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into a Small Open Economy Model**

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CQER Working Paper 10-04

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Abstract: The current financial crisis has made it abundantly clear that business cycle modeling can no longer abstract from financial factors. It is also clear that the current standard approach of modeling labor markets without explicit unemployment has its limitations. We extend what is becoming the standard new Keynesian model in three dimensions. First, we incorporate financial frictions in the accumulation and management of capital. Second, we model the labor market using a search and matching framework. Third, we extend the model into a small open economy setting. Finally, we estimate the model using Bayesian techniques with Swedish data. Our main results are as follows: (1) The financial shock to entrepreneurial wealth is pivotal for explaining business cycle fluctuations. It accounts for two-thirds of the variance in investment and a quarter of the variance in GDP. (2) The marginal efficiency of investment shock has very limited importance. The reason for this is that we match financial market data. (3) In contrast to the existing literature on estimated DSGE models, our model does not need any wage markup shocks or similar shocks with low autocorrelation to match the data. Furthermore, the low-frequency labor preference shock that we do allow is not important in explaining GDP. (4) The tightness of the labor market is unimportant for the cost of adjusting the workforce. In other words, there are costs of hiring but no significant costs of vacancy postings per se.

JEL classification: E0, E3, F0, F4, G0, G1, J6

Key words: DSGE model, financial frictions, labor market frictions, unemployment, small open economy, Bayesian estimation

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Please address questions regarding content to Lawrence J. Christiano, Department of Economics, Northwestern University, 2001 Sheridan Road, Evanston, IL 60208, and NBER, 847-491-8231, l-christiano@northwestern.edu; Mathias Trabandt, European Central Bank, Kaiserstrasse 29, 60311 Frankfurt am Main, Germany, and Sveriges Riksbank, 49-69-1344-6321, mathias.trabandt@ecb.int; or Karl Walentin, Sveriges Riksbank, 103 37 Stockholm, Sweden, 46-8-787-0491, karl.walentin@riksbank.se.

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1. Introduction

The current financial crisis has made it abundantly clear that business cycle modeling no longer can abstract from financial factors. It is also becoming increasingly clear that the stylized modeling of labor markets without explicit unemployment that is the current standard approach has its limitations, and that there are potential benefits from integrating recent progress in labor market modeling into richer macro models. Some questions that the dominating existing business cycle models are mute on, but that we would like to answer are: 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 output and inflation? What are the spillover effects of financial market disturbances to unemployment in a small open economy? Taking into account stock market data, does investment seem primarily driven by demand or supply shocks? Furthermore, what drives the variation in the intensive and extensive margin of labor supply respectively? Can careful labor market modelling reduce the importance of wage markup shocks that is present in many extant models? In order to address these questions we extend what is becoming the standard new Keynesian model, see e.g. Christiano, Eichenbaum and Evans (2005), in three dimensions.

First, we incorporate financial frictions in the accumulation and management of capital similar to Bernanke, Gertler and Gilchrist (1999) and Christiano, Motto and Rostagno (2003, 2008). The financial frictions we introduce reflect that borrowers and lenders are different people, and that they have different information. Thus, we introduce ‘entrepreneurs’. These are agents who have a special skill in the operation and management of capital. Although these agents have their own financial resources, their skill in operating capital is such that it is optimal for them to operate more capital than their own resources can support, by borrowing additional funds. There is a financial friction because the management of capital is risky. Individual entrepreneurs are subject to idiosyncratic shocks which are observed only by them. The agents that they borrow from, ‘banks’, can only observe the idiosyncratic shocks by paying a monitoring cost. This type of asymmetric information implies that it is impractical to have an arrangement in which banks and entrepreneurs simply divide up the proceeds of entrepreneurial activity, because entrepreneurs have an incentive to understate their earnings. It can be shown that the optimal contract instead is a ‘standard debt contract’. Entrepreneurs who suffer an especially bad idiosyncratic income shock and who therefore cannot afford to pay the required interest, are ‘bankrupt’. Banks pay the cost of monitoring these entrepreneurs and take all of their net worth in partial compensation for the interest that they are owed. These monitoring costs are the reason that entrepreneurs have to pay a financing premium, in addition to the risk-free interest rate, on their external financing.

The ultimate source of funds for lending to entrepreneurs is the household. The debt contracts extended by banks to entrepreneurs are financed by issuing liabilities to households. In the model

the interest rate that households receive is nominally non state-contingent. This gives rise to wealth effects of the sort emphasized by Irving 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 produces an economic slowdown.

Second, we include the labor market search and matching framework of Mortensen and Pissarides (1994) and, more recently, Hall (2005a,b,c) and Shimer (2005a,b). We integrate the framework into our environment - which includes capital and monetary factors - following the version of Gertler, Sala and Trigari (2008, henceforth GST) implemented in Christiano, Ilut, Motto and Rostagno (2007, henceforth CIMR). A key feature of the this model is that there are wage-setting frictions, but they do not have a direct impact on on-going worker employer relations. However, wage-setting frictions have an impact on the effort of an employer in recruiting new employees. In this sense, the setup is not vulnerable to the Barro (1977) critique of sticky wages.

There are three main differences of our labor model compared to GST. 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, while we allow for variation in this margin. An important step forward is that we allow for endogenous separation of employees from their jobs. This has been done earlier, e.g. by den Haan, Ramey and Watson (2000), but not in such a rich monetary DSGE model. The importance of time-varying separation rates is motivated by empirical evidence on their cyclicity by Fujita and Ramey (2007). For a paper analyzing the labor market and endogenous job separation in a closed economy monetary DSGE model, see Christiano, Trabandt and Walentin (2010).

In the standard new Keynesian model, the homogeneous labor services are supplied to the competitive labor market by labor retailers (contractors) who combine the labor services of households who monopolistically supply specialized labor services (see Erceg, Henderson and Levin, 2000). Our search-based model dispenses with the specialized labor services abstraction. Labor services are instead supplied to the homogeneous labor market by ‘employment agencies’.

Each employment agency retains a large number of workers. At the beginning of the period a fraction of workers is randomly selected to separate from the firm 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. A nice feature of this approach is the high degree of symmetry with the modeling of entrepreneurial idiosyncratic risk and bankruptcy.

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 by equating the worker's marginal cost to the agency's marginal benefit.

Third, we extend the model into a small open economy setting by incorporating the small open economy structure of Adolfson, Laséen, Lindé and Villani (2005, 2007, 2008) (henceforth ALLV). We model the foreign economy as a vector autoregression (VAR) in foreign inflation, interest rate, output and two worldwide 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 banking, and therefore financing of entrepreneurs, is a purely domestic activity.

We estimate the full model using Bayesian techniques on Swedish data 1995q1-2009q2, 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.

The paper is organized as follows. In section 2 we describe the baseline model which is a small open economy version of Christiano, Eichenbaum and Evans (2005). Section 3 introduces financial frictions while section 4 incorporates employment frictions into the model. Section 5 contains the estimation of the full model which include both financial and employment frictions. Finally, section 6 concludes. 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 based on Christiano, Eichenbaum and Evans (2005) and ALLV from which it inherits most of its open economy structure. 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 Figure A in the Appendix for a graphical illustration. Below we will go 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

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{1}{\lambda_d}} di \right]^{\lambda_d}, \quad 1 \leq \lambda_d < \infty. \quad (2.1)$$

The 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 i^{th} intermediate good producer has the following production function:

$$Y_{i,t} = (z_t H_{i,t})^{1-\alpha} \epsilon_t K_{i,t}^\alpha - z_t^+ \phi, \quad (2.2)$$

where $K_{i,t}$ denotes the capital services rented by the i^{th} 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 (2.2) is defined as:¹

$$z_t^+ = \Psi_t^{\frac{\alpha}{1-\alpha}} z_t.$$

In (2.2), $H_{i,t}$ denotes homogeneous labor services hired by the i^{th} 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

$$R_t^f = \nu_t^f R_t + 1 - \nu_t^f, \quad (2.3)$$

where W_t is the aggregate wage rate, R_t is the risk-free interest rate that apply on working capital loans, and ν_t^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 :

$$mc_t = \tau_t^d \left(\frac{1}{1-\alpha} \right)^{1-\alpha} \left(\frac{1}{\alpha} \right)^\alpha (r_t^k)^\alpha (\bar{w}_t R_t^f)^{1-\alpha} \frac{1}{\epsilon_t}, \quad (2.4)$$

where r_t^k is the nominal rental rate of capital scaled by P_t and $\bar{w}_t = W_t/(z_t^+ P_t)$. 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.

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

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

$$mc_t = \tau_t^d \frac{(\mu_{\Psi,t})^\alpha \bar{w}_t R_t^f}{\epsilon_t (1 - \alpha) \left(\frac{k_{i,t}}{\mu_{z^+,t}} / H_{i,t} \right)^\alpha} \quad (2.5)$$

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

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

where $\kappa_d, \varkappa_d, \kappa_d + \varkappa_d \in (0, 1)$ are parameters, π_{t-1} is the lagged inflation rate and $\bar{\pi}_t^c$ 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., $\check{\pi} = \bar{\pi}$, $\varkappa_d = 1$). 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 i^{th} domestic intermediate good producer which has the opportunity to change price is to maximize discounted profits:

$$E_t \sum_{j=0}^{\infty} \beta^j v_{t+j} \{ P_{i,t+j} Y_{i,t+j} - mc_{t+j} P_{t+j} Y_{i,t+j} \}, \quad (2.6)$$

subject to the requirement that production equal demand. In the above expression, v_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 satisfy demand given by:

$$\left(\frac{P_t}{P_{i,t}} \right)^{\frac{\lambda_d}{\lambda_d-1}} Y_t = Y_{i,t} \quad (2.7)$$

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

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

$$Y_t = G_t + C_t^d + I_t^d + \int_0^1 X_{i,t}^d. \quad (2.8)$$

Here, 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 (2.8) 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:

$$C_t = \left[(1 - \omega_c)^{\frac{1}{\eta_c}} (C_t^d)^{\frac{(\eta_c-1)}{\eta_c}} + \omega_c^{\frac{1}{\eta_c}} (C_t^m)^{\frac{(\eta_c-1)}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c-1}}. \quad (2.9)$$

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:

$$\begin{aligned} c_t^d &= (1 - \omega_c) (p_t^c)^{\eta_c} c_t \\ c_t^m &= \omega_c \left(\frac{p_t^c}{p_t^{m,c}} \right)^{\eta_c} c_t. \end{aligned} \quad (2.10)$$

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:

$$p_t^c = \left[(1 - \omega_c) + \omega_c (p_t^{m,c})^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}}. \quad (2.11)$$

The rate of inflation of the consumption good is:

$$\pi_t^c = \frac{P_t^c}{P_{t-1}^c} = \pi_t \left[\frac{(1 - \omega_c) + \omega_c (p_t^{m,c})^{1-\eta_c}}{(1 - \omega_c) + \omega_c (p_{t-1}^{m,c})^{1-\eta_c}} \right]^{\frac{1}{1-\eta_c}}. \quad (2.12)$$

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

$$I_t + a(u_t) \bar{K}_t = \Psi_t \left[(1 - \omega_i)^{\frac{1}{\eta_i}} (I_t^d)^{\frac{\eta_i-1}{\eta_i}} + \omega_i^{\frac{1}{\eta_i}} (I_t^m)^{\frac{\eta_i-1}{\eta_i}} \right]^{\frac{\eta_i}{\eta_i-1}}.$$

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, $a(u_t) \bar{K}_t$. We discuss maintenance in section 2.4 below. See section B.2 in the Appendix for the functional form of $a(u_t)$. u_t denotes the utilization rate of capital, with capital services being defined by:

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

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, Hercowitz and Krusell (1997)).² As in the consumption good sector the representative investment goods producers takes all relevant prices as given. Profit maximization leads to the following demand for the intermediate inputs in scaled form:

$$i_t^d = (p_t^i)^{\eta_i} \left(i_t + a(u_t) \frac{\bar{k}_t}{\mu_{\psi,t} \mu_{z^+,t}} \right) (1 - \omega_i) \quad (2.13)$$

$$i_t^m = \omega_i \left(\frac{p_t^i}{p_t^{m,i}} \right)^{\eta_i} \left(i_t + a(u_t) \frac{\bar{k}_t}{\mu_{\psi,t} \mu_{z^+,t}} \right) \quad (2.14)$$

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:

$$p_t^i = \left[(1 - \omega_i) + \omega_i (p_t^{m,i})^{1-\eta_i} \right]^{\frac{1}{1-\eta_i}}. \quad (2.15)$$

The rate of inflation of the investment good is:

$$\pi_t^i = \frac{\pi_t}{\mu_{\Psi,t}} \left[\frac{(1 - \omega_i) + \omega_i (p_t^{m,i})^{1-\eta_i}}{(1 - \omega_i) + \omega_i (p_{t-1}^{m,i})^{1-\eta_i}} \right]^{\frac{1}{1-\eta_i}}. \quad (2.16)$$

2.3. Exports and Imports

This section reviews the structure of imports and exports. Both activities involve Calvo price setting frictions, and so 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 is 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

²The empirical importance of this shock has been debated in recent years, see e.g. Justiniano, Primiceri and Tambalotti (2008). 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, Rabanal, Rubio-Ramirez and Vilán (2010).

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 Figure A 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, Eichenbaum and Rebelo (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”). 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 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.

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-shape response of the nominal exchange rate to an 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 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:

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

In scaled form, this is

$$x_t = (p_t^x)^{-\eta_f} y_t^* \quad (2.17)$$

Here, Y_t^* is 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:

$$X_t = \left[\int_0^1 X_{i,t}^{\frac{1}{\lambda_x}} di \right]^{\lambda_x} \quad (2.18)$$

where $X_{i,t}$, $i \in (0, 1)$, are exports of specialized goods. 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:

$$X_{i,t} = \left(\frac{P_{i,t}^x}{P_t^x} \right)^{\frac{-\lambda_x}{\lambda_x - 1}} X_t. \quad (2.19)$$

Combining (2.18) and (2.19), we obtain:

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

The i^{th} specialized export is produced by a monopolist using the following technology:

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

where $X_{i,t}^m$ and $X_{i,t}^d$ are the i^{th} 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:

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

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 :

$$mc_t^x = \frac{\lambda}{S_t P_t^x} = \frac{\tau_t^x R_t^x}{q_t p_t^c p_t^x} \left[\omega_x (p_t^{m,x})^{1-\eta_x} + (1 - \omega_x) \right]^{\frac{1}{1-\eta_x}}, \quad (2.20)$$

where

$$R_t^x = \nu_t^x R_t + 1 - \nu_t^x. \quad (2.21)$$

and where we have used

$$\frac{S_t P_t^x}{P_t} = \frac{S_t P_t^*}{P_t^c} \frac{P_t^c}{P_t} \frac{P_t^x}{P_t^*} = q_t p_t^c p_t^x. \quad (2.22)$$

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

$$X_{i,t}^d = \left(\frac{\lambda}{\tau_t^x R_t^x P_t} \right)^{\eta_x} X_{i,t} (1 - \omega_x) \quad (2.23)$$

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 eq. (2.23) into this integral we derive (see section B.3.3 in the Appendix):

$$X_t^d = \int_0^1 X_{i,t}^d di = \left[\omega_x (p_t^{m,x})^{1-\eta_x} + (1 - \omega_x) \right]^{\frac{\eta_x}{1-\eta_x}} (1 - \omega_x) (\hat{p}_t^x)^{\frac{-\lambda_x}{\lambda_x-1}} (p_t^x)^{-\eta_f} Y_t^* \quad (2.24)$$

where \hat{p}_t^x is a measure of the price dispersion and is defined in the same 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 $\hat{p}_t^x < 1$ and $(\hat{p}_t^x)^{\frac{-\lambda_x}{\lambda_x-1}} > 1$, and more dispersion is reflected in a lower \hat{p}_t^x .

We also require an expression for imported inputs for export production in terms of aggregates. Using a similar derivation it can be shown to be, in scaled terms:

$$x_t^m = \omega_x \left(\frac{\left[\omega_x (p_t^{m,x})^{1-\eta_x} + (1 - \omega_x) \right]^{\frac{1}{1-\eta_x}}}{p_t^{m,x}} \right)^{\eta_x} (\hat{p}_t^x)^{\frac{-\lambda_x}{\lambda_x-1}} (p_t^x)^{-\eta_f} y_t^* \quad (2.25)$$

The i^{th} , $i \in (0, 1)$, export good firm takes (2.19) as its demand curve. This producer sets prices subject to a Calvo sticky-price mechanism. With probability ξ_x the i^{th} export good firm cannot reoptimize its price, in which case it update its price as follows:

$$P_{i,t}^x = \tilde{\pi}_t^x P_{i,t-1}^x, \quad \tilde{\pi}_t^x = (\pi_{t-1}^x)^{\kappa_x} (\pi^x)^{1-\kappa_x-\varkappa_x} (\bar{\pi})^{\varkappa_x}, \quad (2.26)$$

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 section B.3.2 in the Appendix.

