	0.1
N	0.94
CRE	0.052
$.^{f}$	0.7
°	0.6
´	0.5
!	0.75
P; Q; S; P¤	1
"	11
¯	0.989
Á	2
h	0
$\frac{IM}{Y}$	0.11
$b_q; b_{y¤}$	1
$½_{\mu}$	0.5
$½_{Z}$	0.95
$¾_{X}$	0.15

Table 1: Calibration

3.1.5 Monetary Policy & Productivity Shocks

The money supply growth process is assumed to follow an AR(1) process with the autoregressive parameter $½_{\mu}$ = 0:5, following Christiano, Eichenbaum and Evans, (2001). Monetary policy innovations are assumed to be orthogonal to aggregate productivity shocks.

Aggregate productivity shocks are assumed to follow an AR(1) process, with substantial persistence: $½_{z}$ = 0:95. Aggregate productivity is log-normally distributed with mean of unity. It is uncorrelated with idiosyncratic productity shocks, which are also log-normally distributed with mean unity. Idiosyncratic shocks are inidependetly identically distributed across time. The standard deviation of idiosyncratic productivity shocks is set at 0.15, following Walsh (2003).

3.2 Results

This section describes the results of two experiments i) the impulse responses of the model to a monetary shock and ii) evidence on the relative volatilities of key business cycle statistics obtained from stochastic simulations. To emphasise the impact of nominal rigidities and endogenous job destruction as laid out above, we also examine the behaviour of two alternative versions i) a simpli…ed version with search and matching frictions but without endogenous job destruction and ii) a version of the McCallum and Nelson (1999) model modi…ed to conform as closely as possible to the model of endogenous job destruction and sticky prices outlined in the previous section. In particular, we reformulate McCallum and Nelson's model by removing habit persistence in consumption, switch from a money in the utility function approach to a cash in advance constraint for consumption goods, add a cost channel for monetary policy transmission and replace the CES production function with a Cobb Douglas intermediate goods production function exhibiting constant returns to scale, $Y_t^w = Z_t N_t^{1-\alpha} M_t^{\alpha}$. As in the model laid out above we adopt parsimonious Calvo style nominal rigidities at the retail level in place of McCallum's p-bar approach. Finally, we assume exogenous AR(1) money supply rule rather than the interest rate rule used by McCallum and Nelson. Note that despite these modifications, the walrasian labour market of the MN model is not, as formulated, nested as a special case of the model with labour market frictions. So our aim is simply to contrast the behaviour of the sticky price - endogenous job destruction model with a standard DSGE open economy model.

3.2.1 Impulse Responses

Here we examine impulse responses to a shock to money supply growth for the sticky-price endogenous job destruction model (EJD) and the modified McCallum-Nelson (MN) model. The results are displayed in Figures 1-4. Figures (1) and (2) show the response of the MN model to a moderately persistent shock to money supply growth. Figures (3) and (4) document the behaviour of the EJD model. We begin by discussing key characteristics of the impule response function, and procede to try to understand the mechanisms underlying these results.

First consider the MN model. From figure (1), the half-life for the employment (n) and consumption (c) responses is around 5 quarters. Both peak the period after the monetary impulse occurs rather than immediately as is standard in models with forward-looking price of the Calvo type. This is a result of the cash-in-advance specification for money. By contrast the impact of monetary disturbances on consumption and employment in the EJD model is distinctly hump-shaped. This conforms at least qualitatively to the VAR-based evidence documented by Christiano et al. (1999). The response of both consumption and employment to a unit shock to money supply growth is larger under EJD than under MN. The half-life for the consumption response is of the order of 8 quarters, while for employment the half-life is around 10 quarters. It is clear that the persistent response of real variables to monetary shocks.[16]

As is standard in models with forward-looking price setting of the Calvo form, in‡ation (pi) is front loaded. This result obtains independent of the presence of nominal rigidities. In the MN setting however, the initial response of in‡ation is much larger around 1.5 times larger than when combined with endogenous job destruction as in the EJD framework. Equally the half-life for the in‡ation response in the MN setting is around 1.5 quarters, whereas in the EJD framework it is closer to 3 quarters.

