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Search frictions and the business cycle in a small open economy DSGE model [☆]

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ABSTRACT

A labor market specification featuring search frictions and unemployment within an otherwise standard New Keynesian small open economy model significantly improves its ability to explain and predict both labor market data and other macroeconomic variables. We estimate the model with Chilean data and find that variations along the extensive margin of labor supply (i.e., employment) play a crucial role in the propagation of shocks, whereas the intensive margin (i.e., hours) is not important. Furthermore, foreign shocks are the key drivers of the business cycle, which is consistent with the empirical literature on open emerging economies. We conclude that a medium-scale DSGE model with this richer labor market specification is superior to one featuring the standard assumption of a labor market that always clears at a sticky nominal wage (à la Calvo) through variations along the intensive margin.

1. Introduction

Most New Keynesian DSGE models used for policy analysis and forecasting at central banks and other policy institutions assume that the labor market always clears at a sticky nominal wage (à la Calvo) through variations along the intensive margin of labor supply (i.e., hours), but there is no role for adjustment along the extensive margin (i.e., employment).[1] The latter stands in stark contrast to academic research that has emphasized the role of labor market flows based on search and matching theory. According to that literature, search frictions and matching can successfully explain several relevant labor

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[1] Examples of DSGE models used at central banks and other policy institutions that incorporate Calvo-type wage stickiness or some other form of wage stickiness that gives rise to a wage Phillips curve, e.g., due to wage adjustment costs à la Rotemberg, are discussed in Brubakk and Sveen (2009), Burgess et al. (2013), Chung et al. (2010), de Castro et al. (2011), Del Negro et al. (2013), Dorich et al. (2013), Erceg et al. (2006), González et al. (2011), Lees (2009), Medina and Soto (2007), Ratto et al. (2009), Schorfheide et al. (2010), and Smets et al. (2010).

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market facts, such as the existence of involuntary unemployment and the dynamics of job creation and job destruction (see Pissarides, 2011),[2] and the relative unimportance of hours per worker versus employment in the cyclical fluctuation of total hours worked (see Hansen, 1985, and Trigari, 2009).

Some of that disconnect between labor market research and labor market specifications in practical policy models may be due to the fact that the usefulness of search frictions in medium-scale quantitative DSGE models for monetary policy analysis and forecasting is not yet sufficiently well understood. Hence, in this paper we let search frictions compete with the standard labor market specification in a DSGE framework. In particular, we assess whether and how the inclusion of a search and matching specification à la Diamond (1982), Mortensen (1982) and Pissarides (1985), improves the empirical fit and forecasting performance of an otherwise standard New Keynesian small open economy (NK-SOE) model. Our model with search frictions features both the extensive and intensive margins of labor supply; endogenous separations following Mortensen and Pissarides (1994), Cooley and Quadrini (1999) and den Haan et al. (2000), so that fluctuations of employment in response to shocks are due to changes in the vacancies posted by firms, but also in higher or lower firing; and staggered Nash wage bargaining following Gertler et al. (2008), a Calvo-type process for wage determination by which, each period, only a fraction of firms renegotiates the nominal wage with its workforce. The analysis is conducted using Bayesian techniques and Chilean data. While our paper forms part of several recent studies that have investigated the usefulness of labor market search and matching in macroeconomic models, as we discuss below, we are among the first to analyze the benefits of search frictions in a small open economy context. In addition, only few related studies have examined the relevance of endogenous separations with both margins of labor supply in estimated DSGE models.

The shortcomings of labor market specifications in standard DSGE models, both for closed and open economies, become clear from a brief review. In particular, exogenous labor market shocks are typically found to be important drivers of aggregate dynamics in those models: in the Smets and Wouters (2003) euro area model, labor supply preference shocks are the most important drivers of output while wage markup shocks are responsible for the bulk of variations in real wages; whereas in the Smets and Wouters (2007) U.S. model where there is no separate labor supply shock, wage markup shocks account for most of medium- to long-term fluctuations in output and inflation. In Adolfson et al.'s (2007a) NK-SOE model, labor supply shocks are also among the most important shocks to explain output, wage and inflation dynamics in Sweden. The fact that exogenous labor market shocks are so important in standard DSGE models seems unsatisfactory, not only because their underlying determinants are hard to identify, but also because one might expect that labor market outcomes are to a large extent consequences of more structural shocks such as monetary or fiscal policy shocks or, in open economies, foreign shocks (i.e., shocks to foreign interest rates, foreign demand, commodity prices, etc.). In addition, all of the above models rely on relatively large real wage elasticities of individual hours worked to match fluctuations in total hours, which is known to be at odds with micro evidence (see Chetty et al., 2011).

Due to the above shortcomings, recent model developments using search and matching theory have attempted to improve labor market specifications and generate stronger endogenous propagation properties of DSGE models. For instance, Christiano et al. (2011) describe the labor market in a NK-SOE model using a search and matching framework with variations on both margins of labor supply.[3] Their estimation results for Swedish data show that the labor supply shock becomes unimportant in explaining output, the estimated elasticity of individual hours is relatively low, and no wage markup shock is needed. However, the labor supply shock is still the most important shock for both total hours and real wages, and basic foreign shocks are relatively unimportant for aggregate dynamics.[4] An earlier study by Krause et al. (2008) based on a closed economy model with search and matching estimated with U.S. data also found a relatively low elasticity of individual hours and a small role for labor supply shocks. However, in this model price markup and (ad hoc) match efficiency shocks are the dominant force in labor market fluctuations.[5] Part of the failure of this model to explain the fluctuations of both labor market variables and other macroeconomic variables such as output and inflation through more structural shocks may be due to the absence of endogenous separations, in line with the results of Sedláček (2014). Indeed, many studies have found that endogenous separations are important for understanding labor market flows and their interaction with output and inflation (e.g., Trigari, 2009).[6,7]

Hence, the success of search frictions in quantitative DSGE models has so far been mixed. Our results shed additional light on this issue. In particular, we find that the data strongly favor the model with search frictions over the standard model, as reflected by a significantly higher marginal data density, as well as a significantly better ability of the model with search frictions to match the majority of the second moments of the data. Furthermore, in the model with search

[2] See also Krause and Lubik (2014).

[3] See also Adolfson et al. (2013).

[4] This is related to the problem that NK-SOE models tend to have difficulties in accounting for the substantial influence of foreign shocks identified in many time series studies (see Justiniano and Preston, 2010).

[5] Similar results were obtained by Albertini et al. (2012) in a New Keynesian small open economy model estimated with data for New Zealand.

[6] A few recent studies have investigated the implications of search frictions in an emerging market context, including Boz et al. (2015) and Medina and Naudon (2012). However, these studies are based on calibrated models that abstract from nominal rigidities as well as the intensive margin and endogenous separations, unlike in our paper.

[7] Galí (2010) has introduced labor market frictions and unemployment in New Keynesian models without the matching function approach. As he explains, his approach is equivalent to the search and matching approach under a Cobb-Douglas matching function (Galí, 2010, p. 500). Since that is the functional form we use, we do not see any reason to think that his approach would not lead to results similar to ours. We have chosen the more widely used search and matching specification, because we believe it has the potential to resonate with a wider audience.

frictions, foreign shocks are far more important drivers of the business cycle than in the standard model. This finding is consistent with the large literature on the drivers of business cycles in small emerging economies such as Chile.[8] Finally, the forecasting performance of the model, for labor market variables as well as other key variables such as output and inflation, is also significantly improved by the search frictions. Our paper therefore provides further evidence that search frictions are useful to explain aggregate dynamics in quantitative DSGE models for small open economies.

An additional finding of our analysis is that labor search frictions seem to substitute for rigidities in investment. In the model with search frictions and in the standard model, investment is subject to adjustment costs, as is typical in the quantitative DSGE literature. However, the estimated elasticity of adjustment costs is substantially lower in the model with search frictions. When the model features these frictions, capital frictions are less necessary to fit the data, further highlighting the importance of search and matching in the labor market as a propagation mechanism.

The rest of the paper is organized as follows. Section 2 presents our NK-SOE model with search frictions and matching, while the model with the standard labor market specification is described in Section 3.[9] Section 4 describes the calibration and estimation strategy, while Section 5 compares the fit of the model under the two labor market specifications, discusses the role of search frictions in propagating various types of shocks, and provides an analysis of the forecasting performance of the different models. Finally, section 6 concludes.

2. An NK-SOE model with search and matching

This section presents our NK-SOE model with nominal and real rigidities, search and matching à la Diamond (1982), Mortensen (1982) and Pissarides (1985) with endogenous separations in the labor market following Cooley and Quadrini (1999) and den Haan et al. (2000), and staggered Nash wage bargaining following Gertler et al. (2008). The core model shares the structure of the baseline NK-SOE model presented in García-Cicco et al. (2015).[10] Domestic goods are produced with capital and labor, there is habit formation in consumption, there are adjustment costs in investment, firms face a Calvo-pricing problem with partial indexation, and there is imperfect exchange rate pass-through into import prices in the short run due to local currency price stickiness. The economy also exports an exogenous endowment of a commodity good, which captures the importance of commodity exports in many small open economies including Chile. The economy is subject to shocks to preferences, the rate of separation from employment, technology (neutral and investment-specific), commodity production, government expenditures, monetary policy, foreign demand, foreign inflation, foreign interest rates, and the international price of the commodity good.

2.1. Households

There is a continuum of infinitely lived households normalized to one with identical asset endowments and identical preferences. Household members can be either employed or unemployed. All members pool their assets so as to ensure equal consumption, that is, there is perfect insurance of unemployment risk. Each member has the following separable utility function with habit formation[11]:

$$u(C_t, \check{C}_{t-1}) - g(h_t) = \frac{1}{1-\sigma}\left[\left(C_t - \varsigma \check{C}_{t-1}\right)^{1-\sigma} - 1\right] - \Theta_t A_{t-1}^{1-\sigma}\kappa_t \frac{h_t^{1+\phi}}{1+\phi},$$

where C_t is individual consumption of a final good, $\check{C}_t$ is aggregate consumption (which each member takes as given), h_t is hours per worker, κ_t is an exogenous shock to the disutility of labor supply, and A_t is an economy-wide stochastic trend (see below). Following Galí et al. (2011), Θ_t is an endogenous preference shifter that regulates the strength of the wealth effect on labor supply and satisfies[12,13]:

$$\Theta_t \equiv \widetilde{\chi}_t A_{t-1}^{\sigma}(\check{C}_t - \varsigma \check{C}_{t-1})^{-\sigma}, \qquad \widetilde{\chi}_t = \widetilde{\chi}_{t-1}^{1-\upsilon} A_{t-1}^{-\sigma\upsilon}\left(\check{C}_t - \varsigma \check{C}_{t-1}\right)^{\sigma\upsilon}.$$

The parameters σ, ϕ and ς are the inverse elasticity of intertemporal substitution, the inverse Frisch elasticity of hours worked, and the degree of habit formation, respectively. The parameter $\upsilon \in [0, 1]$ regulates the strength of the wealth effect: when $\upsilon = 1$, preferences are of the standard CRRA type; when $\upsilon = 0$, the wealth effect is shut down, as in the preferences in Greenwood et al. (1988). The welfare function of a representative household over time is then given by:

8 See, for example, Fernández et al. (2017, 2018), Kose (2002), and Mendoza (1995).

9 The equilibrium conditions and the strategy for the steady state for both models are provided in the online appendix.

10 The model is a shrinked-down version of the Medina and Soto (2007) model developed for policy analysis and forecasting at the Central Bank of Chile.