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) one produces goods used to produce an intermediate good for the production of investment, and (iii) 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:

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

where $C_{i,t}^m$ is the output of the i^{th} 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 i^{th} 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:

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

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

$$\tau_t^{m,c} S_t P_t^* R_t^{\nu,*}, \tag{2.27}$$

where

$$R_t^{\nu,*} = \nu_t^* R_t^* + 1 - \nu_t^*, \tag{2.28}$$

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 the same currency.³ There is no risk to this firm, because all shocks are realized at the beginning of the period, and so there is no uncertainty within the duration of the working capital loan about the realization of prices and exchanges rates.⁴

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

⁴We 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.

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:

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

where

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

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:

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

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 i^{th} 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 (2.27):

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

Note that this implies 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 . This may seem inconsistent with the property of the domestic economy that domestically produced consumption and investment goods have different relative prices. We assume that (2.27) 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:

$$S_t P_t^* R_t^{\nu,*} I_t^m (\hat{p}_t^{m,i})^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}}, \quad \hat{p}_t^{m,i} = \frac{P_{i,t}^{m,i}}{P_t^{m,i}}, \quad (2.29)$$

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:

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

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,

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

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

$$S_t P_t^* R_t^{\nu,*} X_t^m (\hat{p}_t^{m,x})^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}}, \quad \hat{p}_t^{m,x} = \frac{P_{i,t}^{m,x}}{P_t^{m,x}} \quad (2.30)$$

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

$$P_{i,t}^{m,j} = \tilde{\pi}_t^{m,j} P_{i,t-1}^{m,j}, \quad \tilde{\pi}_t^{m,j} \equiv (\pi_{t-1}^{m,j})^{\kappa_{m,j}} (\bar{\pi}_t^c)^{1-\kappa_{m,j}} \bar{\pi}_t^{\xi_{m,j}}. \quad (2.31)$$

for $j = c, i, x$.

The equilibrium conditions associated with price setting by importers are analogous to the ones derived for domestic intermediate good producers and are reported in section B.3.6 in the Appendix.

2.4. Households

Household preferences are given by:

$$E_0^j \sum_{t=0}^{\infty} \beta^t \left[\zeta_t^c \log(C_t - bC_{t-1}) - \zeta_t^h A_L \frac{(h_{j,t})^{1+\sigma_L}}{1+\sigma_L} \right]. \quad (2.32)$$

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 owns the stock of net foreign assets and determines its rate of accumulation.

2.4.1. Technology for Capital Accumulation

The law of motion of the physical stock of capital takes into account investment adjustment costs as introduced by Christiano, Eichenbaum and Evans (2005):

$$\bar{K}_{t+1} = (1 - \delta) \bar{K}_t + \Upsilon_t \left(1 - \tilde{S} \left(\frac{I_t}{I_{t-1}} \right) \right) I_t,$$

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 Justiniano, Primiceri and Tambalotti (2009). In scaled terms the law of motion of capital can be written⁵

$$\bar{k}_{t+1} = \frac{1 - \delta}{\mu_{z^+,t} \mu_{\Psi,t}} \bar{k}_t + \Upsilon_t \left(1 - \tilde{S} \left(\frac{\mu_{z^+,t} \mu_{\Psi,t} i_t}{i_{t-1}} \right) \right) i_t. \quad (2.33)$$

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

2.4.2. Household Consumption and Investment Decisions

The first order condition for consumption is:

$$\frac{\zeta_t^c}{c_t - bc_{t-1} \frac{1}{\mu_{z^+,t}}} - \beta b E_t \frac{\zeta_{t+1}^c}{c_{t+1} \mu_{z^+,t+1} - bc_t} - \psi_{z^+,t} p_t^c (1 + \tau_t^c) = 0. \quad (2.34)$$

where

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

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 :

$$R_{t+1}^k = \frac{(1 - \tau_t^k) \left[u_{t+1} \bar{r}_{t+1}^k - \frac{p_{t+1}^i}{\Psi_{t+1}} a(u_{t+1}) \right] P_{t+1} + (1 - \delta) P_{t+1} P_{k',t+1} + \tau_t^k \delta P_t P_{k',t}}{P_t P_{k',t}}, \quad (2.35)$$

where

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

is the date t price of the homogeneous investment good and $\bar{r}_t^k = \Psi_t r_t^k$ is the scaled real rental rate of capital. 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 timing of the capital tax rate reflects the assumption that the relevant tax rate is known at the time the investment decision is made. The expression in square brackets in (2.35) 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:

$$R_{t+1}^k = \frac{\pi_{t+1} (1 - \tau_t^k) \left[u_{t+1} \bar{r}_{t+1}^k - p_{t+1}^i a(u_{t+1}) \right] + (1 - \delta) p_{k',t+1} + \tau_t^k \delta \frac{\mu_{\Psi,t+1}}{\pi_{t+1}} p_{k',t}}{\mu_{\Psi,t+1} p_{k',t}}. \quad (2.36)$$

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:

$$\psi_{z^+,t} = \beta E_t \psi_{z^+,t+1} \frac{R_{t+1}^k}{\pi_{t+1} \mu_{z^+,t+1}}. \quad (2.37)$$

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:

$$\begin{aligned}
-\psi_{z^+,t} p_t^i + \psi_{z^+,t} p_{k',t} \Upsilon_t \left[1 - \tilde{S} \left(\frac{\mu_{z^+,t} \mu_{\Psi,t} i_t}{i_{t-1}} \right) - \tilde{S}' \left(\frac{\mu_{z^+,t} \mu_{\Psi,t} i_t}{i_{t-1}} \right) \frac{\mu_{z^+,t} \mu_{\Psi,t} i_t}{i_{t-1}} \right] \\
+ \beta \psi_{z^+,t+1} p_{k',t+1} \Upsilon_{t+1} \tilde{S}' \left(\frac{\mu_{z^+,t+1} \mu_{\Psi,t+1} i_{t+1}}{i_t} \right) \left(\frac{i_{t+1}}{i_t} \right)^2 \mu_{\Psi,t+1} \mu_{z^+,t+1} = 0.
\end{aligned} \tag{2.38}$$

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

$$\bar{r}_t^k = p_t^i a'(u_t). \tag{2.39}$$

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

2.4.3. Financial Assets

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

$$\psi_{z^+,t} = \beta E_t \frac{\psi_{z^+,t+1}}{\mu_{z^+,t+1}} \left[\frac{R_t - \tau_t^b (R_t - \pi_{t+1})}{\pi_{t+1}} \right], \tag{2.40}$$

where τ_t^b is the tax rate on the real interest rate on bond income (for additional discussion of τ^b , see section 2.5.) A consequence of our treatment of the taxation on 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:

$$v_t S_t = \beta E_t v_{t+1} [S_{t+1} R_t^* \Phi_t - \tau^b \left(S_{t+1} R_t^* \Phi_t - \frac{S_t}{P_t} P_{t+1} \right)]. \tag{2.41}$$

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, v_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 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 parentheses 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 principle. 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, eq. (2.41), by multiplying both sides by $P_t z_t^+ / S_t$:

$$\psi_{z^+,t} = \beta E_t \frac{\psi_{z^+,t+1}}{\pi_{t+1} \mu_{z^+,t+1}} [s_{t+1} R_t^* \Phi_t - \tau_t^b (s_{t+1} R_t^* \Phi_t - \pi_{t+1})], \quad (2.42)$$

where

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

The risk adjustment term has the following form:

$$\Phi_t = \Phi(a_t, R_t^* - R_t, \tilde{\phi}_t) = \exp\left(-\tilde{\phi}_a (a_t - \bar{a}) - \tilde{\phi}_s (R_t^* - R_t - (R^* - R)) + \tilde{\phi}_t\right), \quad (2.43)$$

where,

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

and $\tilde{\phi}_t$ is a mean zero shock whose law of motion is discussed below. In addition, $\tilde{\phi}_a$ and $\tilde{\phi}_s$ are positive parameters. In the steady state discussion in the Technical Appendix, we derive the equilibrium outcomes that a_t coincides with \bar{a} and $\Phi_t = 1$ in the non-stochastic steady state.

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 on domestic assets. 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 idea behind 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 ϕ_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 the relative risk in the foreign economy, Φ_t , rises.

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

$$\begin{aligned} \gamma &= \frac{\text{cov}(\log S_{t+1} - \log S_t, R_t - R_t^*)}{\text{var}(R_t - R_t^*)} = \overbrace{1}^{\text{in theory}} \text{ but } \overbrace{< 0}^{\text{in data}} \\ \gamma &= \frac{\text{cov}(\log S_{t+1} - \log S_t, R_t - R_t^*)}{\text{var}(R_t - R_t^*)} = \\ &= \frac{\text{cov}(R_t - R_t^* - \phi_t, R_t - R_t^*)}{\text{var}(R_t - R_t^*)} = \\ &= 1 - \frac{\text{cov}(R_t - R_t^*, \phi_t)}{\text{var}(R_t - R_t^*)} = \\ &= 1 - \tilde{\phi}_s \end{aligned}$$

according to our linearized expression (2.43) 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-shape 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 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.

2.4.4. Wage Setting

Finally, we consider wage setting. We suppose that the specialized labor supplied by households is combined by labor contractors into a homogeneous labor service as follows:

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

where h_j denotes the j^{th} household supply of labor services. Households are subject to Calvo wage setting frictions as in Erceg, Henderson and Levin (2000) (henceforth, EHL). With probability $1 - \xi_w$ the j^{th} household is able to reoptimize its wage and with probability ξ_w it sets its wage according to:

$$W_{j,t+1} = \tilde{\pi}_{w,t+1} W_{j,t} \tag{2.44}$$

$$\tilde{\pi}_{w,t+1} = (\pi_t^c)^{\kappa_w} (\bar{\pi}_{t+1}^c)^{(1-\kappa_w-\varkappa_w)} (\bar{\pi})^{\varkappa_w} (\mu_{z+})^{\vartheta_w}, \tag{2.45}$$

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 j^{th} 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:

$$E_t^j \sum_{i=0}^{\infty} (\beta \xi_w)^i \left[-\zeta_{t+i}^h A_L \frac{(h_{j,t+i})^{1+\sigma_L}}{1+\sigma_L} + v_{t+i} W_{j,t+i} h_{j,t+i} \frac{1-\tau_{t+i}^y}{1+\tau_{t+i}^w} \right], \tag{2.46}$$

where τ_t^y is a tax on labor income and τ_t^w is a payroll tax. Also, recall that v_t is the multiplier on the household's period t budget constraint. The demand for the j^{th} household's labor services, conditional on it having optimized in period t and not again since, is:

$$h_{j,t+i} = \left(\frac{\tilde{W}_t \tilde{\pi}_{w,t+i} \cdots \tilde{\pi}_{w,t+1}}{W_{t+i}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+i}. \tag{2.47}$$

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 section B.3.7 in the Appendix.

2.5. Fiscal and Monetary Authorities

For purposes of estimating our model, we must make assumptions about how policy was conducted in the historical sample. In the case of Sweden there was a break in policy in 1992. In the decade before 1992, the value of the Krona in relation to a basket of currencies was held fixed. Starting in 1995q1 the formal inflation target regime of Sveriges Riksbank was in place, and we therefore chose this as the starting period for the sample when we later estimate the model. From 1995 there are three ways to represent monetary policy. One is to imagine that the Riksbank conducted policy with commitment with the object of maximizing the following criterion:

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

This approach takes the parameters in the criterion, λ_y , $\lambda_{\Delta R}$ and λ_s as unknown parameters to be estimated. A second approach is to suppose that policy was Ramsey-optimal, that is that it was 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. A third approach is to suppose that policy was conducted according to a Taylor rule of the following form:

$$\log \left(\frac{R_t}{R} \right) = \rho_R \log \left(\frac{R_{t-1}}{R} \right) + (1 - \rho_R) \left[r_\pi \log \left(\frac{\pi_t^c}{\bar{\pi}_t^c} \right) + r_y \log \left(\frac{gdp_t}{gdp} \right) \right] + \varepsilon_{R,t}. \quad (2.48)$$

Here too, the parameters would be taken as unknowns to be estimated. gdp denotes measured GDP in the data, which might be different from y in the model. In addition, $\bar{\pi}_t^c$ 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 increase too strongly as inflation falls and the central bank initially does not respond to the fall in the inflation level. The entrepreneurial wealth therefore decrease so much that investment initially falls.

Among these alternatives we choose the Taylor rule approach, eq. (2.48).

We model government consumption expenditures as

$$G_t = g_t z_t^+,$$

where g_t is an exogenous stochastic process, orthogonal to the other shocks in the model. We suppose that

$$\log g_t = (1 - \rho_g) \log g + \rho_g \log g_{t-1} + \varepsilon_t^g.$$

where $g = \eta_g Y$.

The tax rates in our model are:

$$\tau_t^k, \tau_t^b, \tau_t^y, \tau_t^c, \tau_t^w.$$

Details regarding their calibration are in the Appendix, section B.7.1. Based on the evidence reviewed there, we let all the tax rates be constant in the model.

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:

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

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, 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 elements, 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 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 are inconsistent because in our model domestic prices are not predetermined in the period of a monetary policy shock. Second, note from the zeros in the last two columns of the first row in A and C , 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 $\log\left(\frac{\mu_{\psi,t}}{\mu_{\psi}}\right)$ and $\log\left(\frac{\mu_{z,t}}{\mu_z}\right)$ 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 section B.3.8 in the Appendix and can be expressed as:

$$y_t = (\hat{p}_t)^{\frac{\lambda_d}{\lambda_d-1}} \left[\varepsilon_t \left(\frac{1}{\mu_{\Psi,t}} \frac{1}{\mu_{z^+,t}} k_t \right)^\alpha \left(\hat{w}_t^{-\frac{\lambda_w}{1-\lambda_w}} h_t \right)^{1-\alpha} - \phi \right]. \quad (2.49)$$

where \hat{p}_t denotes the degree of price dispersion in the intermediate domestic good.

2.7.1. Resource constraint for domestic homogeneous output

Above we defined real, scaled GDP in terms of aggregate factors of production. It is convenient to also have an expression that exhibits the uses of domestic homogeneous output. Using (2.24),

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

or, after scaling by z_t^+ and using (2.10):

$$\begin{aligned} y_t = & g_t + (1-\omega_c) (p_t^c)^{\eta_c} c_t + (p_t^i)^{\eta_i} \left(i_t + a(u_t) \frac{\bar{k}_t}{\mu_{\psi,t} \mu_{z^+,t}} \right) (1-\omega_i) \\ & + \left[\omega_x (p_t^{m,x})^{1-\eta_x} + (1-\omega_x) \right]^{\frac{\eta_x}{1-\eta_x}} (1-\omega_x) (\hat{p}_t^x)^{\frac{-\lambda_x}{\lambda_x-1}} (p_t^x)^{-\eta_f} y_t^*. \end{aligned} \quad (2.50)$$

When we match GDP to the data we first subtract capital utilization costs from y_t . See section B.8 for details.

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

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:

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

where Φ_t is defined in section 2.4.3. Expenses on imports correspond to the purchases of specialized importers for the consumption, investment and export sectors:

$$\text{expenses on imports}_t = S_t P_t^* R_t^{\nu,*} \left(C_t^m (\hat{p}_t^{m,c})^{\frac{\lambda_{m,c}}{1-\lambda_{m,c}}} + I_t^m (\hat{p}_t^{m,i})^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}} + X_t^m (\hat{p}_t^{m,x})^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}} \right),$$

using (B.22), (2.29) and (2.30). 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, as using (2.22):

$$\begin{aligned} a_t + q_t p_t^c R_t^{\nu,*} \left(c_t^m (\hat{p}_t^{m,c})^{\frac{\lambda_{m,c}}{1-\lambda_{m,c}}} + i_t^m (\hat{p}_t^{m,i})^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}} + x_t^m (\hat{p}_t^{m,x})^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}} \right) \\ = q_t p_t^c p_t^x x_t + R_{t-1}^* \Phi_{t-1} S_t \frac{a_{t-1}}{\pi_t \mu_{z^+,t}}, \end{aligned} \quad (2.51)$$

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

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 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 Bernanke, Gertler and Gilchrist (1999) (henceforth BGG) model implemented in Christiano, Motto and Rostagno (2003). The discussion here borrows heavily from Christiano, Motto and Rostagno (2008).

