Journal of Economic Dynamics & Control 35 (2011) 1999–2041

Contents lists available at SciVerse ScienceDirect

Journal of Economic Dynamics & Control

journal homepage: www.elsevier.com/locate/jedc

Introducing financial frictions and unemployment into a small open economy model

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ARTICLE INFO

Available online 1 October 2011

JEL classification:
E0
E3
F0
F4
G0
G1
J6

Keywords:
DSGE model
Financial frictions
Employment frictions
Small open economy
Bayesian estimation

ABSTRACT

Which are the main frictions and the driving forces of business cycle dynamics in an open economy? To answer this question we extend the standard new Keynesian model in three dimensions: we incorporate financing frictions for capital, employment frictions for labor and extend the model into a small open economy setting. We estimate the model on Swedish data. Our main results are that (i) a financial shock is pivotal for explaining fluctuations in investment and GDP. (ii) The marginal efficiency of investment shock has negligible importance. (iii) The labor supply shock is unimportant in explaining GDP and no high frequency wage markup shock is needed.

1. Introduction

The recent financial crisis has made it clear that business cycle modeling no longer can abstract from financial factors – they appear, both *prima facie* and using more advanced methods, to be the main source and/or propagation mechanism of this downturn. The crisis has also led to a shift in the type of questions that are being asked in macroeconomics, and to be able to answer these questions requires an increased emphasis on financial aspects. It is also becoming increasingly clear that the standard business cycle approach of modeling labor markets without explicit unemployment has its limitations. Aside from the obvious drawback of not having implications for unemployment, the standard approach also relies on wage markup shocks to explain a large fraction of the variation in main macro variables such as GDP and inflation. It also tends to induce too little persistence in hours worked as these are modeled as costless to adjust. We resolve all these limitations by integrating recent progress in labor market modeling into a comprehensive monetary business cycle model. The paper is furthermore motivated by some questions that most existing business cycle models are mute on, but that we would like to answer: How important are financial and labor market frictions for the business cycle dynamics of a small open economy? In particular, what are the quantitative effects of financial shocks on investment and output? How is unemployment affected by a sudden and temporary decrease in export demand or an increase in corporate interest rate

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doi:10.1016/j.jedc.2011.09.005

spreads? Taking into account financial market data, is investment primarily driven by shocks to investment demand or investment supply? Finally, is the cost of increasing employment related to the tightness of the labor market in the way implied by search-matching models of the labor market? In order to address these questions we extend what is becoming the standard empirical new Keynesian model, see e.g. Christiano et al. (2005, henceforth CEE), in three dimensions and estimate it on Swedish data.

First, we incorporate financial frictions in the accumulation and management of capital similar to Bernanke et al. (1999, henceforth BGG) and Christiano et al. (2003, 2008). The financial frictions that we introduce reflect that borrowers and lenders are different agents, and that they have different information. Thus we introduce 'entrepreneurs'. These agents own and manage the capital stock, financed both by internal and borrowed funds. Only the entrepreneurs costlessly observe their own idiosyncratic productivity. The presence of asymmetric information in financing the capital stock leads to a role for the balance sheets of entrepreneurs.

The debt contracts extended by banks to entrepreneurs are financed by issuing liabilities to households. In addition to their accumulated savings, households can also borrow foreign funds to deposit into banks. In the model the interest rate that households receive is nominally non-state-contingent. These nominal contracts give rise to wealth effects of unexpected changes in the price level of the sort emphasized by Fisher (1933). For example, when a shock occurs, which drives the price level down, households receive a wealth transfer. This transfer is taken from entrepreneurs whose net worth thereby is reduced. With the tightening of their balance sheets, the ability of entrepreneurs to invest is reduced, and this generates an economic slowdown. A similar mechanism is set in motion whenever the price of capital changes as this affects the asset side of entrepreneurs' balance sheets.

Second, we include the labor market search and matching framework of Mortensen and Pissarides (1994) and, more recently, Hall (2005a–c) and Shimer (2005,b). We integrate the framework into our environment – which includes physical capital and monetary factors – following the version of Gertler and Trigari (2009, henceforth GT) and Gertler et al. (2008, henceforth GST) implemented in Christiano et al. (2007, henceforth CIMR). A key feature of this model is that there are wage-setting frictions, but they do not have a direct impact on ongoing worker employer relations as long as these are mutually beneficial. However, wage-setting frictions have an impact on the effort of an employer in recruiting new employees. Accordingly, the setup is not vulnerable to the Barro (1977) critique that wages cannot be allocational in ongoing employer–employee relationships (see Hall, 2005c).

There are three main differences between the our labor market modeling and GST. We motivate our choices regarding these three differences in Section 4. GST assume wage-setting frictions of the Calvo type, while we instead work with Taylor-type frictions. GST shut down the intensive margin of labor supply in their empirical specification, while we allow for variation in this margin. An important step forward is that we allow for endogenous separation of employees from their jobs. Endogenous separations have been modeled earlier, e.g. by den Haan et al. (2000), but not in a comprehensive monetary DSGE model.

In the standard new Keynesian model, the homogeneous labor services are supplied to the competitive labor market by labor contractors who combine the labor services of households who monopolistically supply specialized labor services (see Erceg et al., 2000, henceforth EHL). Our labor market model dispenses with the specialized labor services abstraction and the accompanying monopoly power, which commonly is modeled as time-varying ('wage markup' shocks). The reason for this modeling choice is that we do not think this type of union monopoly power, nor its high frequency time-variation, accurately describes the labor market. Labor services are instead supplied to the homogeneous labor market by 'employment agencies' – a modeling construct best viewed as a goods producing firm's human resource division. Each employment agency retains a large number of workers. At the beginning of the period a fraction of workers are randomly selected to separate from the agency and go into unemployment. Also, a number of new workers arrive from unemployment in proportion to the number of vacancies posted by the agency in the previous period. After separation and new arrivals occur, the nominal wage rate is set. Then idiosyncratic shocks to workers' productivities are realized and endogenous separation decisions are made.

The nominal wage paid to an individual worker is determined by Nash bargaining, which occurs once every N periods. Each employment agency is permanently allocated to one of N different cohorts. Cohorts are differentiated according to the period in which they renegotiate their wage. Since there is an equal number of agencies in each cohort, $1/N$ of the agencies bargain in each period. The intensity of labor effort is determined efficiently by equating the worker's marginal cost to the agency's marginal benefit. The efficient provision of labor on the intensive margin implies an important difference to EHL where instead a direct link between the sticky wage and hours worked is assumed.

Third, we extend the model into a small open economy setting by incorporating the small open economy structure of Adolfson et al. (2005, 2007, 2008) (henceforth ALLV). We model the foreign economy as a vector autoregression (VAR) in foreign inflation, interest rate, output and two world-wide unit-root technology shocks, neutral and investment-specific. As ALLV we allow for both an exogenous shock and an endogenous risk-adjustment term that induce deviations from uncovered interest parity (UIP), but our motivation is different, and we therefore choose a different form of endogenous risk-adjustment. The international interaction consists of trade of goods as well as in riskless bonds. The three final goods – consumption, investment and exports – are produced by combining the domestic homogenous good with specific imported inputs for each type of final good. We allow for Calvo price rigidity both of imports and exports and in that way allow for limited pass-through. Finally, it is worth noting that bank lending, and in particular monitoring of defaulting entrepreneurs, is a purely domestic activity.

We estimate the full model using Bayesian techniques on Swedish data 1995q1–2010q3, i.e. including the recent financial crisis. In our estimation we select our model priors endogenously, using a strategy similar to the one suggested by Del Negro and Schorfheide (2008). The estimation allows us to give quantitative answers to the questions posed above.

Let us outline these answers here: we document that adding financial and employment frictions substantially changes the model dynamics and improves the forecasting properties of the model, in particular for inflation. The financial shock to entrepreneurial wealth is pivotal for explaining business cycle fluctuations. It affects investment demand and accounts for three quarters of the variance in investment and a quarter of the variance in GDP. On the other hand, we find that the marginal efficiency of investment shock has very limited importance. This is in sharp contrast to the estimation results of Justiniano et al. (2011, henceforth JPT). The reason for the difference in results is that we match financial market data – corporate interest rate spreads and stock prices. This data indicates that the dominating source of variation is investment demand, not investment supply.

In contrast to the standard new Keynesian literature on estimated DSGE models, our model does not require any wage markup shocks to match the data. Furthermore, the low-frequency labor preference shock that we obtain is not important in explaining GDP, inflation or interest rates. Our interpretation of the stark contrast between our full model and the literature in this respect is that the tight link between the desired real wage and hours worked implied by EHL labor market modeling does not hold in the data, even when this connection is relaxed by assuming wage stickiness. We instead assume efficient provision of labor on the intensive margin without any direct link to the sticky wage, and thereby allow for a high frequency disconnect between wages and hours worked. Fundamentally, our model reflects that labor is not supplied on a spot market, but within long-term relationships. Finally, we find that the tightness of the labor market (measured as vacancies divided by unemployment) is unimportant for the cost of expanding the workforce. In other words, there are costs of hiring, but no costs of vacancy postings *per se*.

The paper is organized as follows. In Section 2 we describe the baseline model, which is a small open economy version of CEE. Section 3 introduces financial frictions, while Section 4 incorporates employment frictions into the model. Section 5 contains the estimation of the full model, which includes both financial and employment frictions. Finally, Section 6 presents our conclusions. The bulk of the model derivations are in the Appendix. A separate Computational Appendix contains additional tables and figures related to the estimation results.

2. The baseline small open economy model

This section describes our baseline model. The model is mostly based on CEE (2005) and its open economy structure builds on ALLV. This also makes it similar to Smets and Wouters (2003, 2007, henceforth SW). The structure of goods production is worth outlining at this point. The three final goods – consumption, investment and exports – are produced by combining the domestic homogenous good with specific imported inputs for each type of final good. See Fig. 1 for a graphical illustration. Below we start the model description by going through the production of all these goods, and describe imports.

2.1. Production of the domestic homogeneous good

A homogeneous domestic good, Y_t, is produced using

$$Y_t = \left[\int_0^1 Y_{i,t}^{1/\lambda_d} \, di \right]^{\lambda_d}, \quad 1 \le \lambda_d < \infty. \tag{1}$$

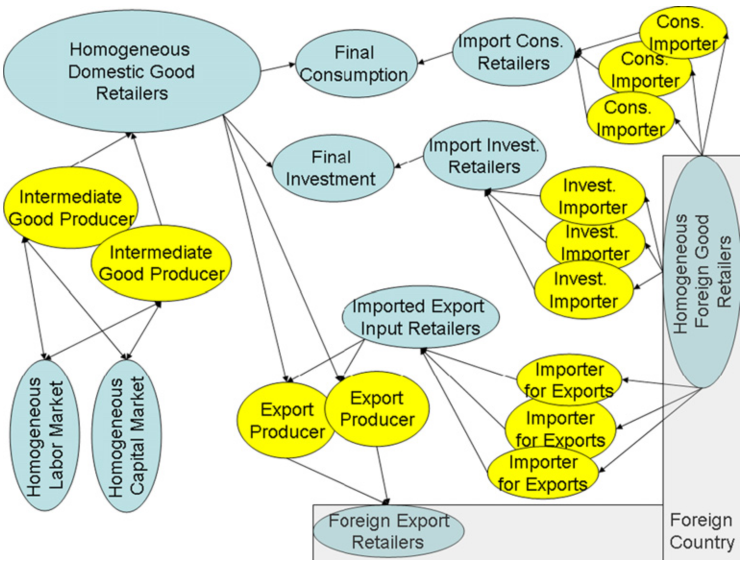

Fig. 1. Graphical illustration of the goods production part of the model.

where $Y_{i,t}$ denotes intermediate goods and $1/\lambda_d$ their degree of substitutability. The homogeneous domestic good is produced by a competitive, representative firm, which takes the price of output, P_t, and the price of inputs, $P_{i,t}$, as given.

The ith intermediate good producer has the following production function:

$$Y_{i,t} = (z_t H_{i,t})^{1-\alpha} \epsilon_t K_{i,t}^{\alpha} - z_t^{+} \phi, \tag{2}$$

where $K_{i,t}$ denotes the capital services rented by the ith intermediate good producer. Also, $\log(z_t)$ is a technology shock whose first difference has a positive mean, $\log(\epsilon_t)$ is a stationary neutral technology shock and ϕ denotes a fixed production cost. The economy has two sources of growth: the positive drift in $\log(z_t)$ and a positive drift in $\log(\Psi_t)$, where Ψ_t is an investment-specific technology (IST) shock. The object, z_t^{+}, in (2) is defined as[1]

$$z_t^{+} = \Psi_t^{\alpha/(1-\alpha)} z_t.$$

In (2), $H_{i,t}$ denotes homogeneous labor services hired by the ith intermediate good producer. Firms must borrow a fraction of the wage bill, so that one unit of labor costs is denoted by

$$W_t R_t^f,$$

with

$$R_t^f = \nu^f R_t + 1 - \nu^f, \tag{3}$$

where W_t is the aggregate wage rate, R_t is the risk-free interest rate that applies to working capital loans and ν^f corresponds to the fraction that must be financed in advance.

The firm's marginal cost, divided by the price of the homogeneous good, is denoted by mc_t

$$mc_t = \tau_t^d \left(\frac{1}{1-\alpha}\right)^{1-\alpha} \left(\frac{1}{\alpha}\right)^{\alpha} (r_t^k)^{\alpha} (\overline{w}_t R_t^f)^{1-\alpha} \frac{1}{\epsilon_t}, \tag{4}$$

where r_t^k is the nominal rental rate of capital scaled by P_t and $\overline{w}_t = W_t/(z_t^{+} P_t)$. Also, τ_t^d is a tax-like shock, which affects marginal cost, but does not appear in a production function. In the linearization of a version of the model in which there are no price and wage distortions in the steady state, τ_t^d is isomorphic to a disturbance in λ_d, i.e., a markup shock.

Productive efficiency dictates that marginal cost is equal to the cost of producing another unit using labor, implying

$$mc_t = \tau_t^d \frac{(\mu_{\Psi,t})^{\alpha} \overline{w}_t R_t^f}{\epsilon_t (1-\alpha) \left(\frac{k_{i,t}}{\mu_{z^+,t}} \Big/ H_{i,t}\right)^{\alpha}}. \tag{5}$$

The ith firm is a monopolist in the production of the ith good and so it sets its price. Price setting is subject to Calvo frictions. With probability ξ_d the intermediate good firm cannot reoptimize its price, in which case

$$P_{i,t} = \tilde{\pi}_{d,t} P_{i,t-1}, \quad \tilde{\pi}_{d,t} \equiv (\pi_{t-1})^{\kappa_d} (\overline{\pi}_t^c)^{1-\kappa_d-\varkappa_d} (\check{\pi})^{\varkappa_d},$$

where κ_d, $\varkappa_d$, $\kappa_d + \varkappa_d \in (0,1)$ are parameters, π_{t-1} is the lagged inflation rate and $\overline{\pi}_t^c$ is the central bank's target inflation rate. Also, $\check{\pi}$ is a scalar, which allows us to capture, among other things, the case in which non-optimizing firms either do not change price at all (i.e., $\check{\pi} = \varkappa_d = 1$) or that they index only to the steady state inflation rate (i.e., $\check{\pi} = \overline{\pi}$, $\varkappa_d = 1$). Note that we get price dispersion in steady state if $\varkappa_d > 0$ and if $\check{\pi}$ is different from the steady state value of π. See Yun (1996) for a discussion of steady state price dispersion.

With probability $1-\xi_d$ the firm can change its price. The problem of the ith domestic intermediate good producer, which has the opportunity to change price, is to maximize discounted profits:

$$E_t \sum_{j=0}^{\infty} \beta^j \upsilon_{t+j} \{P_{i,t+j} Y_{i,t+j} - mc_{t+j} P_{t+j} Y_{i,t+j}\}, \tag{6}$$

subject to the requirement that production equals demand. In the above expression, υ_t is the multiplier on the household's nominal budget constraint. It measures the marginal value to the household of one unit of profits, in terms of currency. In states of nature when the firm can reoptimize price, it does so to maximize its discounted profits, subject to the price setting frictions and to the requirement that it satisfies demand given by

$$\left(\frac{P_t}{P_{i,t}}\right)^{\lambda_d/(\lambda_d-1)} Y_t = Y_{i,t}. \tag{7}$$

The equilibrium conditions associated with the price setting problem and their derivation are reported in Appendix B.3.1.

The domestic intermediate output good is allocated among alternative uses as follows:

$$Y_t = G_t + C_t^d + I_t^d + \int_0^1 X_{i,t}^d. \tag{8}$$

[1] The details regarding the scaling of variables are collected in Appendix B.1. In general, lower-case letters denote scaled variables throughout.

Here, G_t denotes government consumption (which consists entirely of the domestic good), C_t^d denotes intermediate goods used (together with foreign consumption goods) to produce final household consumption goods. Also, I_t^d is the amount of intermediate domestic goods used in combination with imported foreign investment goods to produce a homogeneous investment good. Finally, the integral in (8) denotes domestic resources allocated to exports. The determination of consumption, investment and export demand is discussed below.

2.2. Production of final consumption and investment goods

Final consumption goods are purchased by households. These goods are produced by a representative competitive firm using the following linear homogeneous technology:

$$C_t = [(1-\omega_c)^{1/\eta_c}(C_t^d)^{(\eta_c-1)/\eta_c} + \omega_c^{1/\eta_c}(C_t^m)^{(\eta_c-1)/\eta_c}]^{\eta_c/(\eta_c-1)}. \tag{9}$$

The representative firm takes the price of final consumption goods output, P_t^c, as given. Final consumption goods output is produced using two inputs. The first, C_t^d, is a one-for-one transformation of the homogeneous domestic good and therefore has price, P_t. The second input, C_t^m, is the homogeneous composite of specialized consumption import goods discussed in the next subsection. The price of C_t^m is $P_t^{m,c}$. The representative firm takes the input prices, P_t and $P_t^{m,c}$, as given. Profit maximization leads to the following demand for the intermediate inputs in scaled form:

$$c_t^d = (1-\omega_c)(p_t^c)^{\eta_c} c_t,$$

$$c_t^m = \omega_c \left(\frac{p_t^c}{p_t^{m,c}}\right)^{\eta_c} c_t, \tag{10}$$

where $p_t^c = P_t^c/P_t$ and $p_t^{m,c} = P_t^{m,c}/P_t$. The price of C_t is related to the price of the inputs by

$$p_t^c = [(1-\omega_c) + \omega_c(p_t^{m,c})^{1-\eta_c}]^{1/(1-\eta_c)}. \tag{11}$$

The rate of inflation of the consumption good is

$$\pi_t^c = \frac{P_t^c}{P_{t-1}^c} = \pi_t \left[\frac{(1-\omega_c) + \omega_c(p_t^{m,c})^{1-\eta_c}}{(1-\omega_c) + \omega_c(p_{t-1}^{m,c})^{1-\eta_c}}\right]^{1/(1-\eta_c)}. \tag{12}$$

Investment goods are produced by a representative competitive firm using the following technology:

$$I_t + a(u_t)\overline{K}_t = \Psi_t[(1-\omega_i)^{1/\eta_i}(I_t^d)^{(\eta_i-1)/\eta_i} + \omega_i^{1/\eta_i}(I_t^m)^{(\eta_i-1)/\eta_i}]^{\eta_i/(\eta_i-1)},$$

where we define investment to be the sum of investment goods, I_t, used in the accumulation of physical capital, plus investment goods used in capital maintenance, $a(u_t)\overline{K}_t$. We discuss maintenance in Section 2.4 below. See Appendix B.2 for the functional form of $a(u_t)$. u_t denotes the utilization rate of capital, with capital services being defined by

$$K_t = u_t \overline{K}_t.$$

To accommodate the possibility that the price of investment goods relative to the price of consumption goods declines over time, we assume that the IST shock Ψ_t is a unit root process with a potentially positive drift (see Greenwood et al., 1997).[2] As in the consumption good sector the representative investment goods producers take all relevant prices as given. Profit maximization leads to the following demand for the intermediate inputs in scaled form:

$$i_t^d = (p_t^i)^{\eta_i}\left(i_t + a(u_t)\frac{\overline{k}_t}{\mu_{\psi,t}\mu_{z^+,t}}\right)(1-\omega_i), \tag{13}$$

$$i_t^m = \omega_i \left(\frac{p_t^i}{p_t^{m,i}}\right)^{\eta_i}\left(i_t + a(u_t)\frac{\overline{k}_t}{\mu_{\psi,t}\mu_{z^+,t}}\right), \tag{14}$$

where $p_t^i = \Psi_t P_t^i/P_t$ and $p_t^{m,i} = P_t^{m,i}/P_t$.

The price of I_t is related to the price of the inputs by

$$p_t^i = [(1-\omega_i) + \omega_i(p_t^{m,i})^{1-\eta_i}]^{1/(1-\eta_i)}. \tag{15}$$

[2] The empirical importance of this shock has been debated in recent years, see e.g. Justiniano et al. (2010). In estimated DSGE models a consensus that the IST shock has only marginal effects when the relative price of investment is observed has been established, see Schmitt-Grohé and Uribe (2008) and, for the open economy setting, Mandelman et al. (2011).

The rate of inflation of the investment good is

$$\pi_t^i = \frac{\pi_t}{\mu_{\Psi,t}} \left[\frac{(1-\omega_i)+\omega_i (p_t^{m,i})^{1-\eta_i}}{(1-\omega_i)+\omega_i (p_{t-1}^{m,i})^{1-\eta_i}} \right]^{1/(1-\eta_i)}. \tag{16}$$

2.3. Exports and imports

This section reviews the structure of imports and exports. Both activities involve Calvo price setting frictions, and therefore require the presence of market power. In each case, we follow the Dixit–Stiglitz strategy of introducing a range of specialized goods. This allows there to be market power without the counterfactual implication that there are a small number of firms in the export and import sector. Thus, exports involve a continuum of exporters, each of which is a monopolist, which produces a specialized export good. Each monopolist produces the export good using a homogeneous domestically produced good and a homogeneous good derived from imports. The specialized export goods are sold to foreign, competitive retailers, which create a homogeneous good that is sold to foreign citizens.

In the case of imports, specialized domestic importers purchase a homogeneous foreign good, which they turn into a specialized input and sell to domestic retailers. There are three types of domestic retailers. One uses the specialized import goods to create the homogeneous good used as an input into the production of specialized exports. Another uses the specialized import goods to create an input used in the production of investment goods. The third type uses specialized imports to produce a homogeneous input used in the production of consumption goods. See Fig. 1 for a graphical illustration.

We emphasize two features of this setup. First, before being passed on to final domestic users, imported goods must be combined with domestic inputs. This is consistent with the view emphasized by Burstein et al. (2005, 2007) that there are substantial distribution costs associated with imports. Second, there are pricing frictions in all sectors of the model. The pricing frictions in the homogeneous domestic good sector are standard, and perhaps do not require additional elaboration. Instead we elaborate on the pricing frictions in the part of the model related to imports and exports.

In all cases we assume that prices are set in the currency of the buyer ("pricing to market"). For Sweden the support for this assumption from micro-evidence is mixed – it is well supported for exports, but less so for imports. Friberg and Wilander (2008) document that three quarters of Swedish export goods are denominated in a foreign currency, predominantly the currency of the buyer. Hopkins (2006) documents that one-quarter of imports in goods and services are denominated in Swedish krona.

Pricing frictions in the case of imports help the model account for the evidence that exchange rate shocks take time to pass into domestic prices. Pricing frictions in the case of exports help the model to produce a hump-shape in the response of output to a monetary shock. To see this, it is useful to recall how a hump-shape is produced in a closed economy version of the model. In that version, the hump shape occurs because there are costs to quickly expanding consumption and investment demand. Consumption is not expanded rapidly because of the assumption of habit persistence in preferences and investment is not expanded rapidly because of the assumption that there are adjustment costs associated with changing the flow of investment. When the closed economy is opened up, another potential source of demand in the wake of a monetary policy shock is introduced, namely, exports. Without price rigidities (in terms of the foreign currency) for export goods, the fast response of export good price and quantity might eliminate the hump-shaped response of output to a monetary policy shock.

There are two additional observations worth making concerning the role of price frictions in the export sector. First, it is interesting to note that the price frictions in the import of goods used as inputs into the production of exports work against us. These price frictions increase the need for price frictions in the export sector to dampen the response of X to an expansionary domestic monetary shock. The reason is that in the absence of price frictions on imports, the marginal cost of exports would jump in the face of an expansionary monetary policy shock, as pass through from the exchange rate to the domestic currency price of imports of goods destined for export increases. From the perspective of achieving a hump-shaped response of output to an expansionary monetary policy shock, it is therefore better to treat the import of goods destined for the export sector asymmetrically by supposing there are low price frictions in those goods.

The second observation on the role of price frictions in the export sector is related to the first. We make assumptions in the model that have the effect of also producing a hump-shaped response of the nominal exchange rate to a monetary policy shock. The model captures, in a reduced form way, the notion that holders of domestic assets require less compensation for risk in the wake of an expansionary monetary policy shock. As a result, the model does not display the classic Dornbusch 'overshooting' pattern in the exchange rate in response to a monetary policy shock. Instead, the nominal exchange rate rises slowly in response to an expansionary monetary policy shock. The slow response in the exchange rate reduces the burden on price frictions in P^x to slow down the response of X to a monetary policy shock.