11 Throughout, uppercase letters denote variables containing a unit root in equilibrium (either due to technology or to long-run inflation) while lowercase letters indicate variables with no unit root. Real variables are constructed using the domestic consumption good as the numeraire. In the online appendix we describe how each variable is transformed to achieve stationarity in equilibrium. Variables without time subscript denote non-stochastic steady state values in the stationary model.

12 We assume external habit formation instead of internal habit formation as in García-Cicco et al. (2015) to simplify the analysis.

13 The disutility of work is multiplied by $A_{t-1}^{1-\sigma}$ to maintain a balanced steady-state growth path.

$$E_t \sum_{s=0}^{\infty} \beta^s \varrho_{t+s} \left[u\left(C_{t+s}, \check{C}_{t+s-1}\right) - n_{t+s} g\left(h_{t+s}\right) \right], \tag{1}$$

where $\beta \in (0,1)$ is the intertemporal discount factor, ϱ_t is an exogenous preference shock and n_t is the number of employed household members. Note that, in equilibrium, $C_t = \check{C}_t$ for all t.[14]

Households save and borrow by purchasing nominal domestic currency-denominated government bonds ($P_t B_t$) and by trading foreign currency bonds ($P_t^* B_t^*$) with foreign agents. They also purchase an investment good (I_t) which determines next period's physical capital stock (K_t). Let R_t and R_t^* denote the gross nominal returns on domestic and foreign bonds, respectively, and r_t^K be the gross real return on capital. The employed members earn a real wage of W_t per hour, while unemployed members earn an amount b_t^u of unemployment benefits, which is paid out by the government.[15] Let rer_t be the real exchange rate (i.e., the price of foreign consumption goods in terms of domestic consumption goods), let T_t denote real lump-sum tax payments to the government and let Σ_t collect real dividend income from the ownership of firms. The period-by-period budget constraint of the household (in real terms) is then given by:

$$C_t + I_t + B_t + rer_t B_t^* + T_t = W_t h_t n_t + (1-n_t) b_t^u + \frac{R_{t-1} B_{t-1}}{\pi_t} + rer_t \frac{R_{t-1}^* \xi_{t-1} B_{t-1}^*}{\pi_t^*} + r_t^K K_{t-1} + \Sigma_t, \tag{2}$$

where π_t and π_t^* denote the gross inflation rates of the domestic and foreign consumption-based price indices P_t and P_t^*, respectively. The variable ξ_{t-1} denotes a country premium defined below. The physical capital stock evolves according to the law of motion:

$$K_t = (1-\delta) K_{t-1} + [1 - \Gamma(I_t/I_{t-1})] \varpi_t I_t, \qquad \delta \in (0,1], \tag{3}$$

where I_t denotes investment expenditures and

$$\Gamma\left(\frac{I_t}{I_{t-1}}\right) = \frac{\gamma}{2}\left(\frac{I_t}{I_{t-1}} - \bar{a}\right)^2, \qquad \gamma \geq 0, \qquad \bar{a} \geq 1,$$

are convex investment adjustment costs. The variable ϖ_t is an investment shock that captures changes in the efficiency of the investment process.[16] The household chooses C_t, I_t, K_t, B_t, and B_t^* to maximize (1) subject to (2)-(3), taking W_t, h_t, n_t, R_t, R_t^*, ξ_t, π_t, π_t^*, r_t^K, rer_t, T_t, Σ_t, B_{t-1}, B_{t-1}^* and K_{t-1} as given. The household's employment (n_t), hours worked (h_t), and the real wage (W_t) are determined as outcomes of a search and matching process and a bargaining process (see below).

The real interest rates are defined as

$$r_t = R_{t-1}\pi_t^{-1}, \qquad r_t^* = R_{t-1}^* \xi_{t-1} \left(\pi_t^*\right)^{-1}.$$

The country premium is given by (see Schmitt-Grohé and Uribe, 2003):

$$\xi_t = \bar{\xi} \exp\left[-\psi \frac{rer_t B_t^*/A_{t-1} - rer \times b^*}{rer \times b^*} + \frac{\zeta_t^o - \zeta^o}{\zeta^o} + \frac{\zeta_t^u - \zeta^u}{\zeta^u}\right], \qquad \psi > 0, \qquad \bar{\xi} \geq 1,$$

where ζ_t^o and ζ_t^u are exogenous shocks to the country premium, where we assume that ζ_t^o is observable while ζ_t^u is unobservable. The foreign nominal interest rate R_t^* evolves exogenously, whereas the domestic central bank sets R_t.

2.2. Labor market dynamics

The labor market is subject to Diamond-Mortensen-Pissarides-type search frictions and matching. In order to form new employment relationships (matches), workers must search and firms must post vacancies. We assume that all unemployed workers look for jobs. The number of matches $\mathcal{M}_t$, which begin work in period $t+1$, is given by the matching function $\mathcal{M}_t = m\, v_t^{1-\mu} u_t^{\mu}$, where u_t is the number of searching workers, v_t is the number of vacancies posted, m is a match efficiency parameter, and $\mu \in (0,1)$ is the match elasticity. At the beginning of each period, before new matches are formed, a fraction ρ_t of existing matches terminate. The total separation rate $\rho_t = \rho_t^x + (1-\rho_t^x)\rho_t^n$ includes the exogenous component ρ_t^x and the endogenous component ρ_t^n. Endogenous separations occur if a firm's operating cost F_t is greater than an endogenously determined threshold $\bar{f}_t$. If that is the case, the firm decides not to produce and all its workers are fired.[17] This

[14] Under separable preferences and external habit formation, (1) results from the general specification $E_t \sum_{s=0}^{\infty} \beta^s \varrho_{t+s} \Big[n_{t+s} u\left(C_{t+s}^n, \check{C}_{t+s-1}\right) - n_{t+s} g\left(h_{t+s}\right) + (1-n_{t+s}) u\left(C_{t+s}^u, \check{C}_{t+s-1}\right) \Big]$ since, in equilibrium, $C_t^n = C_t^u$ for all t.

[15] We allow unemployment benefits to grow proportionately with A_{t-1} in order to maintain a balanced steady-state growth path. Then, $b_t^u = \bar{b} A_{t-1}$ with $\bar{b} \geq 0$.

[16] See Greenwood et al. (1997) and Justiniano et al. (2011).

[17] We assume additive idiosyncratic operating costs as in Cooley and Quadrini (1999) to avoid excessive cross-sectional heterogeneity in hours per worker, which would result from a specification as in den Haan et al. (2000) with a multiplicative idiosyncratic productivity shock in the production function.

operating cost is assumed to be i.i.d. across firms and time with c.d.f. $\mathcal{F}^w(\cdot)$. The endogenous separation rate is therefore $\rho_t^n = \Pr(F_t > \bar{f}_t) = 1 - \mathcal{F}^w(\bar{f}_t)$. The evolution of aggregate employment is thus given by $n_t = (1-\rho_t)[n_{t-1} + \mathcal{M}_{t-1}]$, and the number of unemployed workers searching for a job is $u_t = 1 - n_t$. The probability that a searching worker is matched to a new job is then $s_t = \mathcal{M}_t/u_t = m\ (v_t/u_t)^{1-\mu}$, the probability that a firm fills a vacancy is $e_t = \mathcal{M}_t/v_t = m(v_t/u_t)^{-\mu}$, and labor market tightness can be defined as $\theta = v_t/u_t$.

2.3. Determination of wages and hours

As in Gertler et al. (2008), nominal wages are decided through staggered Nash bargaining between a continuum of wholesale firms, indexed by $i \in [0,1]$, and their corresponding labor forces. Each period, the nominal wage is renegotiated with probability $1-\theta^w$; otherwise, it is set to last period's wage indexed to inflation. Workers hired in between negotiations receive the current wage.

Assuming constant returns to scale at the firm level, all workers are the same at the margin. This allows us to focus only on the marginal match when writing the surpluses of each firm i and its marginal worker.

Firm surplus. The value of having another productive worker at time t is:

$$\mathcal{J}_t\left(W_{it}^n\right) = \frac{P_t^w}{P_t} mpn_t - \frac{W_{it}^n}{P_t} h_t - \Phi_t + E_t \Xi_{t,t+1}\left[(1-\rho_{t+1})\,\mathcal{J}_{t+1}\left(W_{it+1}^n\right) + \rho_{t+1}\mathcal{V}_{t+1}\right], \tag{4}$$

where $\Xi_{t,t+1} = \beta\left(\varrho_{t+1}/\varrho_t\right)\Lambda_{t+1}/\Lambda_t$ is the firm's stochastic discount factor for real payoffs, W_{it}^n/P_t is the real wage that firm i is paying, P_t^w/P_t is the price of the wholesale goods in terms of the final good, mpn_t is the marginal product of labor (which is the same across firms due to constant returns to scale), Φ_t is the expected operating cost, conditional on production taking place (see below), and $\mathcal{V}_t$ is the value to firm i of posting a new vacancy, which is given by:

$$\mathcal{V}_t = -\omega_{it} + E_t \Xi_{t,t+1}\left[e_t\,(1-\rho_{t+1})\,\mathcal{J}_{t+1}\left(W_{it+1}^n\right) + (1 - e_t\,(1-\rho_{t+1}))\,\mathcal{V}_{t+1}\right], \tag{5}$$

where ω_{it} is the cost of posting a new vacancy, with $\omega_{it} = \omega_t = A_{t-1}\bar{\omega}$.[18] We assume free-entry of firms to the labor market, which implies that $\mathcal{V}_t = 0$, so $\omega_t/e_t = E_t \Xi_{t,t+1}\,(1-\rho_{t+1})\,\mathcal{J}_{t+1}\left(W_{it+1}^n\right)$ in equilibrium. Given these assumptions, the firm's surplus $\mathcal{F}_t\left(W_{it}^n\right) = \mathcal{J}_t\left(W_{it}^n\right) - \mathcal{V}_t$ is given by:

$$\mathcal{F}_t\left(W_{it}^n\right) = \frac{P_t^w}{P_t} mpn_t - \frac{W_{it}^n}{P_t} h_t - \Phi_t + \frac{\omega_t}{e_t}.$$