Recall from the introduction that households deposit money with 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 Figure A. 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 model, it is typically the practice to compare the net worth of entrepreneurs with a stock market quantity (index), and we follow this route. Whether this is really appropriate is uncertain. A case can be made that the 'bank loans' of entrepreneurs in the model correspond well with actual bank loans *plus* actual equity. It is well known that dividend payments on equity are very smooth. Firms work hard to accomplish this. For example, during the US Great Depression some firms were willing to sell their own physical capital in order to avoid cutting dividends. That this is so is perhaps not surprising. The asymmetric information problems with actual equity are surely as severe as they are for the banks in our model. Under these circumstances one might expect equity holders to demand a payment that is not contingent on the realization of uncertainty within the firm (payments could be contingent upon publicly observed variables). Under this vision, 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 most direct control over the firm. The 'bank loans' in this model would, under this view of things, correspond to the actual loans of firms (i.e., bank loans and other loans such as commercial paper) plus the

outstanding equity. While this is perhaps too extreme, these observations highlight that there is substantial uncertainty over exactly what variable should be compared with net worth in the model. It is important to emphasize, however, that whatever the right interpretation is of net worth, the model potentially captures balance sheet problems very nicely.

3.1. Modifying the Baseline Model

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 as well as their net worth. The financial frictions also allow us to introduce two new shocks. We now provide a formal discussion 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. 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.

3.1.1. 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, \bar{K}_{t+1} , from capital producers. The loan the entrepreneur requires for this is:

$$B_{t+1} = P_t P_{k',t} \bar{K}_{t+1} - N_{t+1}. \quad (3.1)$$

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, \bar{K}_{t+1} , into $\bar{K}_{t+1}\omega$. 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. We denote the cumulative distribution function of ω by $F(\omega; \sigma)$. and its partial derivatives as e.g. $F_\omega(\omega; \sigma)$, $F_\sigma(\omega; \sigma)$

After observing the period $t + 1$ shocks, the entrepreneur sets the utilization rate, u_{t+1} , of capital and rents capital out in competitive markets at 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.4). The entrepreneur then sells the undepreciated part of physical capital to capital producers. Per unit of physical capital purchased, the entrepreneur who draws idiosyncratic shock ω earns a return (after taxes), of $R_{t+1}^k\omega$, where R_{t+1}^k is defined in (2.35) and is displayed below for convenience:

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

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 \bar{K}_{t+1} units of physical capital in period t and who experiences an idiosyncratic productivity shock ω are $P_t P_{k',t} R_{t+1}^k \omega \bar{K}_{t+1}$. There is a cutoff value of ω , $\bar{\omega}_{t+1}$, such that the entrepreneur has just enough resources to pay interest:

$$\bar{\omega}_{t+1} R_{t+1}^k P_t P_{k',t} \bar{K}_{t+1} = Z_{t+1} B_{t+1}. \quad (3.2)$$

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

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

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

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

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 (2.40).

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.⁶ It follows that the bank's cash flow in each state of period $t + 1$ is zero, for

⁶If banks also had access to state contingent securities, then free entry and competition would imply that banks earn zero profits in an ex ante expected sense from the point of view of period t .

each loan amount.⁷ For loans in the amount, B_{t+1} , the bank receives gross interest, $Z_{t+1}B_{t+1}$, from the $1 - F(\bar{\omega}_{t+1}; \sigma_t)$ 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:

$$[1 - F(\bar{\omega}_{t+1}; \sigma_t)] Z_{t+1}B_{t+1} + (1 - \mu) \int_0^{\bar{\omega}_{t+1}} \omega dF(\omega; \sigma_t) R_{t+1}^k P_t P_{k',t} \bar{K}_{t+1} = R_t B_{t+1},$$

or, after making use of (3.2) and rearranging,

$$[\Gamma(\bar{\omega}_{t+1}; \sigma_t) - \mu G(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} \varrho_t = \varrho_t - 1 \quad (3.3)$$

where

$$\begin{aligned} G(\bar{\omega}_{t+1}; \sigma_t) &= \int_0^{\bar{\omega}_{t+1}} \omega dF(\omega; \sigma_t). \\ \Gamma(\bar{\omega}_{t+1}; \sigma_t) &= \bar{\omega}_{t+1} [1 - F(\bar{\omega}_{t+1}; \sigma_t)] + G(\bar{\omega}_{t+1}; \sigma_t) \\ \varrho_t &= \frac{P_t P_{k',t} \bar{K}_{t+1}}{N_{t+1}}. \end{aligned}$$

The expression, $\Gamma(\bar{\omega}_{t+1}; \sigma_t) - \mu G(\bar{\omega}_{t+1}; \sigma_t)$ is the share of revenues earned by entrepreneurs that borrow B_{t+1} , which goes to banks. Note that $\Gamma_{\bar{\omega}}(\bar{\omega}_{t+1}; \sigma_t) = 1 - F(\bar{\omega}_{t+1}; \sigma_t) > 0$ and $G_{\bar{\omega}}(\bar{\omega}_{t+1}; \sigma_t) = \bar{\omega}_{t+1} F_{\bar{\omega}}(\bar{\omega}_{t+1}; \sigma_t) > 0$. It is thus not surprising that the share of entrepreneurial revenues accruing to banks is non-monotone with respect to $\bar{\omega}_{t+1}$. BGG argue that the expression on the left of (3.3) has an inverted ‘U’ shape, achieving a maximum value at $\bar{\omega}_{t+1} = \omega^*$, say. The expression is increasing for $\bar{\omega}_{t+1} < \omega^*$ and decreasing for $\bar{\omega}_{t+1} > \omega^*$. Thus, for any given value of the leverage ratio, ϱ_t , and R_{t+1}^k/R_t , generically there are either no values of $\bar{\omega}_{t+1}$ or two that satisfy (3.3). The value of $\bar{\omega}_{t+1}$ realized in equilibrium must be the one on the left side of the inverted ‘U’ shape. This is because, according to (3.2), the lower value of $\bar{\omega}_{t+1}$ 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 $\bar{\omega}_{t+1}$ falls with a period $t+1$ shock that drives R_{t+1}^k up. The fraction of entrepreneurs that experience bankruptcy is $F(\bar{\omega}_{t+1}; \sigma_t)$, so it follows that a shock which drives up R_{t+1}^k has a negative contemporaneous impact on the bankruptcy rate. According to (2.35), shocks that drive R_{t+1}^k up include anything which raises the value of physical capital and/or the rental rate of capital.

As just noted, we suppose that the equilibrium debt contract maximizes entrepreneurial welfare, subject to the zero profit condition on banks and the specified required return on household bank liabilities. The date t debt contract specifies a level of debt, B_{t+1} and a state $t+1$ -contingent

⁷Absence of state contingent securities markets guarantee 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 quoted in the text.

rate of interest, Z_{t+1} . We suppose that entrepreneurial welfare corresponds to the entrepreneur's expected wealth at the end of the contract. It is convenient to express welfare as a ratio to the amount the entrepreneur could receive by depositing his net worth in a bank:

$$\begin{aligned} & \frac{E_t \int_{\bar{\omega}_{t+1}}^{\infty} [R_{t+1}^k \omega P_t P_{k',t} \bar{K}_{t+1} - Z_{t+1} B_{t+1}] dF(\omega; \sigma_t)}{R_t N_{t+1}} \\ &= \frac{E_t \int_{\bar{\omega}_{t+1}}^{\infty} [\omega - \bar{\omega}_{t+1}] dF(\omega; \sigma_t) R_{t+1}^k P_t P_{k',t} \bar{K}_{t+1}}{R_t N_{t+1}} \\ &= E_t \left\{ [1 - \Gamma(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} \right\} \varrho_t, \end{aligned}$$

after making use of (3.1), (3.2) and

$$1 = \int_0^{\infty} \omega dF(\omega; \sigma_t) = \int_{\bar{\omega}_{t+1}}^{\infty} \omega dF(\omega; \sigma_t) + G(\bar{\omega}_{t+1}; \sigma_t).$$

We can equivalently characterize the contract by a state- $t+1$ contingent set of values for $\bar{\omega}_{t+1}$ and a value of ϱ_t . The equilibrium contract is the one involving $\bar{\omega}_{t+1}$ and ϱ_t which maximizes entrepreneurial welfare (relative to $R_t N_{t+1}$), subject to the bank zero profits condition. The Lagrangian representation of this problem is:

$$\max_{\varrho_t, \{\bar{\omega}_{t+1}\}} E_t \left\{ [1 - \Gamma(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} \varrho_t + \lambda_{t+1} \left([\Gamma(\bar{\omega}_{t+1}; \sigma_t) - \mu G(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} \varrho_t - \varrho_t + 1 \right) \right\},$$

where λ_{t+1} is the Lagrange multiplier which is defined for each period $t+1$ state of nature. The first order conditions for this problem are:

$$\begin{aligned} E_t \left\{ [1 - \Gamma(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} + \lambda_{t+1} \left([\Gamma(\bar{\omega}_{t+1}; \sigma_t) - \mu G(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} - 1 \right) \right\} &= 0 \\ -\Gamma_{\bar{\omega}}(\bar{\omega}_{t+1}; \sigma_t) \frac{R_{t+1}^k}{R_t} + \lambda_{t+1} [\Gamma_{\bar{\omega}}(\bar{\omega}_{t+1}; \sigma_t) - \mu G_{\bar{\omega}}(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} &= 0 \\ [\Gamma(\bar{\omega}_{t+1}; \sigma_t) - \mu G(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} \varrho_t - \varrho_t + 1 &= 0, \end{aligned}$$

where the absence of λ_{t+1} from the complementary slackness condition reflects that we assume $\lambda_{t+1} > 0$ in each period $t+1$ state of nature. Substituting out for λ_{t+1} from the second equation into the first, the first order conditions reduce to:

$$E_t \left\{ [1 - \Gamma(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} + \frac{\Gamma_{\bar{\omega}}(\bar{\omega}_{t+1}; \sigma_t)}{\Gamma_{\bar{\omega}}(\bar{\omega}_{t+1}; \sigma_t) - \mu G_{\bar{\omega}}(\bar{\omega}_{t+1}; \sigma_t)} \left([\Gamma(\bar{\omega}_{t+1}; \sigma_t) - \mu G(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} - 1 \right) \right\} = 0, \quad (3.4)$$

$$[\Gamma(\bar{\omega}_{t+1}; \sigma_t) - \mu G(\bar{\omega}_{t+1}; \sigma_t)] \frac{R_{t+1}^k}{R_t} \varrho_t - \varrho_t + 1 = 0, \quad (3.5)$$

for $t = 0, 1, 2, \dots, \infty$ and for $t = -1, 0, 1, 2, \dots$ respectively.

Since N_{t+1} does not appear in the last two equations, we conclude that ϱ_t and $\bar{\omega}_{t+1}$ are the same for all entrepreneurs, regardless of their net worth. The results for 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 (3.1) and (3.2) we see that the rate of interest paid by the entrepreneur is

$$Z_{t+1} = \frac{\bar{\omega}_{t+1} R_{t+1}^k}{1 - \frac{N_{t+1}}{P_t P_{k',t} \bar{K}_{t+1}}} = \frac{\bar{\omega}_{t+1} R_{t+1}^k}{1 - \frac{1}{\varrho_t}}, \quad (3.6)$$

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

3.1.2. Aggregation Across Entrepreneurs and the External Financing Premium

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

$$V_t = R_t^k P_{t-1} P_{k',t-1} K_t - \Gamma(\bar{\omega}_t; \sigma_{t-1}) R_t^k P_{t-1} P_{k',t-1} K_t$$

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 $\gamma_t \bar{V}_t$. A fraction, $1 - \gamma_t$, of new entrepreneurs arrive. Entrepreneurs who survive or who are new arrivals receive a transfer, W_t^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_t^e transfers have been made and exits and entry have occurred, is $\bar{N}_{t+1} = \gamma_t \bar{V}_t + W_t^e$, or,

$$\begin{aligned} \bar{N}_{t+1} &= \gamma_t \left\{ R_t^k P_{t-1} P_{k',t-1} \bar{K}_t - \left[R_{t-1} + \frac{\mu \int_0^{\bar{\omega}_t} \omega dF(\omega; \sigma_{t-1}) R_t^k P_{t-1} P_{k',t-1} \bar{K}_t}{P_{t-1} P_{k',t-1} \bar{K}_t - \bar{N}_t} \right] \right. \\ &\quad \left. * (P_{t-1} P_{k',t-1} \bar{K}_t - \bar{N}_t) \right\} + W_t^e. \end{aligned} \quad (3.7)$$

where upper bar over a letter denotes its aggregate average value. For a derivation of the aggregation across entrepreneurs, see Appendix B.4.1.

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 equation (3.7). 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 the excess of the interest rate paid by entrepreneurs who are not bankrupt, over R_t , the interest rate spread:

$$Z_{t+1} - R_t = \frac{\bar{\omega}_{t+1} R_{t+1}^k}{1 - \frac{N_{t+1}}{P_{k',t} \bar{K}_{t+1}}} - R_t,$$

according to (3.6).

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,b,c) and Shimer (2005a,b). We integrate the framework into our environment - which includes capital and monetary factors - following the version of GST implemented in CIMR. The main modelling difference compared to GST and CIMR is that we allow for endogenous separation of employees from their jobs, as in e.g. den Haan, Ramey and Watson (2000). Our main motivation for doing this is the *prima facie* cyclical nature of separation rates, confirmed by empirical evidence for the U.S. by Fujita and Ramey (2007). In what follows, we first provide an overview and after that we present the detailed decision problems of agents in the labor market.

Our 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 1995q1-2009q2. The decomposition is

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

where H_t denotes total hours worked, ζ_t hours per worker and L_t number of people employed. H_t and L_t are in per capita terms (of the adult population) and all series are logged and HP-filtered with $\lambda = 1600$. This decomposition indicates that roughly 4/5th of the variation in total hours worked comes from variation in employment and 1/5th from variation in hours per worker.⁸ Accordingly, a model that allows for variation in both margins is needed. Even more strongly these numbers indicate that models that only allow for variation of the intensive margin lack micro foundation. Galí (2009) 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.

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.

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

In the baseline model, the homogeneous labor services are supplied to the competitive labor market by labor retailers (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 to the homogeneous labor market by ‘employment agencies’. See Figure B 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

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 are displayed in Figure C. 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 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 (2.44) and (2.45). 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. We assume this Taylor type wage friction, as opposed to Calvo frictions as in GST, for two reasons: Realism and the ability to check that the wage always is in the bargaining set in later periods of the wage contract. The assumption that newly hired workers get the ‘going wage’ are supported by the survey evidence in Galuščák, Keeney, Nicolitsas, Smets, Strzelecki and Vodopivec (2010). The bargaining arrangement is atomistic, so that each worker bargains separately with a representative of the employment agency.

Next, each worker draws an idiosyncratic productivity shock. A cutoff level of productivity is determined, and workers with lower productivity are laid off. 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. Finally, the intensity of each worker’s labor

⁹An 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.

effort is determined by an efficiency criterion.

After the endogenous layoff decision, the employment agency posts vacancies and the intensity of work effort is chosen efficiently, i.e. by equating the value of labor services to the employment agency with the 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 actual equilibrium conditions are displayed in the Appendix.

4.2. Labor Hours

Labor intensity 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 (2.32):

$$E_t \sum_{l=0}^{\infty} \beta^{l-t} \{ \zeta_{t+l}^c \log(C_{t+l} - bC_{t+l-1}) - \zeta_{t+l}^h A_L \left[\sum_{i=0}^{N-1} \frac{(\zeta_{i,t+l})^{1+\sigma_L}}{1+\sigma_L} [1 - \mathcal{F}(\bar{a}_{t+l}^i)] l_{t+l}^i \right] \}, \quad (4.1)$$

Here, $i \in \{0, \dots, N-1\}$ 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, \bar{a}_t^i denotes the endogenously-determined cutoff such that all workers with $a_t^i < \bar{a}_t^i$ are laid off from the firm. Also, let

$$\mathcal{F}(\bar{a}_t^i) = P[a_t^i < \bar{a}_t^i]$$

denote the cumulative distribution function of the idiosyncratic productivity shock. (In practice, we assume that \mathcal{F} is lognormal with $Ea = 1$ and standard deviation of $\log(a)$ equal to σ_a .) Then,

$$[1 - \mathcal{F}(\bar{a}_t^i)] l_t^i \quad (4.2)$$

denotes the number of workers with an employment agency in the i^{th} cohort who survive the endogenous layoffs.

Let $\varsigma_{i,t}$ denote the number of hours supplied by a worker in the i^{th} 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. 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 utility function in (4.1) 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 that the total fraction of workers employed,

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

as well as the fractions allocated among the different cohorts, $[1 - \mathcal{F}(\bar{a}_t^i)] l_t^i$, $i = 0, \dots, N-1$, 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).