Turning to exchange rate responses. The impact e¤ect on the real exchange rate is both larger and more persistent when real rigidities are combined with sticky prices (EJD) rather than providing the only source of friction (MN). In terms of the nominal exchange rate, the long-run e¤ect of the shock to money supply growth is of course identical across the models. However the combination of real and nominal rigidities in the EJD model leads to a much larger exchange rate over-shoot than for the MN model. The nominal exchange rate response is also more persistent in the EJD model than under the MN framework.

Finally, consider the behaviour of imports, (im), exports (ex) and the implicit response of net exports. Under MN imports rise even under the exchange rate depreciation, but exports increase by a greater amount, so net exports also rise. Under EJD net exports also rise, but now while exports rise imports decline in the face of real depreciation induced by the mnonetary expansion.

To conclude this section we o¤er a discussion of the mechanisms underlying these results. We begin with the MN set up, starting with the impact e¤ects. Given the nominal rigidities in the goods market, a rise in money supply (growth) reduces the nominal (and hence real) interest rate.[17] In addition to the closed economy economy mechanisms (see previous footnote), the fall in the interest rate leads to an exchange rate depreciation. This a¤ects both imports and exports.

[16] Note that employment is a pre-determined variable under EJD and so reacts to the monetary expansion with a 1-period lag.

[17] In a closed economy context this alone would be su¢ cient to raise current consumption (demand). Since output is demand determined labour input must rise. So provided the marginal disutility of labour is positive the marginal cost of production must rise. The rise in marginal cost (reduced markup) generates in‡ation (since under Calvo pricing, in‡ation is the "discounted" present value of future narginal cost terms, see Gali (2003). The fact that Calvo-style nominal price rigidities display persistence means that the subsequent period, and the periods thereafter, adjustment of prices to the monetary shock is incomplete. So the nominal (and real) interest rate increases but remains below the steady state value. As a result both in‡ation and real output are front loaded.

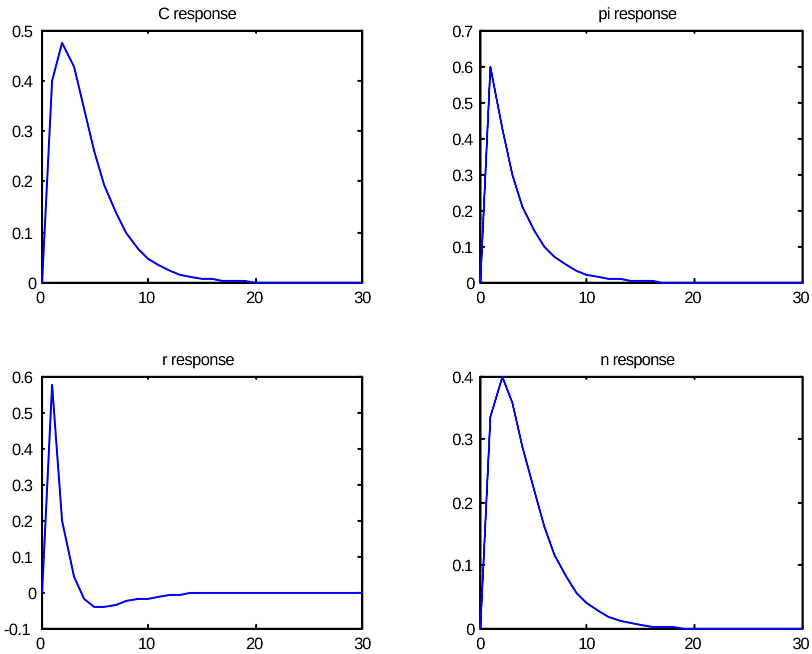

FIGURE 1: MN RESPONSES TO UNIT SHOCK TO Money Growth

Figure 1:

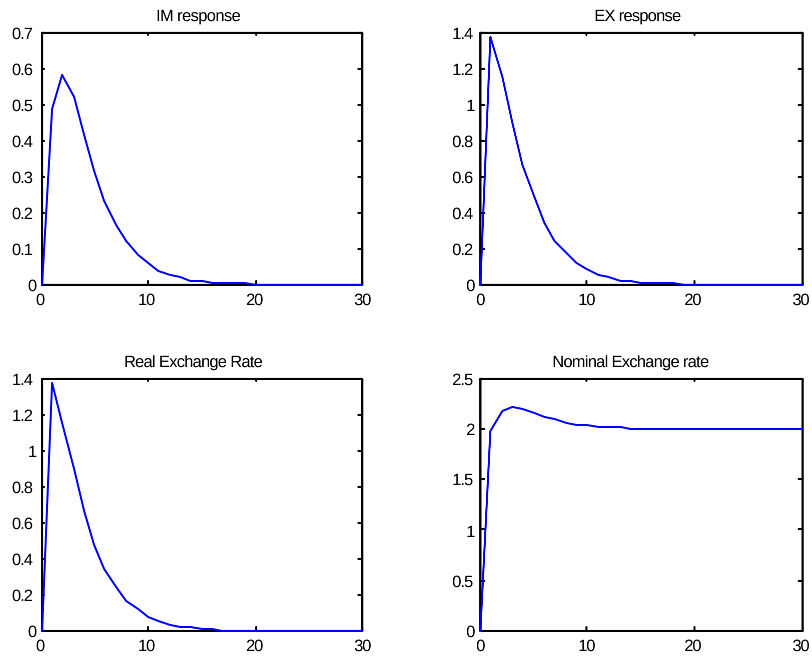

FIGURE 2: MN RESPONSES TO UNIT SHOCK TO Money Growth

Figure 2:

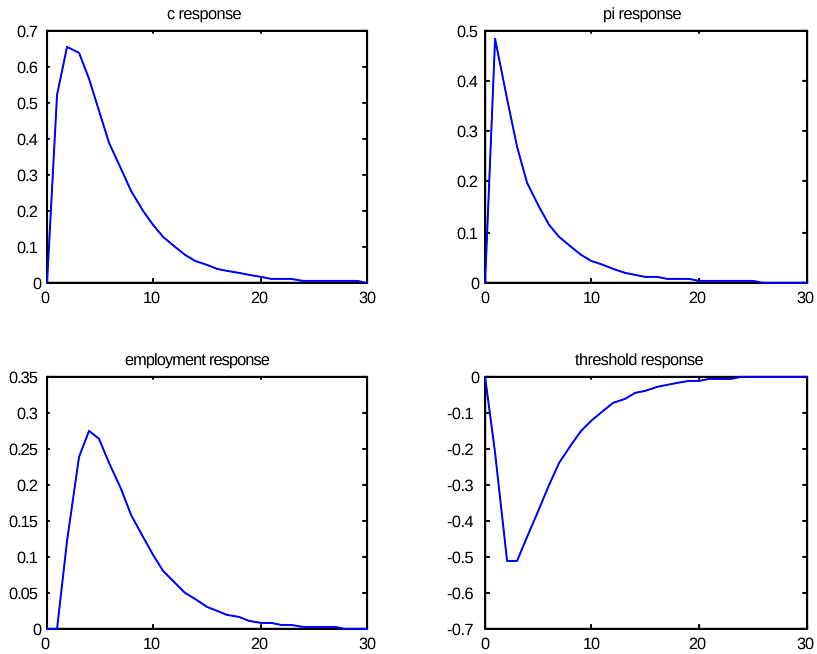

Figure 3:

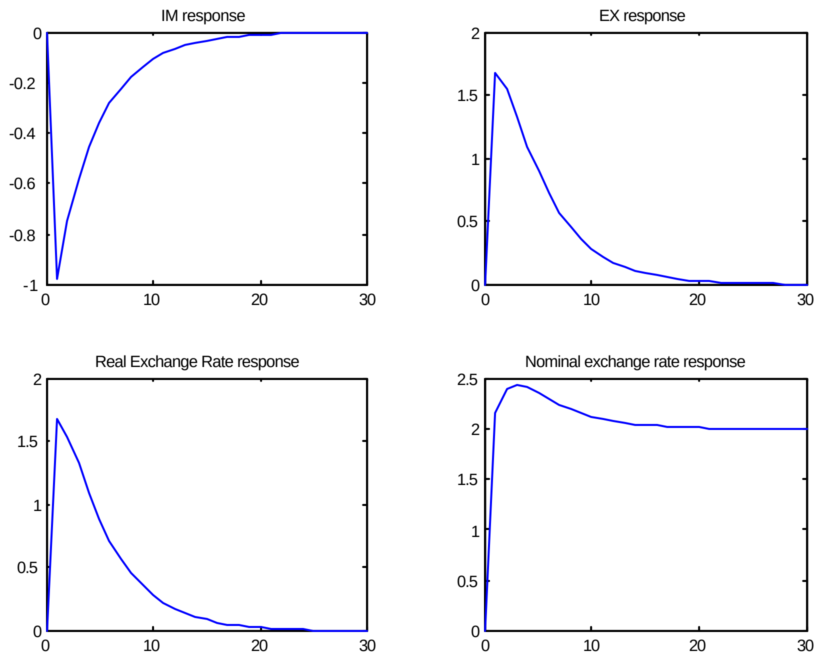

FIGURE 4: EJD RESPONSES TO UNIT SHOCK TO Money Growth

Figure 4:

In particular the exchange rate depreciation, would tend to reduce imports, since the cost of a given amount of imports rises. This leads firms to substitute away from imports and towards labour input. So the marginal cost of producing the existing level of output rises. However we see that imports rise under MN. To understand this note that the exchange rate depreciation raises demand for domestic exports (which boosts demand). As output is demand-determined, the rise in output raises imports (notwithstanding the direct impact of exchange rate depreciation). As a result the impact effect on marginal cost will likely be greater than in the closed economy context. Therefore even though prices are fixed, inflation, the discounted present value of current and future marginal costs, will adjust rapidly rise rapidly. So the exchange rate channel increases the speed with which monetary shocks are propagated through the economy. In stochastic simulations this would tend to increase the volatility of the exchange rate (and net exports) while simultaneously reducing the persistence of these variables. The fact that Calvo-style nominal price rigidities display persistence means that the subsequent period, and the periods thereafter, adjustment of prices to the monetary shock is incomplete. So the nominal (and real) interest rate increases but remains below the steady state value. As a result both inflation and real output are front loaded.

Next consider the mechanism in the EJD model. As in the MN framework, given our assumptions of nominal price rigidities, a monetary expansion will lead to a decline in the nominal (and real) interest rate and also to a nominal (and real) exchange rate depreciation. Yet, depsite the fact that the aggregate demand set up is identical to the MN case, the response of real variables is hump-shaped. So the contrasting response for consumption and employment in the EJD case results from the labour market frictions involved. Responses are presented for employment and the threshold value of idiosyncratic productivity at which matches separate. Consider the impact of the real exchange rate depreciation. There are two effects which work in opposite directions. 1. The first effect is that, for any given match, the depreciation increases the cost of producing a given level of output. Due to the technological constraints of the EJD set up, no individual match can substitute towards greater use of the labour input. The increase in costs would tend to decrease the value of existing matches. This reduces the attractiveness of production activity to matched firm-worker pairs and also to unmatched workers and firms. Potentially this can reduce imports

2. The second e¤ect is that exchange rate depreciation increases exports, and hence demand. In the face of nominal rigidity, with output demand-determined, higher demand requires higher output. However the real rigidity associated with matching frictions raises prevents labour input responding immediately (as under MN) and tends to raise the present value of existing will raise the net present value of existing matches. These quasi-rents raise the value of productive activity from the perspective of unmatched …rms and workers and also from existing …rm-worker pairs.

The net e¤ect, for matched …rm-worker pairs, can be seen in the response of the job-destruction threshold, illustrated in Figure 4, which shows that there is an immediate decline the threshold level of (idiosyncratic) productivity at which matches separate in response to the monetary expansion.[18] So fewer matches separate following a monetary shock. The (temporarily) higher pro…ts for productive units in the face of a monetary expansion (under sticky prices) also lead more matches to form, see …gure (?), but this e¤ect is smoothed out over time by the matching frictions and the nominal rigidities. As a result output and employment do not initially respond strongly. Later however, the increase in the number of productive units prevents marginal cost from responding as strongly under the EJD model. It is this that leads to the more sluggish response of prices, and the greater in‡ation persistence under EJD. The greater in‡ation persistence in the EJD model in turn generates the more extensive nominal exchange rate overshoot, which of course is re‡ected in the real exchange rate. Our discussion is consistent with the observation that imports initially decrease - the sluggish response of output means that the direct e¤ect of exchange rate depreciation on imports outweighs the induced e¤ect through the rise in demand. As a consequence net exports respond more strongly than in the MN framework.