Worker surplus. To the marginal worker, the value of being employed at firm i is:

$$\mathcal{E}_t\left(W_{it}^n\right) = \frac{W_{it}^n}{P_t} h_t - \frac{g\left(h_t\right)}{\Lambda_t} + E_t \Xi_{t,t+1}\left[(1-\rho_{t+1})\,\mathcal{E}_{t+1}\left(W_{it+1}^n\right) + \rho_{t+1}\mathcal{U}_{t+1}\right], \tag{6}$$

where $\mathcal{U}_t$ is the value of unemployment, given by:

$$\mathcal{U}_t = b_t^u + E_t \Xi_{t,t+1}\left[s_t\,(1-\rho_{t+1})\,\bar{\mathcal{E}}_{t+1} + (1 - s_t\,(1-\rho_{t+1}))\,\mathcal{U}_{t+1}\right]. \tag{7}$$

Workers do not direct their search, so the value of unemployment requires defining $\bar{\mathcal{E}}_t = \int_0^1 \mathcal{E}_t\left(W_{it}^n\right)\frac{\mathcal{M}_{it}}{\mathcal{M}_t}di$, which denotes the average value of employment conditional on being a new worker. Thus, the surplus of the marginal worker $\mathcal{W}_t\left(W_{it}^n\right) = \mathcal{E}_t\left(W_{it}^n\right) - \mathcal{U}_t$ is:

$$\mathcal{W}_t\left(W_{it}^n\right) = \frac{W_{it}^n}{P_t} h_t - \frac{g\left(h_t\right)}{\Lambda_t} - b_t^u + E_t \Xi_{t,t+1}\,(1-\rho_{t+1})\left(\mathcal{W}_{t+1}\left(W_{it+1}^n\right) - s_t\overline{\mathcal{W}}_{t+1}\right),$$

where

$$\overline{\mathcal{W}}_t = \bar{\mathcal{E}}_t - b_t^u - E_t \Xi_{t,t+1}\left[s_t\,(1-\rho_{t+1})\,\overline{\mathcal{W}}_{t+1} + \mathcal{U}_{t+1}\right]$$

is the average surplus from employment conditional on being a new worker.

Negotiated wage. The newly negotiated nominal wage W_t^{n*} is chosen to maximize the Nash product of the match subject to staggered wage contracting. Then, for $j \geq 1$:

$$\max_{W_t^{n*}} \left(\mathcal{W}_t\left(W_{it}^n\right)\right)^{\varphi}\left(\mathcal{F}_t\left(W_{it}^n\right)\right)^{1-\varphi}$$

$$\text{s.t. } W_{it+j}^n = \begin{cases} \Gamma_{t+j-1}^W W_{it+j-1}^n \text{ with probability } \theta^w \\ W_{t+j}^{n*} \text{ with probability } 1-\theta^w \end{cases}$$

[18] We allow ω_t to grow proportionately with A_{t-1} to maintain a balanced growth path.

where $\varphi \in (0,1)$ is the worker's relative bargaining power, $\Gamma_t^W = \gamma_t^W \pi_t^{\vartheta_W}$ is a wage indexation variable with $\vartheta_W \in [0,1]$ controlling the degree of indexation to inflation π_t, and $\gamma_t^W = (A_t/A_{t-1})^{\alpha_w} \overline{\pi}^{1-\vartheta_W}$ provides an extra adjustment for productivity growth and trend inflation. Notice that the average duration of the negotiated wage is given by $1/(1-\theta^W)$, so the parameter θ^W measures the degree of nominal wage stickiness. The optimality condition of the Nash bargaining problem is:

$$\varphi \epsilon_t \mathcal{F}_t \left(W_t^{n*}\right) = (1-\varphi)\, \mu_t \mathcal{W}_t \left(W_t^{n*}\right)$$

where

$$\epsilon_t = h_t + \theta^w \Gamma_t^W E_t \left\{ \Xi_{t,t+1} (1-\rho_{t+1}) \frac{P_t}{P_{t+1}} \epsilon_{t+1} \right\},$$
$$\mu_t = h_t + \theta^w \Gamma_t^W (1-e_t) E_t \left\{ \Xi_{t,t+1} (1-\rho_{t+1}) \frac{P_t}{P_{t+1}} \mu_{t+1} \right\}.$$

When $\theta^w = 0$ (i.e., with period-by-period Nash bargaining), $\epsilon_t = \mu_t$, and $\overline{\mathcal{W}}_t = \mathcal{W}_t \left(W_t^{n*}\right)$. It follows that:

$$\frac{W_t^{n*}}{P_t} h_t = \varphi \left(\frac{P_t^w}{P_t} mpn_t - \Phi_t + \theta_t \omega_t \right) + (1-\varphi) \left(b_t^u + \frac{g(h_t)}{\Lambda_t} \right),$$

which is the standard wage equation under period-by-period Nash bargaining. With $\theta^w > 0$, the negotiated wage is implicitly determined by the value functions defined above and the optimality condition for W_t^{n*}.

Average wage. The average nominal wage across workers, $W_t^n = \int_0^1 W_{it}^n \frac{n_{it}}{n_t} di$, can be written as follows:

$$W_t^n = \left(1-\theta^w\right) W_t^{n*} + \theta^w \overline{W}_t^n,$$

where $\overline{W}_t^n = \int_0^1 \left(\Gamma_{t-1}^W W_{it-1}^n\right) \frac{n_{it}}{n_t} di$ is the average nominal wage of non-negotiating workers, which evolves according to:

$$\overline{W}_t^n = \frac{\Gamma_{t-1}^W}{n_t} (1-\rho_t) \left((1-s_{t-1}) W_{t-1}^n n_{t-1} + s_{t-1} \widetilde{W}_{t-1}^n \right),$$

and $\widetilde{W}_t^n = \int_0^1 W_{it}^n di = \left(1-\theta^w\right) W_t^{n*} + \theta^w \Gamma_{t-1}^W \widetilde{W}_{t-1}^n$.

Individual hours of work. Optimal h_t is determined by maximizing the total match surplus, $\mathcal{W}_t + \mathcal{F}_t$. The optimality condition is

$$\frac{g'(h_t)}{\Lambda_t} = mrs_t = \frac{P_t^w}{P_t} \frac{\partial mpn_t}{\partial h_t},$$

which says that individual hours adjust until the marginal rate of substitution between consumption and leisure equates the marginal product of labor of an additional hour.

2.4. Firms

There are different types of firms that are all owned by the households. There is a set of perfectly competitive wholesale firms that produce different varieties of a home good with labor and capital as inputs, a set of monopolistically competitive retail firms that buy and re-sell those varieties, a set of monopolistically competitive importing firms, and three groups of perfectly competitive aggregators: one packing different varieties of the home good into a composite home good, one packing imported varieties into a composite foreign good, and another one that bundles the composite home and foreign goods to create a final good. This final good is purchased by households (C_t, I_t) and the government (G_t).[19] In addition, there is a set of competitive firms producing a homogeneous commodity good that is exported abroad. A proportion of those commodity-exporting firms is owned by the government and the remaining proportion is owned by foreign agents. The productive structure of the model, with its different layers of intermediate and retail goods, and bundlers, is standard in the New Keynesian small open economy literature. It requires more complexity than closed-economy models, most of which need only two sets of firms (wholesale and retail). The total mass of firms in each sector is normalized to one. Throughout, we denote productions/supply with the letter Y and inputs/demand with X.

2.4.1. Final goods

A representative final goods firm demands composite home and foreign goods in the amounts X_t^H and X_t^F, respectively, and combines them according to the technology

$$Y_t^C = \left[(1-o)^{\frac{1}{\eta}} \left(X_t^H\right)^{\frac{\eta-1}{\eta}} + o^{\frac{1}{\eta}} \left(X_t^F\right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \qquad o \in (0,1), \qquad \eta > 0. \tag{8}$$

Let P_t^H/P_t and P_t^F/P_t denote the relative prices of X_t^H and X_t^F in terms of the final good. Subject to (8), the firm maximizes its profits $\Pi_t^C = Y_t^C - (P_t^H/P_t) X_t^H - (P_t^F/P_t) X_t^F$ over the input demands X_t^H and X_t^F taking prices as given.

[19] The final good is also used to pay vacancy posting and operating costs.

2.4.2. Home composite goods

A representative home composite goods firm demands home goods of all varieties $i \in [0, 1]$ in amounts X_{it}^H and combines them according to the technology

$$Y_t^H = \left[\int_0^1 \left(X_{it}^H \right)^{\frac{\epsilon_H - 1}{\epsilon_H}} dj \right]^{\frac{\epsilon_H}{\epsilon_H - 1}}, \qquad \epsilon_H > 0. \tag{9}$$

Let P_{it}^H / P_t^H denote the price of the good of variety i in terms of the home composite good. Subject to (9), the firm maximizes its profits $\Pi_t^H = P_t^H Y_t^H - \int_0^1 P_{it}^H X_{it}^H di$ over the input demands X_{it}^H taking the prices P_t^H and P_{it}^H as given, which yields the input demand functions

$$X_{it}^H = \left(\frac{P_{it}^H}{P_t^H} \right)^{-\epsilon_H} Y_t^H, \quad \text{for all } i. \tag{10}$$