2.3.1. Exports

There is a total demand by foreigners for domestic exports, which takes on the following form:

$$X_t = \left(\frac{P_t^x}{P_t^*} \right)^{-\eta_f} Y_t^*. \tag{17}$$

Here, Y_t^* is the foreign GDP and P_t^* is the foreign currency price of foreign homogeneous goods. Also, P_t^x is an index of export prices, whose determination is discussed below. The goods, X_t, are produced by a representative, competitive foreign retailer firm using specialized inputs as follows:

$$X_t = \left[\int_0^1 X_{i,t}^{1/\lambda_x} \, di \right]^{\lambda_x}, \tag{18}$$

where $X_{i,t}$, $i \in (0,1)$, are the specialized intermediate goods for export good production. The retailer that produces X_t takes its output price, P_t^x, and its input prices, $P_{i,t}^x$, as given. Optimization leads to the following demand for specialized exports:

$$X_{i,t} = \left(\frac{P_{i,t}^x}{P_t^x} \right)^{-\lambda_x/(\lambda_x-1)} X_t. \tag{19}$$

Combining (18) and (19), we obtain

$$P_t^x = \left[\int_0^1 (P_{i,t}^x)^{1/(1-\lambda_x)} \, di \right]^{1-\lambda_x}.$$

The ith specialized export is produced by a monopolist using the following technology:

$$X_{i,t} = [\omega_x^{1/\eta_x} (X_{i,t}^m)^{(\eta_x-1)/\eta_x} + (1-\omega_x)^{1/\eta_x} (X_{i,t}^d)^{(\eta_x-1)/\eta_x}]^{\eta_x/(\eta_x-1)},$$

where $X_{i,t}^m$ and $X_{i,t}^d$ are the ith exporter's use of the imported and domestically produced goods, respectively. We derive the marginal cost associated with the CES production function from the multiplier associated with the Lagrangian representation of the cost minimization problem:

$$C = \min \tau_t^x [P_t^{m,x} R_t^x X_{i,t}^m + P_t R_t^x X_{i,t}^d] + \lambda \{ X_{i,t} - [\omega_x^{1/\eta_x} (X_{i,t}^m)^{(\eta_x-1)/\eta_x} + (1-\omega_x)^{1/\eta_x} (X_{i,t}^d)^{(\eta_x-1)/\eta_x}]^{\eta_x/(\eta_x-1)} \},$$

where $P_t^{m,x}$ is the price of the homogeneous import good and P_t is the price of the homogeneous domestic good. Using the first order conditions of this problem and the production function we derive the real marginal cost in terms of stationary variables, mc_t^x:

$$mc_t^x = \frac{\lambda}{S_t P_t^x} = \frac{\tau_t^x R_t^x}{q_t p_t^c p_t^x} [\omega_x (p_t^{m,x})^{1-\eta_x} + (1-\omega_x)]^{1/(1-\eta_x)}, \tag{20}$$

where

$$R_t^x = \nu^x R_t + 1 - \nu^x, \tag{21}$$

and where we have used

$$\frac{S_t P_t^x}{P_t} = \frac{S_t P_t^*}{P_t^c} \frac{P_t^c}{P_t} \frac{P_t^x}{P_t^*} = q_t p_t^c p_t^x, \tag{22}$$

where q_t denotes the real exchange rate and is defined as

$$q_t = \frac{S_t P_t^*}{P_t^c}. \tag{23}$$

From the solution to the same problem we also get the demand for domestic inputs for export production:

$$X_{i,t}^d = \left(\frac{\lambda}{\tau_t^x R_t^x P_t} \right)^{\eta_x} X_{i,t} (1-\omega_x). \tag{24}$$

The quantity of the domestic homogeneous good used by specialized exporters is

$$\int_0^1 X_{i,t}^d \, di,$$

and this needs to be expressed in terms of aggregates. Plugging (24) into this integral we derive (see Appendix B.3.4)

$$X_t^d = \int_0^1 X_{i,t}^d \, di = [\omega_x (p_t^{m,x})^{1-\eta_x} + (1-\omega_x)]^{\eta_x/(1-\eta_x)} (1-\omega_x) (\mathring{p}_t^x)^{-\lambda_x/(\lambda_x-1)} (p_t^x)^{-\eta_f} Y_t^*, \tag{25}$$

where $\mathring{p}_t^x$ is a measure of the price dispersion and is defined in the same section of the Appendix. Note how the impact of price dispersion operates – to produce a given total of the homogenous export good, X_t, one needs more of the homogeneous input good, X_t^d, to the extent that there is price dispersion. In that case $\mathring{p}_t^x < 1$ and $(\mathring{p}_t^x)^{-\lambda_x/(\lambda_x-1)} > 1$, and more dispersion is reflected in a lower $\mathring{p}_t^x$.

We also require an expression for imported inputs for export production in terms of aggregates. Using a similar derivation as for X_t^d it can be shown to be

$$X_t^m = \omega_x \left(\frac{[\omega_x (p_t^{m,x})^{1-\eta_x} + (1-\omega_x)]^{1/(1-\eta_x)}}{p_t^{m,x}} \right)^{\eta_x} (\overset{\circ}{p}{}_t^x)^{-\lambda_x/(\lambda_x-1)} (p_t^x)^{-\eta_f} Y_t^*. \tag{26}$$

The ith, $i \in (0,1)$, export good firm takes (19) as its demand curve. This producer sets prices subject to a Calvo sticky-price mechanism. With probability ξ_x the ith export good firm cannot reoptimize its price, in which case it updates its price as follows:

$$P_{i,t}^x = \tilde{\pi}_t^x P_{i,t-1}^x, \quad \tilde{\pi}_t^x = (\pi_{t-1}^x)^{\kappa_x} (\pi^x)^{1-\kappa_x-\varkappa_x} (\breve{\pi})^{\varkappa_x}, \tag{27}$$

where $\kappa_x, \varkappa_x, \kappa_x + \varkappa_x \in (0,1)$.

The equilibrium conditions associated with price setting by exporters that do get to reoptimize their prices are analogous to the ones derived for domestic intermediate good producers and are reported in Appendix B.3.3.

2.3.2. Imports

We now turn to a discussion of imports. Foreign firms sell a homogeneous good to domestic importers. The importers convert the homogeneous good into a specialized input (they "brand name it") and supply that input monopolistically to domestic retailers. Importers are subject to Calvo price setting frictions. There are three types of importing firms: (i) one produces goods used to produce an intermediate good for the production of consumption, (ii) another one produces goods used to produce an intermediate good for the production of investment and (iii) the third one produces goods used to produce an intermediate good for the production of exports.

Consider (i) first. The production function of the domestic retailer of imported consumption goods is

$$C_t^m = \left[\int_0^1 (C_{i,t}^m)^{1/\lambda_{m,c}} \, di \right]^{\lambda_{m,c}},$$

where $C_{i,t}^m$ is the output of the ith specialized producer and C_t^m is an intermediate good used in the production of consumption goods. Let $P_t^{m,c}$ denote the price index of C_t^m and let $P_{i,t}^{m,c}$ denote the price of the ith intermediate input. The domestic retailer is competitive and takes $P_t^{m,c}$ and $P_{i,t}^{m,c}$ as given. In the usual way, the demand curve for specialized inputs is given by the domestic retailer's first order necessary condition for profit maximization:

$$C_{i,t}^m = C_t^m \left(\frac{P_t^{m,c}}{P_{i,t}^{m,c}} \right)^{\lambda_{m,c}/(\lambda_{m,c}-1)}.$$

We now turn to the producer of $C_{i,t}^m$, who takes the previous equation as a demand curve. This producer buys the homogeneous foreign good and converts it one-for-one into the domestic differentiated good, $C_{i,t}^m$. The intermediate good producer's marginal cost is

$$\tau_t^{m,c} S_t P_t^* R_t^{\nu,*}, \tag{28}$$

where

$$R_t^{\nu,*} = \nu^* R_t^* + 1 - \nu^*, \tag{29}$$

and R_t^* is the foreign nominal rate of interest. The notion here is that the intermediate good firm must pay the inputs with foreign currency and because they have no resources themselves at the beginning of the period, they must borrow those resources if they are to buy the foreign inputs needed to produce $C_{i,t}^m$. The financing need is in the foreign currency, so the loan is taken in that currency.[3] There is no risk to this working capital loan, because all shocks are realized at the beginning of the period, and so there is no uncertainty within the duration of the loan about the realization of prices and exchange rates.[4]

As in the homogenous domestic good sector, $\tau_t^{m,c}$ is a tax-like shock, which affects marginal cost, but does not appear in a production function. In the linearization of a version of the model in which there are no price and wage distortions in the steady state, $\tau_t^{m,c}$ is isomorphic to a markup shock.

The total value of imports accounted for by the consumption sector is

$$S_t P_t^* R_t^{\nu,*} C_t^m (\overset{\circ}{p}{}_t^{m,c})^{\lambda_{m,c}/(1-\lambda_{m,c})},$$

[3] The working capital loan can be thought of as being extended by the seller.

[4] We are somewhat uncomfortable with this feature of the model. The fact that interest is due and matters indicates that some time evolves over the duration of the loan. Our assumption that no uncertainty is realized over a period of significant duration of time seems implausible. We suspect that a more realistic representation would involve some risk. Our timing assumptions in effect abstract away from this risk, and we conjecture that this does not affect the first order properties of the model.

where

$$\mathring{p}_t^{m,c} = \frac{\mathring{P}_t^{m,c}}{P_t^{m,c}},$$

is a measure of the price dispersion in the differentiated good, $C_{i,t}^m$.

Now consider (ii). The production function for the domestic retailer of imported investment goods, I_t^m, is

$$I_t^m = \left[\int_0^1 (I_{i,t}^m)^{1/\lambda_{m,i}}\, di\right]^{\lambda_{m,i}}.$$

The retailer of imported investment goods is competitive and takes output prices, $P_t^{m,i}$, and input prices, $P_{i,t}^{m,i}$, as given.

The producer of the ith intermediate input into the above production function buys the homogeneous foreign good and converts it one-for-one into the differentiated good, $I_{i,t}^m$. The marginal cost of $I_{i,t}^m$ is the analogue of (28)

$$\tau_t^{m,i} S_t P_t^* R_t^{v,*}.$$

Note that the importing firm's cost is P_t^* (before borrowing costs, exchange rate conversion and markup shock), which is the same cost for the specialized inputs used to produce C_t^m. We assume that (28) applies to both types of producer in order to simplify notation. Below, we suppose that the efficiency of imported investment goods grows over time, in a way that makes our assumptions about the relative costs of consumption and investment hold, whether imported or domestically produced.

The total value of imports associated with the production of investment goods is analogous to what we obtained for the consumption good sector:

$$S_t P_t^* R_t^{v,*} I_t^m (\mathring{p}_t^{m,i})^{\lambda_{m,i}/(1-\lambda_{m,i})}, \quad \mathring{p}_t^{m,i} = \frac{P_{i,t}^{m,i}}{P_t^{m,i}}. \tag{30}$$

Now consider (iii). The production function of the domestic retailer of imported goods used in the production of an input, X_t^m, for the production of export goods is

$$X_t^m = \left[\int_0^1 (X_{i,t}^m)^{1/\lambda_{m,x}}\, di\right]^{\lambda_{m,x}}.$$

The imported good retailer is competitive, and takes output prices, $P_t^{m,x}$, and input prices, $P_{i,t}^{m,x}$, as given. The producer of the specialized input, $X_{i,t}^m$, has marginal cost

$$\tau_t^{m,x} S_t P_t^* R_t^{v,*}.$$

The total value of imports associated with the production of X_t^m is

$$S_t P_t^* R_t^{v,*} X_t^m (\mathring{p}_t^{m,x})^{\lambda_{m,x}/(1-\lambda_{m,x})}, \quad \mathring{p}_t^{m,x} = \frac{P_{i,t}^{m,x}}{P_t^{m,x}}. \tag{31}$$

Each of the above three types of intermediate good firm is subject to Calvo price-setting frictions. With probability $1-\xi_{m,j}$, the jth type of firm can reoptimize its price and with probability $\xi_{m,j}$ it updates its price according to the following relation:

$$P_{i,t}^{m,j} = \tilde{\pi}_t^{m,j} P_{i,t-1}^{m,j}, \quad \tilde{\pi}_t^{m,j} \equiv (\pi_{t-1}^{m,j})^{\kappa_{m,j}} (\overline{\pi}_t^c)^{1-\kappa_{m,j}-\varkappa_{m,j}} \breve{\pi}^{\varkappa_{m,j}}, \tag{32}$$

for $j=c,i,x$ where the restrictions on the indexation parameters are as before.

The equilibrium conditions associated with price setting by importers are analogous to the ones derived for domestic intermediate good producers and are reported in Appendix B.3.3.

2.4. Households

Household preferences are given by

$$E_0^j \sum_{t=0}^{\infty} \beta^t \left[\zeta_t^c \log(C_t - bC_{t-1}) - \zeta_t^h A_L \frac{(h_{j,t})^{1+\sigma_L}}{1+\sigma_L}\right], \tag{33}$$

where ζ_t^c denotes a consumption preference shock, ζ_t^h a disutility of labor shock, b is the consumption habit parameter, h_j denotes the jth household supply of labor services and σ_L denotes the inverse Frisch elasticity. The household owns the economy's stock of physical capital. It determines the rate at which the capital stock is accumulated and the rate at which it is utilized. The household also owns the stock of net foreign assets and determines its rate of accumulation.

2.4.1. Wage setting

We start by considering wage setting. We suppose that the specialized labor supplied by households is combined by labor contractors into a homogeneous labor service as follows:

$$H_t = \left[\int_0^1 (h_{j,t})^{1/\lambda_w}\,dj\right]^{\lambda_w}, \quad 1 \le \lambda_w < \infty.$$

Households are subject to Calvo wage setting frictions as in EHL. With probability $1-\xi_w$ the jth household is able to reoptimize its wage and with probability ξ_w it updates its wage according to

$$W_{j,t+1} = \tilde{\pi}_{w,t+1} W_{j,t}, \tag{34}$$

$$\tilde{\pi}_{w,t+1} = (\pi_t^c)^{\kappa_w} (\overline{\pi}_{t+1}^c)^{(1-\kappa_w-\varkappa_w)} (\breve{\pi})^{\varkappa_w} (\mu_{z^+})^{\vartheta_w}, \tag{35}$$

where $\kappa_w, \varkappa_w, \vartheta_w, \kappa_w + \varkappa_w \in (0,1)$. The wage updating factor, $\tilde{\pi}_{w,t+1}$, is sufficiently flexible that we can adopt a variety of interesting schemes.

Consider the jth household that has an opportunity to reoptimize its wage at time t. We denote this wage rate by $\tilde{W}_t$. This is not indexed by j because the situation of each household that optimizes its wage is the same. In choosing $\tilde{W}_t$, the household considers the discounted utility (neglecting currently irrelevant terms in the household objective) of future histories when it cannot reoptimize

$$E_t^j \sum_{i=0}^{\infty} (\beta\xi_w)^i \left[-\zeta_{t+i}^h A_L \frac{(h_{j,t+i})^{1+\sigma_L}}{1+\sigma_L} + \upsilon_{t+i} W_{j,t+i} h_{j,t+i} \frac{1-\tau^y}{1+\tau^w} \right], \tag{36}$$

where τ^y is a tax on labor income and τ^w is a payroll tax. Also, recall that υ_t is the multiplier on the household's period t budget constraint. The demand for the jth household's labor services, conditional on it having optimized in period t and not again since, is

$$h_{j,t+i} = \left(\frac{\tilde{W}_t \tilde{\pi}_{w,t+i} \cdots \tilde{\pi}_{w,t+1}}{W_{t+i}} \right)^{\lambda_w/(1-\lambda_w)} H_{t+i}. \tag{37}$$

Here, it is understood that $\tilde{\pi}_{w,t+i} \cdots \tilde{\pi}_{w,t+1} \equiv 1$ when $i=0$. The equilibrium conditions associated with this problem, i.e. wage setting of households that do get to reoptimize, are derived and reported in Appendix B.3.9.

2.4.2. Technology for capital accumulation

The law of motion of the physical stock of capital takes into account investment adjustment costs as introduced by CEE[5]

$$\overline{K}_{t+1} = (1-\delta)\overline{K}_t + \Upsilon_t \left(1 - \tilde{S}\left(\frac{I_t}{I_{t-1}}\right)\right) I_t. \tag{38}$$

Here Υ_t denotes the marginal efficiency of investment (MEI) shock that affects how investment is transformed into capital. This is the shock whose importance is emphasized by JPT.

2.4.3. Household consumption and investment decisions

The first order condition for consumption is

$$\frac{\zeta_t^c}{c_t - b c_{t-1}\frac{1}{\mu_{z^+,t}}} - \beta b E_t \frac{\zeta_{t+1}^c}{c_{t+1}\mu_{z^+,t+1} - b c_t} - \psi_{z^+,t} p_t^c (1+\tau^c) = 0, \tag{39}$$

where

$$\psi_{z^+,t} = \upsilon_t P_t z_t^+$$

is the marginal value of wealth in real terms, in particular in terms of one unit of the homogenous domestic good at time t.

To define the intertemporal Euler equation associated with the household's capital accumulation decision, we need to define the rate of return on a period t investment in a unit of physical capital, R_{t+1}^k

$$R_{t+1}^k = \frac{(1-\tau^k)\left[u_{t+1} r_{t+1}^k - \frac{p_{t+1}^i}{\Psi_{t+1}} a(u_{t+1})\right] P_{t+1} + (1-\delta) P_{t+1} P_{k',t+1} + \tau^k \delta P_t P_{k',t}}{P_t P_{k',t}}, \tag{40}$$

where

$$\frac{p_t^i}{\Psi_t} P_t = P_t^i$$

[5] See Appendix B.2 for the functional form of the investment adjustment costs, $\tilde{S}$.

is the date t price of the homogeneous investment good, $\bar{r}_t^k = \Psi_t r_t^k$ is the scaled real rental rate of capital and τ^k the capital tax rate. Here, $P_{k',t}$ denotes the price of a unit of newly installed physical capital, which operates in period $t+1$. This price is expressed in units of the homogeneous good, so that $P_t P_{k',t}$ is the domestic currency price of physical capital. The numerator in the expression for R_{t+1}^k represents the period $t+1$ payoff from a unit of additional physical capital. The expression in square brackets captures the idea that maintenance expenses associated with the operation of capital are deductible from taxes. The last expression in the numerator expresses the idea that physical depreciation is deductible at historical cost. It is convenient to express R_t^k in scaled terms

$$R_{t+1}^k = \frac{\pi_{t+1}}{\mu_{\Psi,t+1}} \frac{(1-\tau^k)[u_{t+1}\bar{r}_{t+1}^k - p_{t+1}^i a(u_{t+1})] + (1-\delta)p_{k',t+1} + \tau^k \delta \frac{\mu_{\Psi,t+1}}{\pi_{t+1}} p_{k',t}}{p_{k',t}}, \tag{41}$$

where $p_{k',t} = \Psi_t P_{k',t}$. Capital is a good hedge against inflation, except for the way depreciation is treated. A rise in inflation effectively raises the tax rate on capital because of the practice of valuing depreciation at historical cost. The first order condition for capital implies

$$\psi_{z^+,t} = \beta E_t \psi_{z^+,t+1} \frac{R_{t+1}^k}{\pi_{t+1}\mu_{z^+,t+1}}. \tag{42}$$

By differentiating the Lagrangian representation of the household's problem with respect to I_t one can derive the investment first order condition in scaled terms:

$$-\psi_{z^+,t} p_t^i + \psi_{z^+,t} p_{k',t} \Upsilon_t \left[1 - \tilde{S}\left(\frac{\mu_{z^+,t}\mu_{\Psi,t} i_t}{i_{t-1}}\right) - \tilde{S}'\left(\frac{\mu_{z^+,t}\mu_{\Psi,t} i_t}{i_{t-1}}\right)\frac{\mu_{z^+,t}\mu_{\Psi,t} i_t}{i_{t-1}}\right]$$
$$+ \beta\psi_{z^+,t+1} p_{k',t+1} \Upsilon_{t+1} \tilde{S}'\left(\frac{\mu_{z^+,t+1}\mu_{\Psi,t+1} i_{t+1}}{i_t}\right)\left(\frac{i_{t+1}}{i_t}\right)^2 \mu_{\Psi,t+1}\mu_{z^+,t+1} = 0. \tag{43}$$

The first order condition associated with capital utilization is, in scaled terms:

$$\bar{r}_t^k = p_t^i a'(u_t). \tag{44}$$

The tax rate on capital income does not enter here because of the deductibility of maintenance costs.

2.4.4. Financial assets

The household does the domestic economy's saving. In addition to physical capital accumulation, period t saving occurs by the acquisition of net foreign assets, A_{t+1}^*, and a domestic bond. The domestic bond is used to finance the working capital requirements of firms. It pays a nominally non-state contingent return from t to $t+1$, R_t The first order condition associated with the domestic bond is:

$$\psi_{z^+,t} = \beta E_t \frac{\psi_{z^+,t+1}}{\mu_{z^+,t+1}}\left[\frac{R_t - \tau^b(R_t - \pi_{t+1})}{\pi_{t+1}}\right], \tag{45}$$

where τ^b is the tax rate on the real interest rate on bond income. A consequence of our treatment of the taxation of domestic bonds is that the steady state real after tax return on bonds is invariant to π.

In the model the tax treatment of domestic agents' earnings on foreign bonds is the same as the tax treatment of agents' earnings on foreign bonds. The date t first order condition associated with the asset A_{t+1}^* that pays R_t^* in terms of foreign currency is

$$\upsilon_t S_t = \beta E_t \upsilon_{t+1}\left[S_{t+1}R_t^*\Phi_t - \tau^b\left(S_{t+1}R_t^*\Phi_t - \frac{S_t}{P_t}P_{t+1}\right)\right]. \tag{46}$$

Recall that S_t is the domestic currency price of a unit of foreign currency. On the left side of this expression, we have the cost of acquiring a unit of foreign assets. The currency cost is S_t and this is converted into utility terms by multiplying by the multiplier on the household's budget constraint, υ_t. The term in square brackets is the after tax payoff of the foreign asset, in domestic currency units. The first term is the period $t+1$ pre-tax interest payoff on A_{t+1}^* is $S_{t+1}R_t^*\Phi_t$. Here, R_t^* is the foreign nominal rate of interest, which is risk free in foreign currency units. The term, Φ_t, represents a relative risk adjustment (domestic relative to foreign risk) of the foreign asset return, so that a unit of the foreign asset acquired in t pays off $R_t^*\Phi_t$ units of foreign currency in $t+1$. The determination of Φ_t is discussed below. The remaining term in brackets pertains to the impact of taxation on the return on foreign assets. If we ignore the term after the minus sign in parentheses, then we see that taxation is applied to the whole nominal payoff on the bond, including principal. The term after the minus sign is designed to ensure that the principal is deducted from taxes. The principal is expressed in nominal terms and is set so that the real value at $t+1$ coincides with the real value of the currency used to purchase the asset in period t. In particular, recall that S_t is the period t domestic currency cost of a unit (in terms of foreign currency) of foreign assets. So, the period t real cost of the asset is S_t/P_t. The domestic currency value in period $t+1$ of this real quantity is $P_{t+1}S_t/P_t$.

We scale the first order condition, (46), by multiplying both sides by $P_t z_t^+/S_t$:

$$\psi_{z^+,t} = \beta E_t \frac{\psi_{z^+,t+1}}{\pi_{t+1}\mu_{z^+,t+1}}[s_{t+1}R_t^*\Phi_t - \tau^b(s_{t+1}R_t^*\Phi_t - \pi_{t+1})], \tag{47}$$

where

$$s_t = \frac{S_t}{S_{t-1}}.$$

The risk adjustment term has the following form:

$$\Phi_t = \Phi(a_t, R_t^* - R_t, \tilde{\phi}_t) = \exp(-\tilde{\phi}_a(a_t - \overline{a}) - \tilde{\phi}_s(R_t^* - R_t - (R^* - R)) + \tilde{\phi}_t), \tag{48}$$

where

$$a_t = \frac{S_t A_{t+1}^*}{P_t z_t^+}$$

and $\tilde{\phi}_t$ is a mean zero shock that we call the country risk premium shock. In addition, $\tilde{\phi}_a$ and $\tilde{\phi}_s$ are positive parameters.

The dependence of Φ_t on a_t ensures, in the usual way, that there is a unique steady state value of a_t that is independent of the initial net foreign assets and the capital stock of the economy. The dependence of Φ_t on the relative level of the interest rate, $R_t^* - R_t$, is designed to allow the model to reproduce two types of observations. The first concerns observations related to uncovered interest parity. The second concerns the hump-shaped response of output to a monetary policy shock.

We first consider interest rate parity. To understand this, consider the standard text book representation of uncovered interest parity:

$$R_t - R_t^* = E_t \log S_{t+1} - \log S_t + \phi_t,$$

where ϕ_t denotes the risk premium. A log linear approximation of our model implies the above expression in which Φ_t corresponds to the log deviation of Φ_t about its steady state value of unity. Consider first the case in which $\phi_t \equiv 0$. In this case, a fall in R_t relative to R_t^* produces an anticipated appreciation of the currency. This drop in $E_t \log S_{t+1} - \log S_t$ is accomplished in part by an instantaneous depreciation in $\log S_t$. The intuition for this is that asset holders respond to the unfavorable domestic rate of return by attempting to sell domestic assets and acquire foreign exchange for the purpose of acquiring foreign assets. This selling pressure pushes $\log S_t$ up, until the anticipated appreciation precisely compensates traders in international financial assets holding domestic assets.

There are two types of evidence that the preceding scenario does not hold in the data. First, vector autoregression evidence on the response of financial variables to an expansionary domestic monetary policy shock suggests that $E_t \log S_{t+1} - \log S_t$ actually rises for a period of time (see, e.g., Eichenbaum and Evans, 1995). Second, regressions of realized future exchange rate changes on current interest rate differentials fail to produce the expected value of unity. Indeed, the typical result is a statistically significant negative coefficient.

One interpretation of these results is that when the domestic interest rate is reduced, say by a monetary policy shock, then risk in the domestic economy falls and that alone makes traders happier to hold domestic financial assets in spite of their lower nominal return and the losses they expect to make in the foreign exchange market. Our functional form for $\boldsymbol{\phi}_t$ is designed to capture this idea. According to this functional form, when a shock occurs, which causes a decrease in R_t, then the assessment of risk in the domestic economy falls.