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

$$(1 - \tau_t^y)(1 - L_t) P_t b^u z_t^+ + \sum_{i=0}^{N-1} W_t^i [1 - \mathcal{F}(\bar{a}_t^i)] l_t^i \varsigma_{i,t} \frac{1 - \tau_t^y}{1 + \tau_t^w} \quad (4.3)$$

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_t^y and a payroll tax τ_t^w that affect the after-tax wage.

Let W_t denote the price received by employment agencies for supplying one unit of labor service. It represents the marginal gain to the employment agency that occurs when an individual worker increases time spent working by one unit. Because the employment agency is competitive in the supply of labor services, it takes W_t as given. We treat W_t as an unobserved variable in the data. In practice, it is the shadow value of an extra worker supplied by the human resources department to a firm.

Following GST, we assume that labor hours are chosen to equate the worker's marginal cost of working with the agency's marginal benefit:

$$W_t \mathcal{G}_t^i = \zeta_t^h A_L \varsigma_{i,t}^{\sigma_L} \frac{1}{v_t \frac{1 - \tau_t^y}{1 + \tau_t^w}} \quad (4.4)$$

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

$$\mathcal{G}_t^i = \frac{\mathcal{E}_t^i}{1 - \mathcal{F}_t^i}, \quad (4.5)$$

where

$$\mathcal{E}_t^i \equiv \mathcal{E}(\bar{a}_t^i; \sigma_{a,t}) \equiv \int_{\bar{a}_t^i}^{\infty} a d\mathcal{F}(a; \sigma_{a,t}) \quad (4.6)$$

$$\mathcal{F}_t^i = \mathcal{F}(\bar{a}_t^i; \sigma_{a,t}) = \int_0^{\bar{a}_t^i} d\mathcal{F}(a; \sigma_{a,t}). \quad (4.7)$$

To understand the expression on the right of (4.4), note that the marginal cost, in utility terms, to an individual worker who increases labor intensity by one unit is $\zeta_t^h A_L \zeta_{i,t}^{\sigma_L}$. This is converted to currency units by dividing by the multiplier, v_t , on the household's nominal budget constraint, and by the tax wedge $(1 - \tau_t^y) / (1 + \tau_t^w)$. The left side of (4.4) represents the increase in revenues to the employment agency from increasing hours worked by one unit (recall, all workers who survive endogenous layoffs work the same number of hours.) Division by $1 - \mathcal{F}_t^i$ is required in (4.5) so that the expectation is relative to the distribution of a conditional on $a \geq \bar{a}_t^j$.

Labor intensity is potentially different across cohorts because \mathcal{G}_t^i in (4.4) 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 (4.4) and that some workers will endogenously separate. Finally, note that labor intensity as determined by (4.4) 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 i^{th} 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:

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

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 (2004) indicate that these costs are convex. Second, linear costs would imply indeterminacy in our setting as dynamic wage dispersion imply that the costs of employees are heterogenous across agencies, while the benefit of employees are the same across agencies and equal to aggregate marginal product of labor. $\kappa z_t^+ / \varphi$ is a cost parameter which is assumed to grow at the same rate as the overall economic growth rate and, as noted above, $[1 - \mathcal{F}(\bar{a}_t^i)] l_t^i$ denotes the number of employees in the i^{th} 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 . We expect the expansion to 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., $\iota = 1$).

To further describe the vacancy decisions of the employment agencies, we require their objective function. We begin by considering $F(l_t^0, \omega_t)$, 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, ω_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 :

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

where $1 - \mathcal{F}_t^j$ denotes the fraction of the beginning-of-period t workforce in cohort j which survives endogenous separations. The agency's hiring rate, χ_t^i , is related to \tilde{v}_t^i by:

$$\chi_t^i = Q_t^{1-i} \tilde{v}_t^i. \quad (4.8)$$

To construct $F(l_t^0, \omega_t)$, we must derive the law of motion of the firm's work force, during the period of the wage contract. If l_t^i is the period t work force just after exogenous separations and new arrivals, then (4.2) is the size of the workforce after endogenous separations. The time $t + 1$ workforce of the representative agency in the i^{th} 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

$$l_{t+1}^{j+1} = (\chi_t^j + \rho) (1 - \mathcal{F}_t^j) l_t^j, \quad (4.9)$$

for $j = 0, 1, \dots, N-1$, with the understanding here and throughout that $j = N$ is to be interpreted as $j = 0$. Expression (4.9) 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:

$$\begin{aligned} F(l_t^0, \omega_t) &= \sum_{j=0}^{N-1} \beta^j E_t \frac{v_{t+j}}{v_t} \max_{(\tilde{v}_{t+j}^j, \tilde{a}_{t+j}^j)} \left[\int_{\tilde{a}_{t+j}^j}^{\infty} (W_{t+j} a - \Gamma_{t,j} \omega_t) \varsigma_{j,t+j} d\mathcal{F}(a) \right. \\ &\quad \left. - P_{t+j} \frac{\kappa z_{t+j}^+}{\varphi} (\tilde{v}_{t+j}^j)^\varphi (1 - \mathcal{F}_{t+j}^j) \right] l_{t+j}^j \\ &\quad + \beta^N E_t \frac{v_{t+N}}{v_t} F(l_{t+N}^0, \tilde{W}_{t+N}), \end{aligned} \quad (4.10)$$

where l_t^j evolves according to (4.9), $\varsigma_{j,t}$ satisfies (4.4) and

$$\Gamma_{t,j} = \begin{cases} \tilde{\pi}_{w,t+j} \cdots \tilde{\pi}_{w,t+1}, & j > 0 \\ 1, & j = 0 \end{cases}. \quad (4.11)$$

Here, $\tilde{\pi}_{w,t}$ is defined in (2.45). The term, $\Gamma_{t,j}\omega_t$, represents the wage rate in period $t+j$, given the wage rate was ω_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 (4.10), \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 solve the maximization problem in (4.10).

It is easily verified using (4.10) that $F(l_t^0, \omega_t)$ is linear in l_t^0 :

$$F(l_t^0, \omega_t) = J(\omega_t)l_t^0, \quad (4.12)$$

where $J(\omega_t)$ is not a function of l_t^0 . The function, $J(\omega_t)$, is the surplus that a firm bargaining in the current period enjoys from a match with an individual worker, when the current wage is ω_t . Although later in the period workers become heterogeneous when they draw an idiosyncratic shock to productivity, the fact that that draw is i.i.d. over time means that workers are all identical at the time that (4.12) 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 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:

$$\begin{aligned} V_t^i = & \Gamma_{t-i,i}\tilde{W}_{t-i}\zeta_{i,t} \frac{1 - \tau_t^y}{1 + \tau_t^w} - A_L \frac{\zeta_t^h \zeta_{i,t}^{1+\sigma_L}}{(1 + \sigma_L) v_t} \\ & + \beta E_t \frac{v_{t+1}}{v_t} [\rho (1 - \mathcal{F}_{t+1}^{i+1}) V_{t+1}^{i+1} + (1 - \rho + \rho \mathcal{F}_{t+1}^{i+1}) U_{t+1}], \end{aligned} \quad (4.13)$$

for $i = 0, 1, \dots, N-1$. In (4.13), \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 (4.13) represent a worker's period t flow utility, converted into units of currency.¹⁰ The terms in square brackets in (4.13) 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} .

¹⁰Note the division of the disutility of work in (4.13) by v_t , the multiplier on the budget constraint of the household optimization problem.

The currency value of being unemployed in period t is:

$$U_t = P_t z_t^+ b^u (1 - \tau_t^y) + \beta E_t \frac{v_{t+1}}{v_t} [f_t V_{t+1}^x + (1 - f_t) U_{t+1}], \quad (4.14)$$

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,

$$V_{t+1}^x = \sum_{i=0}^{N-1} \frac{\chi_t^i (1 - \mathcal{F}_t^i) l_t^i}{m_t} \tilde{V}_{t+1}^{i+1}. \quad (4.15)$$

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

$$m_t = \sum_{j=0}^{N-1} \chi_t^j (1 - \mathcal{F}_t^j) l_t^j. \quad (4.16)$$

In (4.15),

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

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 (4.16).

In (4.15), \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 (4.15) 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 (4.14) by giving the formal definition of \tilde{V}_t^j :

$$\tilde{V}_t^j = \mathcal{F}_t^j U_t + (1 - \mathcal{F}_t^j) V_t^j. \quad (4.17)$$

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 section 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.

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, \bar{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 \bar{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:

$$(V_t^0 - U_t) (1 - \mathcal{F}_t^0) l_t^0. \quad (4.18)$$

To see this, note that each worker among the fraction, $1 - \mathcal{F}_t^0$, workers with $a \geq \bar{a}_t^0$ 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 \bar{a}_t^0 as indicated in (4.7).

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 (4.10). According to (4.12) agency surplus per worker in l_t^0 is given by $J(\omega_t)$ and this is readily confirmed to have the following structure:

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

where

$$\tilde{J}(\omega_t; \bar{a}_t^0) = \max_{\tilde{v}_t^0} \left\{ (W_t \mathcal{G}_t^0 - \omega_t) s_{0,t} - P_t z_t^+ \frac{\kappa}{\varphi} (\tilde{v}_t^0)^\varphi + \beta \frac{v_{t+1}}{v_t} (\chi_t^0 + \rho) J_{t+1}^1(\omega_t) \right\}. \quad (4.19)$$

Here, it is understood that χ_t^0 , \tilde{v}_t^0 are connected by (4.8). Thus, the surplus of the representative agency with workforce, l_t^0 , expressed as a function of an arbitrary value of \bar{a}_t^0 is:

$$\tilde{J}(\omega_t; \bar{a}_t^0) (1 - \mathcal{F}_t^0) l_t^0. \quad (4.20)$$

This expression displays the two ways that \bar{a}_t^0 impacts on firm profits: \bar{a}_t^0 affects the number of workers, $1 - \mathcal{F}_t^0$, employed in period t , as well as their average productivity, \tilde{J} . The impact of \bar{a}_t^0 on the number of workers can be deduced from (4.7). Although at first glance it may appear that the cutoff affects \tilde{J} in several ways, in fact it only affects \tilde{J} through two channels. For example, by the envelope theorem we can ignore the impact of \bar{a}_t^0 on \tilde{J} via its impact on the choice of \tilde{v}_t^0 and χ_t^0 . In addition, the function J_{t+1}^1 is invariant to the choice of \bar{a}_t^0 . As a result, in differentiating $\tilde{J}(\omega_t; \bar{a}_t^0)$ with respect to \bar{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 \bar{a}_t^0 on the agency's future cutoff decisions, \bar{a}_{t+i}^i , $i > 0$.

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

$$\left[s_w (V_t^0 - U_t) + s_e \tilde{J}(\omega_t; \bar{a}_t^0) \right] (1 - \mathcal{F}_t^0) l_t^0. \quad (4.21)$$

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 \bar{a}_t^0 is chosen to optimize (4.21) with $s_w = 0, s_e = 1$ and the total surplus model is the one that optimizes (4.21) with $s_w = s_e = 1$. The first order necessary condition for an interior optimum is:

$$s_w V_t^{0'} + s_e \tilde{J}_{\bar{a}^0}(\omega_t; \bar{a}_t^0) = \left[s_w (V_t^0 - U_t) + s_e \tilde{J}(\omega_t; \bar{a}_t^0) \right] \frac{\mathcal{F}_t^{0'}}{1 - \mathcal{F}_t^0}. \quad (4.22)$$

According to (4.22), \bar{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 \bar{a}_t^0 . The expression on the right side of (4.22) captures the extensive margin, the loss of surplus associated with the $\mathcal{F}_t^{0'}/(1 - \mathcal{F}_t^0)$ workers who do not survive the cut. The equations that characterize the choice of $\bar{a}_t^j, j = 1, \dots, N - 1$ are essentially the same as (4.22) and so the discussion of these appears in the Appendix.

The expression, (4.22), assumes an arbitrary wage outcome, ω_t . In the next subsection we discuss the bargaining problem that determines a value for ω_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

$$\max_{\omega_t} \left(\tilde{V}_t^0 - U_t \right)^\eta J(\omega_t)^{(1-\eta)}.$$

Here, the firm surplus, $J(\omega_t)$, 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 . The above problem has an

interesting structure. Note first (ignoring the impact of ω_t on the vacancy decision):

$$\begin{aligned}
J_{w,t} = & - (1 - \mathcal{F}_t^0) \varsigma_{0,t} \\
& + \beta \frac{v_{t+1}}{v_t} [-\Gamma_{t,1} \varsigma_{1,t+1} \rho (1 - \mathcal{F}_{t+1}^1) (1 - \mathcal{F}_t^0)] \\
& + \beta^2 \frac{v_{t+2}}{v_t} [-\Gamma_{t,2} \varsigma_{2,t+2}] \rho^2 (1 - \mathcal{F}_{t+2}^2) (1 - \mathcal{F}_{t+1}^1) (1 - \mathcal{F}_t^0) \\
& + \dots + \\
& + \beta^{N-1} \frac{v_{t+N-1}}{v_t} [-\Gamma_{t,N-1} \varsigma_{N-1,t+N-1}] \rho^{N-1} (1 - \mathcal{F}_{t+N-1}^{N-1}) \cdots (1 - \mathcal{F}_t^0),
\end{aligned}$$

where $J_{w,t}$ denotes the derivative of the surplus with respect to the wage rate. A rise in the wage reduces J_t only in future states of the world in which the worker survives both exogenous and endogenous separation. If we abstract from taxes it is easy to verify that $J_{w,t} = -\tilde{V}_{w,t}$. That is, a contemplated increase in the wage simply reallocates resources between the firm and the worker.

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, $[\underline{w}_t^i, \bar{w}_t^i]$, $i = 0, 1, \dots, N-1$. 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. that 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 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 , $\sigma_{m,t}$ and $\sigma_{a,t}$ into the model.

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 using employer surplus, i.e. $s_w = 0$ and $s_e = 1$.¹¹

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. Prior this paper, 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, Motto and Rostagno (2008) for the Euro area and the US. Other examples of Bayesian estimated models based on BGG for Euro and/or US data are Christensen and Dib (2008), De Graeve (2008) and Queijo (2009), although none of these three papers match any financial data.

¹¹For a comparison of the dynamics of the model across the various separation criteria, see Christiano, Trabandt and Walentin (2010).

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, Justiniano and Tchakarov (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 Table 1 and Table 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 of rate equal to the (rounded) sample average of 2.25 percent annually. We calibrate the capital share α to 0.375 which yields a capital-output ratio slightly below 2 on an annual basis at the prior mode. The capital share is set higher than in most of the literature to compensate for the effect of a positive external finance premium.

Sample averages are used when available, e.g. for the various import shares $\omega_i, \omega_c, \omega_x$ (obtained from input-output tables), the remaining tax rates, the government consumption share of GDP, η_g , growth rates of technology and several other parameters.¹² To calibrate the steady state value of the inflation target we simply use the inflation target 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 the steady state real growth. The indexation parameters $\varkappa^j, j = d, x, mc, mi, mx, w$ are set so that there is no indexation to the (potentially time-varying) inflation target, but instead to $\tilde{\pi}$ which is set equal to the steady state inflation. This implies that we do not allow for partial indexation in this estimation, which would result in steady state price and wage dispersion.

For the financial block of the model we set $F(\bar{w})$ 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 $n/(p_k k)$ and is set to yield $\gamma = 0.97$ at the prior mean.

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 recruitment costs, ρ and the prior mean of \mathcal{F} is set jointly so that it takes an unemployed person on average 3 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) present evidence of unemployment duration for all unemployment spells being slightly higher, around 4 quarters. The matching function

¹²We 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 $\mu_\psi = 1.0005$. This is so close to unity that we favor simplicity and set $\mu_\psi = 1$.

parameter σ is set so that number of unemployed and vacancies have equal factor shares in the production of matches. 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, Eriksson and Gottfries (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, $n/(p_k k)$, ratio¹³, the steady state real exchange rate $\tilde{\varphi}$ to match the export share $P^x X/(PY)$ in the data and finally we set the disutility of labor scaling parameter 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 presented in Table 1.

	Parameter description	Posterior mean	Moment	Moment value
δ	Depreciation rate of capital	0.032	$p_i i/y$	0.17
γ	Entrepreneurial survival rate	0.946	$n/(p_k k)$	0.5
$\tilde{\varphi}$	Real exchange rate	0.271	$P^x X/(PY)$	0.45
A_L	Scaling of disutility of work	21600	$L\zeta$	0.25

Table 1. Matched moments and corresponding parameters.