2.4.3. Wholesale home goods and the job creation condition

There are competitive wholesale firms that produce home intermediate goods and sell them to retailers. Each firm $i \in [0, 1]$ produces according to the following technology:

$$Y_{it}^H = z_t K_{it-1}^{\alpha} \left(A_t n_{it} h_{it} \right)^{1-\alpha}, \quad \alpha \in [0, 1), \tag{11}$$

where z_t is an exogenous stationary neutral technology shock, while A_t (with $a_t \equiv A_t / A_{t-1}$) is a non-stationary labor-augmenting technology trend, both common to all firms. Wholesale firms choose how much capital to rent and how much labor to hire, subject to an identical vacancy posting cost of ω_t per vacancy and firm-specific operating cost F_{it} (these costs are assumed to be paid in terms of final goods). Firm i's profit is then given by:

$$\Pi_{it}^w = \frac{P_t^w}{P_t} Y_{it}^H - r_t^K K_{it-1} - W_{it} h_{it} n_{it} - \Phi_{it} n_{it} - \omega_t v_{it},$$

where

$$\Phi_{it} n_{it} = n_{it} A_{t-1} \int_0^{\bar{f}_{it}} F_{it} \frac{d\mathcal{F}^w \left(F_{it} \right)}{\mathcal{F}^w \left(\bar{f}_{it} \right)}$$

is the total operating cost of firm i conditional on producing, while $\omega_t v_{it}$ is the total vacancy posting cost with $\omega_t = \omega A_{t-1}$, $\omega \geq 0$.[20] The firm's workforce evolves over time as the number of workers from the previous period plus new hires, whose jobs do not get terminated:

$$n_{it} = (1 - \rho_t) \left(n_{it-1} + e_{t-1} v_{it-1} \right). \tag{12}$$

Since today's choice of v_{it} affects tomorrow's workforce, the firm faces an intertemporal decision problem to maximize expected discounted profits. Hence, the firm chooses K_{it-1}, n_{it} and v_{it} to maximize $E_t \sum_{s=0}^{\infty} \Xi_{t,t+s} \Pi_{it+s}^w$ subject to (11) and (12). Note that the firm takes as given the expected path of wages. If the firm is able to renegotiate, it bargains as previously described over a new wage. If it is not able to renegotiate, it takes the previous period's wage as given, as well as the probability that it will renegotiate in the future. The first-order conditions for this problem yield the job creation condition (where we drop subscripts i due to symmetry)[21]:

$$\frac{\omega_t}{e_t} = E_t \Xi_{t,t+1} \left(1 - \rho_{t+1} \right) \left(\frac{P_{t+1}^w}{P_{t+1}} mpn_{t+1} - \frac{W_{t+1}^n}{P_{t+1}} h_{t+1} - \Phi_{t+1} + \frac{\omega_{t+1}}{e_{t+1}} \right).$$

That is, firms post vacancies to expand employment until que effective cost of posting an additional vacancy (ω_t times the expected duration of the vacancy $1/e_t$) equals the expected marginal product of an extra worker, minus wage payment and average operating cost, plus its expected return from the reduction of vacancy posting costs, conditional on the job not being severed in period $t+1$. Finally, the threshold value $\bar{f}_t$ is obtained by solving $\mathcal{F}_t = 0$. We have that:

$$A_{t-1} \bar{f}_t = \frac{P_t^w}{P_t} mpn_t - \frac{W_t^n}{P_t} h_t + \frac{\omega_t}{e_t}.$$

[20] We allow operating costs and vacancy posting costs to grow proportionately with the technology trend to maintain a balanced steady-state growth path.

[21] To obtain the job creation condition, we have used the fact that the Lagrange multiplier associated with the evolution of the firm's workforce is equivalent to $\mathcal{J}_t$, the value of a marginal job to the firm.

2.4.4. Retail goods

Retail firms buy and distribute wholesale goods. There is one retailer associated with each variety of the wholesale good. The retailer distributing variety i satisfies the demand given by (10), but it has monopoly power for its variety. Given nominal marginal costs $P_t^H mc_{it}^H = P_t^m$, the firm chooses its price P_{it}^H to maximize profits.[22] In setting prices, the firm faces a Calvo-type problem, whereby each period it can change its price optimally with probability $1-\theta_H$, and if it cannot optimally change its price, it indexes its previous price according to a weighted product of past and steady state inflation with weights $\vartheta_H \in [0,1]$ and $1-\vartheta_H$.

2.4.5. Foreign composite goods

A representative foreign composite goods firm demands foreign goods of all varieties $i \in [0,1]$ in amounts X_{it}^F and combines them according to the technology

$$Y_t^F = \left[\int_0^1 \left(X_{it}^F\right)^{\frac{\epsilon_F-1}{\epsilon_F}} dj\right]^{\frac{\epsilon_F}{\epsilon_F-1}}, \qquad \epsilon_F > 0. \tag{13}$$

Let P_{it}^F/P_t^F denote the price of the good of variety i in terms of the foreign composite good. Subject to (13), the firm maximizes its profits $\Pi_t^F = P_t^F Y_t^F - \int_0^1 P_{it}^F X_{it}^F di$ over the input demands X_{it}^F taking the prices P_t^F and P_{it}^F as given. The first-order conditions yield the input demand functions:

$$X_{it}^F = \left(\frac{P_{it}^F}{P_t^F}\right)^{-\epsilon_F} Y_t^F, \quad \text{for all } i. \tag{14}$$

2.4.6. Foreign goods of variety i

Importing firms buy an amount Y_t^m of a homogeneous foreign good at the price P_t^{F*} in the world market and convert this good into varieties Y_{it}^F that are sold domestically, where $Y_t^m = \int_0^1 Y_{it}^F di$. The firm producing variety i satisfies the demand given by (14) but it has monopoly power for its variety. As it takes one unit of the foreign good to produce one unit of variety i, nominal marginal costs in terms of composite goods prices are

$$P_t^F mc_{it}^F = P_t^F mc_t^F = S_t P_t^{F*}, \tag{15}$$

where S_t is the nominal exchange rate (defined as the price of one unit of foreign currency in terms of domestic currency). Given marginal costs, the firm producing variety i chooses its price P_{it}^F to maximize profits. In setting prices, the firm faces a Calvo-type problem, whereby each period it can change its price optimally with probability $1-\theta_F$, and if it cannot optimally change its price, it indexes its previous price according to a weighted product of past and steady state inflation with weights $\vartheta_F \in [0,1]$ and $1-\vartheta_F$. In this way, the model features delayed pass-trough from international to domestic prices.

2.4.7. Commodities

A representative firm produces a quantity Y_t^{Co} of a commodity good in each period. Commodity production evolves exogenously according to the process

$$\log(Y_t^{Co}/A_{t-1}) = (1-\rho_{y^{Co}})\log(\bar{y}^{Co}) + \rho_{y^{Co}}\log(Y_{t-1}^{Co}/A_{t-2}) + \varepsilon_t^{y^{Co}}, \qquad \rho_{y^{Co}} \in [0,1), \qquad \bar{y}^{Co} > 0.$$

The entire production is sold abroad at a given international price P_t^{Co*}. The real foreign and domestic prices are denoted as p_t^{Co*} and p_t^{Co}, respectively, where p_t^{Co*} is assumed to evolve exogenously. The real domestic currency income generated in the commodity sector is therefore equal to $p_t^{Co} Y_t^{Co}$. The government receives a share $\chi \in [0,1]$ of this income and the remaining share goes to foreign agents.

2.5. Fiscal and monetary policy

The government consumes an exogenous stream of final goods (G_t), pays unemployment benefits, levies lump-sum taxes, issues one-period bonds and receives a share of the income generated in the commodity sector. We assume for simplicity that the public asset position is completely denominated in domestic currency. Hence, the government satisfies the following period-by-period constraint

$$G_t + b_t^u u_t + r_t B_{t-1} = T_t + B_t + \chi p_t^{Co} Y_t^{Co}.$$

Monetary policy is carried out according to a Taylor rule of the form

[22] Note that mc_{it}^H is real marginal cost expressed in terms of home composite goods prices.

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\bar{\pi}}\right)^{\alpha_\pi} \left(\frac{Y_t/Y_{t-1}}{a_{t-1}}\right)^{\alpha_y}\right]^{1-\rho_R} \exp(\varepsilon_t^R),$$

where R is the monetary policy rate in the long-run, $\bar{\pi}$ is target inflation and ε_t^R is an n.i.d. shock that captures deviations from the rule.

2.6. Rest of the world

Foreign agents demand home composite goods and buy the domestic commodity production. There are no transaction costs or other barriers to trade. The structure of the foreign economy is identical to the domestic economy, but the domestic economy is assumed to be small relative to the foreign economy. The latter implies that the foreign producer price level P_t^{F*} is identical to the foreign consumption-based price index P_t^*. Further, let P_t^{H*} denote the price of home composite goods expressed in foreign currency. Given full tradability and competitive export pricing, the law of one price holds separately for home composite goods and the commodity good, i.e. $P_t^H = S_t P_t^{H*}$ and $P_t^{Co} = S_t P_t^{Co*}$. That is, domestic and foreign prices of both goods are identical when expressed in the same currency. Due to local currency pricing, a weak form of the law of one price holds for foreign composite goods, i.e. $P_t^F mc_t^F = S_t P_t^{F*}$ from (15). The real exchange rate rer_t therefore satisfies

$$rer_t = \frac{S_t P_t^*}{P_t} = \frac{S_t P_t^{F*}}{P_t} = \frac{P_t^F mc_t^F}{P_t} = p_t^F mc_t^F,$$

and the commodity price in terms of domestic consumption goods is given by

$$p_t^{Co} = \frac{P_t^{Co}}{P_t} = \frac{S_t P_t^{Co*}}{P_t} = \frac{S_t P_t^*}{P_t} p_t^{Co*} = p_t^F p_t^{Co*}.$$

We also have the relation $rer_t/rer_{t-1} = \pi_t^S \pi_t^*/\pi_t$, where $\pi_t^S = S_t/S_{t-1}$ is the gross rate of nominal exchange rate depreciation. Further, foreign demand for the home composite good X_t^{H*} is given by the schedule

$$X_t^{H*} = o^* \left(\frac{P_t^{H*}}{P_t^*}\right)^{-\eta^*} Y_t^*, \qquad o^* \in (0,1), \qquad \eta^* > 0,$$

where Y_t^* denotes foreign aggregate demand or GDP. Both Y_t^* and π_t^* evolve exogenously.

2.7. Aggregation and market clearing

Taking into account the market clearing conditions for the different markets, we can define the trade balance in units of final goods as

$$TB_t = \frac{P_t^H X_t^{H*}}{P_t} + \frac{S_t P_t^{Co*} Y_t^{Co}}{P_t} - \frac{S_t P_t^{F*} Y_t^m}{P_t}.$$

Further, we define real GDP as follows:

$$Y_t = C_t + I_t + G_t + X_t^{H*} + Y_t^{Co} - Y_t^m.$$

Then, the GDP deflator P_t^Y is implicitly defined as

$$\frac{P_t^Y}{P_t} Y_t = C_t + I_t + G_t + TB_t.$$

Finally, the net foreign asset position evolves according to

$$B_t^* + (1-\chi) \frac{P_t^{Co*} Y_t^{Co}}{P_t^*} = r_t^* B_{t-1}^* + \frac{TB_t}{rer_t}.$$

2.8. Driving forces

For each exogenous variable in the model, we assume a process of the form

$$\log(x_t/\bar{x}) = H_x \log(x_{t-1}/\bar{x}) + \varepsilon_t^x, \qquad H_x \in [0,1), \qquad \bar{x} > 0,$$

for $x = \{\varrho, \kappa, \rho^x, \varpi, z, a, \zeta^o, \zeta^u, R^*, \pi^*, p^{Co*}, y^{Co}, y^*, g\}$, where the ε_t^x are i.i.d. shocks. The model economy is buffeted by shocks to: consumption preferences (ϱ), labor supply preferences (κ), the separation rate (ρ^x), investment technology (ϖ), observed (ζ^o) and unobserved (ζ^u) components of the country premium, foreign interest rates (R^*), foreign inflation (π^*), the commodity price (p^{Co*}), foreign demand (y^*), and government consumption (g).