We now turn to the regression interpretation of the uncovered interest parity result. It is useful to consider the regression coefficient:

$$\gamma = \frac{cov(\log S_{t+1} - \log S_t, R_t - R_t^*)}{var(R_t - R_t^*)} = \overbrace{1}^{\text{in theory}} \text{ but } \overbrace{<0}^{\text{in data}}.$$

Also note that

$$\gamma = \frac{cov(\log S_{t+1} - \log S_t, R_t - R_t^*)}{var(R_t - R_t^*)} = \frac{cov(R_t - R_t^* - \phi_t, R_t - R_t^*)}{var(R_t - R_t^*)} = 1 - \frac{cov(R_t - R_t^*, \phi_t)}{var(R_t - R_t^*)} = 1 - \tilde{\phi}_s,$$

according to our linearized version of (48) above.

Thus, any specification of ϕ_t which causes it to have a positive covariance with the interest rate differential, will help in accounting for the regression coefficient specification of the uncovered interest rate puzzle. More specifically and given our functional form assumption, $\tilde{\phi}_s > 1$ implies that the regression coefficient γ is negative, as the value typically found in the data.

We now turn to the connection between Φ_t, and the hump-shaped response of output to an expansionary monetary policy shock. As explained in Section 2.3, a key ingredient in obtaining this type of response lies in factors that slow the response of demand to an expansionary monetary policy shock. The response of foreign purchases of domestic goods in the wake of such a shock depends on how much the exchange rate depreciates. The mechanism we have described slows the depreciation by creating a hump-shaped response of the nominal exchange rate to monetary policy shocks, and this simultaneously reduces the expansion of foreign demand.

2.5. Fiscal and monetary authorities

We assume that monetary policy is conducted according to a Taylor rule of the following form[6]:

$$\log\left(\frac{R_t}{R}\right) = \rho_R \log\left(\frac{R_{t-1}}{R}\right) + (1-\rho_R)\left[\log\left(\frac{\overline{\pi}_t^c}{\pi^c}\right) + r_\pi \log\left(\frac{\pi_t^c}{\overline{\pi}_t^c}\right) + r_y \log\left(\frac{gdp_t}{gdp}\right)\right] + \varepsilon_{R,t}, \tag{49}$$

where gdp denotes measured GDP in the data, which might be different from y in the model. In addition, $\overline{\pi}_t^c$ is an exogenous process that characterizes the central bank's consumer price index inflation target and its steady state value corresponds to the steady state of actual inflation. Regarding the timing of the Taylor rule it is important to note that a rule reacting to lagged inflation (as in e.g. ALLV) implies counterfactual dynamics if one allows for nominal debt-contracts for entrepreneurs as we do in the financial frictions extension of the model (see Section 3). That kind of rule leads to an initial decrease in investment following a positive stationary technology shock, for almost all reasonable parameterizations. The reason is that the real value of debt increases too strongly as inflation falls and the central bank initially does not respond to the fall in the inflation rate. The entrepreneurial wealth therefore decreases so much that investment initially falls.

When we later estimate our model we choose the start date of the sample so that it coincides with the start date of the formal inflation target regime of Sveriges Riksbank, 1995q1. In this way we make sure that it is reasonable to assume that policy followed a time-invariant rule for the entire sample.

We model government expenditures as

$$G_t = g_t z_t^+,$$

where g_t is an exogenous stochastic process.

The tax rates in our model are

$$\tau^k, \quad \tau^b, \quad \tau^y, \quad \tau^c, \quad \tau^w.$$

Details regarding their calibration are in Appendix B.8. Any difference between government expenditures and tax revenue is offset by lump-sum transfers.

2.6. Foreign variables

Below, we describe the stochastic process driving the foreign variables. Our representation takes into account our assumption that foreign output, Y_t^*, is affected by disturbances to z_t^+, just as domestic variables are. In particular, our model of Y_t^* is

$$\log Y_t^* = \log y_t^* + \log z_t^+ = \log y_t^* + \log z_t + \frac{\alpha}{1-\alpha}\log \psi_t,$$

where $\log(y_t^*)$ is assumed to be a stationary process. We assume

$$\begin{pmatrix} \log\left(\frac{y_t^*}{y^*}\right) \\ \pi_t^* - \pi^* \\ R_t^* - R^* \\ \log\left(\frac{\mu_{z,t}}{\mu_z}\right) \\ \log\left(\frac{\mu_{\psi,t}}{\mu_\psi}\right) \end{pmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} & \frac{a_{24}\alpha}{1-\alpha} \\ a_{31} & a_{32} & a_{33} & a_{34} & \frac{a_{34}\alpha}{1-\alpha} \\ 0 & 0 & 0 & \rho_{\mu_z} & 0 \\ 0 & 0 & 0 & 0 & \rho_{\mu_\psi} \end{bmatrix} \begin{pmatrix} \log\left(\frac{y_{t-1}^*}{y^*}\right) \\ \pi_{t-1}^* - \pi^* \\ R_{t-1}^* - R^* \\ \log\left(\frac{\mu_{z,t-1}}{\mu_z}\right) \\ \log\left(\frac{\mu_{\psi,t-1}}{\mu_\psi}\right) \end{pmatrix} + \begin{bmatrix} \sigma_{y^*} & 0 & 0 & 0 & 0 \\ c_{21} & \sigma_{\pi^*} & 0 & c_{24} & \frac{c_{24}\alpha}{1-\alpha} \\ c_{31} & c_{32} & \sigma_{R^*} & c_{34} & \frac{c_{34}\alpha}{1-\alpha} \\ 0 & 0 & 0 & \sigma_{\mu_z} & 0 \\ 0 & 0 & 0 & 0 & \sigma_{\mu_\psi} \end{bmatrix} \begin{pmatrix} \varepsilon_{y^*,t} \\ \varepsilon_{\pi^*,t} \\ \varepsilon_{R^*,t} \\ \varepsilon_{\mu_z,t} \\ \varepsilon_{\mu_\psi,t} \end{pmatrix},$$

where the ε_t's are mean zero, unit variance, Gaussian i.i.d. processes uncorrelated with each other. In matrix form

$$X_t^* = AX_{t-1}^* + C\varepsilon_t,$$

in obvious notation. Note that the matrix C has 10 non-zero coefficients (given α), so that the order condition for identification is satisfied, since CC' represents 15 independent equations.

We now briefly discuss the intuition underlying the zero restrictions in A and C. First, we assume that the shock, $\varepsilon_{y^*,t}$, affects the first three variables in X_t^*, while $\varepsilon_{\pi^*,t}$ only affects the second two and $\varepsilon_{R^*,t}$ only affects the third. The assumption about $\varepsilon_{R^*,t}$ corresponds to one strategy for identifying a monetary policy shock, in which it is assumed that inflation and

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[6] Two alternative ways to model monetary policy are worth mentioning. First, one can assume that the central bank conducts policy with commitment with the object of maximizing the following criterion:

$$E_t \sum_{j=0}^{\infty} \beta^j \left\{ (100[\pi_t^c \pi_{t-1}^c \pi_{t-2}^c \pi_{t-3}^c - (\overline{\pi}_t^c)^4])^2 + \lambda_y \left(100 \log\left(\frac{gdp_t}{gdp}\right)\right)^2 + \lambda_{\Delta R}(400[R_t - R_{t-1}])^2 + \lambda_s (S_t - \overline{S})^2 \right\}.$$

This approach takes the parameters in the criterion, λ_y, $\lambda_{\Delta R}$ and λ_s as unknown parameters to be estimated. This type of approach is pursued by Adolfson et al. (forthcoming). Second, one can suppose that policy is Ramsey-optimal, i.e. chosen with commitment to maximize the discounted social welfare criterion. A virtue of this approach is that there are no policy parameters to be estimated.

output are predetermined relative to the monetary policy shock. Under this interpretation of $\varepsilon_{R^*,t}$, our treatment of the foreign monetary policy shock and the domestic one is inconsistent because in our model domestic prices are not predetermined in the period of a monetary policy shock. Second, the zeros in the last two columns of the first row in A and C show that the technology shocks do not affect y_t^*. This reflects our assumption that the impact of technology shocks on Y_t^* is completely taken into account by z_t^+, while all other shocks to Y_t^* are orthogonal to z_t^+ and they affect Y_t^* via y_t^*. Third, the A and C matrices capture the notion that innovations to technology affect foreign inflation and the interest rate via their impact on z_t^+. Fourth, our assumptions on A and C imply that $\log(\mu_{\psi,t}/\mu_\psi)$ and $\log(\mu_{z,t}/\mu_z)$ are univariate first order autoregressive processes driven by $\varepsilon_{\mu_\psi,t}$ and $\varepsilon_{\mu_z,t}$, respectively. This is a standard assumption made on technology shocks in DSGE models.

2.7. Resource constraints

The fact that we potentially have steady state price dispersion both in prices and wages complicates the expression for the domestic homogeneous good, Y_t in terms of aggregate factors of production. The relationship is derived in Appendix B.3.11 and can be expressed as

$$y_t = (\mathring{p}_t)^{\lambda_d/(\lambda_d-1)}\left[\epsilon_t\left(\frac{1}{\mu_{\Psi,t}}\frac{1}{\mu_{z^+,t}}k_t\right)^{\alpha}\left(\mathring{w}_t^{-\lambda_w/(1-\lambda_w)}h_t\right)^{1-\alpha}-\phi\right], \tag{50}$$

where $\mathring{p}_t$ denotes the degree of price dispersion in the intermediate domestic good and $\mathring{w}$ denotes the degree of wage dispersion.

2.7.1. Resource constraint for domestic homogeneous output

Above we defined real, scaled output in terms of aggregate factors of production. It is convenient to also have an expression that exhibits the uses of domestic homogeneous output. Using (25)

$$z_t^+ y_t = G_t + C_t^d + I_t^d + [\omega_x(p_t^{m,x})^{1-\eta_x}+(1-\omega_x)]^{\eta_x/(1-\eta_x)}(1-\omega_x)(\mathring{p}_t^{x})^{-\lambda_x/(\lambda_x-1)}(p_t^x)^{-\eta_f}Y_t^*,$$

or, after scaling by z_t^+ and using (10)

$$y_t = g_t + (1-\omega_c)(p_t^c)^{\eta_c}c_t + (p_t^i)^{\eta_i}\left(i_t + a(u_t)\frac{\overline{k}_t}{\mu_{\psi,t}\mu_{z^+,t}}\right)(1-\omega_i) + [\omega_x(p_t^{m,x})^{1-\eta_x}+(1-\omega_x)]^{\eta_x/(1-\eta_x)}(1-\omega_x)(\mathring{p}_t^{x})^{-\lambda_x/(\lambda_x-1)}(p_t^x)^{-\eta_f}y_t^*. \tag{51}$$

When we match GDP to the data we first subtract capital utilization costs from y_t. See Appendix B.9 for details

$$gdp_t = y_t - (p_t^i)^{\eta_i}\left(a(u_t)\frac{\overline{k}_t}{\mu_{\psi,t}\mu_{z^+,t}}\right)(1-\omega_i).$$

2.7.2. Trade balance

We begin by developing the link between net exports and the current account. Expenses on imports and new purchases of net foreign assets, A_{t+1}^*, must equal income from exports and from previously purchased net foreign assets:

$$S_t A_{t+1}^* + \textit{expenses}\text{ on imports}_t = \textit{receipts}\text{ from exports}_t + R_{t-1}^*\Phi_{t-1}S_t A_t^*,$$

where Φ_t is defined in Section 2.4.4. Expenses on imports correspond to the purchases of specialized importers for the consumption, investment and export sectors:

$$\textit{expenses}\text{ on imports}_t = S_t P_t^* R_t^{\nu,*}[C_t^m(\mathring{p}_t^{m,c})^{\lambda_{m,c}/(1-\lambda_{m,c})} + I_t^m(\mathring{p}_t^{m,i})^{\lambda_{m,i}/(1-\lambda_{m,i})} + X_t^m(\mathring{p}_t^{m,x})^{\lambda_{m,x}/(1-\lambda_{m,x})}],$$

using (B.23), (30) and (31). Note the presence of the price distortion terms here. To understand these terms, recall that, for example, C_t^m is produced as a linear homogeneous function of specialized imported goods. Because the specialized importers only buy foreign goods, it is their total expenditures that interests us here. When the imports are distributed evenly across differentiated goods, then the total quantity of those imports is C_t^m, and the value of imports associated with domestic production of consumption goods is $S_t P_t^* R_t^{\nu,*} C_t^m$. When there are price distortions among imported intermediate goods, then the sum of the homogeneous import goods is higher for any given value of C_t^m.

We conclude that the current account can be written as follows in scaled form, using (22):

$$a_t + q_t p_t^c R_t^{\nu,*}[c_t^m(\mathring{p}_t^{m,c})^{\lambda_{m,c}/(1-\lambda_{m,c})} + i_t^m(\mathring{p}_t^{m,i})^{\lambda_{m,i}/(1-\lambda_{m,i})} + x_t^m(\mathring{p}_t^{m,x})^{\lambda_{m,x}/(1-\lambda_{m,x})}] = q_t p_t^c p_t^x x_t + R_{t-1}^*\Phi_{t-1}s_t\frac{a_{t-1}}{\pi_t\mu_{z^+,t}}, \tag{52}$$

where, recall, $a_t = S_t A_{t+1}^*/(P_t z_t^+)$. This completes the description of the baseline model. Additional equilibrium conditions and the complete list of endogenous variables are in the Appendix.

3. Introducing financial frictions into the model

3.1. Overview of the financial frictions model

A number of the activities in the model of the previous section require financing. Producers of specialized inputs must borrow working capital within the period. The management of capital involves financing because the construction of capital requires a substantial initial outlay of resources, while the return from capital comes in over time as a flow. In the model of the previous section financing requirements affect the allocations, but not very much. This is because none of the messy realities of actual financial markets are present. There is no asymmetric information between borrower and lender, there is no risk to lenders. In the case of capital accumulation, the borrower and the lender are actually the same household, who puts up the finances and later reaps the rewards. When real-world financial frictions are introduced into a model, then intermediation becomes distorted by the presence of balance sheet constraints and other factors.

Although the literature shows how to introduce financial frictions much more extensively, here we proceed by assuming that only the accumulation and management of capital involves frictions. We will continue to assume that working capital loans are frictionless. Our strategy of introducing frictions in the accumulation and management of capital follows the variant of the BGG model implemented in Christiano et al. (2003). The discussion and derivation here borrows heavily from Christiano et al. (2008).

Recall from the introduction that households deposit money at banks, and that the interest rate that households receive is nominally non-state-contingent. This gives rise to potentially interesting wealth effects of the sort emphasized by Irving Fisher (1933). The banks then lend funds to entrepreneurs using a standard nominal debt contract, which is optimal given the asymmetric information. For a graphical illustration of the financing problem in the capital market, see Fig. 2. The amount that banks are willing to lend to an entrepreneur under the standard debt contract is a function of the entrepreneur's net worth. This is how balance sheet constraints enter the model. When a shock occurs that reduces the value of the entrepreneur's assets, this cuts into their ability to borrow. As a result, they acquire less capital and this translates into a reduction in investment and ultimately into a slowdown in the economy.

Although individual entrepreneurs are risky, banks themselves are not. We suppose that banks lend to a sufficiently diverse group of entrepreneurs that the uncertainty that exists in individual entrepreneurial loans washes out across all loans. Extensions of the model that introduce risk into banking have been developed, but it is not clear that the added complexity is justified.

With this type of model, it is typically the practice to empirically measure the net worth of entrepreneurs using a stock market index, and we follow this route. Whether this is really appropriate can be discussed. A case can be made that the 'bank loans' of entrepreneurs in the model correspond to all external financing of the firm in the data, i.e. actual bank loans plus some fraction of actual equity. Under this view, the net worth in the model would correspond not to a measure of the aggregate stock market, but to the ownership stake of the managers and others who exert the most direct control over the firm. If the fraction of equity owned by this group remains constant, then stock market value is a perfect proxy for net worth. In reality, we can only hope that this is approximately true. It is important to emphasize, however, that whatever the right interpretation is of net worth, the model potentially captures balance sheet problems very nicely.

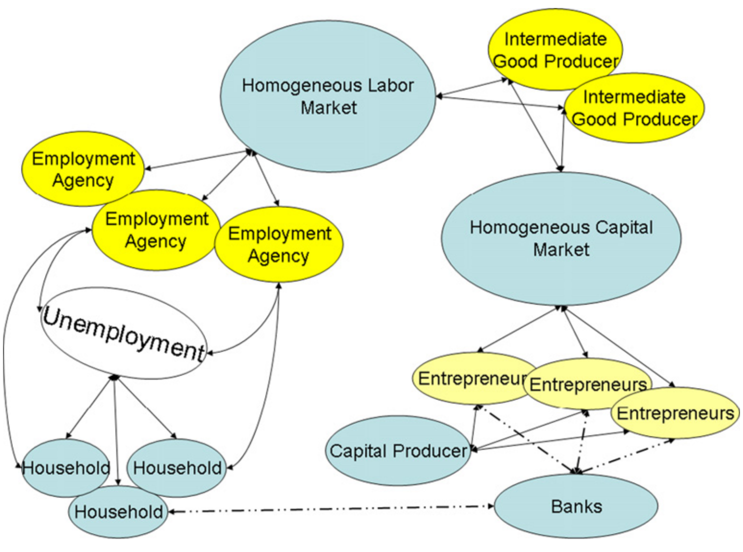

Fig. 2. Graphical illustration of the labor and capital markets of the model.

As we shall see, entrepreneurs all have different histories, as they experience different idiosyncratic shocks. Thus, in general, solving for the aggregate variables would require also solving for the distribution of entrepreneurs according to their characteristics and for the law of motion for that distribution. However, as emphasized in BGG, the right functional form assumptions have been made in the model to guarantee the result that the aggregate variables associated with entrepreneurs are not a function of distributions. First of all, entrepreneurs are assumed to have linear utility in consumption. The loan contract specifies that all entrepreneurs, regardless of their net worth, receive the same interest rate. Also, the loan amount received by an entrepreneur is proportional to his level of net worth. These characteristics are enough to guarantee the aggregation result.

The financial frictions bring a net increase of two equations over the equations in the model of the previous section. In addition, they introduce two new endogenous variables, one related to the interest rate paid by entrepreneurs and the other to their net worth. The financial frictions also allow us to introduce two new shocks. We now provide a formal discussion of the model.

3.2. The individual entrepreneur

At the end of period t each entrepreneur has a level of net worth, N_{t+1}. The entrepreneur's net worth, N_{t+1}, constitutes his state at this time, and nothing else about his history is relevant. We imagine that there are many entrepreneurs for each level of net worth and that for each level of net worth, there is a competitive bank with free entry that offers a loan contract. The contract is defined by a loan amount and by an interest rate, both of which are derived as the solution to a particular optimization problem.

Consider a type of entrepreneur with a particular level of net worth, N_{t+1}. The entrepreneur combines this net worth with a bank loan, B_{t+1}, to purchase new, installed physical capital, $\overline{K}_{t+1}$, from capital producers. The loan the entrepreneur requires for this is

$$B_{t+1} = P_t P_{k',t}\overline{K}_{t+1} - N_{t+1}. \tag{53}$$

The entrepreneur is required to pay a gross interest rate, Z_{t+1}, on the bank loan at the end of period $t+1$, if it is feasible to do so. After purchasing capital the entrepreneur experiences an idiosyncratic productivity shock, which converts the purchased capital, $\overline{K}_{t+1}$, into $\overline{K}_{t+1}\omega$. Here, ω is a unit mean, lognormally and independently distributed random variable across entrepreneurs. The variance of $\log \omega$ is σ_t^2. The t subscript indicates that σ_t is itself the realization of a random variable. This allows us to consider the effects of an increase in the riskiness of individual entrepreneurs and we call σ_t the shock to idiosyncratic uncertainty. We denote the cumulative distribution function of ω by $F(\omega;\sigma)$ and its partial derivatives as $F_\omega(\omega;\sigma)$ and $F_\sigma(\omega;\sigma)$.

After observing the period $t+1$ shocks, the entrepreneur sets the utilization rate, u_{t+1}, of capital and rents out capital in competitive markets at the nominal rental rate, $P_{t+1}r_{t+1}^k$. In choosing the capital utilization rate, the entrepreneur takes into account that operating one unit of physical capital at rate u_{t+1} requires $a(u_{t+1})$ of domestically produced investment goods for maintenance expenditures, where a is defined in (B.3). The entrepreneur then sells the undepreciated part of physical capital to capital producers. Per unit of physical capital purchased, the entrepreneur who draws idiosyncratic productivity ω earns a return (after taxes), of $R_{t+1}^k\omega$, where R_{t+1}^k is defined in (40) and is displayed below for convenience:

$$R_{t+1}^k = \frac{(1-\tau^k)\left[u_{t+1}r_{t+1}^k - \frac{p_{t+1}^i}{\Psi_{t+1}}a(u_{t+1})\right]P_{t+1} + (1-\delta)P_{t+1}P_{k',t+1} + \tau^k\delta P_t P_{k',t}}{P_t P_{k',t}}.$$

Because the mean of ω across entrepreneurs is unity, the average return across all entrepreneurs is R_{t+1}^k.

After entrepreneurs sell their capital, they settle their bank loans. At this point, the resources available to an entrepreneur who has purchased $\overline{K}_{t+1}$ units of physical capital in period t and who experiences an idiosyncratic productivity shock ω are $P_t P_{k',t}R_{t+1}^k\omega\overline{K}_{t+1}$. There is a cutoff value of ω, $\overline{\omega}_{t+1}$, such that the entrepreneur has just enough resources to pay interest:

$$\overline{\omega}_{t+1}R_{t+1}^k P_t P_{k',t}\overline{K}_{t+1} = Z_{t+1}B_{t+1}. \tag{54}$$

Entrepreneurs with $\omega < \overline{\omega}_{t+1}$ are bankrupt and turn over all their resources:

$$R_{t+1}^k\omega P_t P_{k',t}\overline{K}_{t+1},$$

which is less than $Z_{t+1}B_{t+1}$, to the bank. In this case, the bank monitors the entrepreneur, at the cost:

$$\mu R_{t+1}^k\omega P_t P_{k',t}\overline{K}_{t+1},$$

where $\mu \geq 0$ is a parameter.

Banks obtain the funds loaned in period t to entrepreneurs by issuing deposits to households at gross nominal rate of interest, R_t. The subscript on R_t indicates that the payoff to households in $t+1$ is not contingent on the period $t+1$ uncertainty. This feature of the relationship between households and banks is simply assumed. There is no risk in household bank deposits, and the household Euler equation associated with deposits is exactly the same as (45).

We suppose that there is competition and free entry among banks, and that banks participate in no financial arrangements other than the liabilities issued to households and the loans issued to entrepreneurs. It follows that the bank's cash flow in each state of period $t+1$ is zero, for each loan amount.[7] For loans of the amount, B_{t+1}, the bank receives gross interest, $Z_{t+1}B_{t+1}$, from the fraction $1-F(\overline{\omega}_{t+1};\sigma_t)$ of entrepreneurs who are not bankrupt. The bank takes all the resources possessed by bankrupt entrepreneurs, net of monitoring costs. Thus, the state-by-state zero profit condition is

$$[1-F(\overline{\omega}_{t+1};\sigma_t)]Z_{t+1}B_{t+1}+(1-\mu)\int_0^{\overline{\omega}_{t+1}}\omega\, dF(\omega;\sigma_t)R^k_{t+1}P_tP_{k',t}\overline{K}_{t+1}=R_tB_{t+1},$$

or, after making use of (54) and rearranging

$$[\Gamma(\overline{\omega}_{t+1};\sigma_t)-\mu G(\overline{\omega}_{t+1};\sigma_t)]\frac{R^k_{t+1}}{R_t}\varrho_t=\varrho_t-1, \tag{55}$$

where

$$G(\overline{\omega}_{t+1};\sigma_t)=\int_0^{\overline{\omega}_{t+1}}\omega\, dF(\omega;\sigma_t),$$

$$\Gamma(\overline{\omega}_{t+1};\sigma_t)=\overline{\omega}_{t+1}[1-F(\overline{\omega}_{t+1};\sigma_t)]+G(\overline{\omega}_{t+1};\sigma_t),$$

$$\varrho_t=\frac{P_tP_{k',t}\overline{K}_{t+1}}{N_{t+1}}.$$

The expression, $\Gamma(\overline{\omega}_{t+1};\sigma_t)-\mu G(\overline{\omega}_{t+1};\sigma_t)$, is the share of revenues earned by entrepreneurs that borrow B_{t+1}, which goes to the banks. Note that $\Gamma_{\overline{\omega}}(\overline{\omega}_{t+1};\sigma_t)=1-F(\overline{\omega}_{t+1};\sigma_t)>0$ and $G_{\overline{\omega}}(\overline{\omega}_{t+1};\sigma_t)=\overline{\omega}_{t+1}F_{\overline{\omega}}(\overline{\omega}_{t+1};\sigma_t)>0$. It is thus not surprising that the share of entrepreneurial revenues accruing to banks is non-monotone with respect to $\overline{\omega}_{t+1}$. BGG argue that the expression on the left of (55) has an inverted 'U' shape, achieving a maximum value at say $\overline{\omega}_{t+1}=\omega^*$. The expression is increasing for $\overline{\omega}_{t+1}<\omega^*$ and decreasing for $\overline{\omega}_{t+1}>\omega^*$. Thus, for any given value of the leverage ratio, ϱ_t, and R^k_{t+1}/R_t, generically there are either no values of $\overline{\omega}_{t+1}$ or two that satisfy (55). The value of $\overline{\omega}_{t+1}$ realized in equilibrium must be the one on the left side of the inverted 'U' shape. This is because, according to (54), the lower value of $\overline{\omega}_{t+1}$ corresponds to a lower interest rate for entrepreneurs, which yields them higher welfare. As discussed below, the equilibrium contract is one that maximizes entrepreneurial welfare subject to the zero profit condition on banks. This reasoning leads to the conclusion that $\overline{\omega}_{t+1}$ falls with a period $t+1$ shock that drives R^k_{t+1} up. The fraction of entrepreneurs that experience bankruptcy is $F(\overline{\omega}_{t+1};\sigma_t)$, so it follows that a shock, which drives up R^k_{t+1}, has a negative contemporaneous impact on the bankruptcy rate. According to (40), shocks that drive R^k_{t+1} up include anything, which raises the value of physical capital and/or the rental rate of capital.