¹³We used micro data to calculate the average equity/total assets during the sample period both for all Swedish firms and for only the stock market listed firms. In the first case book values were used, and in the second case market value of equity was used. Both ratios are close to 0.5.

Parameter	Value	Description
α	0.375	Capital share in production
β	0.9986	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
η_g	0.3	Government consumption share on 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	1.0042	Steady state growth rate of neutral technology
μ_ψ	1.00	Steady state growth rate of investment technology
$\bar{\pi}$	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 $j = d; x; m, c; m, i; m, x; w$
$\bar{\pi}$	1.005	Third indexing base
$F(\bar{\omega})$	0.01	Steady state bankruptcy rate
W_e/y	0.001	Transfers to entrepreneurs
L	1-0.08	Steady state fraction of employment
N	4	Number of agency cohorts/length of wage contracts
φ	2	Curvature of recruitment costs
ρ	0.9735	Exogenous survival rate of a match
σ	0.5	Unemployment share in matching technology
σ_m	0.5475	Level parameter in matching function
ι	1	Employment adj. costs dependence on tightness, V/U

Table 2. Calibrated parameters.

5.2. Choice of Priors

We select our model priors endogenously, using a strategy similar to the one suggested by Del Negro and Schorfheide (2008). We use a sequential-learning interpretation of the data. 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 of the model implied variables.

5.2.1. Independent Priors

We estimate 28 structural parameters, 16 VAR parameters for the foreign economy, 8 AR1 coefficients and 17 shock standard deviations. The priors are displayed in tables A1 and A2. The general approach has been to choose non-informative priors, with the exceptions to this rule detailed below.

For the exogenous technology processes where we use tight priors with a standard deviation of 0.075 on the persistence parameters and a mean of 0.85. For the Calvo price stickiness parameters we use a mean of 0.75 corresponding to annual price setting based on micro evidence in Apel, Friberg and Hallsten (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 for export production, 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. We truncate the prior for r_y at 0. Regarding the parameters for indexation to past inflation we are agnostic and use a non-informative beta prior centered at 0.5. We follow SW in setting a prior for σ_a around 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 (1995). We truncate the prior and exclude elasticities below 1 for computational reasons. We set the prior mean of the UIP risk adjustment parameter $\tilde{\phi}_s$ equal to 1.25 to get 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 2.4.3.

The persistence of the entrepreneurial wealth shock γ_t have the same prior as the technology processes. The prior mean for the monitoring cost μ is set to yield a 1.6% annual external finance premium, as this is the sample average. 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.

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

men and similar values have been found by later studies. For the fraction of GDP spent on hiring costs 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 Gali (2010). We set the mean for the replacement rate for unemployed workers, $bshare$, slightly above the average statutory replacement ratio after tax which was 0.71 for our sample period. The reason to put the prior above the statutory rate is that the latter ignores the utility value of leisure and 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 1995Q1-2009Q2. All real quantities are in per capita terms. We use the same 15 macro variables as ALLV and 4 additional data series: government consumption, a broad stock price index (the ‘OMX Stockholm PI’ index), a corporate interest spread and the unemployment rate. The stock prices are included as a measure of real net worth, and are therefore scaled by the domestic price level. 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 loans to non-financial corporations and the interest rate on government bonds with a duration of 6 months.¹⁶ The choice of government bond duration is made to match the duration of the corporate debt.

We match the levels of the following 6 time series:

$$R_t^{data}, \pi_t^{d,data}, \pi_t^{c,data}, \pi_t^{i,data}, \pi_t^{*,data}, R_t^{*,data}.$$

For hours worked we match the deviation from steady state, \hat{H}_t^{data} .

For the remaining 12 time series we take logs and first differences.

$$\begin{aligned} &\Delta \log(W_t/P_t)^{data}, \Delta \log C_t^{data}, \Delta \log I_t^{data}, \Delta \log q_t^{data}, \Delta \log Y_t^{data}, \Delta \log X_t^{data} \\ &\Delta \log M_t^{data}, \Delta \log Y_t^{*,data}, \Delta \log G_t^{data}, \Delta \log N_t^{data}, \Delta Spread_t^{data}, \Delta \log Unemprate_t^{data}. \end{aligned}$$

In addition we remove the mean from each of the first-differenced time series because in our sample variables such as output, consumption, real wages, investment, exports, imports and stock prices grow on average at substantially different rates. The model, however, allows for only two different real long-run growth rates. In order to match these different trends in the data the estimation would be likely to result in a series of negative or positive shocks for some exogenous

¹⁵Formally the steady state recruitment share is defined as

$$recruitshare = \frac{\kappa}{2} N \bar{v}^2 l / y$$

¹⁶Ideally one would like to match interest rate data on newly issued loans for the same duration as in the model, i.e. one quarter. Unfortunately, such data is not available for Sweden.

process. We want to avoid this and therefore demean the data. After the estimation we compare the growth rates of the data with those implied by the model.

See Figure D in the Appendix for plots of the above data used in the estimation. The measurement equations are described in detail in the Appendix, section B.8.

5.4. Shocks and Measurement Errors

In total, there are 23 exogenous stochastic variables in the model. 12 of these evolve according to AR(1) processes:

$$\epsilon, \Upsilon, \bar{\pi}^c, \zeta^c, \zeta^h, \tilde{\phi}, \sigma, \gamma, g, \eta, \sigma_m, \sigma_a$$

Further, we have 6 shock processes that are i.i.d.:

$$\tau^d, \tau^x, \tau^{mc}, \tau^{mi}, \tau^{mx}, \varepsilon_R.$$

Finally, the last 5 shock processes are assumed to follow a VAR(1):

$$y^*, \pi^*, R^*, \mu_z, \mu_\Psi.$$

In the estimation we only allow for 17 shocks. Accordingly we shut down six shocks present in the theoretical model: the inflation target shock $\bar{\pi}^c$, the shock to bargaining power η , the shock to matching technology σ_m , the shock to the standard deviation of idiosyncratic productivity of workers σ_a , the shock to investment-specific technology μ_Ψ and the idiosyncratic entrepreneur risk shock σ . Indeed for our sample, 1995-2009, the *de jure* inflation target has been in place the entire period and has been constant. Shocks to η also seems superfluous as we already have the standard labor supply shock - the labor preference shock ζ^h . We excluded μ_Ψ and σ as they did not contribute substantially to explaining any variable in preliminary estimations. The fact that the IST shock μ_Ψ is negligible when investment prices are observed are in line with the results in Schmitt-Grohé and Uribe (2008) and Mandelman *et al.* (2010).

Similarly to Adolfson, Laséen, Lindé and Villani (2007, 2008) we allow for measurement errors, except for in the domestic nominal interest rate and the foreign variables, since Swedish macro data is measured with substantial noise. We calibrate the variance of the measurement errors so that they correspond to 10% of the variance of each data series. As can be seen in Figure D the size of the measurement errors are small: data 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.

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 100 000 draws and with an acceptance rate tuned to 0.22. Parameters

and, more importantly, shock standard deviations have been scaled to be the same or similar order of magnitude so as to facilitate optimization.¹⁷ Prior-posterior plots and convergence statistics are presented in a separate Computational Appendix.¹⁸

5.5.1. Posterior Parameter Values

We start by commenting briefly on the parameter estimates. These are reported in the prior-posterior tables, Table A1 and A2, in the Appendix. We focus our discussion on the posterior mean which is also used for all computations below.

All Calvo price rigidity parameters except ξ_{mx} have a posterior mean of roughly 0.8, with ξ_d and ξ_{mc} the highest. Imported inputs for export production are instead substantially more flexible, and are re-set optimally more than twice per year, $\xi_{mx} = 0.39$. The price rigidities on both import and export prices are substantially below earlier work on Swedish data by ALLV (2008). Both the later sample and the additional internal propagation in our richer model might contribute to this difference. We find only a moderate degree of indexation to lagged inflation, in the interval $1/4 - 1/2$, with the exception of κ_d which is even lower at 0.15. We imposed that the working capital share, $\nu^j, \{j = *, x, f\}$, is equal across the different types of producers. It is estimated to be 0.42.

Both the capacity utilization parameter $\sigma_a = 0.12$ and the investment adjustment costs parameter $S'' = 0.20$ 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 were introduced to generate. The low σ_a allows for substantial variation in utilization. For the estimated Taylor rule parameters r_π is in line with the existing literature, while r_y is closer to zero than found in ALLV or Smets and Wouters (2003, 2007).

The posterior median of μ of 0.56 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 replacement ratio of 0.93, i.e. substantially higher than the statutory replacement rate of the public Swedish unemployment insurance, and in the vicinity of the calibration in Hagedorn and Manovskii (2008). The recruitment costs as a fraction of GDP is estimated to be 0.31 percent, corresponding to $\kappa = 5.5$, which is reasonably large compared to values in the literature. The endogenous breakup rate \mathcal{F} is estimated to be 0.18% implying that 7% of job separations are endogenous. The bargaining power of workers, η , is solved for to yield a steady state unemployment rate matching the sample average. The value of η at the posterior mean is 0.31. This is substantially lower than $\eta = 0.9$ reported by GST, and lower

¹⁷What 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.

¹⁸In particular, we confirm that the posterior parameter distribution is the same in the two parts of the chain when we extend the Metropolis-Hasting chain by another 500 000 draws.

than the conventional wisdom which suggests values around 0.5, see Mortensen and Nagypal (2007). Nevertheless, our estimate of η is substantially higher than Hagedorn and Manovskii (2008) calibration of 0.05.

In principle the fact that we match data series for both total hours and employment should allow for identification of the intensive margin of labor supply. Judging from the posterior distribution of σ_L the data is not informative though. The posterior mean of σ_L is 7.4, implying a Frisch elasticity of $1/7.4=0.135$. This is very close to the prior based on micro evidence and substantially higher than most macro models.

As we will see in the impulse response functions (IRFs) below the posterior mean of $\tilde{\phi}_s = 1.1$ generate a hump-shaped response of the nominal exchange rate to monetary policy shocks.

We note from the posterior standard deviations in Table A1, and from the prior-posterior plots in the Computational Appendix that data is informative about all the estimated parameters, with the exception of the labor supply curvature σ_L and the foreign VAR parameter c_{24} .

5.5.2. Smoothed Shock Processes and Impulse Response Functions

Figure E presents the smoothed values for the shock processes. The current financial crisis shows up as extreme values in several shocks: high values of the MEI shock Υ_t , the markup shock for exports $\tau_{x,t}$ and the country risk-premium $\tilde{\phi}_t$, while extreme low values is obtained for the wealth shock γ_t and both the stationary and unit root neutral technology shocks ϵ_t and $\mu_{z,t}$.

We now discuss the impulse response functions. For comparison purposes and to quantify the importance of the different frictions we plot the IRFs, 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 4.¹⁹ 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.). 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 for the monetary policy shock has the following characterization: A 49 basis point temporary increase in the nominal interest rate cause 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. Accordingly, the interest rate risk spread increase by 14 basis points to compensate for the increased default risk. Comparing across models we see how the increased spread generate

¹⁹One parameter is recalibrated between models: α has to be re-set to keep the capital-output ratio unchanged in the baseline and unemployment model specifications. The absence of financial frictions in these two versions of the model imply that the required rate of return on capital is substantially lower. We therefore set $\alpha = 0.1856$ to keep the capital-output ratio constant.

amplification in the response of investment. The amplification is quite small though, and the key for this result is the low estimated investment adjustment cost curvature S'' that makes the decrease of the price of capital, and thereby entrepreneurial net worth, small in response to the monetary policy shock.²⁰

We note that our assumed mechanism for the country risk premium 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 also implies an increase in the level of unemployment by a maximum of 0.14% after 3 quarters. 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. 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 responds nearly as much as the marginal product of labor, so the nominal wage rigidity imply substantial real wage rigidity, and also this result is general across shocks.

The response to a stationary technology shock in our estimated model is reasonably standard: inflation decreases and consumption, investment and net exports increase. Both margins of labor supply fall substantially initially. Real wages decrease slightly in the models with employment frictions. We note that financial frictions dampens the response of investment substantially as net worth of entrepreneurs initially falls. This is a standard result for supply shocks in the presence of the Fisher debt deflation mechanism, which in turn is generated by nominal debt contracts.

The response to the entrepreneurial wealth shock has some of the characteristics of a classic demand shock: It drives up both CPI inflation, consumption, investment and GDP . The responses of consumption and GDP are very persistent. 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.²¹ It is interesting to compare the wealth shock to the MEI shock, Υ_t , whose importance is emphasized in Justiniano, Primiceri and Tambalotti (2009). 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

²⁰Keeping other parameters fixed at their estimated values and setting S'' to its prior mean value of 0.5 would imply that financial financial frictions amplify the response of investment by 60%.

²¹The characteristic that consumption increases in response to the wealth shock is not entirely robust across parameters and setup. For our full model and the estimated parameter vector, shutting down either the open economy dimension or the wage stickiness would make consumption decrease the first couple of quarters in response to the wealth shock.

possible to disentangle the contributions and empirical relevance of these two shocks. More on the comparison of these two shocks below.

5.5.3. Model Moments and Variance Decomposition

In Table A3 we present a comparison of 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 the reason why we demeaned the growth rates in the first place, before matching the model to the data.

Comparing the volatility of the data and the model implied variables we note that the endogenous priors work fine: most standard deviations are similar in the data and the model. The exceptions are for the dataserie with high sampling uncertainty, where the prior over the moments accordingly is less informative.²²

We compute the variance decomposition and present it in Table A4 (1, 4, 8 and 20 quarters forecast horizon).²³ We focus the analysis below on the 8 quarters horizon. First, note the importance of the entrepreneurial wealth shock γ_t . It explains 2/3rds of the variation in investment, a quarter of GDP and slightly more than half of both of the financial variables. Note the spillover from the financial shock into the labor market: it explains roughly 10% of the unemployment variation. The wealth shock also seems to “crowd out” the MEI shock, which has limited importance for all variables except the spread.

Second, note the high importance of the stationary technology shock for key macroeconomic variables, in particular for consumption, GDP , total hours, the nominal interest rate and CPI inflation.

Third, note how the variation in total hours and unemployment is quite evenly spread out over many different shocks, while hours per worker (the intensive margin of labor supply) to a very large degree, 3/4ths, is determined by the labor preference shock. The labor preference shock is also the most important shock for both total hours and real wages, but unimportant for the other variables. Unemployment (the extensive margin) is primarily explained by domestic markup, monetary policy and consumption preference.

Finally a word on the i.i.d. markup shocks. All of the markup shocks are important in explaining their respective inflation series (only π^c reported here). The markup shock to imported inputs for export production, τ_{mx} also has substantial effects on net exports and GDP .²⁴ It can

²²In 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 and the nominal interest rates, while volatilities of real quantities were matched well.

²³The foreign variables and the foreign stationary shocks 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, μ_z . The foreign stationary shocks have very limited effects on the domestic variables, except regarding the nominal exchange rate.

²⁴Note that exports as a fraction of GDP is high, 45%, both in the data and the model so that variation in net exports affect GDP strongly.

not be ruled out that a substantial part of the high frequency variation in the quarterly inflation series consists of measurement error, and in that case the volatility of the markup shocks are over-stated. We explore this in the next subsection.

5.5.4. Estimations of Alternative Specifications

Larger Inflation Measurement Errors To explore the importance of the price markup shock we estimate an alternative specification where we calibrate the measurement errors of the inflation series to be 25% of their respective variance instead of our benchmark 10%. The estimated structural parameters remain roughly unchanged, and only the shock standard deviations adjust. In particular, and not surprisingly, the standard deviation decreases by roughly 30% for τ_d , 40% for τ_x , 75% for τ_{mi} and by a smaller amount for the remaining two markup shocks.

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, although our setting is a small open economy with financial and employment frictions. With this setup we get a similar result as they do: The MEI shock becomes very important in the variance decomposition: On the 8 quarter horizon it explains 55% of the variance of investment and 8% of GDP, to be compared with 10% of investment and 4% of GDP in our main estimation. A substantial role for the MEI shock was also present in ALLV which is estimated on Swedish data without matching the financial time series. Our conclusion is that the large role for the MEI shock reflects that the appropriate data is not matched - the MEI shock has counterfactual implications for the stock market and the spread, and is only important if these data series are not included in the estimation. 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. Christiano, Motto and Rostagno (2009) have made the same argument using estimation results for the Euro area and the U.S.

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

$$\frac{\kappa z_t^+}{2} \left(\frac{Q_t^\iota v_t^i}{[1 - \mathcal{F}(\bar{a}_t^i)] l_t^i} \right)^\varphi [1 - \mathcal{F}(\bar{a}_t^i)] l_t^i,$$

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 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 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 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 reliable such 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 (2009) documents a similar tendency for U.S. as we obtain for Sweden. In that paper the low matching rates in slack labor markets is interpreted as a procyclical variation in the matching productivity. We instead interpret this result as reflecting that employment adjustment costs pre-dominantly are a function of hiring rates.