3.2.2 Dynamic Simulations

Here we analyse the business cycle statistics obtained from stochastic simulations. Initially, following the approach of Chari, Kehoe and McGrattan (2002), we suppress aggregate productivity shocks and focus initially on the ability of monetary shocks alone to account for observed volatility of key variables at business cycle frequencies. In each case the standard deviation of monetary

[18] The reason for this decline is that the a monetary expansion causes a decline in the nominal interest rate. This cost channel e¤ect leads all matches to produce higher pro…ts. Clearly for the parameter values used this e¤ect outweighs the impact, through imports, of exchange rate depreciation.

shocks $\sigma_{\varepsilon_{\mu}}$ is chosen to match the volatility of (HP-detrended) output in US data. Business cycle statistics are obtained by averaging across 100 simulations.

Table 2 reports both US data,[19] and results for the augmented McCallum and Nelson model (column MN), the model outlined in section 3 (column EJD) and a version of this model with search amd matching frictions but with the endogenous job destruction channel suppressed. the model (column SM). The calibration for the SM version follows that of the endogenous job destruction model. For the MN model it is necessary to specify the elasticity of labour supply. Following McCallum and Nelson, labour supply is assumed completely inelastic, ex ante, but employment is demand determined ex post .

In terms of ability to match the observed volatility of real and nominal exchange rate, the EJD model performs substantially better than the MN model, while producing substantial persistence in both real and nominal exchange rate fluctuations in response to monetary shocks. Indeed, on the baseline parameter values (with a level of price stickiness not supported by the micro data), the EJD model produces too much persistence in the exchange rate. While none of the models captures the contemporaneous cross-correlation patterns of real and nominal exchange rates- although here too the EJD model seems to outperform the others.

The EJD model somes closest to matching historical patterns of volatilities of employment and jobs flows. Compared with the MN model, EJD recreates more accurately the volatility patterns for employment: In particular, employment simply responds too much to monetary shocks. Equally without the endogenous job destruction feature the SM model produces lower employment variability than in either the EJD approach or the data. Compared with the SM model which lacks the endogenous job destruction feature, the benchmark EJD model provides an improved match to the volatility of job destruction, but predicts job creation volatility to be almost twice the value observed in the data whereas the SM model matches the job creation volatility in US data but produces a job destruction volatility only one half as large as that observed in the data. This tendency of models with endogenous job destruction to produce overly volatile job-creation is

[19] These values (taken from Cooley and Quadrini (1999)), cover the period 1959:1 - 1996:4 with the exception of exchange rate and net exports, (taken from Chari, Kehoe and McGrattan (2002)) which instead cover the period 1973:1 - 1994:4.

noted by Den Haan, Ramey and Watson in the context of productivity shocks; clearly this anomaly carries over to an environment (with price-stickiness) in which monetary shocks are the prime driving force for economic ‡uctuations. While the origins of the job creation volatility anomaly is interesting in its own right it is not the principal focus here. Su¢ce to say that combined, with the improved persistence properties outlined in the impulse response analysis of the previous section it appears that endogeneity of job destruction appears an attractive starting point for understanding labour market behaviour at business cycle frequencies in monetary economies.

It appears that while the EJD model comes closest to matching US data, all the models fail to a reasonable job of matching the (relative) volatility of consumption, at least in comparison to the work of Chari, Kehoe and McGrattan. However, their work incorporates capital stock and allows for adjustment costs in investment activity. In fact they choose the capital adjustment cost parameter in order to match the relative volatility of consumption and investment to GDP.

One area where all three models perform poorly is in accounting for variability of net exports. All three models suggest volatilities of net exports some 30 times historical US values. This is rather problematic and needs further attention. One possible explanation lies in the assumption concerning exchange rate pass-through made in the McCallum and Nelson framework and used in this paper. The McCallum-Nelson framework assumes incomplete pass-through of exchange rate shocks to domestic …nal goods prices. However there is complete exchange rate pass through for imports and also for domestic exports (where prices are …xed in terms of producer currency). As a result, given the form of demand for imports and exports captured in equations (12) and (24) both these variables are likely to respond extremely rapidly to exchange rate ‡uctuations.

Next we examine the robustness of the EJD results to variations in the model and the baseline parameterisation. With such a rich framework there are numerous avenues for explanation. We focus here on just two - the impact of shocks from other sources and of the extent of nominal rigidity. The results are summarised in Table 3.