We derive the optimal contract in Appendix B.4.1. There, we conclude from (B.45) and (B.46) that ϱ_t and $\overline{\omega}_{t+1}$ are the same for all entrepreneurs, regardless of their net worth. This result for the leverage ratio, ϱ_t, implies that

$$\frac{B_{t+1}}{N_{t+1}}=\varrho_t-1,$$

i.e. that an entrepreneur's loan amount is proportional to his net worth. Rewriting (53) and (54) we see that the rate of interest paid by the entrepreneur is

$$Z_{t+1}=\frac{\overline{\omega}_{t+1}R^k_{t+1}}{1-\frac{N_{t+1}}{P_tP_{k',t}\overline{K}_{t+1}}}=\frac{\overline{\omega}_{t+1}R^k_{t+1}}{1-\frac{1}{\varrho_t}}, \tag{56}$$

which also is the same for all entrepreneurs, regardless of their net worth.

3.3. Aggregation across entrepreneurs and the external financing premium

The law of motion for the net worth of an individual entrepreneur is

$$V_t=R^k_tP_{t-1}P_{k',t-1}K_t-\Gamma(\overline{\omega}_t;\sigma_{t-1})R^k_tP_{t-1}P_{k',t-1}K_t.$$

Each entrepreneur faces an identical and independent probability $1-\gamma_t$ of being selected to exit the economy. With the complementary probability, γ_t, each entrepreneur remains. Because the selection is random, the net worth of the entrepreneurs who survive is simply $\gamma_t\overline{V}_t$. A fraction, $1-\gamma_t$, of new entrepreneurs arrive. Entrepreneurs who survive or who are new arrivals receive a transfer, W^e_t where $W^e_t=Z^+_tW^e$. This ensures that all entrepreneurs, whether new arrivals or survivors that experienced bankruptcy, have sufficient funds to obtain at least some amount of loans. The average net worth across all entrepreneurs, after the W^e_t transfers have been made and exits and entry have occurred,

[7] Absence of state contingent securities markets guarantees that cash flow is non-negative. Free entry guarantees that ex ante profits are zero. Given that each state of nature receives positive probability, the two assumptions imply the state by state zero profit condition referred to in the text.

is $\overline{N}_{t+1} = \gamma_t \overline{V}_t + W_t^e$, or

$$\overline{N}_{t+1} = \gamma_t \{ R_t^k P_{t-1} P_{k',t-1} \overline{K}_t - \left[R_{t-1} + \frac{\mu \int_0^{\overline{\omega}_t} \omega \, dF(\omega;\sigma_{t-1}) R_t^k P_{t-1} P_{k',t-1} \overline{K}_t}{P_{t-1} P_{k',t-1} \overline{K}_t - \overline{N}_t} \right] (P_{t-1} P_{k',t-1} \overline{K}_t - \overline{N}_t) \} + W_t^e, \tag{57}$$

where a bar over a letter denotes its aggregate average value. Because of its direct effect on entrepreneurial net worth we refer to γ_t as the shock to net worth (or entrepreneurial wealth). For a derivation of the aggregation across entrepreneurs, see Appendix B.4.2.

We now turn to the external financing premium for entrepreneurs. The cost to the entrepreneur of internal funds (i.e., his own net worth) is the interest rate, R_t, which he loses by applying it to capital rather than buying a risk-free domestic asset. The average payment by all entrepreneurs to the bank is the entire object in square brackets in Eq. (57). So, the term involving μ represents the excess of external funds over the internal cost of funds. As a result, this is one measure of the financing premium in the model. Another is $Z_{t+1} - R_t$, the excess of the interest rate paid by entrepreneurs who are not bankrupt over the risk-free interest rate, where Z_{t+1} is given by (56). We call this the interest rate spread.

4. Introducing employment frictions into the model

This section replaces the model of the labor market in our baseline model with the search and matching framework of Mortensen and Pissarides (1994) and, more recently, Hall (2005a–c) and Shimer (2005,b). We integrate the framework into our environment – which includes physical capital and monetary factors – following the version of GT/GST implemented in CIMR. The main modeling difference compared to GT/GST and CIMR is that we allow for endogenous separation of employees from their jobs, as in e.g. den Haan et al. (2000). Our main motivation for doing this is the *prima facie* cyclicality of job layoff rates. One clear indication is that mass layoffs increase by a factor 3–5 at the beginning of a downturn in Sweden. The importance of cyclical separation rates is confirmed by empirical evidence for the U.S. by Fujita and Ramey (2009) and Elsby et al. (2009). An implication of this modeling choice is increased volatility in unemployment.

In addition to the arguments mentioned in the introduction, one motivation for replacing the EHL labor market modeling of our baseline model is simple and empirical: most of the variation in hours worked is generated by the extensive margin of labor supply. We apply the simple data analysis method of Hansen (1985) on Swedish data 1995q1–2010q3. The decomposition is

$$var(H_t) = var(\varsigma_t) + var(L_t) + 2\, covar(\varsigma_t, L_t),$$

where H_t denotes total hours worked, ς_t hours per employee and L_t number of people employed. H_t and L_t are in per capita terms and all series are logged and expressed in terms of deviation from their respective HP-filter trend with $\lambda = 1600$. This decomposition indicates that four-fifth of the variation in total hours worked comes from variation in employment and one-fifth from variation in hours per employee.[8] Accordingly, a model that allows for variation in both margins is needed. We therefore differ from GST by allowing variations in the intensive margin in our empirical specification. Even more strongly these numbers indicate that models that only allow for variation of the intensive margin lack micro foundation. Galí (2011) reformulates the EHL labor market model as concerning the extensive margin of labor supply. Although that is a promising approach we choose to explicitly model employment frictions and allow for both margins of labor supply.

A final difference compared to GST is that we assume Taylor type wage frictions, as opposed to Calvo frictions. We do this for two reasons: realism – empirically wage contracts normally have a fixed duration – and the ability to check that the wage always remains in the bargaining set in later periods of the wage contract.

4.1. Sketch of the model

As in the discussion of Section 2.1, we adopt the Dixit–Stiglitz specification of homogeneous goods production. A representative, competitive retail firm aggregates differentiated intermediate goods into a homogeneous good. Intermediate goods are supplied by monopolists, who hire labor and capital services in competitive factor markets. The intermediate good firms are assumed to be subject to the same Calvo price setting frictions as in the baseline model.

In the baseline model, the homogeneous labor services are supplied to the competitive labor market by labor contractors who combine the labor services supplied to them by households who monopolistically supply specialized labor services (see EHL and Section 2.1). Here, in the modified model, we dispense with the specialized labor services abstraction. Labor services are instead supplied by ‘employment agencies’ to the homogeneous labor market where it is bought by the intermediate goods producers. See Fig. 2 for a graphical illustration. The change leaves the equilibrium conditions associated with the production of the homogeneous good unaffected. Key labor market activities – vacancy postings, layoffs, labor bargaining, setting the intensity of labor effort – are all carried out inside the employment agencies.[9]

[8] The covariance term is close to 0, which is in line with previous Swedish evidence and institutional factors that discourage over-time work.

[9] An alternative, perhaps more natural, formulation would be for the intermediate good firms to do their own employment search. We instead separate the task of finding workers from production of intermediate goods in order to avoid adding a state variable to the intermediate good firm, which would complicate the solution of their price-setting problem.

Each household is composed of many workers, each of which is in the labor force. A worker begins the period either unemployed or employed with a particular employment agency. Unemployed workers do undirected search. They find a job with a particular agency with a probability that is proportional to the efforts made by the agency to attract workers. Workers are separated from employment agencies either exogenously, or because they are actively cut. Workers pass back and forth between unemployment and employment – there are no agency to agency transitions.

The events during the period in an employment agency take place in the following order. Each employment agency begins a period with a stock of workers. That stock is immediately reduced by exogenous separations and it is increased by new arrivals that reflect the agency's recruiting efforts in the previous period. Then, the economy's aggregate shocks are realized.

At this point, each agency's wage is set. The bargaining arrangement is atomistic, so that each worker bargains separately with a representative of the employment agency. The agencies are allocated permanently into N equal-sized cohorts and each period $1/N$ agencies establish a new wage by Nash bargaining. When a new wage is set, it evolves over the subsequent $N-1$ periods according to (34) and (35). The wage negotiated in a given period covers all workers employed at an agency for each of the subsequent $N-1$ periods, even those that will not arrive until later. The assumption that newly hired workers get the 'going wage' are supported by the survey evidence in Galuščák et al. (2010) and by theoretical arguments in Akerlof and Yellen (1990) emphasizing fair wages, e.g. in the sense of the same wage for similar jobs in the same firm.

Next, each worker draws an idiosyncratic productivity shock. A cutoff level of productivity is determined, and workers with lower productivity are laid off. From a technical point of view this modeling is symmetric to the modeling of entrepreneurial idiosyncratic risk and bankruptcy. We consider two mechanisms by which the cutoff is determined. One is based on the total surplus of a given worker and the other is based purely on the employment agency's interest.

After the endogenous layoff decision, the employment agency posts vacancies and the intensive margin of labor supply is chosen efficiently by equating the marginal value of labor services to the employment agency with the marginal cost of providing it by the household. At this point the employment agency supplies labor to the labor market.

We now describe these various labor market activities in greater detail. We begin with the decisions at the end of the period and work backwards to the bargaining problem. This is a convenient way to develop the model because the bargaining problem internalizes everything that comes after. The equilibrium conditions are displayed in the Appendix.

4.2. Hours per worker

The intensive margin of labor supply is chosen to equate the value of labor services to the employment agency with the cost of providing it by the household. To explain the latter, we display the utility function of the household, which is a modified version of (33)

$$E_t \sum_{l=0}^{\infty} \beta^{l-t} \left\{ \zeta_{t+l}^c \log(C_{t+l} - bC_{t+l-1}) - \zeta_{t+l}^h A_L \left[\sum_{i=0}^{N-1} \frac{(\varsigma_{i,t+l})^{1+\sigma_L}}{1+\sigma_L} [1-\mathcal{F}(\overline{a}_{t+l}^i; \sigma_{a,t+l})] l_{t+l}^i \right] \right\}. \tag{58}$$

Here, $i \in \{0, \ldots, N-1\}$ indexes the cohort to which the employment agency belongs. The index, $i=0$ corresponds to the cohort whose employment agency renegotiates the wage in the current period, $i=1$ corresponds to the cohort that renegotiated in the previous period, and so on. The object, l_t^i, denotes the number of workers in cohort i, after exogenous separations and new arrivals from unemployment have occurred. Let a_t^i denote the idiosyncratic productivity shock drawn by a worker in cohort i. Then, $\overline{a}_t^i$ denotes the endogenously determined cutoff such that all workers with $a_t^i < \overline{a}_t^i$ are laid off from the firm. Also, let

$$\mathcal{F}_t^i = \mathcal{F}(\overline{a}_t^i; \sigma_{a,t}) = \int_0^{\overline{a}_t^i} d\mathcal{F}(a; \sigma_{a,t}), \tag{59}$$

denote the cumulative distribution function of the idiosyncratic productivity. We assume that $\mathcal{F}$ is lognormal with $Ea=1$ and standard deviation of $\log(a)$ equals to σ_a. Accordingly

$$[1-\mathcal{F}_t^i] l_t^i \tag{60}$$

denotes the number of workers with an employment agency in the ith cohort who survive the endogenous layoffs.

Let $\varsigma_{i,t}$ denote the number of hours supplied by a worker in the ith cohort. The absence of the index, a, on $\varsigma_{i,t}$ reflects our assumption that each worker who survives endogenous layoffs in cohort i works the same number of hours, regardless of the realization of their idiosyncratic level of productivity. One justification for this is that any connection between hours and idiosyncratic productivity might induce workers to manipulate real or perceived productivity downwards. The disutility experienced by a worker that works $\varsigma_{i,t}$ hours is

$$\zeta_t^h A_L \frac{(\varsigma_{i,t})^{1+\sigma_L}}{1+\sigma_L}.$$

The household utility function (58) sums the disutility experienced by the workers in each cohort.

Although the individual worker's labor market experience – whether employed or unemployed – is determined by idiosyncratic shocks, each household has sufficiently many workers so that the total fraction of workers employed

$$L_t = \sum_{i=0}^{N-1}[1-\mathcal{F}_t^i]l_t^i,$$

as well as the fractions allocated among the different cohorts, $[1-\mathcal{F}_t^i]l_t^i$, $i=0,\dots,N-1$, are the same for each household. We suppose that all the household's workers are supplied inelastically to the labor market, i.e., labor force participation is constant. For a model that endogenizes labor force participation, see Christiano et al. (2011).

The household's currency receipts arising from the labor market are

$$(1-\tau^y)(1-L_t)P_t b^u z_t^+ + \sum_{i=0}^{N-1} W_t^i[1-\mathcal{F}_t^i]l_t^i \varsigma_{i,t}\frac{1-\tau^y}{1+\tau^w}, \tag{61}$$

where W_t^i is the nominal wage rate earned by workers in cohort $i=0,\dots,N-1$. The presence of the term involving b^u indicates the assumption that unemployed workers, $1-L_t$, receive a pre-tax payment of $b^u z_t^+$ final consumption goods. These unemployment benefits are financed by lump sum taxes. As in our baseline model, there is a labor income tax τ^y and a payroll tax τ^w that affect the after-tax wage.

Let W_t denote the price, or "shadow wage", received by employment agencies for supplying one unit of (effective) labor service to the intermediate goods producers. It represents the marginal gain to the employment agency that occurs when an individual worker increases time spent working by one (effective) unit. Because the employment agency is competitive in the supply of labor services, it takes W_t as given, and in equilibrium it coincides with the marginal product of labor and is connected to the marginal cost of the intermediate goods producers through (4) and (5). A real world interpretation is that it is the shadow value of an extra hour of work supplied by the human resources department to a firm.

Following the version of GST that allows for an intensive margin, we assume that hours per worker are chosen to equate the worker's marginal cost of working with the agency's marginal benefit

$$W_t \mathcal{G}_t^i = \zeta_t^h A_L \varsigma_{i,t}^{\sigma_L} \frac{1}{\upsilon_t \frac{1-\tau^y}{1+\tau^w}}, \tag{62}$$

for $i=0,\dots,N-1$. Here, $\mathcal{G}_t^i$ denotes expected productivity of workers who survive endogenous separation

$$\mathcal{G}_t^i = \frac{\mathcal{E}_t^i}{1-\mathcal{F}_t^i}, \tag{63}$$

where

$$\mathcal{E}_t^i \equiv \mathcal{E}(\overline{a}_t^i;\sigma_{a,t}) \equiv \int_{\overline{a}_t^i}^{\infty} a d\mathcal{F}(a;\sigma_{a,t}). \tag{64}$$

To understand the expression on the right of (62), note that the marginal cost, in utility terms, to an individual worker who increases hours worked by one unit is $\zeta_t^h A_L \varsigma_{i,t}^{\sigma_L}$. This is converted to currency units by dividing by the multiplier, υ_t, on the household's nominal budget constraint, and by the tax wedge $(1-\tau^y)/(1+\tau^w)$. The left side of (62) represents the increase in revenues to the employment agency from increasing hours worked by one unit. Division by $1-\mathcal{F}_t^i$ is required in (63) so that the expectation is relative to the distribution of a conditional on $a \geq \overline{a}_t^i$.

Labor intensity is potentially different across cohorts because $\mathcal{G}_t^i$ in (62) is indexed by cohort. When the wage rate is determined by Nash bargaining, it is taken into account that labor intensity is determined according to (62) and that some workers will endogenously separate. Finally, note that labor intensity as determined by (62) is efficient and unaffected by the negotiated wage and its rigidity. It is therefore not subject to the Barro (1977) critique.

4.3. *Vacancies and the employment agency problem*

The employment agency in the ith cohort determines how many employees it will have in period $t+1$ by choosing vacancies, v_t^i. The costs associated with v_t^i are

$$\frac{\kappa z_t^+}{\varphi}\left(\frac{Q_t^i v_t^i}{[1-\mathcal{F}_t^i]l_t^i}\right)^{\varphi}[1-\mathcal{F}_t^i]l_t^i,$$

units of the domestic homogeneous good. The parameter $\varphi > 1$ determines the curvature of the cost function. We assume convex costs of adjusting the work force for two reasons. First, the empirical evidence in Merz and Yashiv (2007) indicates that these costs are convex. Second, linear costs would imply indeterminacy in our setting as dynamic wage dispersion implies that the costs of employees are heterogenous across agencies, while the benefit of an additional employee is the same across agencies. $\kappa z_t^+/\varphi$ is a cost parameter, which is assumed to grow at the same rate as the overall economic growth rate and, as noted above, $[1-\mathcal{F}_t^i]l_t^i$ denotes the number of employees in the ith cohort after endogenous separations have occurred. Also, Q_t is the probability that a posted vacancy is filled, a quantity that is exogenous to an individual employment agency. The functional form of our cost function reduces to the function used in GT and GST when $\iota=1$. With this parameterization, costs are a function of the number of people hired, not the number of vacancy postings *per se*. We interpret this as reflecting that the GT and GST specifications emphasize internal costs (such as training and other) of adjusting the work force, and not search costs. In models used in the search literature (see e.g. Shimer, 2005a), vacancy posting costs are independent of Q_t, i.e., $\iota=0$. To understand the implications for our type of empirical analysis, consider a shock that triggers an economic expansion and also produces a fall in the probability of filling a vacancy, Q_t. Then the expansion will be smaller in a version of the model that emphasizes search costs (i.e., $\iota=0$) than in a version that emphasizes internal costs (i.e., $\iota=1$). More generally, unemployment will have lower volatility in models with search costs.

To further describe the vacancy decisions of the employment agencies, we require their objective function. We begin by considering $F(l_t^0,\mathring{\omega}_t)$, the value function of the representative employment agency in the cohort, $i=0$, that negotiates its wage in the current period. The arguments of F are the agency's workforce after beginning-of-period exogenous separations and new arrivals, l_t^0, and an arbitrary value for the nominal wage rate, $\mathring{\omega}_t$. That is, we consider the value of the firm's problem after the wage rate has been set.

We suppose that the firm chooses a particular monotone transform of vacancy postings, which we denote by $\tilde{v}_t^i$:

$$\tilde{v}_t^i \equiv \frac{Q_t^{\iota} v_t^i}{(1-\mathcal{F}_t^j) l_t^i}.$$

The agency's hiring rate, χ_t^i, is related to $\tilde{v}_t^i$ by

$$\chi_t^i = Q_t^{1-\iota}\tilde{v}_t^i. \tag{65}$$

To construct $F(l_t^0,\mathring{\omega}_t)$, we must derive the law of motion of the firm's work force, during the period of the wage contract. The time $t+1$ workforce of the representative agency in the ith cohort at time t is denoted l_{t+1}^{i+1}. That workforce reflects the endogenous separations in period t as well as the exogenous separations and new arrivals at the start of period $t+1$. Let ρ denote the probability that an individual worker attached to an employment agency at the start of a period survives the exogenous separation. Then, given the hiring rate, χ_t^i, we have

$$l_{t+1}^{j+1} = (\chi_t^j+\rho)(1-\mathcal{F}_t^j) l_t^j, \tag{66}$$

for $j=0,1,\ldots,N-1$, with the understanding here and throughout that $j=N$ is to be interpreted as $j=0$.[10] Expression (66) is deterministic, reflecting the assumption that the representative employment agency in cohort j employs a large number of workers.

The value function of the firm is

$$F(l_t^0,\mathring{\omega}_t) = \sum_{j=0}^{N-1}\beta^j E_t \frac{\upsilon_{t+j}}{\upsilon_t} \max_{(\tilde{v}_{t+j}^j,\bar{a}_{t+j}^j)} \left[\int_{\bar{a}_{t+j}^j}^{\infty} (W_{t+j}a - \Gamma_{t,j}\mathring{\omega}_t)\varsigma_{j,t+j}\, d\mathcal{F}(a) - P_{t+j}\frac{\kappa z_{t+j}^{+}}{\varphi}(\tilde{v}_{t+j}^j)^{\varphi}(1-\mathcal{F}_{t+j}^j)\right] l_{t+j}^j$$
$$+\beta^N E_t \frac{\upsilon_{t+N}}{\upsilon_t} F(l_{t+N}^0, \tilde{W}_{t+N}), \tag{67}$$

where l_t^j evolves according to (66), $\varsigma_{j,t}$ satisfies (62) and

$$\Gamma_{t,j} = \begin{cases} \tilde{\pi}_{w,t+j}\cdots\tilde{\pi}_{w,t+1}, & j>0 \\ 1 & j=0 \end{cases}. \tag{68}$$

Here, $\tilde{\pi}_{w,t}$ is defined in (35). Recall that W_{t+j} denotes the price paid to the employment agency for supplying one unit of labor to the intermediate goods producers in period $t+j$. The term, $\Gamma_{t,j}\mathring{\omega}_t$, represents the wage rate in period $t+j$, given the wage rate was $\mathring{\omega}_t$ at time t and there have been no wage negotiations in periods $t+1$, $t+2$, up to and including period $t+j$. In (67), $\tilde{W}_{t+N}$ denotes the Nash bargaining wage that is negotiated in period $t+N$, which is when the next round of bargaining occurs. At time t, the agency takes the state $t+N$-contingent function, $\tilde{W}_{t+N}$, as given. The vacancy decision of employment agencies solves the maximization problem in (67).

It is easily verified using (67) that $F(l_t^0,\mathring{\omega}_t)$ is linear in l_t^0:

$$F(l_t^0,\mathring{\omega}_t) = J(\mathring{\omega}_t) l_t^0, \tag{69}$$

where $J(\mathring{\omega}_t)$ is not a function of l_t^0. The function, $J(\mathring{\omega}_t)$, is the surplus that a firm bargaining in the current period enjoys from a match with an individual worker, when the current wage is $\mathring{\omega}_t$. Although later in the period workers become

[10] An interesting technical aspect is that the model dynamics for each of the cohort employment variables, l_t^i, contain a unit root. Nevertheless, total employment, L_t, is stationary. The presence of unit roots in the model could in principle induce computational problems given the solution method of linearizing around the steady state. We have confirmed that no such problem is present by checking that the relevant characteristics of the model only change very marginally if we remove the unit root by imposing an *ad hoc* adjustment of Eq. (66) that induces a stationary process for l_t^i. Another possible route to avoid the presence of unit-roots is to assume that labor from different cohorts is not perfectly substitutable.

heterogeneous when they draw an idiosyncratic shock to productivity, the fact that this draw is i.i.d. over time means that workers are all identical at the time when (69) is evaluated.

4.4. Worker value functions

In order to discuss the endogenous separation decisions, as well as the bargaining problem, we must have the value functions of the individual worker. For the bargaining problem, we require the worker's value function before he knows what his idiosyncratic productivity draw is. For the endogenous separation problem, we need to know the worker's value function after he knows that he has survived the endogenous separation. For both the bargaining and separation problem, we need to know the value of unemployment to the worker.

Let V_t^i denote the period t value of being a worker in an agency in cohort i, after that worker has survived that period's endogenous separation

$$V_t^i = \Gamma_{t-i,i}\tilde{W}_{t-i}\varsigma_{i,t}\frac{1-\tau^y}{1+\tau^w} - A_L\frac{\zeta_t^h \varsigma_{i,t}^{1+\sigma_L}}{(1+\sigma_L)\upsilon_t} + \beta E_t\frac{\upsilon_{t+1}}{\upsilon_t}\left[\rho(1-\mathcal{F}_{t+1}^{i+1})V_{t+1}^{i+1} + (1-\rho+\rho\mathcal{F}_{t+1}^{i+1})U_{t+1}\right], \tag{70}$$

for $i=0,1,\ldots,N-1$. In (70), $\tilde{W}_{t-i}$ denotes the wage negotiated i periods in the past, and $\Gamma_{t-i,i}\tilde{W}_{t-i}$ represents the wage received in period t by workers in cohort i. The two terms after the equality in (70) represent a worker's period t flow utility, converted into units of currency.[11] The terms in square brackets in (70) correspond to utility in the two possible period $t+1$ states of the world. With probability $\rho(1-\mathcal{F}_{t+1}^{i+1})$ the worker survives the exogenous and endogenous separations in period $t+1$, in which case its value function in $t+1$ is V_{t+1}^{i+1}. With the complementary probability, $1-\rho+\rho\mathcal{F}_{t+1}^{i+1}$, the worker separates into unemployment in period $t+1$, and enjoys utility, U_{t+1}.

The currency value of being unemployed in period t is

$$U_t = P_t z_t^+ b^u(1-\tau^y) + \beta E_t\frac{\upsilon_{t+1}}{\upsilon_t}\left[f_t V_{t+1}^x + (1-f_t)U_{t+1}\right], \tag{71}$$

where f_t is the probability that an unemployed worker will land a job in period $t+1$. Also, V_{t+1}^x is the period $t+1$ value function of a worker who knows that he has matched with an employment agency at the start of $t+1$, but does not know which one. In particular

$$V_{t+1}^x = \sum_{i=0}^{N-1}\frac{\chi_t^i(1-\mathcal{F}_t^i)l_t^i}{m_t}\tilde{V}_{t+1}^{i+1}. \tag{72}$$

Here, total new matches at the start of period $t+1$, m_t, is given by

$$m_t = \sum_{j=0}^{N-1}\chi_t^j(1-\mathcal{F}_t^j)l_t^j. \tag{73}$$

In (72),

$$\frac{\chi_t^i(1-\mathcal{F}_t^i)l_t^i}{m_t}$$

is the probability of finding a job in $t+1$ in an agency belonging to cohort i in period t. Note that this is a proper probability distribution because it is positive for each i and it sums to unity by (73).