5.5.5. Validation Using Bankruptcy Rates

As a form of validation we compare the model implied time series for corporate bankruptcy rates with the data, i.e. a data series that was not used in the estimation except to calibrate the steady state level of defaults.²⁵ The model implied series at the posterior mean is plotted against the data series in Figure F. Qualitatively the two series comove nicely, but the model implied series is more volatile and the correlation is only 0.53. The model implied time series for bankruptcies instead follows the (matched) spread closely, with a correlation close to 0.9.

6. Summary and Conclusions

This paper incorporates three important extensions of the emerging standard monetary DSGE model of the CEE type. We add financial frictions in the accumulation of capital in a well established way, based on Bernanke, Gertler and Gilchrist (1999) and Christiano, Motto and Rostagno (2008). We then add labor market frictions building on a large literature where we are closest to Gertler, Sala and Trigari (2008) and Christiano, Ilut, Motto and Rostagno (2007). We incorporate the model in a small open economy setting closely following the work of ALLV. We make a contribution to the literature by endogenizing the job separation decision in this rich setting. We estimate the full model using Bayesian techniques on Swedish data 1995q1-2009q2. The key empirical insights from the paper are:

1. The financial shock to entrepreneurial wealth is pivotal for explaining business cycle fluctuations. In terms of variance decomposition it accounts for 2/3rds of the variance in investment and a quarter of the variance in GDP.
2. The marginal efficiency of investment shock has very limited importance in variance decomposition horizons beyond 4 quarters. This contrasts starkly with Justiniano, Primiceri and Tambalotti (2009), and the reason for this is that we match financial market data and

²⁵The data on bankruptcies from “UC AB” was provided to us by the authors of Jacobson, Lindell, Lindé and Roszbach (2008).

allow for a financial shock. When we re-estimate the model without matching the stock market index or the corporate interest rate spread 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 is not matched, and that the MEI shock has counterfactual implications for the stock market valuation and the corporate interest spread.

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 wage data series. Furthermore, the low-frequency labor preference shock that we do allow 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 in GST that the tightness of the labor market is unimportant for the cost of adjusting 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. Finally, on the open economy dimension our country risk-adjustment term is important and generates a hump-shape in the estimated 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.

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A. Tables and Figures

	Distr.	Prior		Posterior			
		Mean	s.d.	Mean	s.d.	5%	95%
ξ_d	β	0.75	0.075	0.877	0.0180	0.8476	0.9064
ξ_x	β	0.75	0.075	0.785	0.0326	0.7341	0.8398
ξ_{mc}	β	0.75	0.075	0.850	0.0223	0.8124	0.8857
ξ_{mi}	β	0.75	0.075	0.779	0.0414	0.7154	0.8491
ξ_{mx}	β	0.66	0.10	0.390	0.0810	0.2580	0.5194
κ_d	β	0.50	0.15	0.154	0.0596	0.0572	0.2457
κ_x	β	0.50	0.15	0.490	0.1047	0.3214	0.6662
κ_{mc}	β	0.50	0.15	0.288	0.0890	0.1401	0.4324
κ_{mi}	β	0.50	0.15	0.412	0.1112	0.2304	0.5958
κ_{mx}	β	0.50	0.15	0.379	0.1423	0.1455	0.6074
κ_w	β	0.50	0.15	0.377	0.1223	0.1728	0.5726
ν^j	β	0.50	0.25	0.419	0.2378	0.0286	0.7815
σ_L	Γ	7.50	2.00	7.39	1.789	4.427	10.251
b	β	0.65	0.15	0.630	0.0687	0.5166	0.7437
S''	Γ	5.00	1.50	2.00	0.308	1.497	2.476
σ_a	Γ	0.20	0.075	0.117	0.0428	0.0498	0.1816
ρ_R	β	0.80	0.10	0.817	0.0243	0.7792	0.8561
r_π	N	1.70	0.15	1.841	0.1272	1.6378	2.0557
r_y	trunc- N	0.125	0.05	0.010	0.0068	0.0000	0.0197
η_x	trunc- Γ	1.50	0.25	1.306	0.1939	1.0000	1.5750
η_c	trunc- Γ	1.50	0.25	1.628	0.1988	1.2943	1.9413
η_i	trunc- Γ	1.50	0.25	1.526	0.2128	1.1835	1.8593
η_f	trunc- Γ	1.50	0.25	1.548	0.2183	1.1902	1.9044
ϕ_s	Γ	1.25	0.10	1.094	0.0891	0.9492	1.2415
μ	β	0.33	0.075	0.563	0.0711	0.4468	0.6787
$recshare, \%$	Γ	0.10	0.075	0.307	0.0632	0.2031	0.4060
$bshare$	β	0.75	0.075	0.934	0.0126	0.9141	0.9554
$F, \%$	β	0.25	0.05	0.183	0.0337	0.1273	0.2371
ρ_{μ_z}	β	0.50	0.20	0.861	0.0469	0.7897	0.9354
ρ_ε	β	0.85	0.075	0.853	0.0411	0.7845	0.9184
ρ_Υ	β	0.85	0.075	0.551	0.0890	0.4072	0.6997
ρ_{ζ^c}	β	0.85	0.075	0.718	0.0792	0.5913	0.8465
ρ_{ζ^h}	β	0.85	0.075	0.798	0.0475	0.7209	0.8756
$\rho_{\bar{\phi}}$	β	0.85	0.075	0.670	0.0573	0.5739	0.7619
ρ_g	β	0.85	0.075	0.800	0.0789	0.6768	0.9301
ρ_γ	β	0.85	0.075	0.785	0.0433	0.7153	0.8543
a_{11}	N	0.50	0.50	0.936	0.0284	0.8927	0.9849
a_{22}	N	0.00	0.50	0.057	0.1566	-0.2004	0.3175
a_{33}	N	0.50	0.50	0.677	0.0978	0.5216	0.8370
a_{12}	N	0.00	0.50	-0.466	0.2786	-0.9236	-0.0172
a_{13}	N	0.00	0.50	-0.393	0.1912	-0.7089	-0.0878
a_{21}	N	0.00	0.50	0.069	0.0341	0.0134	0.1225
a_{23}	N	0.00	0.50	0.092	0.2126	-0.2468	0.4471
a_{24}	N	0.00	0.50	0.486	0.3666	-0.1407	1.0844
a_{31}	N	0.00	0.50	0.056	0.0173	0.0274	0.0839
a_{32}	N	0.00	0.50	-0.066	0.0466	-0.1428	0.0076
a_{34}	N	0.00	0.50	0.693	0.1984	0.3623	1.0106
c_{21}	N	0.00	0.50	0.079	0.0669	-0.0306	0.1889
c_{31}	N	0.00	0.50	0.067	0.0179	0.0375	0.0960
c_{32}	N	0.00	0.50	0.021	0.0425	-0.0484	0.0889
c_{24}	N	0.00	0.50	-0.082	0.4704	-0.8607	0.6784
c_{34}	N	0.00	0.50	0.434	0.1821	0.1315	0.7305

Table A1. Estimation results. Parameters. Based on 400 000 metropolis draws.

	Distr.	Prior		Posterior			
		Mean	d.f.	Mean	s.d.	5%	95%
100 σ_{μ_z}	Inv- Γ	0.15	2	0.079	0.0207	0.0472	0.1116
100 σ_{ϵ}	Inv- Γ	0.50	2	0.529	0.0892	0.3869	0.6751
10 σ_{τ}	Inv- Γ	0.15	2	0.262	0.0548	0.1722	0.3457
10 σ_{ζ^c}	Inv- Γ	0.15	2	0.175	0.0345	0.1203	0.2271
10 σ_{ζ^h}	Inv- Γ	0.15	2	0.644	0.1482	0.4021	0.8849
100 $\sigma_{\tilde{\phi}}$	Inv- Γ	0.15	2	0.703	0.1230	0.4984	0.9007
100 σ_{ϵ_R}	Inv- Γ	0.15	2	0.129	0.0128	0.1084	0.1494
100 σ_g	Inv- Γ	0.50	2	0.778	0.0697	0.6634	0.8902
10 σ_{τ^d}	Inv- Γ	0.50	4	2.740	0.7963	1.4397	3.9303
10 σ_{τ^x}	Inv- Γ	0.50	4	2.489	0.7627	1.3362	3.7711
10 $\sigma_{\tau^{mc}}$	Inv- Γ	0.50	4	2.847	0.8607	1.5424	4.1007
10 $\sigma_{\tau^{mi}}$	Inv- Γ	0.50	4	1.597	0.6996	0.6457	2.7356
10 $\sigma_{\tau^{mx}}$	Inv- Γ	0.50	4	3.292	1.2560	1.5204	5.0095
100 σ_{γ}	Inv- Γ	0.50	2	0.352	0.0375	0.2918	0.4128
100 σ_{y^*}	Inv- Γ	0.50	2	0.542	0.0397	0.4759	0.6062
100 σ_{π^*}	Inv- Γ	0.50	2	0.223	0.0202	0.1910	0.2566
1000 σ_{R^*}	Inv- Γ	0.50	2	0.250	0.0664	0.1480	0.3478

Table A2. Estimation results. Standard deviation of shocks. Based on 400 000 metropolis draws.

Variable	Explanation	Means		Standard deviations		$\sqrt{diag\left(\frac{\hat{S}}{T}\right)}$ Data
		Data	Model	Data	Model	
π^d	Domestic inflation	1.69	2	1.84	2.01	0.58
π^c	CPI inflation	1.5	2	1.38	1.85	0.54
π^i	Invest. price inflation	1.52	2	2.14	2.51	0.83
R	Nom. interest rate	3.74	4.25	1.73	1.61	1.30
\hat{H}	Total hours deviation	0	0	1.63	1.74	0.50
Δy	GDP growth	0.42	0.42	0.96	1.00	0.60
Δw	Real wage growth	0.64	0.42	0.72	0.68	0.11
Δc	Consumption growth	0.41	0.42	0.78	0.77	0.20
Δi	Investment growth	0.65	0.42	2.97	2.90	3.73
Δq	Real exch. rate growth	0.25	0	2.77	2.57	2.29
Δg	Gov. cons. growth	0.08	0.42	0.95	0.89	0.47
$\Delta exports$	Export growth	1.05	0.42	2.44	2.29	2.55
$\Delta imports$	Import growth	0.89	0.42	2.63	2.38	2.95
Δn	Stock market growth	1.13	0.42	10.74	4.95	24.78
$\Delta spread$	Interest spread growth	0.24	0	13.06	15.29	51.5
ΔU	Unemployment growth	-0.43	0	4.47	4.59	5.25
R^*	Foreign nom. int. rat	3.79	4.25	1.11	1.14	0.28
π^*	Foreign inflation	1.81	2	1.01	1.03	0.36
Δy^*	Foreign GDP growth	0.31	0.42	0.64	0.59	0.24

Table A3. Data and model moments (in percent). The last column is a measure of the sampling uncertainty in the data.

1 quarter	R	π^c	GDP	C	I	NX/GDP	H	H/E	U	w	q	N	Spread
ϵ	1.4	2.4	17.4	5.1	0	7.5	10.5	7.5	11.8	0	2.5	0.9	1.2
Υ	0	0	0	0.3	34.3	7.3	0.7	0.4	2.2	0.3	0	13.9	17.1
ζ^c	0.5	0.7	3.3	76.7	0	7.5	2.7	1.6	5.5	0.4	2.4	0.8	0.9
ζ^h	0.7	1.3	13.8	2	0	7.5	43.8	60	24.4	9.6	1.1	0.4	0.6
ε_R	45.1	0.4	1.5	6.2	15.6	3.5	0	0.2	4	0.7	1	21.2	17.4
g	0.1	0.1	1.9	0.2	0	1.5	1.4	1	2	0.2	0.1	0.1	0.1
τ^d	24.9	42	1.5	6.1	2.2	0.6	1	0.3	7.4	84.9	1.4	2	0
τ^x	0.1	0.2	4.5	0.3	0	1.9	3.7	2.1	8.6	0.9	0.2	0.1	0.2
τ^{mc}	25.5	42.9	0.1	1.7	2.3	2.7	0.6	0.4	0.8	0	0	4.4	3.3
τ^{mi}	0	0	0.7	0	0.2	0.9	0.2	0.1	0.5	0	0	7.3	7
τ^{mx}	0.1	0	50.9	0.6	0	54.1	34	25.7	27.7	1.5	0.8	0	0
γ	0.3	0.5	2.7	0.1	45.2	2.4	0.1	0	1.2	0.1	2.2	47	49.8
ϕ	1.1	1.8	1.5	0.3	0.2	1.3	1	0.5	3.2	0.2	83.4	1.1	1.1
μ_z	0.3	0.5	0	0.5	0	0	0	0	0.3	1.1	0.7	0.8	1.1
4 quarters													
ϵ	6.8	5.7	14.8	10.4	0.4	3.7	13.6	6	10.2	0.6	4.6	0.5	1.2
Υ	0	0	2.1	0.6	17.3	8.2	1.7	0.3	2.8	1.2	0	11.8	18.5
ζ^c	2.8	2.1	9	63.3	0.1	11.3	10	2.5	11	2.3	4.6	0.7	0.8
ζ^h	3.1	2.6	9.1	4.1	0.2	3.6	28.6	73.3	14.6	37.4	2.1	0.3	0.6
ε_R	30.7	1.2	6.6	6.5	15.5	9	2.7	0.1	9.6	4.5	2.2	16.9	11.8
g	0.2	0.1	2	0.3	0	0.8	2	0.7	2	0.6	0.2	0	0.1
τ^d	24	36.4	6	8.1	2.7	1.8	6.7	0.2	18.2	41.6	2.5	1.9	0.1
τ^x	0.6	0.4	9.3	0.6	0	1.5	9.8	2.2	12.2	3.4	0.3	0.1	0.2
τ^{mc}	23.4	38.2	0.2	1.2	1.6	5.9	0.8	0.3	1.1	2.1	0	3.3	2.3
τ^{mi}	0	0	0.7	0	0.4	1.7	0.4	0.1	0.4	0	0.1	6.6	6.6
τ^{mx}	0.2	0.4	23.5	1.4	0.1	34	16.7	13.5	5.7	1.2	1.4	0.1	0
γ	2	1.5	12.6	0.1	60.5	11.7	2.4	0.1	5.2	2.1	4.1	56.3	55.6
ϕ	3.6	2.9	3.8	0.4	0.7	5.4	4.2	0.7	6	2	68.8	1	1.2
μ_z	2.3	2	0.2	2.6	0.4	0.4	0.4	0	0.7	1	1.5	0.4	0.9
8 quarters													
ϵ	11.6	6.3	13.2	16.1	1.3	4.8	11.7	5.7	7.2	0.9	6.7	0.4	1.5
Υ	0	0	3.7	1.2	9.9	6.9	1.5	0.3	2.4	1.2	0	9.5	18.8
ζ^c	5.1	2.4	7.4	47.4	0.6	9.7	11.3	2.6	11	2.2	6.4	0.7	1
ζ^h	4.9	2.8	7	6.1	0.5	3.6	25	75.3	9.4	39.4	3	0.2	0.7
ε_R	23.9	1.4	9.4	6.2	13.1	9.4	4.9	0.1	12.3	6	3.5	14.8	9.8
g	0.3	0.1	1.4	0.4	0	0.7	1.8	0.6	1.7	0.5	0.2	0	0.1
τ^d	20.8	34.7	7.8	8.8	2.7	2.2	10.2	0.2	23.7	35.6	3.6	1.7	0.2
τ^x	0.7	0.4	6.6	0.7	0	1.3	9	2	9.9	2.9	0.4	0.1	0.2
τ^{mc}	17.8	37.6	0.2	0.9	0.9	5.2	1.1	0.3	2.2	2.5	0.1	2.8	2
τ^{mi}	0	0	0.4	0	0.3	1.6	0.3	0.1	0.2	0.1	0.1	5.8	6.6
τ^{mx}	0.8	0.6	14.2	2.6	0.4	29.3	13.2	12	4.1	1.2	1.9	0.1	0
γ	4	1.7	24.6	0.5	67.5	17.2	5.1	0.1	9.4	4.4	5.7	62.1	56.4
ϕ	3.6	2.9	2.7	0.3	0.8	5.8	4.2	0.6	5.7	2.1	54.6	1	1.5
μ_z	5.9	2.9	1.4	8	2	1.7	0.6	0.1	0.7	1.2	2.6	0.7	1
20 quarters													
ϵ	13.5	6.4	10.4	15.5	2.1	5.2	10.7	5.7	6.5	2.4	9.9	0.6	2.1
Υ	0.1	0.1	4.7	2.9	7	6.4	1.3	0.4	2	1.2	0	8.4	18.3
ζ^c	6.3	2.4	3.9	30.8	1.3	10.8	10.9	2.7	9.6	2.1	8.3	0.5	1.3
ζ^h	5.5	2.8	4.6	5.7	0.8	3.6	24.5	74.7	8	36.6	4.3	0.2	0.9
ε_R	20.2	1.4	9.1	4.8	10.2	9	5.5	0.2	12.6	6	4.6	12.6	9.3
g	0.3	0.1	0.7	0.4	0	0.7	1.7	0.6	1.5	0.4	0.3	0	0.1
τ^d	18.2	34.2	6.3	6.8	2.4	2.1	11.8	0.2	25.4	33.5	6	1.7	0.4
τ^x	0.7	0.4	3.3	0.6	0	1.3	8.2	1.9	8.1	2.6	0.5	0	0.2
τ^{mc}	15.8	37.3	0.2	1.7	0.9	5.9	1.7	0.3	4.1	3.1	0.3	2	2.1
τ^{mi}	0	0	0.2	0	0.2	1.7	0.3	0.1	0.3	0.1	0.1	4	6.5
τ^{mx}	1.2	0.6	7.1	3.2	0.7	27.4	12.1	11.6	3.5	1.1	2.3	0.1	0.1
γ	4.5	1.8	39.6	7.9	66.6	16	6.3	0.5	12.8	6.6	6.1	64.2	55.4
ϕ	3.4	3	1.4	0.7	0.7	6.4	4	0.6	5.1	2	35.5	0.7	1.6
μ_z	9.8	3.4	8.4	18.3	6.8	2.6	0.8	0.5	0.6	2.3	5.5	4.8	1.4

Table A4a. Variance decomposition (in percent).