We further assume that the idiosyncratic shock F_t is log-normally distributed with mean 0 and standard deviation σ_w.[23]

3. The standard model

This section briefly describes the model with the standard labor market specification, in which employment varies only at the intensive margin (hours), the labor market always clears, and there is monopolistic wage setting à la Calvo, following Schmitt-Grohé and Uribe (2006, 2007). Most of the model is identical to the model with search frictions. The differences are discussed below.

3.1. Households

Expected discounted utility of a representative household is given by

$$E_t \sum_{s=0}^{\infty} \beta_{t+s}^s \varrho_{t+s} \left[\frac{1}{1-\sigma} \left(C_{t+s} - \varsigma C_{t+s-1} \right)^{1-\sigma} - \Theta_{t+s} \kappa_{t+s} A_{t+s-1}^{1-\sigma} \frac{h_{t+s}^{1+\phi}}{1+\phi} \right]. \tag{16}$$

The period-by-period budget constraint of the household is given by:

$$C_t + I_t + B_t + rer_t B_t^* + T_t = W_t h_t + \frac{R_{t-1} B_{t-1}}{\pi_t} + rer_t \frac{R_{t-1}^* \xi_{t-1} B_{t-1}^*}{\pi_t^*} + r_t^K K_{t-1} + \Sigma_t. \tag{17}$$

The household chooses C_t, I_t, K_t, B_t, and B_t^* to maximize (16) subject to (17) and the capital stock level, taking R_t, R_t^*, ξ_t, π_t, π_t^*, r_t^K, rer_t, T_t, Σ_t, B_{t-1}, B_{t-1}^* and K_{t-1} as given.

3.2. Labor union

Following Schmitt-Grohé and Uribe (2006, 2007), labor decisions are made by a central authority, a union, which supplies labor monopolistically to a continuum of labor markets indexed by $i \in [0, 1]$. Households are indifferent between working in any of these markets. In each market, the union faces a demand for labor given by $h_{it} = \left[W_{it}^n / W_t^n \right]^{-\epsilon_W} h_t^d$, where W_{it}^n denotes the nominal wage charged by the union in market i, W_t^n is an aggregate hourly wage index that satisfies $\left(W_t^n\right)^{1-\epsilon_W} = \int_0^1 \left(W_{it}^n\right)^{1-\epsilon_W} di$, and h_t^d denotes aggregate labor demand by firms. The union takes W_t^n and h_t^d as given and, once wages are set, it satisfies all labor demand. In addition, the total number of hours allocated to the different labor markets must satisfy the resource constraint $h_t = \int_0^1 h_{it} di$. Wage setting is subject to a Calvo-type problem, whereby each period the household (or union) can set its nominal wage optimally in a fraction $1 - \theta_W$ of randomly chosen labor markets, and in the remaining markets, the past wage rate is indexed to a weighted product of past and steady state inflation with weights $\vartheta_W \in [0, 1]$ and $1 - \vartheta_W$.

3.3. Wholesale home goods

Wholesale goods of variety i are produced according to the technology

$$Y_{it}^H = z_t K_{it-1}^{\alpha} [A_t h_{it}^d]^{1-\alpha}, \qquad \alpha \in [0, 1). \tag{18}$$

Firm i's profit is given by $\Pi_{it}^m = p_{it}^m Y_{it}^H - r_t^K K_{it-1} - W_t h_{it}^d$. The firm chooses K_{it-1} and h_{it}^d to maximize Π_{it}^m subject to (18). From the labor market clearing conditions we then obtain that $h_t = h_t^d \Delta_t^W$ in equilibrium, where Δ_t^W is a wage dispersion term.

3.4. Driving forces

The standard model features the same driving forces as the model with search frictions, with the exception of the exogenous separation shock ρ_t^x, which does not apply.

[23] Several alternative distributions of the idiosyncratic shock have been used in the literature. Mortensen and Pissarides (1994) use a uniform distribution on the interval $[-1, 1]$ for the idiosyncratic shock. Den Haan et al. (2000) and Walsh (2005) use a log-normal distribution with mean 0. Guerrieri (2008) considers shocks distributed according to uniform, Pareto and log-normal distributions and finds no significant difference. Similarly, Tortorice (2013) finds that there is very little difference when using the uniform distribution in comparison to the log-normal distribution. Hence, we simply follow most of the literature and use a log-normal distribution.

Table 1
Selected calibrated parameters and targeted steady state values.

Parameter	Description	Value	Source
Search model			
u	Unemployment rate in st. st.	0.08	Average (1987-2014)
e	Firm matching rate	0.7	den Haan et al. (2000)
ρ	Total separation rate	0.0755	Jones and Naudon (2009)
ρ^x	Exog. separation rate	$\frac{2}{3}\rho$	den Haan et al. (2000)
μ_F	Log-normal mean of F	0	Normalization
Standard model			
ϵ_W	E.o.s. wages	11	Medina and Soto (2007)

Note: The table shows the parameters related to the labor market block of the models. See the online appendix for a complete list of calibrated parameters and targeted steady state values. All rates are annualized figures.

4. Parametrization strategy

Our empirical strategy combines both calibrated and estimated parameters. The calibrated parameters and targeted steady state values that are related to the labor market block of the models are presented in Table 1. For most of the parameters not related with the labor market, which are presented in detail in the online appendix, we draw from related studies for Chile, while others are endogenously determined in steady state to target some first moments. The values of the parameters related to the labor market are either chosen to match observed statistics and available evidence for Chile, or following related studies for other countries.

We derive the vacancy posting cost (ω) from the steady state calculations to match an average unemployment rate (u) of around 8 percent between 1987 and 2014.[24] The implied vacancy cost to GDP ratio is approximately 4 percent, which is close to the value in Trigari (2009). Following Cooley and Quadrini (1999), den Haan et al. (2000) and other related studies, we set the probability of filling a vacancy in steady state (e) to 0.7. We further fix the total separation rate in steady state (ρ) based on evidence reported by Jones and Naudon (2009), who calculate quarterly labor status transition probabilities from micro survey data for Chile and find a probability of changing status from employed to unemployed, $p^{E,U}$, of about 0.04 as well as a probability of changing status from unemployed to employed, $p^{U,E}$, of about 0.47. These probabilities imply a value for ρ of approximately 7.5 percent, which is at the lower end of the range of quarterly U.S. worker separation rates of 8 to 10 percent reported by Hall (1995) and the values typically used in the literature.[25] Following den Haan et al. (2000), the exogenous separation rate (ρ^x) is then set to two thirds times the total separation rate. We further normalize the log-normal mean of the firm's operating cost to 0. For the standard model, we set the elasticity of substitution of the differentiated labor services offered by the union to 11, following Medina and Soto (2007).

We also calibrate the parameters characterizing those exogenous processes for which we have a data counterpart with the values obtained from estimating univariate AR(1) processes. In particular, for R^* we use the 3-month U.S. dollar London Interbank Offered Rate, for y^* we use linearly detrended real GDP of commercial partners while for π^* we use CPI inflation (in dollars) of commercial partners (both trade-weighted), for p^{Co*} we use the price of refined copper at the London Metals Exchange (in dollars) deflated by the same price index used to construct π^*, and for g we use linearly detrended real government consumption.[26]

The other parameters of the model were estimated using Bayesian techniques, solving the model with a log-linear approximation around the non-stochastic steady state. A list of selected parameters and their corresponding priors are described in columns one to five of Table 4; the online appendix contains the complete list of estimated parameters. The prior distributions are fairly loose, with means set to represent (when available) the estimates of related papers for the Chilean economy (e.g., Medina and Soto, 2007). For parameters that have not been studied in the Chilean context, such as the worker's bargaining power φ, we use prior distributions from the broader literature, such as those in Gertler et al. (2008).

For the model with search frictions and the standard model, the following observable variables were used (all for a sample from 2001Q3, when the inflation targeting regime is implemented in Chile, to 2016Q1): the growth rates of real non-mining GDP, private consumption, and investment, the CPI inflation rate, the monetary policy rate, the multilateral real exchange rate, the growth rate of real wages,[27] total hours worked (hours per worker times employment divided by the labor force), the EMBI Chile (which we match by the endogenous component of the country premium ξ_t plus the observed shock to the country premium ζ_t^o), and production in the copper sector. We also include as observables the variables used

[24] The average unemployment rate over the sample period from 2001Q3 to 2015Q2 was also about 8 percent.

[25] The value of ρ is calculated from (6) which implies that $p^{E,U} = \rho(1 - p^{U,E})$ in steady state, such that $\rho = p^{E,U}/(1 - p^{U,E}) \approx 0.0755$.

[26] The data source is the Central Bank of Chile's statistical database; see http://si3.bcentral.cl/Siete.

[27] Specifically, for the real wage we use IREM, an index of hourly wages deflated by the CPI. The index is compiled, seasonally adjusted, and deflated by the CPI by the National Statistics Institute.

Table 2
Marginal data densities.

	Search		Standard
	With ρ_t^x	Without ρ_t^x	
$\log p(X^T \text{ without } u^T \| \theta)$	-1453.17	-1456.04	-1473.38

Note: X^T denotes the full data set, X^T without u^T the set excluding the unemployment rate. For the model with search frictions, we also compute the marginal likelihood after shutting down the exogenous separation shock (ρ_t^x). The online appendix contains marginal data densities for the model when the unemployment rate is part of the set of observable variables. The marginal data densities are Laplace approximations at the mean of the posterior distribution.

to estimate the exogenous processes previously described.[28] In addition, for the model including search frictions we also use as observable the unemployment rate. All nominal variables are deflated using the CPI, so that our modeling assumption that all goods are measured in units of the final good is consistent with the data used to estimate the model.[29]

Overall, we use 16 observed variables in the estimation. Our estimation strategy also includes i.i.d. measurement errors for all observables. The variance of the latter was set to 10% of the variance of the corresponding observables.