In (72), $\tilde{V}_{t+1}^{i+1}$ is the analog of V_{t+1}^{i+1}, except that the former is defined before the worker knows if he survives the endogenous productivity cut, while the latter is defined after survival. The superscript $i+1$ appears on $\tilde{V}_{t+1}^{i+1}$ because the probabilities in (72) refer to activities in a particular agency cohort in period t, while in period $t+1$ the index of that cohort is incremented by unity.

We complete the definition of U_t in (71) by giving the formal definition of $\tilde{V}_t^j$

$$\tilde{V}_t^j = \mathcal{F}_t^j U_t + (1-\mathcal{F}_t^j)V_t^j. \tag{74}$$

That is, at the start of the period, the worker has probability $\mathcal{F}_t^j$ of returning to unemployment, and the complementary probability of surviving in the firm to work and receive a wage in period t.

4.5. Separation decision

This subsection describes the separation decision of employment agencies. We discuss the separation decision of a representative agency in the $j=0$ cohort, which renegotiates the wage in the current period. The decisions of other cohorts are made in a similar way. Details appear in the Appendix.

[11] Note the division of the disutility of work in (70) by υ_t, the multiplier on the budget constraint of the household optimization problem.

Just prior to the realization of idiosyncratic worker uncertainty, the number of workers attached to the representative agency in the $j=0$ cohort is l_t^0. Each of the workers in l_t^0 independently draws a productivity, a, from the cumulative distribution function, $\mathcal{F}$. The workers who draw a value of a below a productivity cutoff, $\overline{a}_t^0$, are separated from the agency and the rest remain. The productivity cutoff is selected by the representative agency taking as given all variables determined outside the agency. We consider alternative criteria for selecting $\overline{a}_t^0$. The different criteria correspond to different ways of weighting the surplus enjoyed by the agency and the surplus enjoyed by the workers, l_t^0, attached to the agency.

The aggregate surplus across all the l_t^0 workers in the representative agency is given by

$$(V_t^0 - U_t)(1-\mathcal{F}_t^0)l_t^0. \tag{75}$$

To see this, note that each worker among the fraction, $1-\mathcal{F}_t^0$, workers with $a \geq \overline{a}_t^0$ who stay with the agency experiences the same surplus, $V_t^0 - U_t$. The fraction, $\mathcal{F}_t^0$, of workers in l_t^0 who leave enjoys zero surplus. The object, $\mathcal{F}_t^0$, is a function of $\overline{a}_t^0$ as indicated in (59).

The surplus enjoyed by the representative employment agency before idiosyncratic worker uncertainty is realized and when the workforce is l_t^0, is given by (67). According to (69) agency surplus per worker in l_t^0 is given by $J(\dot{\omega}_t)$ and this is readily confirmed to have the following structure:

$$J(\dot{\omega}_t) = \max_{\overline{a}_t^0} \tilde{J}(\dot{\omega}_t; \overline{a}_t^0)(1-\mathcal{F}_t^0),$$

where

$$\tilde{J}(\dot{\omega}_t; \overline{a}_t^0) = \max_{\tilde{\upsilon}_t^0} \left\{ (W_t \mathcal{G}_t^0 - \dot{\omega}_t)\varsigma_{0,t} - P_t z_t^+ \frac{\kappa}{\varphi} (\tilde{\upsilon}_t^0)^{\varphi} + \beta \frac{\upsilon_{t+1}}{\upsilon_t} (\chi_t^0 + \rho) J_{t+1}^1(\dot{\omega}_t) \right\} \tag{76}$$

denotes the value of an agency in cohort 0 of an employee after endogenous separation has taken place. Here, it is understood that χ_t^0, $\tilde{\upsilon}_t^0$ are connected by (65). Thus, the surplus of the representative agency with workforce, l_t^0, expressed as a function of an arbitrary value of $\overline{a}_t^0$ is

$$\tilde{J}(\dot{\omega}_t; \overline{a}_t^0)(1-\mathcal{F}_t^0)l_t^0. \tag{77}$$

This expression displays the two ways that $\overline{a}_t^0$ impacts on firm profits: $\overline{a}_t^0$ affects the number of workers, $1-\mathcal{F}_t^0$, employed in period t, as well as their average productivity and thereby the value to the employer of an employee, $\tilde{J}$. The impact of $\overline{a}_t^0$ on the number of workers can be deduced from (59). Although at first glance it may appear that the cutoff affects $\tilde{J}$ in several ways, in fact it only affects $\tilde{J}$ through the above two channels. For example, by the envelope theorem we can ignore the impact of $\overline{a}_t^0$ on $\tilde{J}$ via its impact on the choice of $\tilde{\upsilon}_t^0$ and χ_t^0. In addition, the function J_{t+1}^1 is invariant to the choice of $\overline{a}_t^0$. As a result, in differentiating $\tilde{J}(\dot{\omega}_t; \overline{a}_t^0)$ with respect to $\overline{a}_t^0$ we can ignore J_{t+1}^1 and any variables whose values are determined in the maximization problem implicit in J_{t+1}^1. For example, we can ignore the impact of $\overline{a}_t^0$ on the agency's future cutoff decisions, $\overline{a}_{t+i}^i$, $i>0$.

The surplus criterion governing the choice of $\overline{a}_t^0$ is specified to be a weighted sum of the worker surplus and employer surplus described above:

$$\left[s_w(V_t^0 - U_t) + s_e \tilde{J}(\dot{\omega}_t; \overline{a}_t^0) \right] (1-\mathcal{F}_t^0) l_t^0. \tag{78}$$

The parameters s_w, $s_e \in \{0,1\}$ allow for a variety of interesting surplus measures. If $s_w=0$ and $s_e=1$ we have employer surplus. If $s_w=1$ and $s_e=1$ we have total surplus. Accordingly, the employer surplus model is the one in which $\overline{a}_t^0$ is chosen to optimize (78) with $s_w=0$, $s_e=1$ and the total surplus model is the one that optimizes (78) with $s_w = s_e = 1$. The first order necessary condition for an interior optimum is

$$s_w V_t^{0\prime} + s_e \tilde{J}_{\overline{a}^0}(\dot{\omega}_t; \overline{a}_t^0) = \left[s_w(V_t^0 - U_t) + s_e \tilde{J}(\dot{\omega}_t; \overline{a}_t^0) \right] \frac{\mathcal{F}_t^{0\prime}}{1-\mathcal{F}_t^0}. \tag{79}$$

According to (79), $\overline{a}_t^0$ is selected to balance the impact on surplus along intensive and extensive margins. The expression on the left of the equality characterizes the impact on the intensive margin: the surplus per worker that survives the cut increases with $\overline{a}_t^0$. The expression on the right side of (79) captures the extensive margin, the loss of surplus associated with the $\mathcal{F}_t^{0\prime}/(1-\mathcal{F}_t^0)$ workers who do not survive the cut. The equations that characterize the choice of $\overline{a}_t^j$, $j=1,\ldots,N-1$, are essentially the same as (79) and so the discussion of these appears in the Appendix.

The expression (79) assumes an arbitrary wage outcome, $\dot{\omega}_t$. In the next subsection we discuss the bargaining problem that determines a value for $\dot{\omega}_t$.

4.6. Bargaining problem

We suppose that bargaining occurs among a continuum of worker–agency representative pairs. Each bargaining session takes the outcomes of all other bargaining sessions as given. Because each bargaining session is atomistic, each session ignores its impact on the wage earned by workers arriving in the future during the contract. We assume that those future workers are simply paid the average of the outcome of all bargaining sessions. Since each bargaining problem is identical, the wage that solves each problem is the same and so the average wage coincides with the wage that solves the individual bargaining problem. Because each bargaining session is atomistic, it also ignores the impact of the wage bargain on decisions like vacancies and separations, taken by the firm.

The Nash bargaining problem that determines the wage rate is a combination of the worker surplus and firm surplus:

$$\max_{\dot{\omega}_t}(\tilde{V}_t^0-U_t)^{\eta_t}J(\dot{\omega}_t)^{(1-\eta_t)},$$

where η_t is a time varying exogenous AR(1) process.

Here, the firm surplus, $J(\dot{\omega}_t)$, reflects that the outside option of the firm in the bargaining problem is zero. We denote the wage that solves this problem by $\tilde{W}_t$.

Until now we have implicitly assumed that the negotiated wage paid by an employment agency, which has renegotiated most recently i periods in the past, is always inside the bargaining set, $[\underline{w}_t^i,\overline{w}_t^i]$, $i=0,1,\ldots,N-1$. In other words, the wage paid is not lower than the workers' reservation wage and not higher than the wage an employment agency is willing to pay. The fact that we allow for endogenous separations when either total or employer surplus of a match is negative does not strictly guarantee that wages are in the bargaining set, i.e. both employer and worker have a non-negative surplus of the match. In Appendix B.5.7 we describe how we check that the wage of each cohort always is within the bargaining set.

This completes the description of the employment friction representation of the labor market. This version of the model also brings the three new shocks η_t, $\sigma_{a,t}$ and $\sigma_{m,t}$ into the model where $\sigma_{m,t}$ denotes a shifter to the matching function.

5. Estimation

We estimate the full model, which includes both financial and labor market frictions using Bayesian techniques. The equilibrium conditions of the full model are summarized in Appendix B.6. We choose the version of the labor market where endogenous breakups are determined by using the employer surplus criterion, i.e. $s_w=0$ and $s_e=1$. The reason for the choice of $s_w=0$ is that including worker surplus in the separation criterion, would introduce a tendency for job separations to decrease at the beginning of recessions as the value to the worker of holding on his jobs then increases. This tendency appears counterfactual.

There is an existing literature on estimated models containing one or the other of the mechanisms that we consider, in general for closed economies. On the labor side we are most closely related to GST. Trigari (2009) also estimated a model with endogenous separation, but in a simpler macroeconomic setting. On the financial side the most related paper is Christiano et al. (2008) for the Euro area and the US. Other examples of estimated models based on BGG for Euro and/or US data are Christensen and Dib (2008), De Graeve (2008) and Queijo von Heideken (2009), although none of these three papers match any financial data. Meier and Müller (2006) use impulse response matching to a monetary policy shock to estimate a BGG style model and do include the interest coverage ratio as an observed financial variable. Estimated models of financial frictions in open economy settings have so far focused on emerging markets and, in contrast to the present paper, assumed that entrepreneurs (or banks) are financed in the foreign currency, see e.g. Elekdag et al. (2006).

5.1. Calibration

We calibrate and later estimate our model using Swedish data. The time unit is a quarter. The calibrated values are displayed in Tables 1 and 2. Parameters that are related to "great ratios"and other observable quantities related to steady state values are calibrated. These include the discount factor β and the tax rate on bonds τ_b, which are calibrated to yield a real interest rate equal to 2.25% annually. We calibrate the capital share α to 0.375, which yields a capital–output ratio around 2 on an annual basis at the prior mode. The capital share is higher than in most of the literature to compensate for the effect of a positive external finance premium on the capital stock.

Sample averages are used when available, e.g. for the various import shares ω_i, ω_c, ω_x (obtained from input–output tables), the remaining tax rates, the government expenditure share of GDP, η_g, growth rates of technology and several other parameters.[12] To calibrate the steady state of the inflation target we simply use the value publicly stated by Sveriges Riksbank.

We let the steady state of all price markups be 1.2, following a wide literature. We set ϑ_w so that there is full indexation of wages to steady state real growth. We set the other indexation parameters $\varkappa^j$, $j=d,x,mc,mi,mx,w$ so as to get full indexation and thereby avoid steady state price and wage dispersion.

For the financial block of the model we set $F(\overline{\omega})$ equal to the sample average bankruptcy rate according to micro data from the leading Swedish credit registry, called "UC AB". W_e/y has no other noticeable effect than jointly with γ determining the net worth to assets ratio, $n/(p_{k'}k)$, and is set to yield $\gamma=0.97$ at the prior mean.

[12] We let the composite of technology growth, μ_{z^+}, equal the average growth rate of GDP. Using relative investment prices to disentangle investment-specific technology from neutral technology we arrive at $\mu_\psi=1.0003$. This is so close to unity that we favor simplicity and set $\mu_\psi=1$.

Table 1
Calibrated parameters.

Parameter	Value	Description
α	0.375	Capital share in production
β	0.9994	Discount factor
ω_i	0.43	Import share in investment goods
ω_c	0.25	Import share in consumption goods
ω_x	0.35	Import share in export goods
$\tilde{\phi}_a$	0.01	Elasticity of country risk to net asset position
η_g	0.3	Government expenditure share of GDP
τ_k	0.25	Capital tax rate
τ_w	0.35	Payroll tax rate
τ_c	0.25	Consumption tax rate
τ_y	0.30	Labor income tax rate
τ_b	0	Bond tax rate
μ_z	1.0050	Steady state growth rate of neutral technology
μ_ψ	1	Steady state growth rate of investment technology
$\overline{\pi}$	1.005	Steady state gross inflation target
λ_j	1.2	Price markups, $j=d;x;m,c;m,i;m,x$
ϑ_w	1	Wage indexation to real growth trend
$\varkappa^j$	$1-\kappa^j$	Indexation to inflation target for $j=d;x;m,c;m,i;m,x;w$
$\breve{\pi}$	1.005	Third indexing base
$F(\overline{\omega})$	0.01	Steady state bankruptcy rate
W_e/y	0.001	Transfers to entrepreneurs
L	$1-0.078$	Steady state fraction of employment
N	4	Number of agency cohorts/length of wage contracts
φ	2	Curvature of hiring costs
ρ	0.972	Exogenous survival rate of a match
σ	0.5	Unemployment share in matching technology
σ_m	0.57	Level parameter in matching function
ι	1	Employment adj. costs dependence on tightness, V/U

Table 2
Matched moments and corresponding parameters.

Parameter	Parameter description	Posterior mean	Moment	Moment value
δ	Depreciation rate of capital	0.032	$p_i i/y$	0.18
γ	Entrepreneurial survival rate	0.950	$n/(p_{k'}k)$	0.5
$\tilde{\varphi}$	Real exchange rate	0.287	$SP^xX/(PY)$	0.44
A_L	Scaling of disutility of work	38,811	$L\varsigma$	0.25

For the labor block, $1-L$ is set to the sample average unemployment rate, the length of a wage contract N to annual negotiation frequency, $\varphi=2$ to yield quadratic hiring costs, ρ and the prior mean of $\mathcal{F}$ is set jointly so that it takes an unemployed person on average three quarters to find a job (i.e. $f=1/3$), in line with the evidence presented in Forslund and Johansson (2007) for completed unemployment spells. Holmlund (2006) presents evidence of unemployment duration for all unemployment spells being slightly higher, around four quarters. The matching function is specified so that the number of unemployed and vacancies have equal factor shares in the production of matches. The level shifter of the matching function, σ_m is calibrated to match the probability $Q=0.9$ of filling a vacancy within a quarter, although this is merely a normalization. We assume hiring costs, and not search costs by setting $\iota=1$ and thereby follow GST. In an extension below we instead estimate this parameter. We are reinforced in this calibration by the limited importance of search costs that has been documented using Swedish micro data by Carlsson et al. (2006).

Four observable ratios are chosen to be exactly matched throughout the estimation, and accordingly we recalibrate four corresponding parameters for each parameter draw: we set the depreciation rate δ to match the ratio of investment over output, $p_i i/y$, the entrepreneurial survival rate γ to match the net worth to assets ratio, $n/(p_{k'}k)$, the steady state real exchange rate $\tilde{\varphi}$ to match the export share of GDP, $SP^xX/(PY)$, in the data and finally we set the scaling parameter for disutility of labor, A_L, to fix the fraction of their time that individuals spend working. The values at the posterior mean of the parameter values calibrated this way are documented in Table 2.

5.2. Choice of priors

We select our priors using a strategy that is motivated by sequential Bayesian learning. This is an 'endogenous priors' approach because the priors are to some extent a function of observations (for an alternative approach, see Del Negro and

Schorfheide (2008)). We begin with an initial set of priors, specified below. These have the form that is typical in Bayesian analyses, with the priors on different parameters being independent. Then, we suppose we are made aware of several moments or statistics, in particular the standard deviations of the observed variables, that have been estimated in a sample of data that is independent of the data currently under analysis (we refer to these data as the 'pre-sample'). We use classical large sample theory to form a large sample approximation to the likelihood for the pre-sample statistics. The product of the initial priors and the likelihood of the pre-sample statistics form the endogenous priors we take to the sample of data currently under analysis. See Appendix B.7 for details and a more general description of this method. In practice we use the actual sample as our 'pre-sample' to compute the standard deviations of the observed variables, as no other suitable data is available. By applying this method we avoid the common problem of overpredicting the variances implied by the model.[13]

5.2.1. Initial priors

We estimate 28 structural parameters, 16 VAR parameters for the foreign economy, 8 AR(1) coefficients and 17 shock standard deviations. The priors are displayed in Tables 3 and 4. The general approach has been to choose non-informative priors, with the exceptions to this rule detailed below.

For the stationary shock process persistences we use tight priors with a standard deviation of 0.075 and a mean of 0.85. For the unit root technology persistence we instead have prior mean of 0.5. For the Calvo price stickiness parameters we use a mean of 0.75 corresponding to annual price setting based on micro-evidence in Apel et al. (2005) and tight priors. An exception is made for ξ_{mx} where we use a less informative prior with a lower mean, to allow for low pass-through to marginal cost of export producers, as discussed in Section 2.3. For habit formation we follow a wide literature by setting the prior mean at 0.65. For the Taylor rule we only allow for reaction to contemporaneous inflation and GDP. For these parameters we use the same priors as Smets and Wouters (2003) and ALLV. Regarding the parameters for indexation to past inflation we are agnostic and use a non-informative beta prior centered at 0.5. We follow Smets and Wouters (2003) in setting a prior mean for σ_a of 0.2. For the elasticities of substitution between foreign and domestic goods, and for the foreign demand elasticity, we choose prior means of 1.5 based on values used in the macro-literature and the estimate in Whalley (1985). We truncate the prior and exclude elasticities below unity based on economic theory. We set the prior mean of the UIP risk adjustment parameter $\tilde{\phi}_s$ equal to 1.25 to be consistent with a hump-shape in the nominal exchange rate response to a monetary policy shock and to be qualitatively in line with the typical, negative, coefficient value obtained when regressing future realized exchange rate changes on current interest rate differentials, as discussed in Section 2.4.4.

The prior mean for the monitoring cost μ is set to yield an annual external finance premium equal to the sample average of 1.6%. We estimate the parameter μ so as to let data determine the elasticity of the finance premium in terms of basis points, as this is the main effect of μ for the dynamics of the economy.[14]

For the labor block we use a diffuse prior for σ_L centered around 7.5, implying a Frisch elasticity of $1/7.5 = 0.13$. Because we have both an extensive and an intensive margin of labor supply in the model we choose this prior to be closer to micro-evidence than what is normally assumed in macro-models with only an intensive margin. MacCurdy (1986) found a Frisch elasticity of 0.15 for U.S. men and similar values have been found by later studies, although substantial uncertainty and disagreement regarding this parameter exists. For hiring costs as a fraction of GDP, *hshare*, we use a non-informative prior with a mean of 0.1% corresponding to $\kappa = 2.3$.[15] This is slightly below the value of 0.14% used by Galí (2010). We also estimate *bshare*, the ratio of the flow value of utility provided to the household of a worker of being unemployed to the flow value of utility of a worker being employed.[16,17] We set the prior mean of *bshare* slightly above the average public replacement ratio after tax, which was 0.71 for our sample period. In addition to the disutility of labor, this value is set higher than the public rate to incorporate any private unemployment insurance, which is reasonably common. Finally we set the prior mean of the endogenous employer–employee match separation rate, $\mathcal{F}$, to 0.25%, i.e. roughly 10% of the total job separation rate.

5.3. Data

We estimate the model using Swedish data. Our sample period is 1995Q1–2010q3. We use 19 observable time series. We match the levels of the following time series: nominal interest rate, domestic inflation, CPI inflation, investment inflation, foreign inflation and foreign nominal interest rate. For total hours worked we match the deviation from steady

[13] In preliminary estimations without endogenous priors there was a tendency for the standard deviations implied by the model to be higher than in the data for the inflation rates, the nominal interest rate and the spread, while volatilities of real quantities were matched well.

[14] In this way we are not constrained by the assumption for the functional form of the idiosyncratic risk.

[15] Formally the steady state hiring cost share is defined as $hshare = (\kappa/\varphi)N\tilde{\upsilon}^{\varphi}l/y(1-\mathcal{F})$.

[16] Formally

$$bshare = \frac{b^u(1-\tau^y)}{(1-\tau^y)/(1-\tau^w)\tilde{W}\varsigma - A_L\frac{\zeta^h\varsigma^{1+\sigma_L}}{(1+\sigma_L)\upsilon}}$$

[17] Note that due to the assumption of perfect consumption insurance within the household, which is made in this type of model workers always have higher utility when unemployed than when employed. See Christiano et al. (2011) for a model in which the unemployed are worse off than the employed.

Table 3
Estimated parameters. Based on a single metropolis chain with 400,000 draws after a burn-in period of 200,000 draws. Note that truncated priors, denoted by $\Gamma_{>1}$, with no mass below 1 have been used for the elasticity parameters, η_j where $j=\{x,c,i,f\}$.

Parameter	Parameter description	Prior			Posterior		5%	95%
		Distr.	Mean	s.d.	Mean	s.d.		
ξ_d	Calvo, domestic	β	0.75	0.075	0.887	0.018	0.857	0.917
ξ_x	Calvo, exports	β	0.75	0.075	0.816	0.025	0.776	0.856
ξ_{mc}	Calvo, imported consumption	β	0.75	0.075	0.874	0.025	0.832	0.914
ξ_{mi}	Calvo, imported investment	β	0.75	0.075	0.792	0.036	0.731	0.851
ξ_{mx}	Calvo, imported exports	β	0.66	0.10	0.396	0.074	0.280	0.524
κ_d	Indexation, domestic	β	0.50	0.15	0.148	0.060	0.054	0.241
κ_x	Indexation, exports	β	0.50	0.15	0.513	0.099	0.353	0.678
κ_{mc}	Indexation, imported consumption	β	0.50	0.15	0.380	0.115	0.190	0.568
κ_{mi}	Indexation, imported investment	β	0.50	0.15	0.417	0.129	0.203	0.626
κ_{mx}	Indexation, imported exports	β	0.50	0.15	0.340	0.135	0.114	0.545
κ_w	Indexation, wages	β	0.50	0.15	0.434	0.150	0.183	0.676
ν^j	Working capital share, same for all j	β	0.50	0.25	0.463	0.245	0.054	0.839
σ_L	Inverse Frisch elasticity	Γ	7.50	2.00	7.77	2.00	4.624	10.88
b	Habit in consumption	β	0.65	0.15	0.659	0.077	0.538	0.783
S''	Investment adjustment costs	Γ	5.00	1.50	2.58	0.447	1.854	3.28
σ_a	Variable capital utilization	Γ	0.20	0.075	0.145	0.047	0.069	0.215
ρ_R	Taylor rule, lagged interest rate	β	0.80	0.10	0.819	0.022	0.783	0.854
r_π	Taylor rule, inflation	N	1.70	0.15	1.909	0.127	1.706	2.124
r_y	Taylor rule, output	N	0.125	0.05	0.023	0.009	0.008	0.037
η_x	Elasticity of subst., exports	$\Gamma_{>1}$	1.50	0.25	1.232	0.170	1.000	1.480
η_c	Elasticity of subst., consumption	$\Gamma_{>1}$	1.50	0.25	1.685	0.202	1.357	2.007
η_i	Elasticity of subst., investment	$\Gamma_{>1}$	1.50	0.25	1.546	0.215	1.189	1.890
η_f	Elasticity of subst., foreign	$\Gamma_{>1}$	1.50	0.25	1.632	0.219	1.269	1.985
$\tilde{\phi}_s$	Country risk adjustment coefficient	Γ	1.25	0.10	1.096	0.086	0.953	1.230
μ	Monitoring cost	β	0.33	0.075	0.527	0.075	0.406	0.651
hshare (%)	Hiring costs	Γ	0.10	0.075	0.388	0.070	0.275	0.504
bshare	Utility flow, unemployed	β	0.75	0.075	0.924	0.015	0.900	0.948
$\mathcal{F}$ (%)	Endogenous separation rate	β	0.25	0.05	0.147	0.028	0.101	0.191
ρ_{μ_z}	Persistence, unit-root tech.	β	0.50	0.075	0.590	0.069	0.481	0.705
ρ_ε	Persistence, stationary tech.	β	0.85	0.075	0.840	0.048	0.766	0.918
ρ_Υ	Persistence, MEI	β	0.85	0.075	0.624	0.088	0.482	0.771
ρ_{ζ^c}	Persistence, consumption prefs	β	0.85	0.075	0.663	0.097	0.508	0.822
ρ_{ζ^h}	Persistence, labor prefs	β	0.85	0.075	0.786	0.052	0.701	0.871
$\rho_{\tilde{\phi}}$	Persistence, country risk premium	β	0.85	0.075	0.699	0.053	0.610	0.788
ρ_g	Persistence, gov. expenditures	β	0.85	0.075	0.904	0.044	0.838	0.975
ρ_γ	Persistence, entrepren. wealth	β	0.85	0.075	0.818	0.037	0.761	0.880
a_{11}	Foreign VAR parameter	N	0.50	0.50	0.942	0.039	0.877	1.003
a_{22}	Foreign VAR parameter	N	0.00	0.50	0.105	0.150	−0.148	0.347
a_{33}	Foreign VAR parameter	N	0.50	0.50	0.908	0.042	0.843	0.968
a_{12}	Foreign VAR parameter	N	0.00	0.50	0.319	0.242	−0.079	0.712
a_{13}	Foreign VAR parameter	N	0.00	0.50	−0.485	0.152	−0.725	−0.244
a_{21}	Foreign VAR parameter	N	0.00	0.50	0.062	0.033	0.010	0.114
a_{23}	Foreign VAR parameter	N	0.00	0.50	−0.112	0.120	−0.305	0.081
a_{24}	Foreign VAR parameter	N	0.00	0.50	0.272	0.196	−0.055	0.586
a_{31}	Foreign VAR parameter	N	0.00	0.50	0.015	0.012	−0.004	0.036
a_{32}	Foreign VAR parameter	N	0.00	0.50	0.092	0.050	0.008	0.172
a_{34}	Foreign VAR parameter	N	0.00	0.50	0.009	0.092	−0.140	0.158
c_{21}	Foreign VAR parameter	N	0.00	0.50	0.155	0.091	0.008	0.304
c_{31}	Foreign VAR parameter	N	0.00	0.50	0.139	0.025	0.097	0.180
c_{32}	Foreign VAR parameter	N	0.00	0.50	0.051	0.043	−0.021	0.120
c_{24}	Foreign VAR parameter	N	0.00	0.50	0.063	0.298	−0.405	0.562
c_{34}	Foreign VAR parameter	N	0.00	0.50	0.070	0.072	−0.052	0.182

state. For the following time series we take logs and first differences: GDP, consumption, investment, exports, imports, government expenditures, real wages, real exchange rate, real stock prices, the corporate interest rate spread, the unemployment rate and foreign GDP. All real quantities are in per capita terms. In addition we remove the mean from each of the first-differenced time series because most of these variables' trend growth differs substantially in the data. The model, however, allows for only two different real trend growth rates (and with our calibration of $\mu_\psi = 1$, only one trend growth rate). In order to match these different trends in the data the estimation would be likely to result in trending exogenous processes. We avoid this

Table 4
Estimated standard deviation of shocks. Based on a single metropolis chain with 400,000 draws after a burn-in period of 200,000 draws.