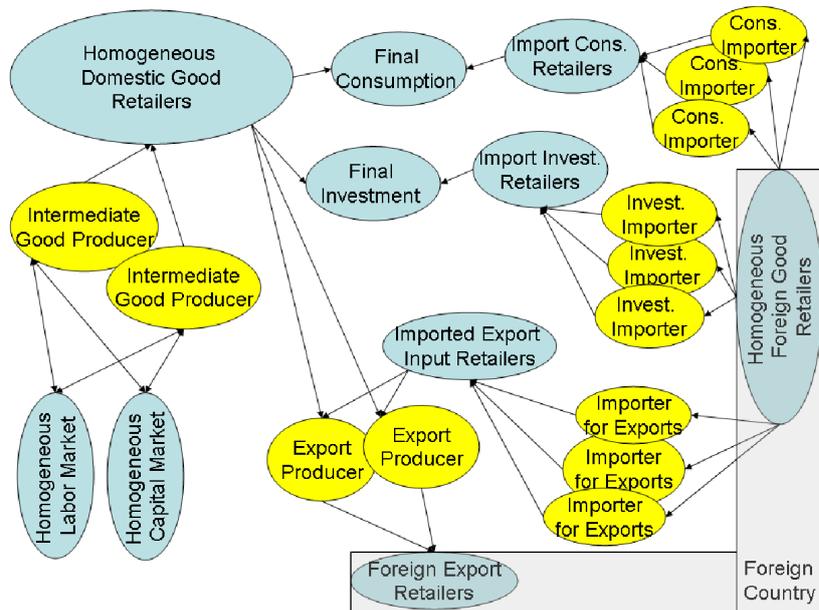


Figure A. Graphical illustration of the goods production part of the model.

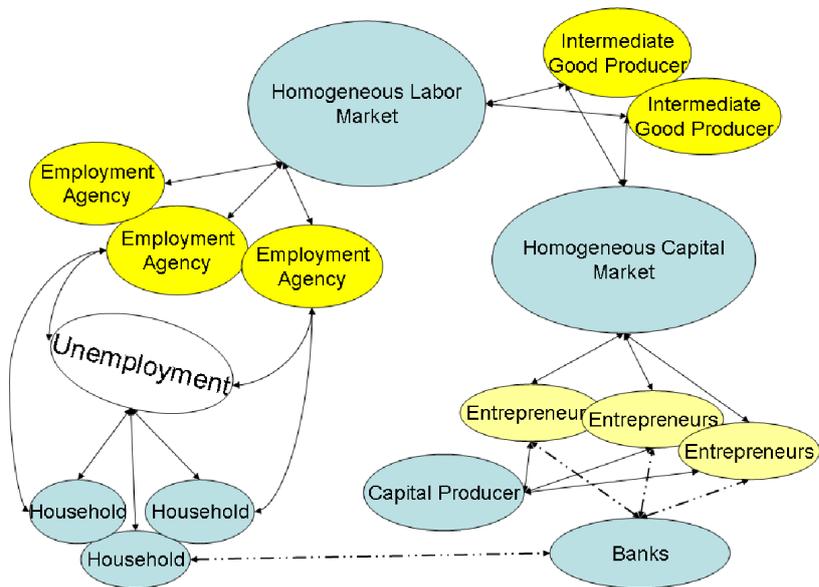


Figure B. Graphical illustration of the labor and capital markets of the model.

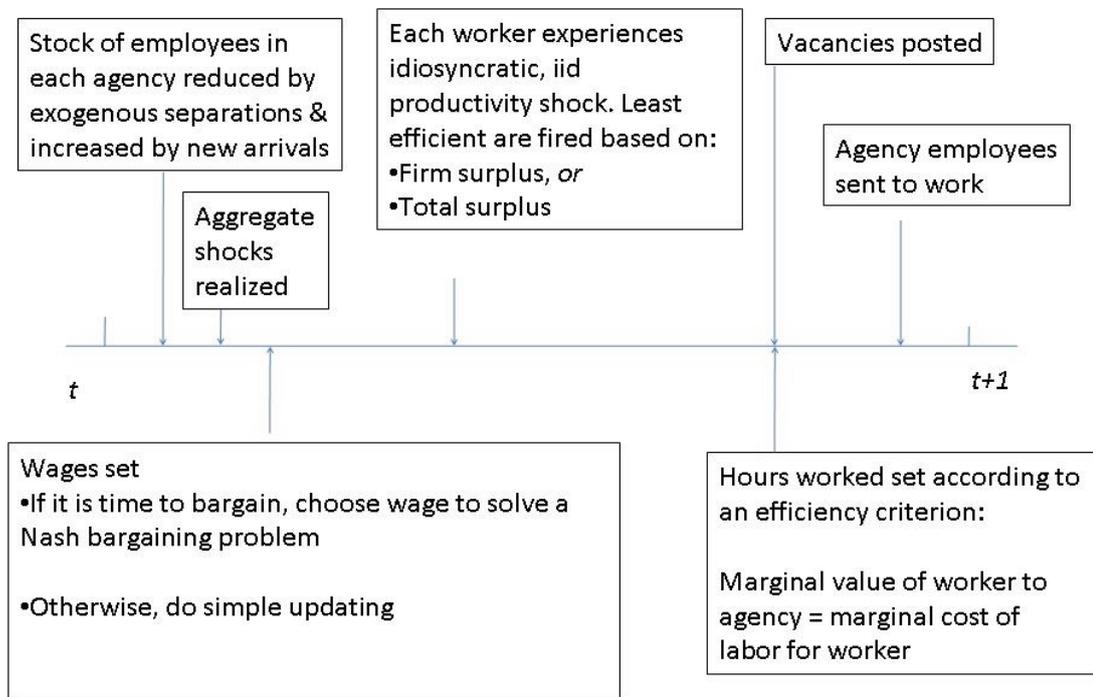


Figure C. Timeline for the labor market in the employment frictions model.

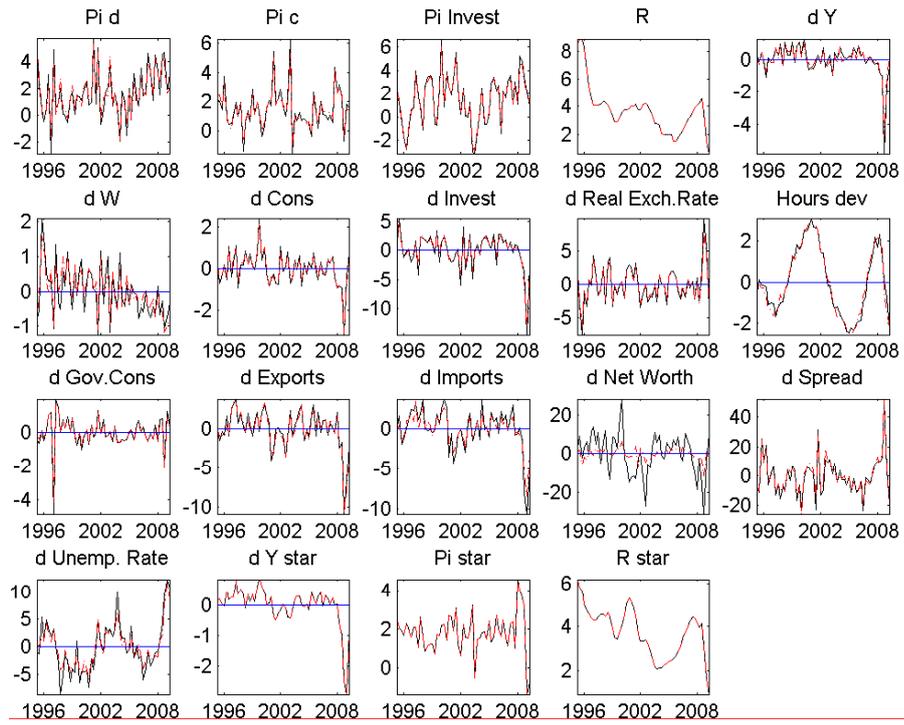


Figure D. Data series used in estimation (solid black) and smoothed variables without measurement error (in dashed red).

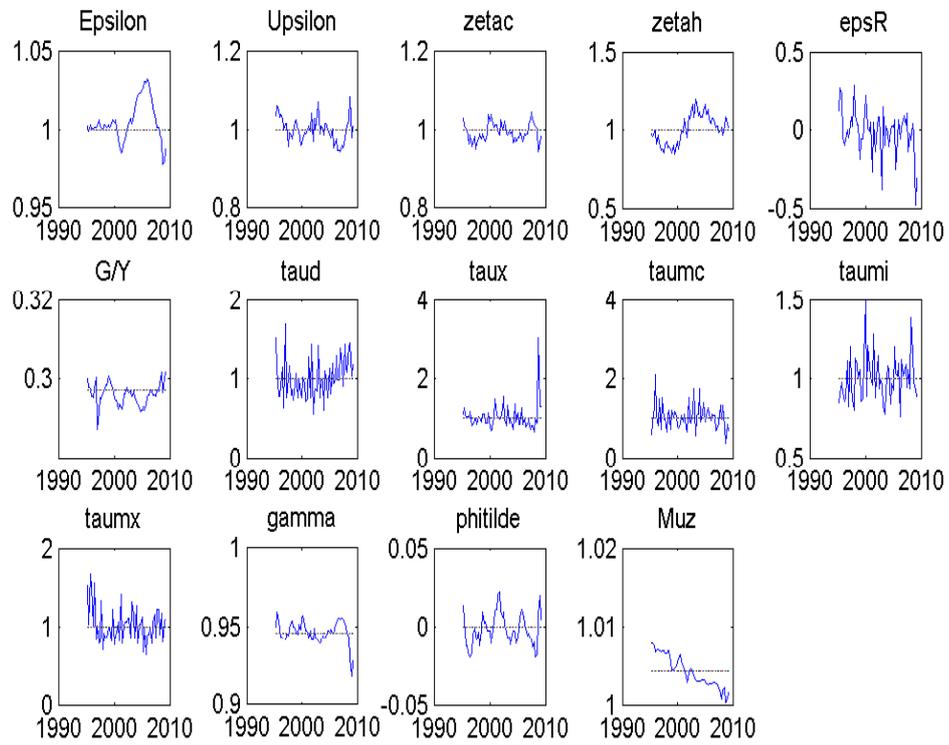


Figure E. Smoothed shock processes, except epsR (ε_R) which is the innovation to the monetary policy rule.

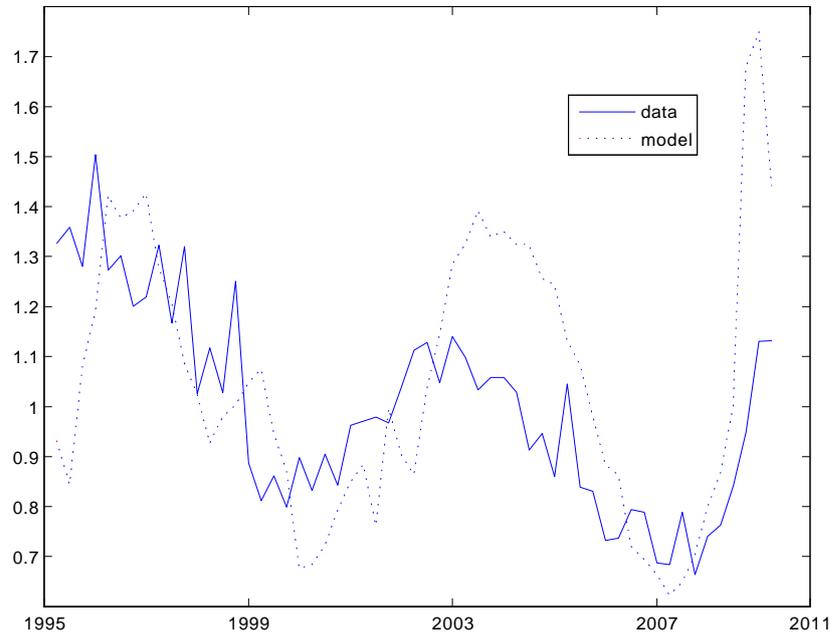
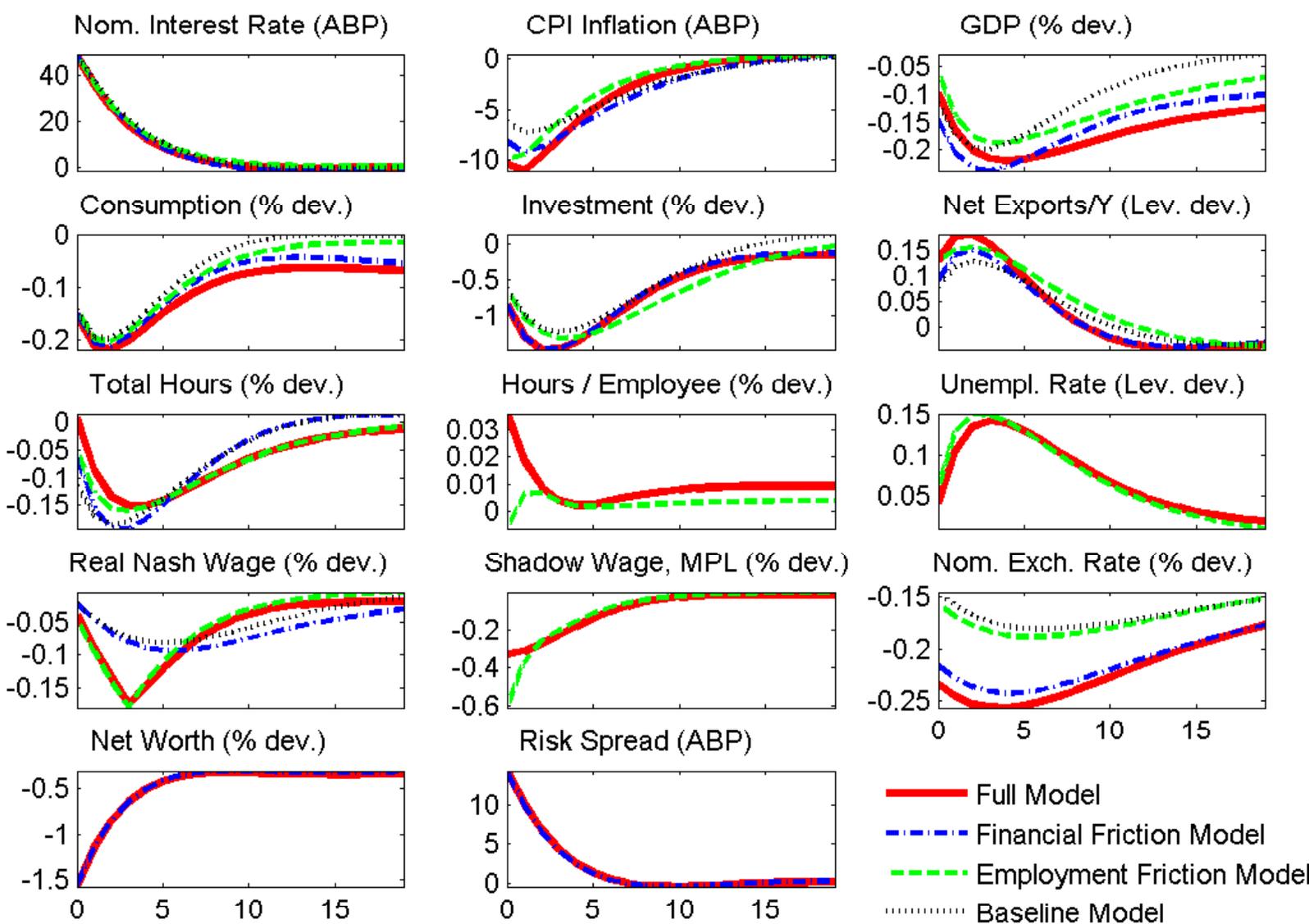