5. Results

In this section, we first assess the goodness of fit of the model under the different labor market specifications, in order to understand if and how the presence of search and matching helps to improve the ability of the model to account for the dynamics observed in the data. We then discuss the differences in the inferred parameters and compare the variance decomposition to find out which shocks are the most important drivers of the dynamics under the standard specification and its counterpart with search frictions. In addition, we analyze the impulse responses to selected shocks to understand the propagation properties of the different labor market specifications. We also study whether labor search frictions can substitute for capital frictions, as suggested by estimates of the elasticity of investment adjustment costs. Finally, we compare the forecasting performance of the two model variants against each other and against reduced-form Bayesian vector autoregressive (BVAR) benchmark forecasting models.

5.1. Goodness of fit

To have an overall measure of goodness of fit, we compute the marginal data density implied by the posterior distribution of the parameters for each model. The marginal data densities for the estimation samples are not immediately comparable, since the model with search frictions is estimated with an additional observable variable—the unemployment rate. Moreover, the model with search frictions has an additional shock—that to the exogenous component of the separation rate, which may give this model additional degrees of freedom to match the data compared to the standard model. We therefore re-estimate the model with search frictions, excluding the unemployment rate (u^T) from the full data set (x^T), and shutting down the shock to the exogenous component of the separation rate, and compute the marginal data density of the re-estimated model.[30]

The results in Table 2 show that the overall fit of the model with search frictions is significantly better than the fit of the standard model, independently of whether the exogenous separation shock is active or not. The difference between the marginal data densities is more than 17 log points. According to the usual scales of interpretation, this constitutes strong evidence in favor of the model with search frictions.[31,32,33]

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[28] While the parameters of these exogenous processes were calibrated, including these variables in the data set is informative for the inference of the innovations associated with the other exogenous processes.

[29] Note that the inflation target in Chile is set explicitly for the CPI.

[30] The marginal data densities were computed through the Laplace approximation at the mean of the posterior distribution of the parameters.

[31] See Jeffreys (1961) and Kass and Raftery (1995).

[32] The online appendix contains additional results on the overall goodness of fit of the models. In particular, it includes marginal data densities when the model with search frictions is estimated on the full data set, i.e., when the unemployment rate is part of the set of observable variables. It also includes results of estimations of the search model when the endogenous component of the separation rate is lowered in equilibrium. We reduce endogenous separations by calibrating σ_w, the standard deviation of the log-normally distributed operating cost F, at a value that is two times larger than its estimated posterior mean. This analysis shows that the model with search frictions fits the data better than the standard model even when endogenous separations are lower.

[33] Our results are not driven by the priors of parameters that appear only in the model with search frictions, which has three additional estimated parameters. In fact, our results are robust to re-estimating the model with looser priors on these three parameters. Specifically, we check for robustness when we increase the standard deviation of the prior distribution of parameters φ, μ, and σ_w by 2.5 times (see Table 4 for details on the parameters and prior distributions). Re-estimating the model with these looser priors implies a marginal data density of -1436.83 when the exogenous separation shock is turned off, and -1433.69 when it is active. For both estimations, the unemployment rate is excluded from the set of observable variables.

Table 3
Second moments.

Variable	Description	s.d. (%)			AC order 1		
		Data	Search	Standard	Data	Search	Standard
$\Delta \log Y^{NM}$	Non-mining GDP	1.14	1.66	1.92	0.20	0.00	0.61
$\Delta \log C$	Consumption	1.21	1.28	1.72	0.36	0.47	0.66
$\Delta \log I$	Investment	3.75	4.69	6.02	0.20	0.47	0.74
π	Inflation	0.69	0.79	1.23	0.60	0.49	0.63
R	MPR	0.42	0.47	0.85	0.88	0.88	0.94
rer	Real exch. rate	5.17	6.69	10.29	0.75	0.76	0.89
ξ	EMBIG Chile	0.15	0.26	0.27	0.83	0.94	0.95
$\Delta \log W$	Real wage	0.58	0.69	1.25	0.36	0.44	0.48
$h \times n$	Total hours worked	1.87	1.97	7.61	0.73	0.90	0.89
u	Unemployment rate	1.43	1.37	–	0.96	0.87	–

Note: In addition to standard deviations and first-order autocorrelation coefficients, the online appendix reports correlation coefficients with non-mining GDP. The model moments are the theoretical moments at the posterior mean.

To obtain a more detailed view of which variables are better matched by each model, Table 3 reports the standard deviations and first-order autocorrelation coefficients of selected variables implied by the posterior mean of the parameters, and compares these statistics with the corresponding empirical moments. In terms of the standard deviations shown in the third to fifth columns of the table, the model with search frictions matches all of the variables better than the standard model. The standard model grossly overstates the standard deviation of hours worked, real wages and the real exchange rate. Likely related to the latter, it also overstates the standard deviation of inflation and the monetary policy rate. The autocorrelation coefficients in the sixth to eighth columns of the table show that the model with search frictions matches the persistence of almost all variables better than the standard model. Note that the standard model overstates the persistence of all variables.[34]

Overall, this goodness-of-fit analysis yields as a main conclusion that the model with search frictions performs significantly better than the standard model in terms of fitting both labor market data and other macroeconomic data. We examine next which properties of the model with search frictions explain this difference.

5.2. Estimated parameters and dynamics

Columns six to nine in Table 4 display the posterior mean and the 90% highest posterior density intervals of selected estimated parameters of the two model variants that we wish to highlight (the online appendix contains the full list of estimated parameters).

One important parameter whose estimated value is different between the two models is the inverse Frisch elasticity of hours worked (ϕ), whose posterior mean is 5 times higher in the model with search frictions. Hence, the intensive margin is less important in that model compared to the standard model. This result is in line with the findings of Christiano et al. (2011) and other calibrations of search and matching models with both margins of labor supply (e.g., Trigari, 2009).

In terms of the parameters related to nominal wage rigidity, the model with search frictions suggests an average duration of nominal wage contracts of little over 4 quarters ($\theta_W = 0.78$), whereas the standard model suggests a much higher duration of 10 quarters ($\theta_W = 0.90$). In the standard model, indexation of nominal wages to past inflation (ϑ_W) is also estimated to be higher than in the model with search frictions. Also, the standard model has a significantly higher Calvo parameter for home prices (θ_H). Taken together, these results imply that both wages and inflation tend to be highly persistent in that model, which is consistent with the results in Table 3.

For the model with search frictions, the estimation suggests a value of 0.75 for the match elasticity parameter μ. This value lies towards the higher end of those used in the literature (see Shimer, 2005), although this literature focuses on advanced economies. For the worker's bargaining power parameter φ, the estimation obtains a value of 0.3, which suggests lower bargaining power in the small open emerging country of Chile compared to the values typically used in the literature, which are again focused on advanced economies and lie in the range of 0.5–0.7 (see the discussion in Gertler et al., 2008).[35]

Other parameters that differ significantly between the two models are related to real rigidities. In particular, the standard model has a higher degree of habit formation (ς) and a significantly higher elasticity of investment adjustment costs (γ). This may explain the relatively large size (i.e., the estimated innovation standard deviation and autocorrelation coefficient)

[34] The online appendix includes the correlations with non-mining GDP of the selected variables. On this dimension, both models seem to perform reasonably well.

[35] The parameter estimates are robust to allowing for larger measurement error in the real wage, an important observable variable for labor market parameters. Since real wage data are known to be noisy, not just in Chile but in many countries, we checked the robustness of our estimation to increasing the variance of the measurement error of the real wage to 30% of the variance of the observable series, three times larger than in the baseline estimation. The estimated parameters are very similar to the baseline estimates. In particular, the parameter that governs nominal wage rigidity θ^W is estimated at 0.76 in this exercise and 0.78 in the baseline estimation.

Table 4
Selected estimated parameters.

Param.	Description	Prior			Posterior			
					Search		Standard	
		Dist.	Mean	s.d.	Mean	90% HPDI	Mean	90% HPDI
ϕ	Inv. elast. of h	norm	2	2	5.09	[2.90, 7.30]	1.00	[0.00, 2.16]
ς	Habit formation	beta	0.7	0.1	0.75	[0.66, 0.83]	0.82	[0.74, 0.89]
γ	Inv. adj. cost	norm	4	1.5	0.81	[0.11, 1.77]	5.48	[3.59, 7.44]
φ	Bargaining power	beta	0.5	0.1	0.27	[0.09, 0.45]	–	–
σ_w	s.d. of F	norm	0.1	0.05	0.30	[0.25, 0.36]	–	–
μ	Match elast.	beta	0.5	0.1	0.75	[0.65, 0.84]	–	–
θ_W	Nom. W stickiness	beta	0.5	0.1	0.78	[0.67, 0.89]	0.90	[0.87, 0.95]
ϑ_W	Index. past infl. W	beta	0.5	0.15	0.24	[0.10, 0.36]	0.40	[0.21, 0.60]
θ_H	Calvo prob. H	beta	0.5	0.1	0.33	[0.24, 0.42]	0.56	[0.50, 0.61]
ϑ_H	Index. past infl. H	beta	0.5	0.15	0.51	[0.27, 0.76]	0.21	[0.08, 0.35]
θ_F	Calvo prob. F	beta	0.5	0.1	0.82	[0.77, 0.86]	0.57	[0.50, 0.63]
ϑ_F	Index. past infl. F	beta	0.5	0.15	0.64	[0.48, 0.80]	0.54	[0.29, 0.77]
ρ_ϱ	AC cons. pref. sh.	beta	0.75	0.1	0.64	[0.50, 0.79]	0.74	[0.60, 0.88]
ρ_κ	AC labor pref. sh.	beta	0.75	0.1	0.77	[0.64, 0.91]	0.74	[0.58, 0.90]
ρ_{ρ^x}	AC exo. sep. sh.	beta	0.75	0.1	0.88	[0.81, 0.95]	–	–
ρ_ϖ	AC inv. sh.	beta	0.75	0.1	0.65	[0.51, 0.79]	0.85	[0.78, 0.92]
σ_ϱ	s.d. cons. pref. sh.	invg	0.01	Inf	0.04	[0.03, 0.05]	0.06	[0.04, 0.08]
σ_κ	s.d. labor pref. sh.	invg	0.01	Inf	0.03	[0.02, 0.04]	0.13	[0.03, 0.23]
σ_{ρ^x}	s.d. separation sh.	invg	0.01	Inf	0.15	[0.10, 0.20]	–	–
σ_ϖ	s.d. inv. shock	invg	0.01	Inf	0.03	[0.01, 0.05]	0.08	[0.05, 0.10]

Note: The results are based on 500,000 draws from the posterior distribution using the Metropolis-Hastings (MH) algorithm, dropping the first 250,000 draws to achieve convergence. The average acceptation rate of the MH algorithm was approximately 25% for each model. HPDI are the highest posterior density intervals. The priors for the parameters ϕ and α_π were truncated at 0 and 1, respectively. The computations were conducted using Dynare 4.5.5. See the online appendix for the complete list of estimated parameters.

of the consumption preference shock (ϱ) and the investment-specific technology shock (ϖ) in that model. In addition, the standard model seems to require a relatively large labor supply preference shock (κ). We study the interaction between labor and capital frictions in more detail in the next subsection.