Parameter	Description	Prior			Posterior		5%	95%
		Distr.	Mean	d.f.	Mean	s.d.		
$100\sigma_{\mu_z}$	Unit-root technology	Inv-Γ	0.15	2	0.214	0.044	0.142	0.286
$100\sigma_{\varepsilon}$	Stationary technology	Inv-Γ	0.50	2	0.470	0.099	0.317	0.622
$10\sigma_{\Upsilon}$	MEI	Inv-Γ	0.15	2	0.233	0.052	0.151	0.311
$10\sigma_{\zeta^c}$	Consumption prefs	Inv-Γ	0.15	2	0.201	0.043	0.131	0.268
$10\sigma_{\zeta^h}$	Labor prefs	Inv-Γ	0.15	2	0.730	0.160	0.464	0.974
$100\sigma_{\tilde{\phi}}$	Country risk premium	Inv-Γ	0.15	2	0.626	0.111	0.443	0.813
$100\sigma_{\varepsilon_R}$	Monetary policy	Inv-Γ	0.15	2	0.121	0.012	0.102	0.140
$100\sigma_g$	Government expenditures	Inv-Γ	0.50	2	0.679	0.060	0.581	0.777
$10\sigma_{\tau^d}$	Markup, domestic	Inv-Γ	0.50	2	3.261	1.133	1.636	5.008
$10\sigma_{\tau^x}$	Markup, exports	Inv-Γ	0.50	2	3.229	0.854	1.877	4.639
$10\sigma_{\tau^{m,c}}$	Markup, imports for consumption	Inv-Γ	0.50	2	3.271	1.663	1.245	5.124
$10\sigma_{\tau^{m,i}}$	Markup, imports for investment	Inv-Γ	0.50	2	0.778	0.547	0.163	1.381
$10\sigma_{\tau^{m,x}}$	Markup, imports for exports	Inv-Γ	0.50	2	3.967	1.197	2.032	5.782
$100\sigma_{\gamma}$	Entrepreneurial wealth	Inv-Γ	0.50	2	0.350	0.037	0.289	0.408
$100\sigma_{y^*}$	Foreign GDP	Inv-Γ	0.50	2	0.476	0.041	0.410	0.545
$100\sigma_{\pi^*}$	Foreign inflation	Inv-Γ	0.50	2	0.229	0.023	0.192	0.266
$1000\sigma_{R^*}$	Foreign interest rate	Inv-Γ	1.50	2	0.493	0.070	0.375	0.602

problem by demeaning the first-differenced variables that we match. See Fig. B1 in the Computational Appendix for plots of the above data used in the estimation. The measurement equations are documented in detail in Appendix B.9.

A brief comment on some of the observable time series. CPI inflation is measured using the time series 'CPIX', i.e. an inflation measure that excludes the imputed interest rate costs of owner-occupied housing. The stock prices are included as a proxy of entrepreneurs' net worth and are measured using the stock price index covering all stocks on the main stock exchange (the 'OMX Stockholm PI' index). The corporate interest spread is a proxy for the external finance premium entrepreneurs face. We compute the spread as the difference between the interest rate on all outstanding bank loans to non-financial corporations and the interest rate on government bonds with a similar average duration, i.e. 6 months.[18] The real exchange rate and all foreign variables are constructed using weighted averages of Swedish goods trading partners. The weights, 'TCW', are computed by Statistics Sweden.

5.4. Shocks and measurement errors

In total, there are 23 exogenous stochastic variables in the model. There are four technology shocks – stationary neutral technology, ϵ; stationary marginal efficiency of investment, Υ; unit-root neutral technology, μ_z; unit-root investment specific technology, μ_{Ψ}. There is an inflation target shock, $\overline{\pi}^c$, and a regular monetary policy shock, ε_R. There are shocks for consumption preferences, ζ^c, and disutility of labor supply, ζ^h. There is a shock to government expenditure, g, and a country risk premium shock that affects the relative riskiness of foreign assets compared to domestic assets, $\tilde{\phi}$. There are five markup shocks, one for each type of intermediate good. The financial frictions added two shocks – one to idiosyncratic uncertainty, σ, and one to entrepreneurial wealth, γ. The employment frictions added three shocks – a shock to the bargaining power of workers, η; a shock to the matching productivity, σ_m and a shock to the productivity dispersion among workers, affecting the endogenous job separations, σ_a. We also allow for shocks to each of the foreign observed variables – foreign GDP, y^*, foreign inflation, π^*, and foreign nominal interest rate, R^*.

We now describe the stochastic structure of the exogenous variables. Twelve of these evolve according to AR(1) processes:

$$\varepsilon_t, \Upsilon_t, \overline{\pi}^c_t, \zeta^c_t, \zeta^h_t, g_t, \tilde{\phi}_t, \sigma_t, \gamma_t, \eta_t, \sigma_{m,t}, \sigma_{a,t}.$$

Further, we have six shock processes that are i.i.d.:

$$\tau^d_t, \tau^x_t, \tau^{m,c}_t, \tau^{m,i}_t, \tau^{m,x}_t, \varepsilon_{R,t}.$$

Finally, the last five shock processes are assumed to follow a VAR(1):

$$y^*_t, \pi^*_t, R^*_t, \mu_{z,t}, \mu_{\Psi,t}.$$

In the estimation we only allow for 17 shocks. We shut down six shocks present in the theoretical model: the inflation target shock, $\overline{\pi}^c_t$; the shock to bargaining power, η_t; the shock to matching technology, $\sigma_{m,t}$; the shock to the standard deviation of

[18] Ideally one would like to match interest rate data on newly issued loans with the same duration as in the model, i.e. one quarter. Unfortunately, such data are not available for our sample.

idiosyncratic productivity of workers, $\sigma_{a,t}$; the shock to unit-root investment specific technology, $\mu_{\Psi,t}$ and the idiosyncratic entrepreneur risk shock, σ_t. Indeed for our sample, 1995–2010, the *de jure* inflation target has been in place the entire period and has been constant. Shocks to η_t also seems superfluous as we already have the standard labor supply shock – the labor preference shock ζ_t^h. $\sigma_{m,t}$ is immaterial given that we calibrate $\iota = 1$, i.e. employment frictions are in terms of hiring not in terms of vacancies posted, and that we do not observe vacancies. We shut down $\mu_{\Psi,t}$ and σ_t as they did not contribute much to explaining any variable in preliminary estimations. The fact that the IST shock $\mu_{\Psi,t}$ is negligible when investment prices are observed are in line with the results in Schmitt-Grohé and Uribe (2008) and Mandelman et al. (2011). Opposite results are obtained in Justiniano et al. (2010) where investment prices are not observed. For a discussion of the limited importance of σ_t, see Section 5.5.7 below.

Similarly to Adolfson et al. (2007, 2008) we allow for measurement errors, except for the domestic nominal interest rate and the foreign variables, since Swedish macro data are measured with considerable noise. We calibrate the variance of the measurement errors so that they correspond to 10% of the variance of each data series, except for the inflation series, which contain additional high-frequency noise and we therefore let the measurement errors account for 25% of their variance.[19,20]

5.5. Estimation results

We obtain the estimation results using a random walk Metropolis–Hasting chain with 400,000 draws after a burn-in of 200,000 draws and with an acceptance rate tuned to 0.21. Parameters and, more importantly, shock standard deviations have been scaled to be the same or similar order of magnitude so as to facilitate optimization.[21] Prior-posterior plots and convergence statistics are presented in the Computational Appendix.[22]

5.5.1. Posterior parameter values

We start by commenting briefly on some of the parameter estimates. These are reported in the prior-posterior tables, Tables 3 and 4. We focus our discussion on the posterior mean, which is also used for all computations below.

All Calvo price rigidity parameters except ξ_{mx} are in the interval 0.8–0.9, with ξ_d and ξ_{mc} the highest. Prices of imported inputs for export production are instead substantially more flexible, and are re-set optimally more than twice per year, $\xi_{mx} = 0.40$. The price rigidities on both import and export prices are substantially below earlier estimates using Swedish data by ALLV (2008). Both the later sample and the additional internal propagation in our more detailed model might contribute to this difference. We find a moderate degree of indexation to lagged inflation, in the interval $1/3-1/2$, with the exception of indexation of the homogenous domestic good, which is substantially lower at $\kappa_d = 0.15$.

Both the capacity utilization parameter, $\sigma_a = 0.15$, and the investment adjustment costs parameter, $S'' = 2.6$, are estimated to be low compared to the literature. In the case of S'' it is clear that the financial frictions induce the gradual response that the investment adjustment mechanism was introduced to generate.[23] The low σ_a allows for considerable variation in utilization. For the estimated Taylor rule parameters r_π and ρ_R are in line with the literature, while r_y is closer to zero than reported in ALLV or SW.

The estimated value of $\mu = 0.53$ is substantially above the prior mean of 0.33, indicating that the elasticity of the interest rate spread, in terms of basis points, is higher than implied by the functional form assumption we have made.

Moving on to the labor block we find a *bshare* of 0.92, i.e. much higher than the replacement rate of the public Swedish unemployment insurance, and in the vicinity of the calibration in Hagedorn and Manovskii (2008).[24] The hiring cost as a fraction of GDP is estimated to be 0.39%, corresponding to $\kappa = 6.4$, which is reasonably large compared to values in the literature. The endogenous breakup rate $\mathcal{F}$ is estimated to be 0.15% implying that 6% of job separations are endogenous. The bargaining power of workers, η, is solved to yield a steady state unemployment rate matching the sample average. The value of η at the posterior mean is 0.29. This is much lower than $\eta = 0.9$ reported by GST, and closer to the conventional wisdom, which suggests values around 0.5, see Mortensen and Nagypal (2007). Furthermore, our estimate of η is substantially higher than Hagedorn and Manovskii's (2008) calibration of 0.05.

Finally, the persistence of the autoregressive shocks are all at or below 0.90. Also note that the persistence of the labor preference shock, ρ_{ζ^h} is quite high, 0.79. Both these characteristics are different than the literature, both generally and specifically for SW, ALLV and GST.[25] The contrast is confirmed when we estimate our submodel with EHL labor market

[19] Calibrating these measurement errors to 10% instead of 25% of the variance has negligible effects on posterior parameter values, except regarding the estimated standard deviations of the corresponding markup shocks.

[20] As can be seen in the figure in the Computational Appendix the size of the measurement errors is small: the data series and the smoothed series of the model without measurement errors are almost indistinguishable, with the exception of net worth where the realized measurement error is substantial.

[21] What matters for the optimization is that the derivatives are of the same order of magnitude, so our scaling is only an imperfect step in the right direction, but probably the best one can do using only *a priori* information.

[22] In particular, we confirm that the posterior parameter distribution is the same in the first and the second half of the metropolis chain.

[23] This mechanism is confirmed by comparing the estimates of S'' in the various submodels reported in Table B3 in the Computational Appendix.

[24] Note that this parameter includes disutility of work. The model implied ratio of after-tax unemployment benefits to labor income is 0.82.

[25] As opposed to ALLV and GST, Smets and Wouters do not obtain a low estimate of an AR(1) process for a labor supply shock. Instead they capture high-frequency variation in labor supply in two alternative ways: Smets and Wouters (2003) allow for an i.i.d. wage markup shock while Smets and Wouters (2007) use an ARMA(1,1) structure.

modeling and get the same qualitative result as obtained in the literature: large amounts of high frequency variation in this shock is needed to fit the data – ρ_{ζ^h} equal to 0.4 and σ_{ζ^h} increases by a factor 4 (see Table B3 and B4 in the Computational Appendix for details). Our interpretation of the stark difference between our full model and the literature is that the tight link between the desired real wage and total hours worked (through the marginal rate of substitution between leisure and consumption) implied by EHL labor market modeling does not hold in the data, even when this link is relaxed by assuming wage stickiness. Our labor market model instead implies efficient provision of labor on the intensive margin without any direct link to the (sticky, bargained) wage, and thereby allows for a high frequency disconnect between wages and hours worked. Fundamentally, our model reflects that labor is not supplied on a spot market, but within long-term relationships. In the spirit of Barro (1977), and in contrast to EHL, wages are not allocational for ongoing relationships so no money is "left on the table" on the intensive margin of labor supply.[26] The difference between our model and GST is substantially smaller, but still clear. In their setup, with no intensive margin of labor supply and no endogenous separation, any variation in hours must be captured by variation in vacancy postings due to changes in expected surplus to the firm of a new job. It is therefore not surprising that GST need high frequency variation in the bargaining power to match the data for hours worked.

The explanation for the result that we do not obtain any autoregressive coefficients close to unity is that we match demeaned growth rates of most data series. Thus, the exogenous shock processes do not have to soak up discrepancies between the joint balanced growth trends implied by most macro models and the various time series' trends in the data.

We note from the posterior standard deviations in Table 3, and from the posterior plots in the Computational Appendix that data are informative about all the estimated parameters, with the exception of the labor supply curvature σ_L and the common working capital shares, ν^j.[27] Apart from these two, posterior parameter uncertainty appears to be quite small.

5.5.2. Impulse response functions

We now discuss the impulse response functions. For comparison purposes and to quantify the importance of the different frictions we plot the IRF for the same fixed parameter vector for smaller versions of the model as well: a baseline CEE/SW/ALLV style model with EHL labor market and no financial frictions as described in Section 2; a model with (only) financial frictions added as in Section 3 and a model with (only) employment frictions added as in Section 4.[28] The units on the *y*-axis are either in terms of percentage deviation from steady state, annualized basis points (ABP), or level deviation. Unless otherwise noted all below remarks on the dynamics concern the full model. The IRFs not commented on below are presented in a separate Computational Appendix.

The IRFs in Fig. 3 for the monetary policy shock, $\varepsilon_{R,t}$, can be characterized as follows: a 47 basis point temporary increase in the nominal interest rate causes hump-shaped reductions in CPI inflation, consumption, investment and *GDP*. Entrepreneurial net worth is reduced both because of the falling price of capital and because of the surprise disinflation that increases the real value of the nominal debt, i.e. the Fisher debt deflation mechanism. Accordingly, the interest rate spread on corporate loans increases by 13 basis points to compensate for the increased default risk. Comparing across models we see how the increased spread generates amplification in the response of both investment and *GDP* by roughly one-third in terms of the amplitude of the IRF (i.e. proportional to the additional change in the corporate borrowing rate). The low estimate of the investment adjustment cost parameter, S'', is important for this moderate amplification of investment. It reduces the sensitivity of price of capital to demand shocks, and thereby dampens the effect on entrepreneurial net worth in response to the monetary policy shock.

We note that our functional form for the country risk premium in combination with the estimated parameters implies that the nominal exchange rate moves substantially less than one-for-one with the nominal interest rate, and in a hump-shaped manner. In line with the VAR evidence in Lindé (2003), and as in the theoretical model by Kollmann (2001), the monetary policy shock induces a domestic demand contraction that generates an increase in net exports for all models, and this is most pronounced in the models with financial frictions because of the larger decrease in imported investment as investment goods have higher import content than consumption goods, $\omega_i > \omega_c$. The exchange rate accordingly appreciates most in those models.

The monetary policy shock implies an increase in the level of unemployment by a maximum of 0.12% after 3–4 quarters, and this IRF is approximately unaffected by financial frictions. In the models with employment frictions total hours respond less and real wages more than in the EHL labor market models, and this is a general tendency for almost all shocks. The hours response is also more gradual with employment frictions, which is one reason that we introduced them. Note that the decrease in hours is entirely on the extensive margin – hours per employee actually increase, although by a negligible amount, because of the increase in marginal value of wealth. In none of the models does the real wage respond nearly as much as the marginal product of labor, so the nominal wage rigidity implies substantial real wage rigidity, and also this result is general across shocks.

Fig. 4 shows that the response to a stationary technology shock, ϵ_t, in our estimated model is reasonably standard: inflation decreases suddenly and then gradually recovers and the nominal interest rate is reduced accordingly.

[26] Barro (1977) instead emphasizes a binary decision – whether to break up the employment relationship or not.

[27] In principle the fact that we match data series for both total hours worked and employment should allow for identification of the intensive margin of labor supply, so this result for σ_L is disappointing.

[28] One parameter is recalibrated between models: in the baseline and unemployment model α has to be re-set to 0.200 to keep the capital–output ratio equal to 2 as in the full model. The reason for this recalibration is that in these two models financial frictions are absent.

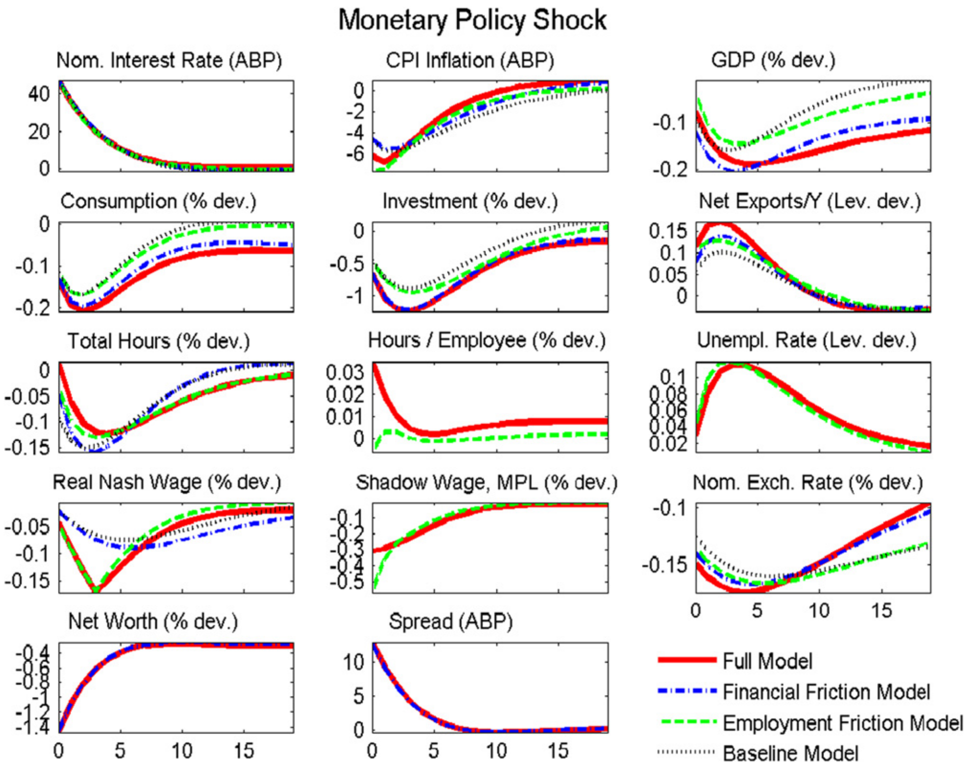

Fig. 3. Impulse responses to the monetary policy shock, $\varepsilon_{R,t}$. The units on the *y*-axis are either in terms of percentage deviation (% dev.) from steady state, annualized basis points (ABP) or level deviation (Lev. dev.).

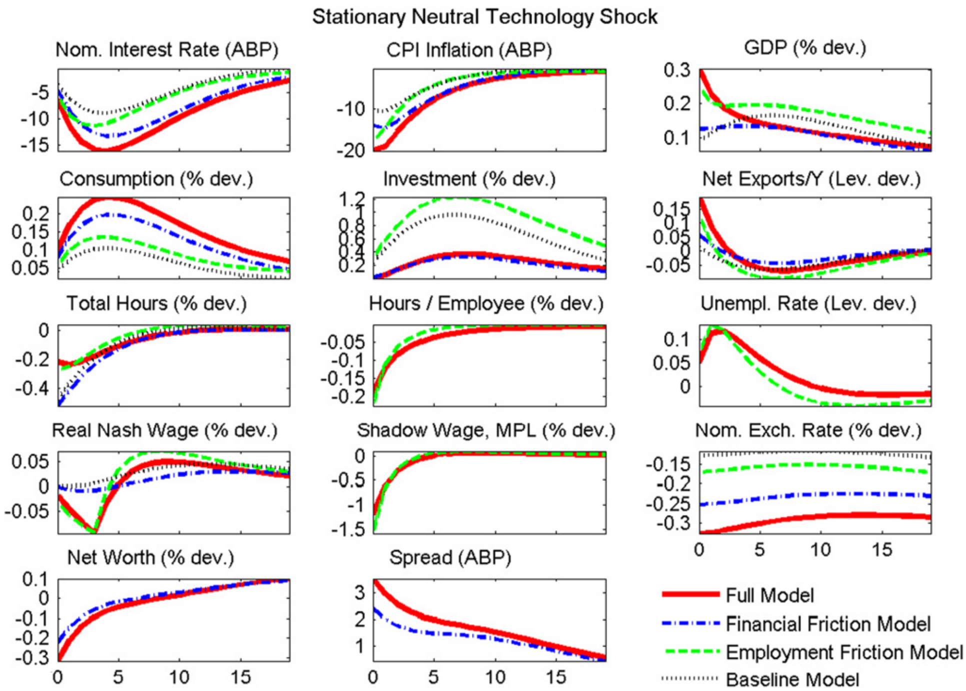

Fig. 4. Impulse responses to the stationary neutral technology shock, ϵ_t.

Consumption and investment increase persistently while net exports increase only temporarily. Both margins of labor supply fall substantially initially. In the models with employment frictions real wages decrease (more), total hours decrease less and the responses of all other variables are amplified. We note that financial frictions dampen the response of

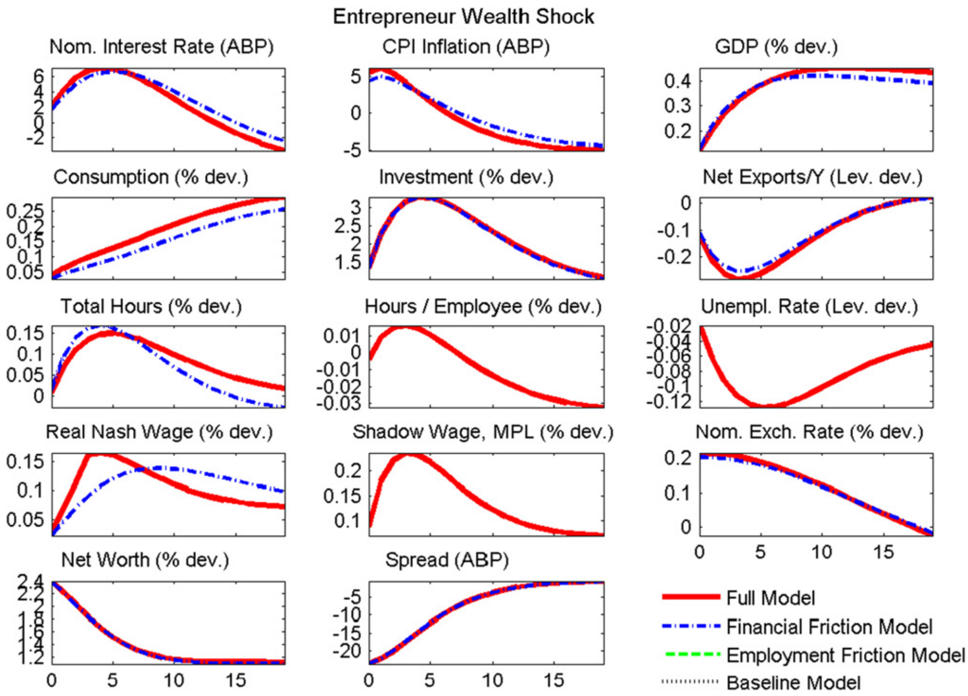

Fig. 5. Impulse responses to the entrepreneur wealth shock, γ_t.

investment substantially as net worth of entrepreneurs initially falls. This is a standard result for supply shocks in the presence of nominal debt contracts.