Clearly monetary shocks are not the only source of variation in an economy. Here we allow for aggregate productivity shocks (using a baseline RBC parameterisation with $½_z$ = 0:95 and $¾_{"_z}$ = 0:007.) The standard deviation of monetary shocks is then chosen to match US output

Statistic	Data	MN	SM	EJD
Std. Dev. wrt GDP				
Q	4.362	6.056	3.501	5.891
S	4.676	22.219	7.671	6.643
N	0.671	2.161	0.157	0.455
CRE	2.895	-	2.704	4.918
DES	4.868	-	2.163	4.863
C	0.830	1.123	0.694	0.687
NX	0.110	4.736	5.891	6.089
Serial Correlation				
Q	0.831	0.738	0.808	0.901
S	0.866	0.949	0.935	0.957
Cross Correlation				
Q; S	0.991	0.394	0.557	0.627

Table 2: Business Cycle Statistics: Cross Model Comparison

variability, other parameters (in particular the degree of price rigidity) remain at the baseline values. Productivity shocks and monetary shocks are assumed to be independent. The introduction of (persistent) aggregate productivity shocks tends to reduce the variability of all the variables - presumably to match US levels of real and nominal exchange rate variability one should reduce the extent of price stickiness. Finally, and unsurprisingly, the greater persistence of the exogenous forcing variables raises the persistence of the simulated exchange rate series.

The lastl three columns of Table 3 report the results of allowing for variation in the extent of price stickiness (with only monetary shocks). The …nal column corresponds to the baseline parameterisation of the EJD model in Table 2. Only monetary shocks are present and it appears that reducing the extent of price stickiness to value constistent with the microeconomic data tends to impair the EJD model's ability to explain the real and nominal exchange rate volatility, the persistence properties of the nominal exchange rate, the contemporaneous correlation of real and nominal exchange rates and net export volatility.

4 Conclusions

In this paper we examined the dynamic behaviour of a small open economy model with search and matching friction in the labour market and nominal rigidities in the goods market. The model we developed is rich enough to address a wide range of issues, but, in the spirit of Dornbush (1976), we focussed on the behaviour of exchange rates in response to (monetary) shocks. The combination of

Statistic	Data	Real Shocks	$\omega = 0.5$	$\omega = \frac{2}{3}$	$\omega = \frac{3}{4}$
Std. Dev. wrt GDP					
Q	4.362	2.502	4.039	3.629	5.891
S	4.676	2.004	23.522	9.296	6.643
N	0.671	0.405	0.332	0.441	0.455
CRE	2.895	4.235	4.428	4.829	4.918
DES	4.868	4.246	4.762	4.755	4.863
C	0.830	0.501	0.634	0.680	0.687
NX	0.110	3.980	7.033	6.222	6.089
Serial Correlation					
Q	0.831	0.985	0.788	0.877	0.901
S	0.866	0.983	0.999	0.962	0.957
Cross Correlation					
Q, S	0.991	0.499	0.344	0.538	0.627

Table 3: Business Cycle Statistics: Effects of Parameter Variation

matching frictions in the labour market and nominal price rigidity in the goods market provides a much better account of the persistence of real and nominal variables than available in the current generation of DSGE monetary models based on nominal price stickiness alone, e.g. Gali and Monacelli (2003), McCallum and Nelson (1999). Reassuringly, the existence of an exchange rate channel for monetary transmission does not overturn the persistent response to monetary shocks obtained in an analagous closed economy model, Walsh (2003). Instead the model outperforms exisiting international monetary DSGE models with nominal rigidities in terms of its ability to replicate both the persistence and the volatility of real (and nominal) exchange rates. So it appears that a combination of real and nominal rigidities may help to understand a variety of exchange rate puzzles posed by the existing literature. However work remains to be done as the model poses difficulties for understanding the response of some variables including net exports.

Future work should focus on deepening our understanding of the mechanisms at work within the model and analysing the robustness of the results. For instance, there are several channels for monetary transmission within the model: the traditional interest rate channel, the exchange rate channel and the cost channel. It would seem to be important to analyse the extent to which each contributes to the persistence and volatility results obtained above, as well as the consider the robustness of these in the face of parameter variations. Another issue to be addressed is the behaviour of the exchange rate when monetary policy follows an interest rate rule, for example a Taylor rule. Besides the impact of domestic monetary disturbances , one might also study response of the economy to disturbances such as deviations from UIP or foreign price / output shocks. Finally, the present paper makes specific assumptions about the form of exchange rate pass through, it would be of interest to examine how robust the results are to variations in the extent of exchange rate pass-through.

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