It is also instructive to study how the different shocks explain aggregate fluctuations. To that end, Table 5 displays the unconditional variance decomposition obtained for each version of the model for selected variables, computed at the respective posterior mean.[36] In the standard model, technology shocks are the dominant driving force for most variables, followed far behind by foreign shocks. On the other hand, in the model with search frictions, foreign shocks are the most important driving forces for most variables.[37] The literature has found these to be the most important driving forces of aggregate fluctuations in small open emerging economies, with numerous articles emphasizing the role of foreign shocks.[38] Moreover, Justiniano and Preston (2010) show that it is difficult for DSGE models to replicate the importance of foreign shocks found, for example, in vector autoregressive analyses. Our results suggest that search frictions may contribute to mitigate this shortcoming of SOE DSGE models. Finally, note that the exogenous separation rate shock explains about half of the variance of the unemployment rate, but that technological and foreign shocks are also highly relevant.

To illustrate how shocks are propagated, we examine next the estimated impulse responses to selected shocks. In particular, we analyze the responses to a foreign interest rate shock and a domestic monetary policy shock, which are shown in Figs. 1 and 2, respectively. In each figure, we compare the estimated impulse responses from the model with search frictions (blue solid lines) to the responses of the standard model (red dash-dotted lines).[39]

Fig. 1 shows the effects of a foreign interest rate shock. It generates a contraction in output, consumption and investment. In the model with search frictions, the contraction is driven by a decline in employment, and not in hours worked, as in the standard model. That is, in the model with search frictions, the extensive margin of labor supply is the relevant margin of adjustment: firms post less vacancies, dismiss workers, and the unemployment rate increases; the resulting slackness in the labor market leads to lower pressure on wage growth.

Fig. 2 shows responses to a domestic monetary policy shock. Again, the response of the extensive margin of labor supply is critical in the model with search frictions: the unemployment rate increases in response to a contractionary shock and the labor market becomes more slack. In the standard model, the decline in output hinges on a decline in hours worked.

[36] In Table 5, several shocks are grouped in sub-categories, as explained in the note to the table. The online appendix contains the detailed variance decomposition with the contribution of each individual shock.

[37] Additionally, monetary policy shocks play an important role in inflation dynamics.

[38] See, for example, Fernández et al. (2017, 2018), Kose (2002), and Mendoza (1995).

[39] To have the impulse responses comparable, the parameters associated to the shock process (persistence and volatility) are fixed at the prior mean, which is common across models. The online appendix also includes impulse-responses for the case in which endogenous separations are lower in equilibrium.

Table 5
Variance decomposition.

Variable	Shocks							
	Tech.	**Pref.**	MP rate	Gov. cons.	**Risk**	**Foreign**	Co. prod.	Exo. sep.
	A. Search							
y^{NM}	34	10	0	0	7	37	2	9
c	5	16	0	0	8	64	6	0
i	22	6	1	0	19	49	2	1
π	60	7	12	0	7	9	0	4
R	48	5	7	0	11	27	1	1
rer	5	1	1	0	46	46	1	0
ξ	2	0	0	0	40	54	2	0
w	9	2	0	0	15	68	5	2
$h \times n$	19	27	2	0	5	22	2	24
u	21	2	3	0	3	16	1	53
	B. Standard							
y^{NM}	83	9	1	0	1	6	0	–
c	23	23	0	0	5	44	4	–
i	80	4	0	0	2	13	1	–
π	55	5	5	0	20	15	0	–
R	60	8	3	0	13	17	0	–
rer	30	3	1	0	19	45	3	–
ξ	15	1	0	0	33	47	4	–
w	32	6	0	0	7	51	4	–
$h \times n$	81	12	1	0	2	4	0	–

Note: The table entries are the fraction of the unconditional theoretical variances at the posterior mean (in %) explained by the shocks. Categories in bold face group several shocks (the online appendix includes the contribution of each individual shock). **Tech**: technology shocks, includes transitory (z) and permanent (a) TFP shocks, and investment technology (ϖ) shocks. **Pref**: preference shocks, includes consumption (ϱ), and labor supply (κ) shocks. MP rate: monetary policy rate shocks. Gov. cons.: shocks to government consumption. **Risk**: includes shocks to observed (ζ^{o}) and unobserved (ζ^{u}) components of the country premium. **Foreign**: includes shocks to the foreign interest rate (R^*), foreign inflation (π^*), commodity price (p^{Co*}), and foreign demand (y^*). Co. Prod.: shocks to commodity production. Exo. sep.: exogenous separations.

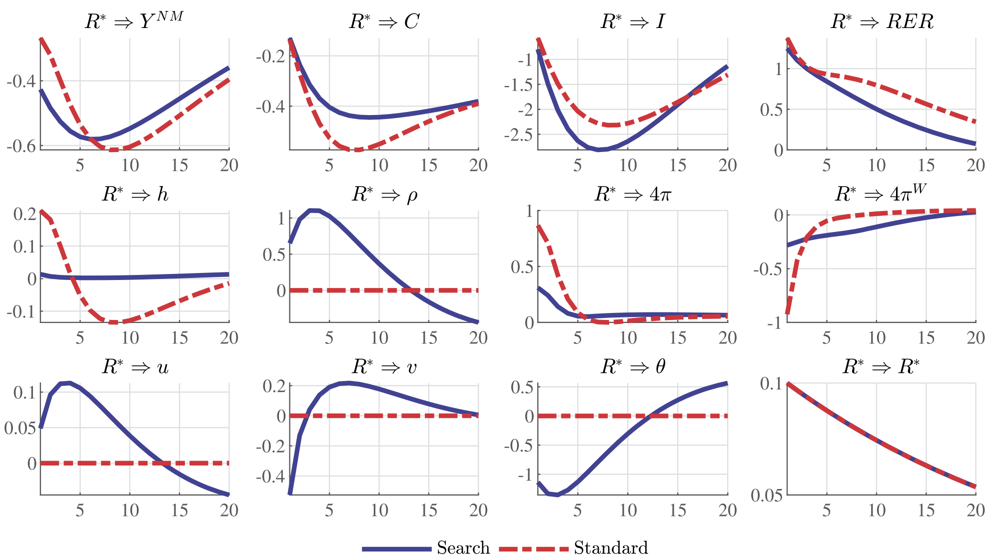

Fig. 1. Impulse responses to a foreign interest rate shock (R^*). Note: The blue solid lines correspond to the model with search frictions, and the red dash-dotted lines to the standard model. In all cases the parameters associated to the shock process (persistence and volatility) are fixed at the prior mean, which is common across models. The variables are real non-mining GDP (Y^{NM}), household consumption (C), investment (I), the real exchange rate (rer), hours per worker (h), the separation rate (ρ), annualized CPI inflation (4π), annualized real wage growth ($4\pi^W$), the unemployment rate (u), vacancies (v), and labor market tightness (θ). All variables are expressed as percentage deviations from steady state. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

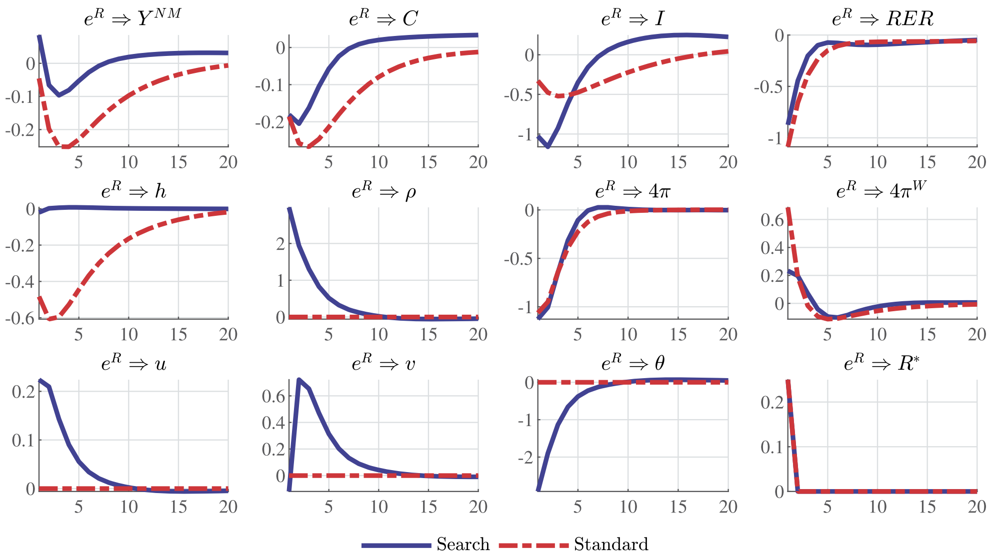

Fig. 2. Impulse responses to a domestic monetary policy shock (e^R). Note: See Fig. 1.

The analysis above leads us to conclude that search frictions and matching generate quantitatively relevant additional endogenous propagation properties of the model through variations of labor supply along the extensive margin, while the intensive margin becomes relatively less important, a finding that is well established in the literature (e.g., Den Haan et al., 2000; Trigari, 2009).

5.3. Labor and capital frictions

Labor search frictions seem to substitute for rigidities in investment as a propagation mechanism. As shown in Table 4, the estimated elasticity of investment adjustment costs (γ) is more than 80% smaller in the model with search frictions (0.81 in the model with search frictions and 5.48 in the standard model). We have highlighted the role of fluctuations in employment (the extensive margin of labor supply) in the model with search frictions. The extensive margin, which embodies the search friction, is a key margin of adjustment to shocks in that model. The standard model, which lacks search frictions, needs other rigidities to fit the data. In the standard model, therefore, investment adjustment costs are far more important than in the model with search frictions. We show in this subsection that when we limit investment rigidities in the standard model, other frictions are not sufficient to compensate, and the model loses ability to fit the data.

To gain insight on the extent to which search frictions can substitute for rigidities in investment, we re-estimate the standard model after fixing the elasticity of investment adjustment costs (γ) to the value estimated in the model with search frictions. As we show below, imposing a smaller capital friction on the standard model reduces its ability to fit the data, even when all other parameters are re-estimated.