The response to the entrepreneurial wealth shock, γ_t, documented in Fig. 5 has some of the characteristics of a classic demand shock: it drives up both CPI inflation, consumption, investment and *GDP*. The responses of these real quantity variables are very persistent while inflation falls below steady state within 2 years. The shock causes both margins of labor supply to increase, wages to increase, the nominal exchange rate to depreciate and net exports to decrease due to domestic demand outpacing supply. It is interesting to compare the wealth shock to the MEI shock, Υ_t, documented in Fig. 6. The importance of the MEI shock was emphasized in JPT. The key difference versus the MEI shock is that the wealth shock implies, actually fundamentally consists of, an increase in the stock market (net worth) value. This characteristic makes it possible to disentangle the contributions and empirical relevance of these two shocks. More on the comparison of these two shocks below.

5.5.3. *The importance of the open economy dimension and the endogenous separations*

In Fig. 7 we illustrate the importance of the open economy dimension by contrasting the full model IRF with a model where the open economy dimension has been shut down. The first row of the figure displays how CPI inflation and GDP respond faster or stronger in the closed economy to monetary policy shock, $\varepsilon_{R,t}$. This result is general to all demand shocks: both inflation and GDP respond stronger in the closed economy setting. The intuition for this result is that foreign demand is less affected than domestic demand by these types of shocks. The second row shows that for the stationary technology shock, ϵ, inflation initially responds stronger while GDP responds less on impact in the closed economy. Supply shocks imply a general result for real quantities: they respond slower or less in the closed economy setting. For inflation there is no clear pattern across different supply shocks.

Fig. 8 analogously illustrates the effects of endogenous separations by contrasting the full model with a model without endogenous job separations. As is apparent from the figure, one difference is that endogenous separations allow unemployment to react on impact of any shock. They also allow for an amplified response compared to the exogenous separation case. We note that this amplification in the response of the unemployment rate is substantial. In the full model, with endogenous separations, the response is faster and the amplitude 17% larger for $\varepsilon_{R,t}$, and 47% larger for ϵ_t. Wages (not plotted) instead respond slightly less in the presence of endogenous separations. For both shocks (and more generally) differences in responses of GDP and its components are very moderate.[29]

[29] An additional reason to allow for endogenous separations is that the model otherwise would imply that unemployment is predetermined (although other ways around this problem exist). Predetermined unemployment is problematic when taking the model to the data, e.g. when using the model for forecasting.

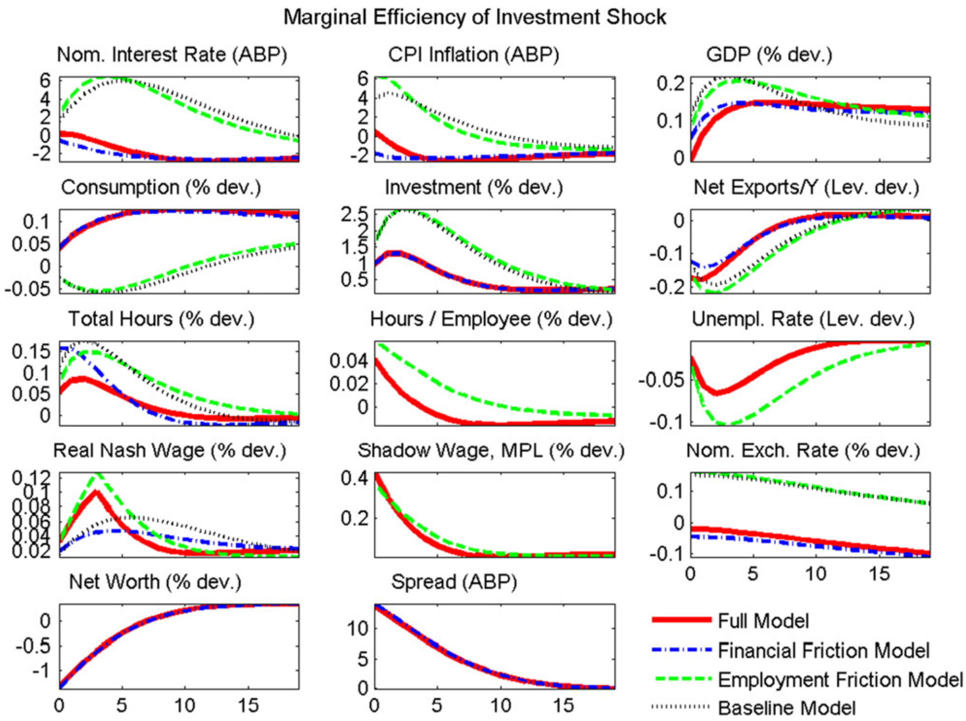

Fig. 6. Impulse responses to the marginal efficiency of investment (MEI) shock, Υ_t.

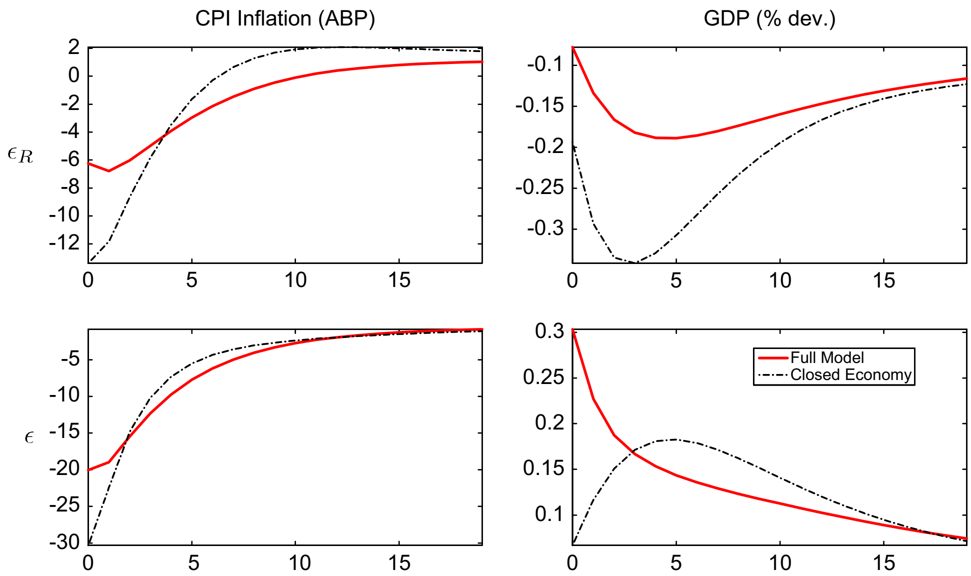

Fig. 7. Comparison of open and closed economy dynamics. The top row documents the IRF to a monetary policy shock, $\varepsilon_{R,t}$. The bottom row documents the IRFs to a stationary technology shock, ϵ_t.

5.5.4. *Model moments and variance decomposition*

In Table 5 we present data and model means and standard deviations for the observed time series. We note a substantial variation of real growth rates in the data, which is why we demeaned the growth rates before matching the model to the data in the first place.

Comparing the volatility of the data and the model we note that the endogenous priors work well: most standard deviations are very similar in the data and the model. The exceptions are for the data series with high sampling uncertainty, where the prior over the moments accordingly is less informative.

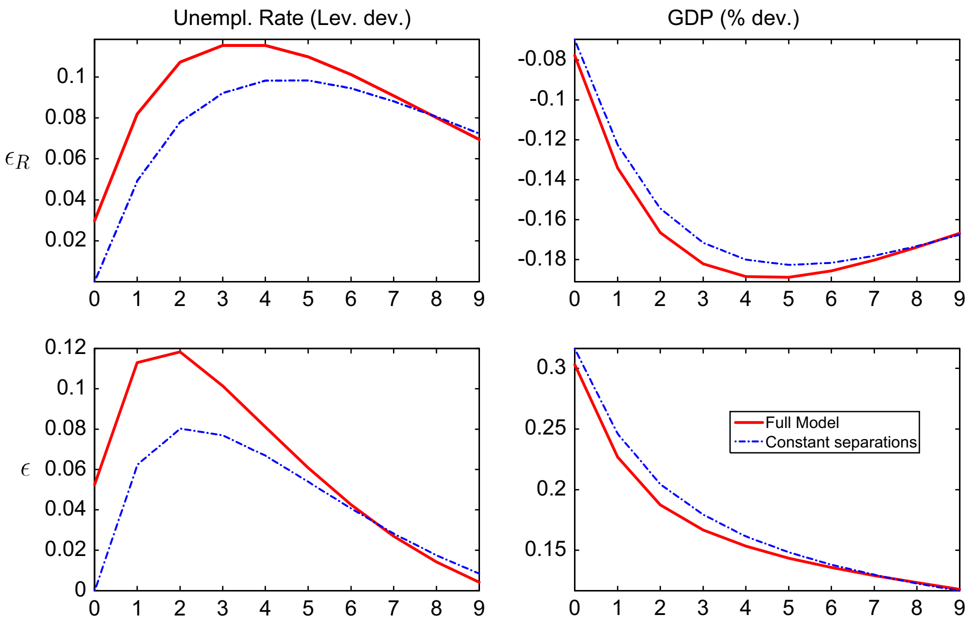

Fig. 8. Comparison of full model and a model without endogenous separations. The top row documents the IRF to a monetary policy shock, $\varepsilon_{R,t}$. The bottom row documents the IRFs to a stationary technology shock, ϵ_t.

Table 5
Data and model moments (in percent). The last column is a measure of the sampling uncertainty in the data.

Variable	Description	Means		Standard deviations		$\sqrt{diag\left(\frac{\hat{S}}{T}\right)}$
		Data	Model	Data	Model	data
π	Domestic inflation	1.56	2	1.93	2.16	0.69
π^c	CPI inflation	1.50	2	1.42	1.80	0.52
π^i	Investm. inflation	1.46	2	1.74	1.88	0.56
R	Nom. interest rate	3.46	4.25	1.91	1.58	1.4
$\hat{H}$	Total hours deviation	0	0	1.69	1.74	0.54
Δy	GDP growth	0.50	0.5	1.03	1.05	0.51
Δw	Real wage growth	0.59	0.5	0.84	0.74	0.14
Δc	Consumption growth	0.48	0.5	0.78	0.81	0.14
Δi	Investment growth	0.73	0.5	2.53	2.55	4.17
Δq	Real exch. rate growth	0.06	0	2.66	2.44	1.90
Δg	Gov. expenditure growth	0.10	0.5	0.73	0.78	0.30
Δx	Export growth	1.18	0.5	2.49	2.31	2.16
Δm	Import growth	1.12	0.5	2.70	2.43	2.30
Δn	Stock market growth	1.63	0.5	10.6	4.83	24.9
Δ spread	Interest spread growth	0.29	0	13.6	15.0	53.2
Δu	Unemployment growth	-0.30	0	4.22	4.27	4.73
Δy^*	Foreign GDP growth	0.31	0.5	0.59	0.58	0.20
π^*	Foreign inflation	1.75	2	1.03	1.05	0.38
R^*	Foreign nom. int. rate	3.54	4.25	1.42	1.20	0.56

We compute the variance decomposition and present it in Table 6.[30] We document and analyze the eight quarters forecast horizon, but results are roughly similar for any business cycle horizon. First, note the importance of the entrepreneurial wealth shock γ_t. It explains almost three quarters of the variation in investment, I, a quarter of GDP and two-thirds of both of the financial variables: net worth N and the spread. Note the spillover from the financial shock into the labor market: it explains one-tenth of the variation in unemployment, U. The wealth shock also appears to "crowd out"

[30] The foreign variables had to be excluded from the table to save space. The variance decomposition for the foreign variables point to the importance of the world-wide unit-root shock to technology, $\mu_{z,t}$.

Table 6
Variance decomposition (%). Eight quarters forecast horizon. Posterior mean and, in parenthesis, 90% probability interval.

Shock	Description	R	π^c	GDP	C	I	NX/GDP	H	H/L	U	w	q	N	Spread
ϵ_t	Stationary technology	8.5	5.8	9.2	10.6	0.9	3.7	8.9	4.3	6.0	1.3	2.6	0.5	1.3
		(1.8,14.5)	(1.3,10.0)	(4.2,14.7)	(1.1,19.6)	(0.0,2.2)	(1.9,5.4)	(4.0,13.0)	(2.7,6.1)	(1.3,10.3)	(0.2,2.7)	(0.4,5.0)	(0.0,1.1)	(0.4,2.3)
Υ_t	MEI	0.2	0.2	3.9	2.2	9.6	6.7	1.5	0.2	2.8	1.7	0.1	12.3	21.5
		(0.0,0.4)	(0.0,0.5)	(0.7,7.0)	(0.1,4.5)	(1.9,16.0)	(1.8,11.8)	(0.2,2.9)	(0.1,0.3)	(0.3,5.5)	(0.2,3.4)	(0.0,0.3)	(2.3,22.0)	(5.2,34.7)
ζ_t^c	Consumption prefs	5.8	2.8	6.9	45.2	0.8	8.7	10.1	2.9	9.4	2.0	5.2	0.6	1.0
		(1.5,10.4)	(0.7,4.9)	(2.6,10.8)	(30.3,57.9)	(0.1,1.8)	(4.0,14.1)	(4.5,16.1)	(0.9,4.9)	(3.3,15.1)	(0.1,3.9)	(1.2,9.1)	(0.0,1.2)	(0.3,1.8)
ζ_t^h	Labor prefs	5.6	4.0	7.9	6.0	0.5	4.4	28.4	73.5	11.1	39.1	1.9	0.4	1.1
		(1.6,10.1)	(1.1,6.9)	(3.4,12.7)	(0.9,10.8)	(0.0,1.0)	(1.5,7.0)	(18.2,38.9)	(61.3,85.2)	(3.2,18.7)	(19.2,59.3)	(0.2,3.6)	(0.0,0.9)	(0.2,1.9)
$\varepsilon_{R,t}$	Monetary policy	25.6	0.7	6.5	5.3	9.6	7.0	3.1	0.1	8.7	4.5	1.2	12.1	8.4
		(10.5,40.2)	(0.1,1.3)	(4.2,9.1)	(2.1,8.5)	(5.3,12.8)	(4.2,10.1)	(1.4,4.7)	(0.0,0.2)	(5.1,12.7)	(1.8,7.1)	(0.1,2.4)	(8.9,15.8)	(5.9,11.0)
g_t	Gov. expenditures	0.6	0.2	1.4	1.6	0.1	0.4	2.0	0.6	1.9	0.4	0.2	0.0	0.1
		(0.2,0.9)	(0.1,0.5)	(0.8,2.0)	(0.3,3.0)	(0.0,0.1)	(0.2,0.5)	(1.2,2.8)	(0.4,0.9)	(1.0,2.7)	(0.1,0.8)	(0.0,0.4)	(0.0,0.1)	(0.0,0.2)
τ_t^d	Markup, domestic	23.4	44.8	7.4	8.1	2.8	2.0	9.3	0.2	23.7	31.1	0.2	2.3	0.3
		(9.7,36.0)	(17.1,69.5)	(1.3,13.0)	(2.4,13.2)	(0.4,5.3)	(0.5,3.7)	(1.9,16.5)	(0.0,0.4)	(4.8,41.2)	(7.9,53.4)	(0.0,0.5)	(0.1,4.8)	(0.0,0.6)
τ_t^x	Markup, exports	1.0	0.5	7.8	0.8	0.0	1.1	10.3	2.4	11.9	3.8	0.3	0.1	0.2
		(0.1,1.8)	(0.0,0.8)	(2.8,13.1)	(0.0,2.0)	(0.0,0.1)	(0.0,2.7)	(3.4,15.8)	(0.5,4.0)	(4.7,18.4)	(0.5,6.8)	(0.0,0.7)	(0.0,0.2)	(0.0,0.4)
τ_t^{mc}	Markup, imp. for cons.	17.0	33.7	0.2	0.9	0.8	4.1	1.0	0.2	2.2	2.4	4.2	3.0	2.3
		(1.6,28.8)	(4.2,57.3)	(0.0,0.5)	(0.0,1.7)	(0.2,1.5)	(0.3,7.7)	(0.0,2.1)	(0.0,0.5)	(0.0,4.8)	(0.1,5.2)	(0.3,8.5)	(0.4,5.8)	(0.1,4.5)
τ_t^{mi}	Markup, imp. for inv.	0.0	0.0	0.1	0.0	0.1	0.3	0.1	0.0	0.1	0.0	0.0	1.0	1.2
		(0.0,0.0)	(0.0,0.0)	(0.0,0.1)	(0.0,0.0)	(0.0,0.1)	(0.0,0.4)	(0.0,0.1)	(0.0,0.0)	(0.0,0.1)	(0.0,0.0)	(0.0,0.1)	(0.4,1.7)	(0.4,2.0)
τ_t^{mx}	Markup, imp. for exp.	0.7	0.8	16.4	2.2	0.4	25.2	14.4	14.1	3.8	1.5	2.4	0.1	0.1
		(0.2,1.4)	(0.2,1.4)	(4.3,27.4)	(0.4,3.8)	(0.1,0.7)	(9.1,41.2)	(4.0,23.9)	(3.9,25.8)	(1.2,6.5)	(0.2,2.9)	(0.3,4.5)	(0.0,0.2)	(0.0,0.2)
γ_t	Entrepreneurial wealth	2.3	1.1	24.7	3.3	71.4	23.5	4.9	0.1	10.5	5.9	2.9	63.9	59.7
		(0.0,5.4)	(0.0,2.4)	(15.0,33.5)	(0.0,8.1)	(58.4,82.6)	(9.2,37.5)	(1.2,8.2)	(0.0,0.3)	(3.6,17.6)	(0.8,10.6)	(0.0,6.7)	(53.5,75.1)	(46.8,74.9)
$\tilde{\phi}_t$	Country risk premium	5.0	3.4	2.7	0.6	1.1	6.7	4.3	0.7	5.9	2.3	73.2	1.1	1.7
		(0.6,9.7)	(0.5,6.4)	(0.6,4.6)	(0.0,1.3)	(0.1,2.4)	(0.7,13.4)	(0.9,7.7)	(0.2,1.2)	(1.1,11.1)	(0.2,4.7)	(58.7,88.4)	(0.0,2.2)	(0.2,3.3)
$\mu_{z,t}$	Unit-root technology	2.3	1.6	4.1	11.5	1.5	2.2	0.7	0.2	0.8	3.7	2.0	2.1	0.5
		(0.0,4.8)	(0.0,3.3)	(1.8,6.6)	(3.6,19.9)	(0.1,2.8)	(0.0,4.4)	(0.0,1.4)	(0.0,0.3)	(0.0,1.7)	(2.0,5.4)	(0.0,4.6)	(0.8,3.5)	(0.0,1.1)
	5 foreign[a]	9.3	5.4	7.6	13.8	3.0	12.9	6.0	1.4	7.9	6.3	78.8	3.7	2.8
	All foreign[b]	28.0	40.4	32.1	17.7	4.3	43.6	31.8	18.1	25.9	14.0	85.7	7.9	6.6

[a] '5 foreign' is the sum of the foreign stationary shocks, R_t^*, π_t^*, Y_t^*, the country risk premium shock, $\tilde{\phi}_t$, and the world-wide unit root neutral technology shock, $\mu_{z,t}$.
[b] 'All foreign' includes the five shocks in 'a' as well as the markup shocks on imports and exports, i.e. $\tau_t^{mc}, \tau_t^{mi}, \tau_t^{mx}$ and τ_t^x.

the MEI shock, which has limited importance for all variables except the spread. Both shocks primarily affect investment, and our results indicate that business cycle variation in investment is primarily driven by variation in demand, not in supply.

Second, note how the variation in unemployment is quite evenly spread out over many different shocks. Hours per worker, H/L, is instead to a very large degree, three quarters, determined by the labor preference shock, ζ_t^h. This is also the most important shock for both total hours worked, H, and real wages, w, but unimportant for the other variables. It explains only 8% (4%) of GDP (π^c) at the 8 quarters horizon, and 4% (3%) of GDP (π^c) at the 20 quarters horizon (the longer horizon not documented in the table). This is in sharp contrast to SW where this type of shock dominates the variation of GDP and π^c, also on longer horizons. For an explanation of this difference with respect to the ζ_t^h shock, see the discussion in Section 5.5.1.

A discussion of the importance of the open economy dimension is warranted. The purely foreign stationary shocks R_t^*, π_t^* and Y_t^* (omitted from the table) have very limited effects ($<1\%$) on the domestic variables, except regarding net exports, NX/GDP, and the real exchange rate, q. Nevertheless, the open economy part of the model matters for the variance decomposition as both the world-wide unit root neutral technology shock, $\mu_{z,t}$, and the country risk premium shock, $\tilde{\phi}_t$, explain non-negligible fractions of the variance. Toward the end of Table 6 we document the importance of the foreign shocks by presenting the sum of the contributions of $R_t^*, \pi_t^*, Y_t^*, \mu_{z,t}$ and $\tilde{\phi}_t$. These five shocks explain 8% of GDP, 5% of π^c, 9% of the nominal interest rate, R and 8% of unemployment. The sum in the last row of the table also includes the markup shocks on imports and exports. The corresponding numbers are 32% of GDP, 40% of π^c, 28% of R and 26% of unemployment. One can discuss to what degree these markup shocks originate in the foreign economy, but it is indisputable that the open economy dimension is needed to capture the substantial importance for the domestic economy of the observed open economy variables: the real exchange rate, imports, exports and the three foreign macro-variables.

Finally, we note from the 90% probability intervals also documented in Table 6 that the variance decomposition has reasonable precision – the exact fraction of a variable explained by a specific shock is uncertain, but there is e.g. only 5% probability that the entrepreneurial wealth shock, γ_t, explains less than 58% of the variation in investment or less than 15% of GDP.[31]

5.5.5. Smoothed shock processes and historical decomposition

Fig. 9 presents the smoothed values for the shock processes. The recent financial crisis shows up as extreme values in several shocks: high values of the MEI shock, Υ_t, the markup shock for exports, $\tau_{x,t}$, the country risk-premium, $\tilde{\phi}_t$, and, slightly after the crisis, government expenditures, g_t. We also note extreme low values, contributing to the downturn, for the wealth shock γ_t and both the stationary and unit root neutral technology shocks ϵ_t and $\mu_{z,t}$. A surprising result is that the zero lower bound for the nominal interest rate never was binding in the recent downturn in the sense that the estimated Taylor rule prescribed a higher interest rate than the actual rate. This observation comes from the fact that the monetary policy shocks were negative during the entire crisis. The reason that the Taylor rule implied a non-negative interest rate was that CPI inflation, with the exception of a few quarters, was above the 2% target during the crisis period (in terms of annualized quarterly rates, see the data plot in Fig. 11). From a computational point of view this is comforting as our solution method does not take into account the non-linearity induced by the zero lower bound.

We document the driving forces for the key variables, GDP, CPI inflation, the corporate interest rate spread and unemployment in the period 2006–2010, i.e. including the financial crisis period. The historical decomposition for these variables is plotted in Figs. 10–13. We focus our analysis on the shocks that contributed to the extreme downturn in 2009 – a year in which GDP decreased by more than 5%. Where appropriate we also try to point out counteracting shocks and key shocks affecting variables negatively in 2010.

Let us first give the overall picture: for all variables of interest the financial shock, γ_t, contributed substantially to the economic downturn, often as the most important shock.

We start by commenting on GDP and mention shocks in order of importance.[32] γ_t was the most important negative shock to GDP in both the second half of 2009 and in 2010. Export markups, τ_t^x, foreign GDP, y_t^*, and consumption demand, ζ_t^c, also had large negative impacts, and were partially offset by the expansionary monetary policy captured in $\varepsilon_{R,t}$.

For CPI inflation the first thing to note is that it was not particularly low during the crisis. Nevertheless, we focus on the shocks that drove π^c down. The negative pressure at the onset of the crisis was dominated by decreasing import markups, $\tau_t^{m,c}$, and later by decreased domestic markups, τ_t^d, in 2009. For both 2009 and 2010 shocks to foreign GDP, y_t^* drove down inflation. To a lesser degree the financial shock, γ_t, the unit-root neutral technology shock, $\mu_{z,t}$, and the consumption demand shock, ζ_t^c, also contributed negatively, while monetary policy shocks, $\varepsilon_{R,t}$, and, mainly in 2009, negative technology shocks, ϵ_t, counteracted.

The huge increase in the corporate spreads was to a very large degree driven by γ_t. y_t^* and $\mu_{z,t}$ also contributed while monetary policy shocks to a large degree offset the increase. It is also interesting to see how important both γ_t and the investment-specific shock, Υ_t, were in pushing down spreads far below their historical average in the years leading up to the crisis.

[31] Note that these type of measures only capture parameter uncertainty, not model uncertainty.

[32] All variables in the historical decomposition are plotted and analyzed in terms of deviation from their steady state level.