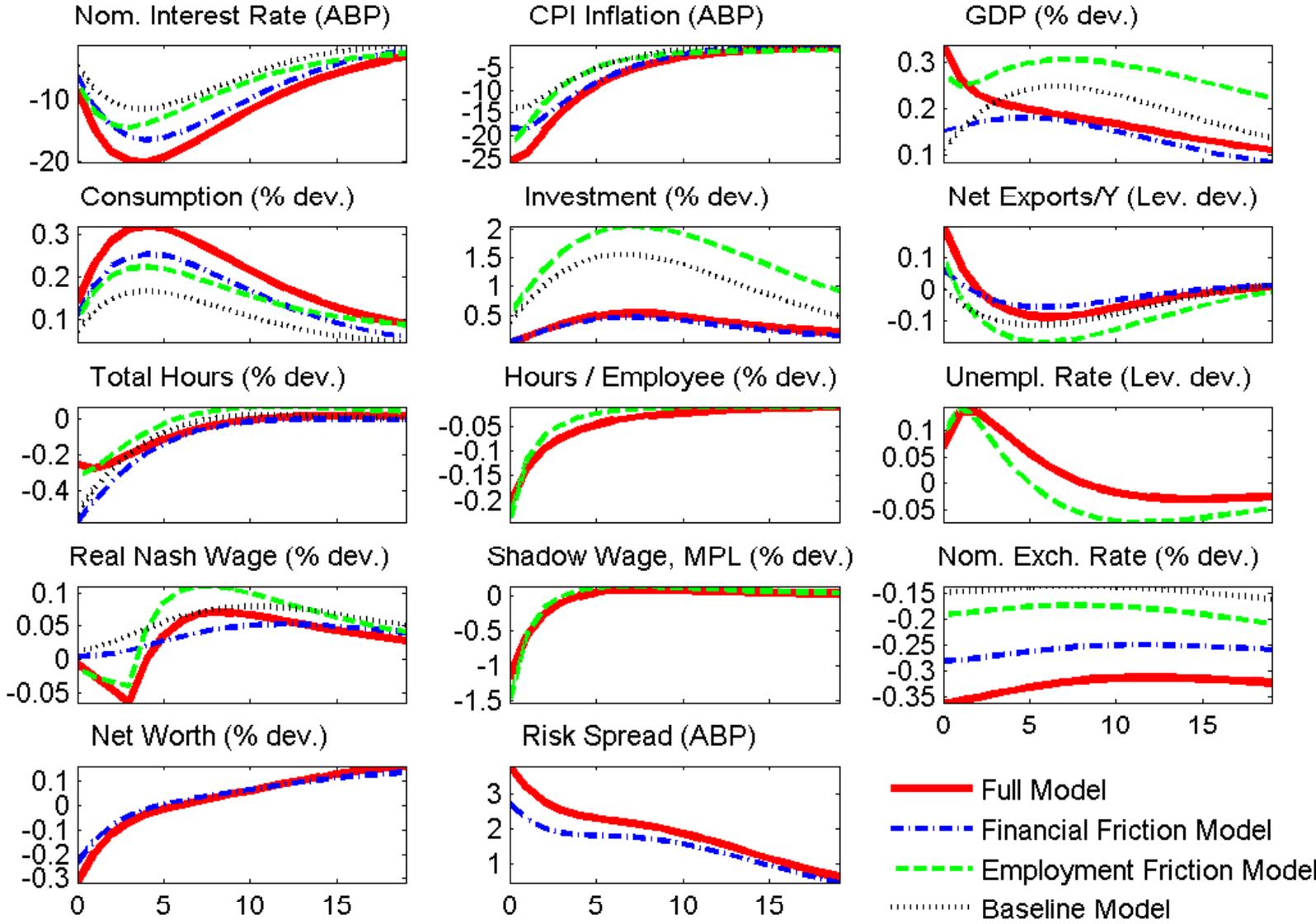
Figure F. Quarterly corporate bankruptcy frequencies in model and data (percent).

Monetary Policy Shock

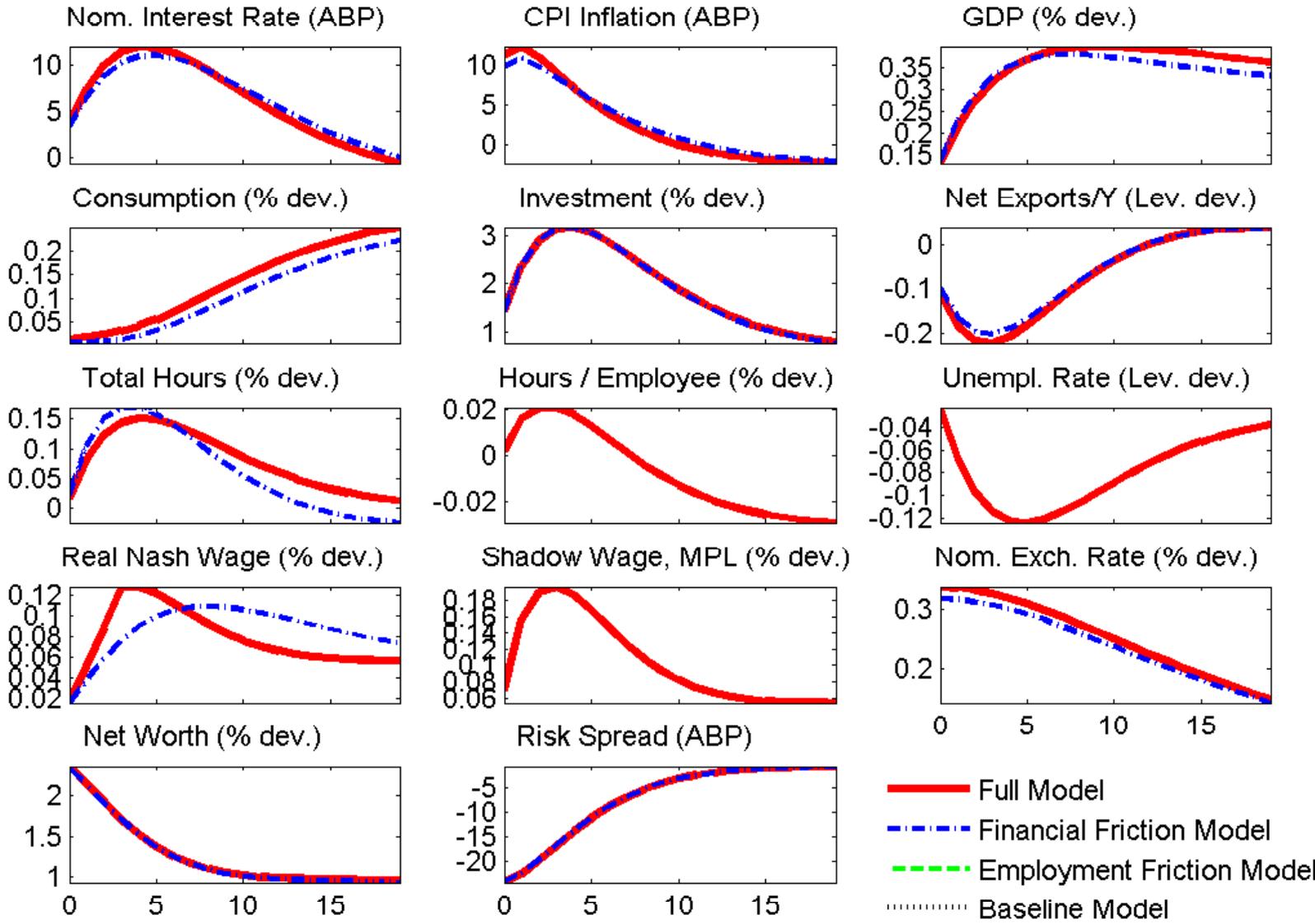


The units on the y-axis are either in terms of percentage deviation (% dev.) from steady state, annualized basis points (ABP), or level deviation (Lev. dev.).

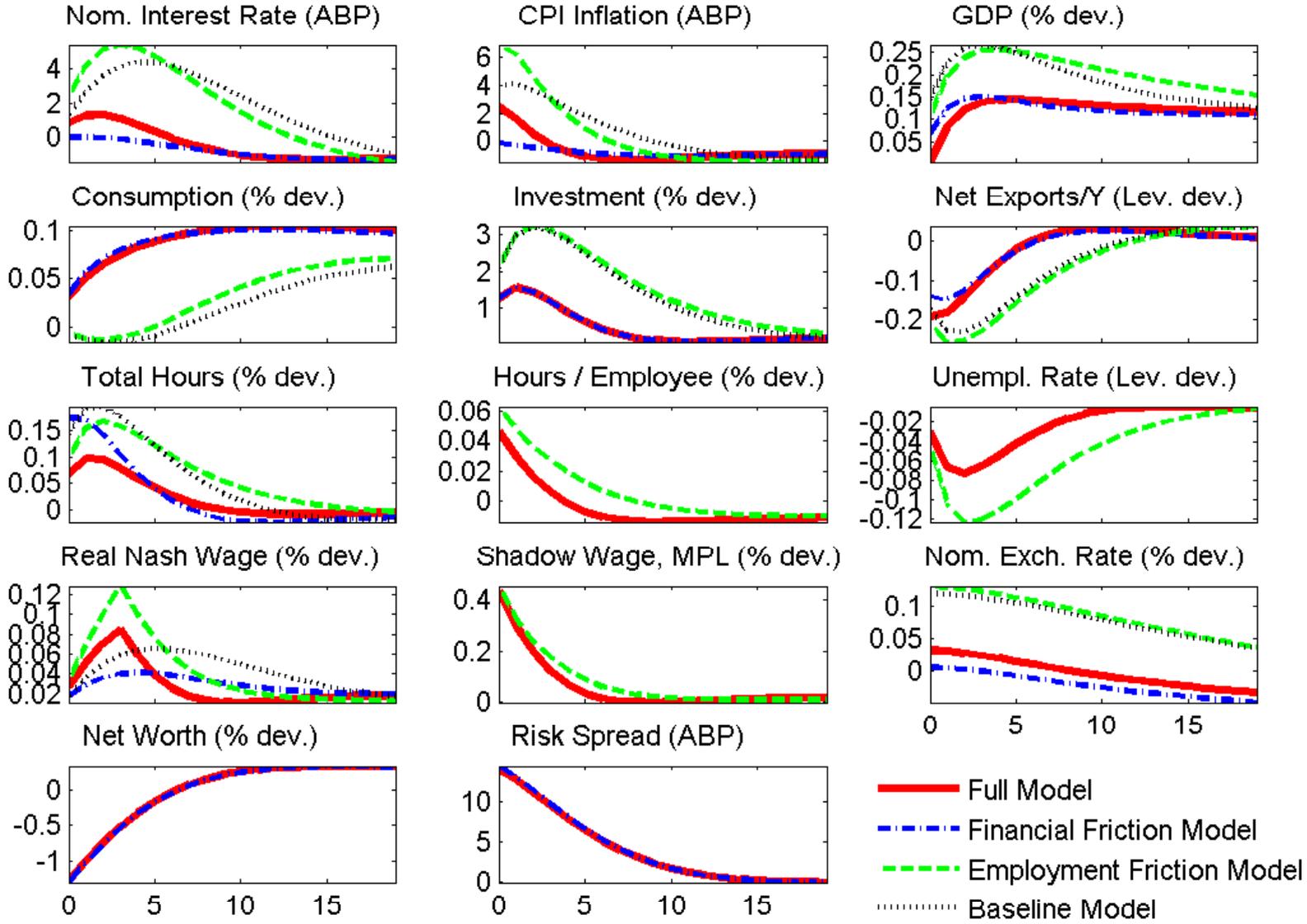
Stationary Neutral Technology Shock



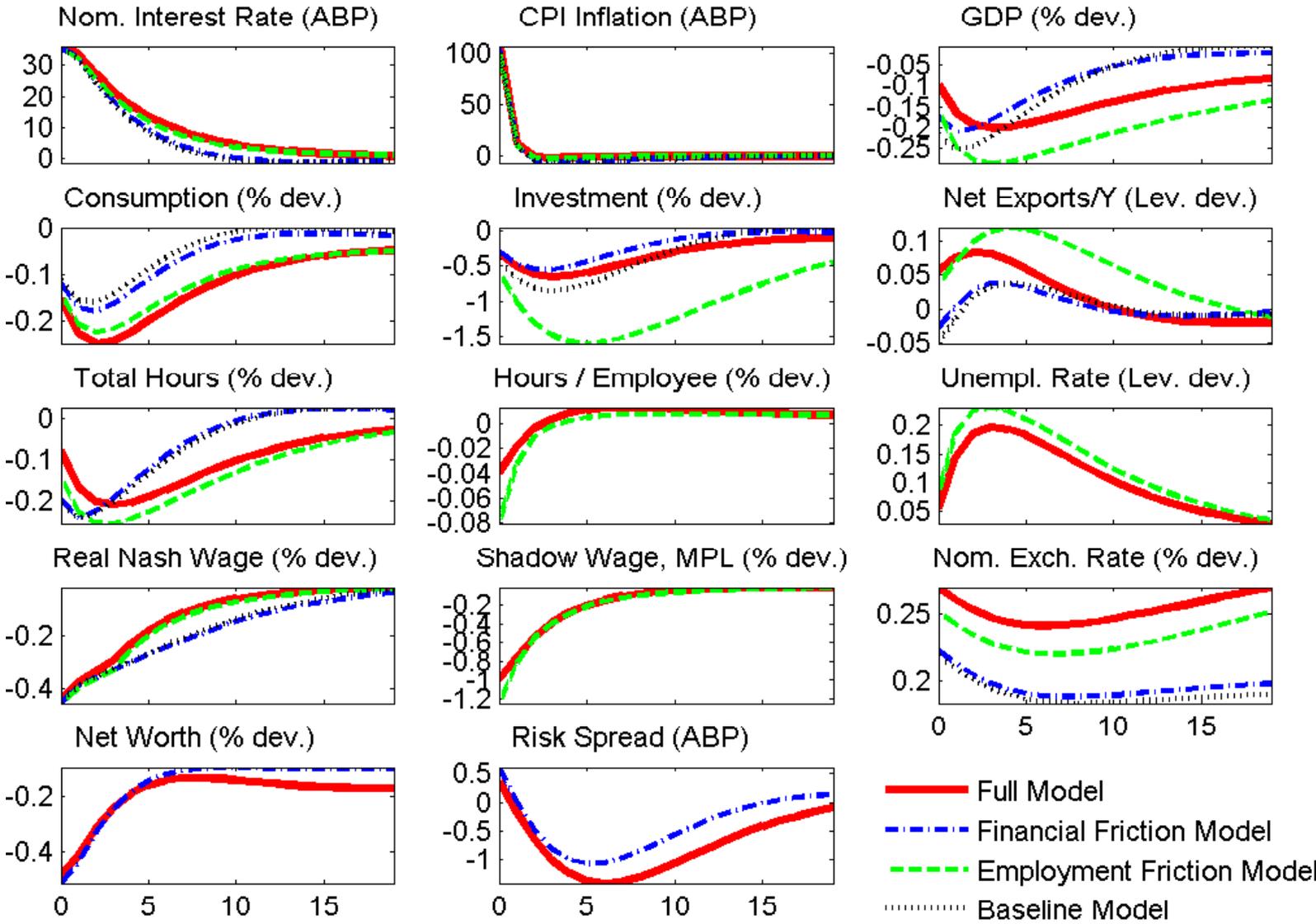
Entrepreneur Wealth Shock



Marginal Efficiency of Investment Shock



Domestic Markup Shock



Import Export Markup Shock