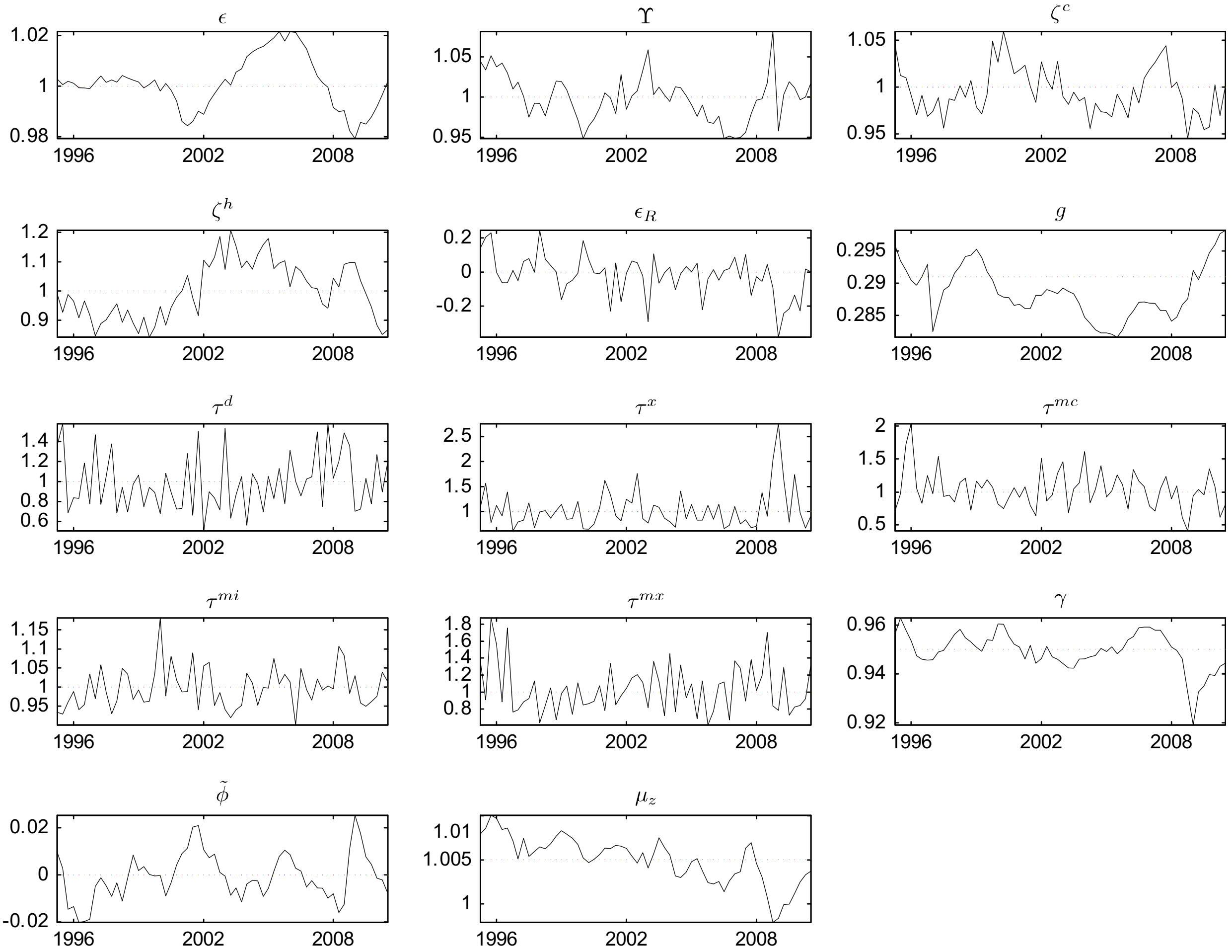

Fig. 9. Smoothed shock processes, except $\varepsilon_{R,t}$, which is the innovation to the interest rate rule.

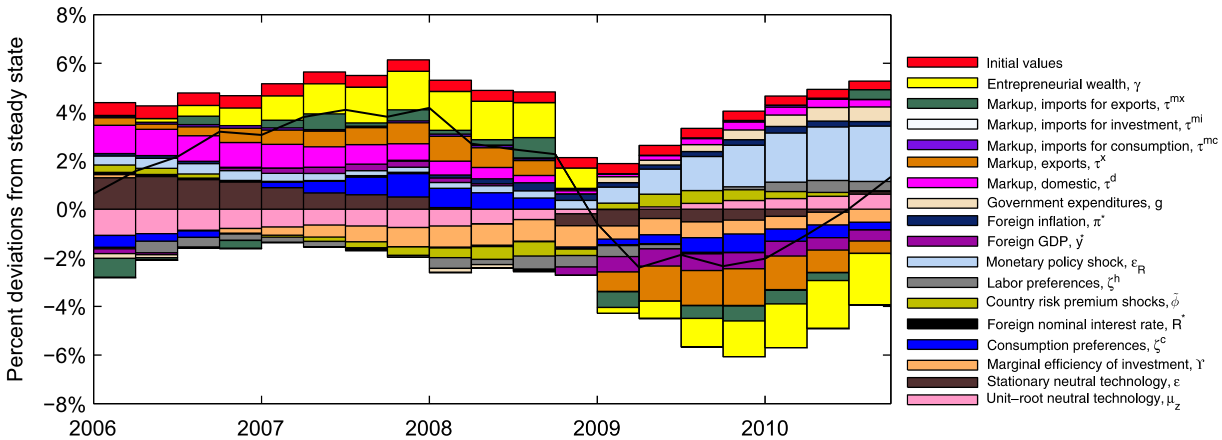

Fig. 10. Decomposition of GDP, gdp_t, 2006:q1–2010q3.

Finally, increased unemployment, just as GDP, was mainly driven by γ_t and export markups, τ_t^x. At the onset of the crisis also τ_t^d contributed, while y_t^* and both preference shocks, ζ_t^c and ζ_t^h, played an increasing role over time. Monetary policy shocks, $\varepsilon_{R,t}$, dampened the increase, initially assisted by negative technology shocks.

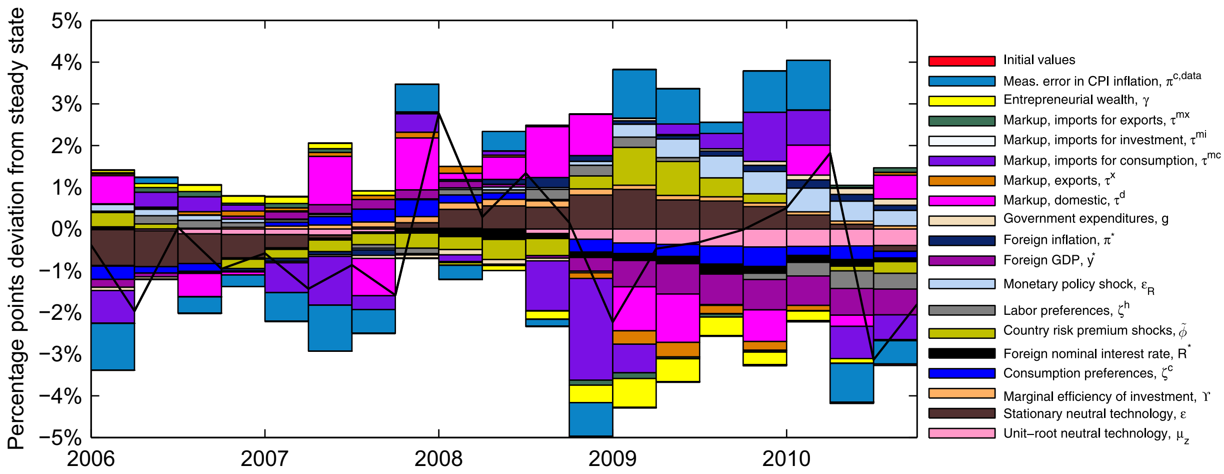

Fig. 11. Decomposition of annualized quarterly CPI inflation, $\pi_t^{c,data}$, 2006:q1–2010q3.

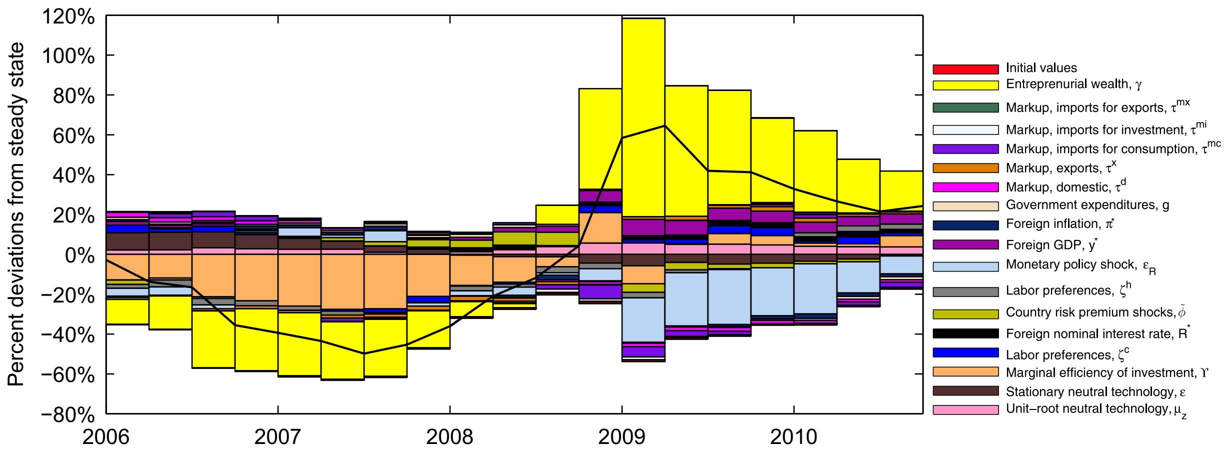

Fig. 12. Decomposition of the corporate interest rate spread, $Z_{t+1}-R_t$, 2006:q1–2010q3.

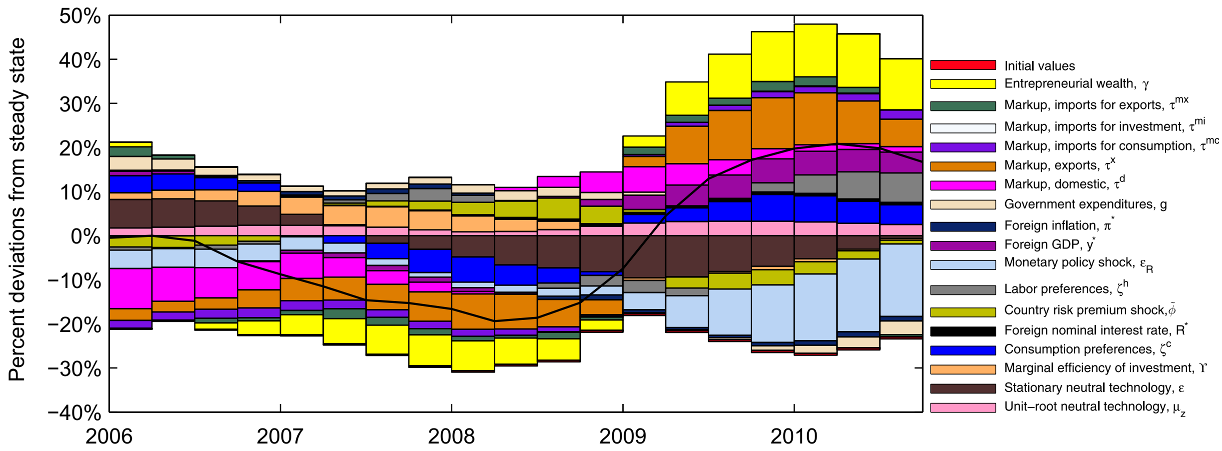

Fig. 13. Decomposition of unemployment, $1-L_t$, 2006:q1–2010q3.

Table 7
Relative out-of-sample root mean square error (RMSE) compared to the full model which includes both financial frictions and employment frictions. In this table a number greater than unity indicates that the submodel in question makes worse forecasts than the full model. Sample used for estimation: 1995q1–2004q4. Evaluation sample: 2005q1–2010q3.

Model	1q			4q			8q			12q		
	π^c	R	Δy	π^c	R	Δy	π^c	R	Δy	π^c	R	Δy
Baseline	1.05	1.29	0.90	1.39	1.24	0.96	1.21	1.10	1.01	0.98	1.12	0.99
Financial fric.	1.02	1.15	0.92	1.16	1.11	0.96	1.15	1.08	1.00	0.93	1.12	0.99
Employment fric.	1.06	1.06	0.99	1.29	1.08	0.95	1.11	1.09	0.97	0.95	1.08	0.99

Table 8
Relative out-of-sample mean absolute errors (MAE) compared to the full model which includes both financial frictions and employment frictions. In this table a number greater than unity indicates that the submodel in question makes worse forecasts than the full model. Sample used for estimation: 1995q1–2004q4. Evaluation sample: 2005q1–2010q3.

Model	1q			4q			8q			12q		
	π^c	R	Δy	π^c	R	Δy	π^c	R	Δy	π^c	R	Δy
Baseline	1.05	1.34	0.91	1.38	1.30	1.02	1.36	1.09	1.01	1.13	1.07	1.00
Financial fric.	0.99	1.19	0.92	1.06	1.16	1.02	1.29	1.08	1.00	1.07	1.08	1.00
Employment fric.	1.13	1.00	0.97	1.31	1.02	0.88	1.24	1.09	0.98	1.07	1.05	1.00

To summarize our historical decomposition, the main drivers of the recent crisis were the financial shock and the shocks to export demand (shocks to export markups and foreign GDP).

5.5.6. Relative forecasting performance

One important dimension of the model is its forecasting performance. In particular, it is interesting to compare the full model to the various submodels in this dimension. To do so, we compare the out-of-sample root mean square error (RMSE) of the models. To perform this exercise we estimate all four models (baseline, financial frictions, employment frictions and the full model) on a subsample, 1995q1–2004q4, of the available data, and use the remaining observations, 2005q1–2010q3 for forecast evaluation. We use the priors documented in Section 5.2 for all models.[33] We use as many data series as applicable for each submodel.[34] We perform this exercise for point forecasts from the posterior mean parameter values. The posterior parameter distributions for each subsample estimation are documented in the Computational Appendix.

Good forecasting performance for closed economy DSGE models has been established widely (see e.g. Smets and Wouters, 2003, 2007). For open economy models and Swedish data the most relevant reference is Adolfson et al. (2007) who establish that a model very close to our baseline model does as well as a BVAR in terms of forecast performance 1–8 quarters ahead for GDP-growth, Δy; slightly worse for the nominal interest rate, R and better than a BVAR for long forecast horizons (>6 quarters) for CPI-inflation, π^c. As Adolfson et al. (2007), we perform the forecast evaluation for annual inflation and GDP-growth and the annualized interest rate.

Our results for the relative RMSE of each submodel are presented in Table 7. Note that the full model outperforms all the submodels substantially for π^c and R forecasts, except for π^c at the 12 quarters horizon. For π^c the RMSE are 11% (employment frictions) to 21% (baseline) larger for the eight quarters horizon.[35] This superior forecasting ability, in particular of π^c, is a key argument why the full model is better suited for central bank use. For Δy the full model forecasts are instead worse than the baseline and financial frictions models on horizons up to a year, but equally good for the eight quarters horizon. The employment friction model slightly outperforms the full model for Δy at all horizons. All differences in RMSE between models for Δy are small though – never larger than 10% and mostly 1–4%.[36]

[33] The following two exceptions apply: in the baseline and financial friction models all labor adjustment is on the intensive margin and the parameter σ_L therefore has a different meaning. We accordingly lower the σ_L prior to $\Gamma(3.0,1.5)$. We encountered numerical problems during the optimization as the posterior mode of the elasticity of substitution for imported consumption goods, η_c, was driven to its lower economic bound, 1, in all three submodels. To avoid this issue we calibrated it at its prior mean value, 1.5.

[34] For the baseline model we have to leave out the corporate spread, net worth and unemployment, for the financial friction model we have to leave out unemployment, and for the employment friction model we have to leave out the corporate spread and net worth.

[35] We note that for the unemployment model the relative RMSE compared to the full model has similar shape over forecast horizons for real wage inflation, Δw and π^c. We conjecture that inferior predictions of future wage increases are the main cause of the unemployment model's inferior π^c forecast. The obvious alternative hypothesis is that inferior forecasts of domestic inflation, π, drive forecasts for both π^c and Δw, but this is not the case. For the two remaining submodels the pattern of relative RMSE is less clear, and the relevant causes multifaceted.

[36] We do not want to attribute too much weight to any of the RMSE results as the evaluation sample by necessity is very short. This problem is most pronounced for the longer forecast horizons.

Differences in forecast performance between models are very small for other variables we looked at (real exchange rate, total hours worked, unemployment), with the exception of real wage inflation, Δw, where the full model outperforms all the submodels by around 5%. We abstain from

To check the robustness of the above results we also summarize the forecast errors in terms of mean absolute errors (MAE) in Table 8. They give the same qualitative picture as the RMSEs. For the key variable, π^c, the MAE is 24% (employment frictions) to 36% (baseline) larger for the eight quarters horizon. Note that in contrast to the RMSE metric the full model is superior also on the 12 quarters horizon for π^c.

A second robustness check is to compare the average RMSE or MAE for the 4–8 quarters horizon – the most relevant horizons for monetary policy decisions. In that metric the full model does even better than indicated by the comparisons at 4 and 8 quarters horizons, indicating that it is even more superior at the 5–7 quarters horizon.

We also evaluated the forecasts of the various submodels for the fixed parameter vector from the full model's posterior mean. The same qualitative relative RMSE results as above are obtained. Also quantitatively the differences are small compared to re-estimating each model. This is unsurprising as the posterior mean of the parameters are quite similar across models.

5.5.7. *Estimations of alternative specifications*

To address a couple of interesting questions we re-estimate three variations of the model, specified below. Unless otherwise indicated we report results for the posterior mean. The posterior parameter distributions for each alternative specification are documented in the Computational Appendix.

Shutting down the financial shock: To increase the comparability with JPT we re-estimate the model, but without any financial shock and without matching the two financial time series, i.e. roughly the exercise they perform, but in a small open economy setting with financial and employment frictions. With this setup we get a similar result as they do: first, as in JPT the IRF of a positive MEI shock, Υ_t, drives up inflation and initially drives down consumption, in contrast to our main estimation results. Second, and more importantly, the MEI shock becomes very important in the variance decomposition: at the 8 quarters horizon it explains 52% of the variance of investment and 6% of GDP, to be compared with 10% of investment and 4% of GDP in our main specification. We have repeated this exercise in the submodels without labor frictions, and the results are very similar – if financial observables and the financial shock are included the MEI shock loses its importance. Our conclusion is that the large role for the MEI shock obtained in JPT reflects that the appropriate data are not matched – the MEI shock has counterfactual implications for the stock market and the spread, and is therefore only important if these data series are not included in the estimation.[37] In other words, we make an analogous argument as made previously by other authors regarding the IST shock, which is only important if investment prices are not observed.

The role of shocks to idiosyncratic uncertainty: Shocks to uncertainty receive attention in the literature (e.g. Bloom, 2009). Christiano et al. (2009) estimate a model with similarities to the one presented here. They find that the shock to idiosyncratic uncertainty, σ_t, as well as signal (news) shocks to σ_t generate a lot of the volatility of business cycles.

We have explored the role of this shock in various ways for our model and dataset. First of all we included it in our main specification, where the shock to entrepreneurial wealth, γ_t, is also present. In that specification the σ_t shock plays no role for the variance decomposition – it explains less than half a percent of any variable other than the spread and only 3% of the variation of the spread. Note that endogenous priors are key for this result – with traditional priors both σ_t and γ_t are quantitatively important in terms of the variance decomposition. But they are partially offsetting each other so the model implied variances of several observed variables, in particular the corporate spread, become over-predicted.[38]

In a second exercise we turned off the γ_t shock and in that setting the σ_t shock does play a non-negligible role, although never accounting for more than 10% of the variance of any variable but the spread. Its IRF mainly has the expected properties: negative hump-shaped effects on nominal interest rate, inflation, GDP and investment. It should be noted that consumption increases in response to increased risk, and this result is in contrast to Christiano et al. (2009). Plausibly the open economy dimension is the reason for this difference – net exports decrease in response to this shock as the nominal exchange rate appreciates on impact. In terms of data fit this specification is dominated by our benchmark model specification – the log likelihood of the σ_t specification is 35 points lower. We have also confirmed that signal shocks to σ_t does not substantially alter any of these results.

Vacancy posting costs vs. hiring costs: Recall that the costs associated with posting vacancies v_t^i are

$$\frac{\kappa z_t^+}{\varphi}\left(\frac{Q_t^\iota v_t^i}{[1-\mathcal{F}_t^i]l_t^i}\right)^{\varphi}[1-\mathcal{F}_t^i]l_t^i,$$

units of the domestic homogeneous good. The denominator in this expression is simply the labor stock at the time of the vacancy decision. In our main specification we calibrate $\iota = 1$ implying that the costs of adjusting employment is related to

(*footnote continued*)
reporting the log determinant of the mean square error, which is a multivariate measure of forecast performance as Adolfson et al. (2007) have shown that this measure is unreliable for DSGE model forecast evaluation.

[37] Christiano et al. (2009) have made the same argument using estimation results based on data for the Euro area and the U.S.

[38] Without endogenous priors, the smoothed innovations to γ and σ are strongly correlated (correlation coefficient around 0.5) and have opposite signs in their effect on several variables thereby partially offsetting each other.

the hiring rate (as $Q_t^1 v_t^i$ is the number of new hires), but unaffected by the number of vacancies posted *per se*, and thereby by the tightness of the labor market. To be agnostic in this exercise we estimate the parameter iota and use a beta prior centered at 0.5 and with a standard deviation of 0.25. The posterior mean of ι is 0.88 and the 90% probability interval is [0.76, 1.00]. This means that the data series that we match strongly indicate that the tightness of the labor market is unimportant for the costs of hiring. This is in line with the micro evidence in Carlsson, Eriksson and Gottfries (2006). But, our result is weakened by the fact that we do not match any data series for vacancies, as there is no such reliable series for Sweden. For Israeli data, Yashiv (2000) estimated a convex combination of vacancy costs and hiring costs, $\lambda v_t + (1-\lambda)Q_t v_t$ and obtained $\lambda = 0.3$, but was unable to rule out $\lambda = 0$, i.e. no role for vacancy costs. A recent paper by Cheremukhin and Restrepo-Echavarria (2010) documents a similar tendency for the U.S. as we obtain for Sweden. In that paper the low matching rates in slack labor markets are interpreted as a procyclical variation in the matching productivity. We instead interpret this result as reflecting misspecification of the standard search-matching model – employment adjustment costs are a function of hiring rates, not vacancy posting rates. This is in line with Lechthaler et al. (2010) who criticize the standard search-matching model for its counterfactually high predicted job creation in slack labor markets. In particular they point to a counterfactually positive correlation between job creation and job separations in models with endogenous separations, and propose a model of hiring and firing costs instead. Because of our assumption of hiring costs, $\iota = 1$, our model is not subject to this problem – it implies a large and negative correlation between job creation and job separation.

6. Summary and conclusions

This paper incorporates three important extensions of the emerging standard empirical monetary DSGE model. We add financial frictions in the accumulation of capital in a well established way, based on BGG and Christiano et al. (2008). We also add employment frictions building on a large body of literature where we are closest to GST and CIMR. We incorporate the model in a small open economy setting closely following ALLV. We make a theoretical contribution to the literature by endogenizing the job separation decision in this comprehensive setting. We estimate the full model using Bayesian techniques on Swedish data 1995q1–2010q3.

Comparing the full model to simpler models which abstracts from financial frictions or employment frictions, we note that the full model has superior forecasting performance for CPI inflation and the nominal interest rate. Nevertheless, in our view neither the main aim of the model nor its main advantage in central bank policy use is its forecasting abilities compared to smaller models. Rather, it is the model's ability to better characterize the driving forces of the economy that adds value. For policy use, the main advantage is the ability to make consistent quantitative scenarios for a rich set of variables: How is unemployment affected by a sudden and temporary decrease in export demand or an increase in corporate interest rate spreads? We also believe that the historical decomposition of the driving forces behind the recent recession – mainly the financial shock and shocks to export demand – is more accurate because the model incorporates financial and employment frictions. A model based analysis of the recent increase in unemployment would be severely misleading without including these frictions.

The key empirical insights from the paper with general implications for the literature are as follows:

1. The financial shock to entrepreneurial wealth is pivotal for explaining business cycle fluctuations. In terms of variance decomposition it accounts for three quarters of the variance in investment, a quarter of the variance in GDP but only a negligible part of CPI inflation at business cycle horizons.
2. The marginal efficiency of investment shock has very limited importance in terms of variance decomposition. This contrasts starkly with JPT, and the reason for this result is that we match financial market data – a stock market index and the corporate interest spread – and allow for a financial shock. When we re-estimate the model without these features, we obtain the same qualitative result as JPT, i.e. that the MEI shock becomes pivotal in explaining variation in investment and important for GDP and other macro-variables. Our conclusion is that the large role for the MEI shock reflects that the appropriate data are not matched, and that the MEI shock has counterfactual implications for the stock market valuation and the corporate interest spread. In other words, taking into account the appropriate data we conclude that business cycle variation in investment is primarily driven by shocks to investment demand, not to investment supply.
3. In contrast to the existing literature of estimated DSGE models, e.g. SW, ALLV and GST, our model does not contain any wage markup shocks or similar shocks (labor preferences, wage bargaining) with low autocorrelation, and we still match both hours worked, unemployment and real wage data series. Furthermore, the (low frequency) labor preference shock that we obtain is not important in explaining key macro variables such as GDP, inflation and the nominal interest rate. This is in sharp contrast to SW and ALLV.
4. We confirm the assumption made in GST that the tightness of the labor market is unimportant for the cost of expanding the workforce. In other words, there are costs of hiring, but no significant costs of vacancy postings. This is in contrast to what is assumed in most search and matching models for the labor market.
5. The open economy dimension generally dampens the effects of demand shocks, but amplifies supply shock effects on real quantities. Our endogenous country risk-adjustment term is important and generates a hump-shape in the nominal exchange rate response to a monetary policy shock. A contractionary monetary policy shock generates an increase in net exports, in line with Kollmann (2001), but contrary to ALLV. Finally, note that foreign shocks are important. They explain

approximately a third of the variation in GDP, CPI inflation, nominal interest rates and unemployment when using a broad definition of foreign shocks, i.e. including import and export markup shocks.

Acknowledgments

We are grateful for comments from the editors and two anonymous referees. We have received valuable feedback from Malin Adolfson, Mikael Carlsson, Ferre De Graeve, Christopher Erceg, Ichirou Fukunaga, Simon Gilchrist, Jesper Hansson, Skander Van den Heuvel, Zoltan Jakab, Stefan Laséen, Jesper Lindé, Henrik Lundvall, Paolo Pesenti, Massimo Rostagno, Tom Sargent, Etsuro Shioji, Lars E.O. Svensson, Ulf Söderström, Antonella Trigari, Mattias Villani, Anders Vredin, Peter Welz and participants at various presentations. The first co-author is grateful for the hospitality of the Riksbank during two visits during which some of the work on this manuscript was completed. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Executive Board of Sveriges Riksbank or of the European Central Bank.

Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jedc.2011.09.005.

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