The top panel of Table 6 shows that when we fix the elasticity of investment adjustment costs γ in the standard model to the low value of 0.81, its goodness of fit deteriorates substantially. The marginal data density of the standard model declines by more than 15 log points: -1489.98 with a fixed and smaller capital friction, compared to -1473.38 in the baseline case in which the capital friction is estimated to be much bigger.

The bottom panel of Table 6 shows the posterior mean of selected parameters (the online appendix contains the full list of estimated parameters). When we limit the capital friction in the standard model, investment is more volatile, so the Bayesian estimation tries to compensate by limiting the sensitivity of hours—the inverse elasticity of hours doubles (from 1.00 to 2.08), and the wealth effect on the intensive margin of labor supply is almost completely shut down (from 0.34 to 0.05). We have seen this compensation is insufficient in terms of goodness of fit. We now go into more detail by showing the response of key variables to interest rate shocks.

Fig. 3 presents impulse-responses to a foreign interest rate shock in the top panel, and to a domestic monetary policy shock in the bottom panel. The green dashed lines are the responses of the standard model with a small capital friction. With respect to the baseline results for the standard model (red dash-dotted lines), investment is more volatile when we limit the capital friction. Since it is easier for investment to adjust to the desired level, its decline is about twice as large as in the baseline case. The higher volatility of investment translates into a larger response of non-mining GDP. Note that even though the parameters that govern the sensitivity of hours worked, inverse Frisch elasticity and size of wealth effect, point to lower unconditional sensitivity of hours in the standard model with a smaller capital friction, hours drop strongly, albeit more briefly, in response to the contractionary interest rate shocks. Taken together, these results suggest that the labor search frictions do substitute for rigidities in investment. Without the labor search friction, the standard model has

Table 6
Standard model with smaller capital friction.

Marginal data densities			
	Search	Standard	
		Baseline	Low γ
$\log p(X^T \text{ without } u^T \mid \theta)$	-1456.04	-1473.38	-1489.98

Selected estimated parameters

Param.	Description	Posterior mean		
		Search	Standard	
			Baseline	Low γ
υ	Wealth effect size	0.10	0.34	0.05
ϕ	Inv. elast. of h	5.09	1.00	2.08
ς	Habit formation	0.75	0.82	0.84
γ	Inv. adj. cost	0.81	5.48	0.81

Note: The top panel presents marginal data densities (Laplace approximations). To make results for the model with search frictions comparable, we exclude the unemployment rate and shut down the exogenous separation shock; see Subsection 5.1 for more details. For the standard model, we reproduce the density from the baseline estimation, and, in the last column, add results from re-estimating the model after fixing the elasticity of adjustment costs γ to the lower value of 0.81 obtained for the model with search frictions. The lower panel shows the posterior means of selected parameters. The last column refers to the standard model with the fixed value of γ. See the note to Table 4 for more details.

no other way to make sense of the data than with a strong elasticity of investment adjustment costs, in order to avoid excessive fluctuations in investment in response to variations in hours. A re-estimated version of the standard model with a fixed and smaller capital friction loses ability to fit the data.

5.4. Forecasting performance

As a final step of the analysis, we conduct an out-of-sample forecasting experiment in order to judge how well the two models we analyze predict labor market data and other key variables such as output and inflation. For this experiment we estimated the model recursively and, for each estimation, forecasted the evolution of the observed variables several quarters ahead, starting in 2007Q1. Thus, the first estimation sample is 2001Q3-2006Q4 while the last sample is 2001Q3-2015Q1. The experiment is similar to that in Adolfson et al. (2007b), who evaluate the forecasting performance of a small open economy DSGE model for Swedish output, inflation and the monetary policy rate, and Christiano et al. (2011), who extend that analysis to a model with search and matching and financial frictions. In addition to output, inflation and the monetary policy rate, we also analyze the forecasting performance of the two models for the real exchange rate, total hours worked and real wage growth.

Fig. 4 shows the recursive forecasts for those variables from the model with search frictions (left-hand side) and the standard model (right-hand side). The results show that the model with search frictions does a better job than the standard model in forecasting the evolution of all variables. In particular, real wages as well as total hours worked are predicted significantly better by the model with search frictions, but also inflation, the monetary policy rate and—with less but still noticeable differences—output and the real exchange rate. Note that the standard model strongly overstates the persistence of inflation, in line with Section 5.1, which seems to be partly due to bad forecasts of real wage growth (given adequate predictions of the exchange rate).

To analyze the forecasting performance at different horizons, we also compute the root mean squared errors (RMSE) of the recursive forecasts at different horizons for the two models. As a benchmark, we compare the RMSE with those implied by three reduced-form BVARs that differ in the type of information that they incorporate. In particular, we estimate a basic model that includes real GDP growth, inflation, the monetary policy rate, the real exchange rate, total hours worked and real wage growth (BVAR1), as well as two bigger models that include all of the previous variables plus the growth rates of real private consumption and investment and real government consumption (BVAR2), or alternatively commercial partners' real GDP, the foreign interest rate, the copper price and commercial partners' inflation (BVAR3). All BVARs are estimated with a standard Minnesota-type prior following Doan et al. (1983) and include four lags.

The RMSE for the different DSGE models and BVARs are shown in Fig. 5. The results show that, while the standard DSGE model predicts most variables roughly as well or better than the different BVARs, it is outperformed by the model with search frictions for almost all variables and horizons considered (1-10 quarters). Especially at short horizons, the RMSE for inflation, the monetary policy rate, the real exchange rate and hours worked from the model with search frictions are small (relative to the observed standard deviations). Hence, while the standard DSGE model does perform relatively

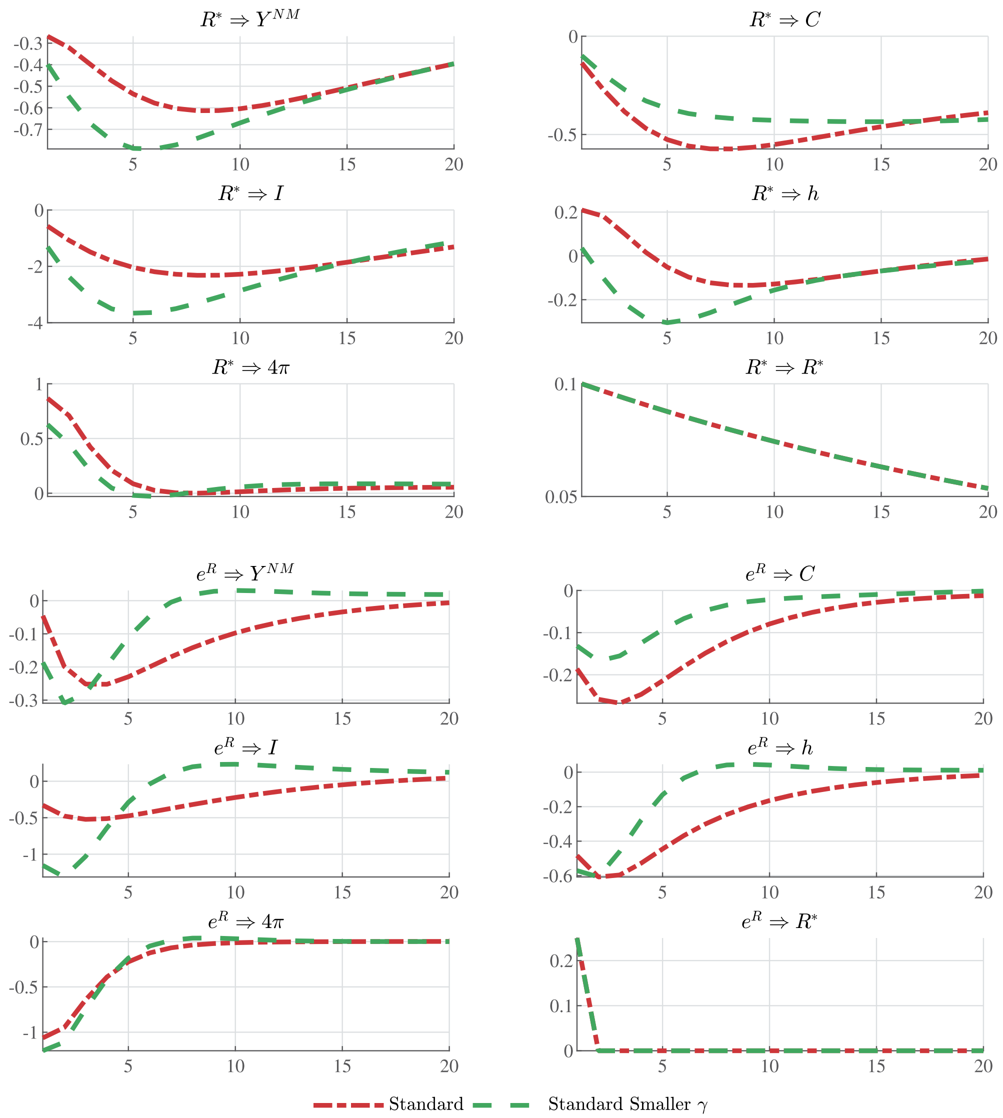

Fig. 3. Impulse responses of the standard model with a smaller capital friction. Note: The green dashed lines correspond to the standard model with a fixed and lower value for the elasticity of investment adjustment costs γ. See the note to Fig. 1 for more details.

well compared to reduced-form empirical alternatives, which is a well-established finding in the literature (e.g., Smets and Wouters, 2003, 2007; Adolfson et al., 2007b), the forecasting performance of the model is strongly improved by the inclusion of search frictions. The improved forecasting performance seems to be due to the fact that the model with search frictions can successfully explain the joint evolution of labor market data and other variables.

6. Conclusions

In this paper we have conducted a horse race of the standard labor market specification versus a search and matching specification with endogenous separations and staggered Nash wage bargaining in an otherwise standard New Keynesian DSGE model for a small open economy. Our estimation results for Chilean data lead us to conclude that the search and matching specification “wins” by a wide margin as it significantly improves the model’s ability to explain and predict both labor market data such as total hours worked and real wages and other macroeconomic variables such as output and inflation.

Our results thereby confirm several findings from previous studies and extend those findings to the context of an emerging market economy. In particular, similarly as Trigari (2009) we find that the model with search and matching explains variations in total hours mainly through the extensive margin of labor supply while the intensive margin is less important. Furthermore, similarly as Christiano et al. (2011) and Krause et al. (2008), we find that labor supply shocks are relatively

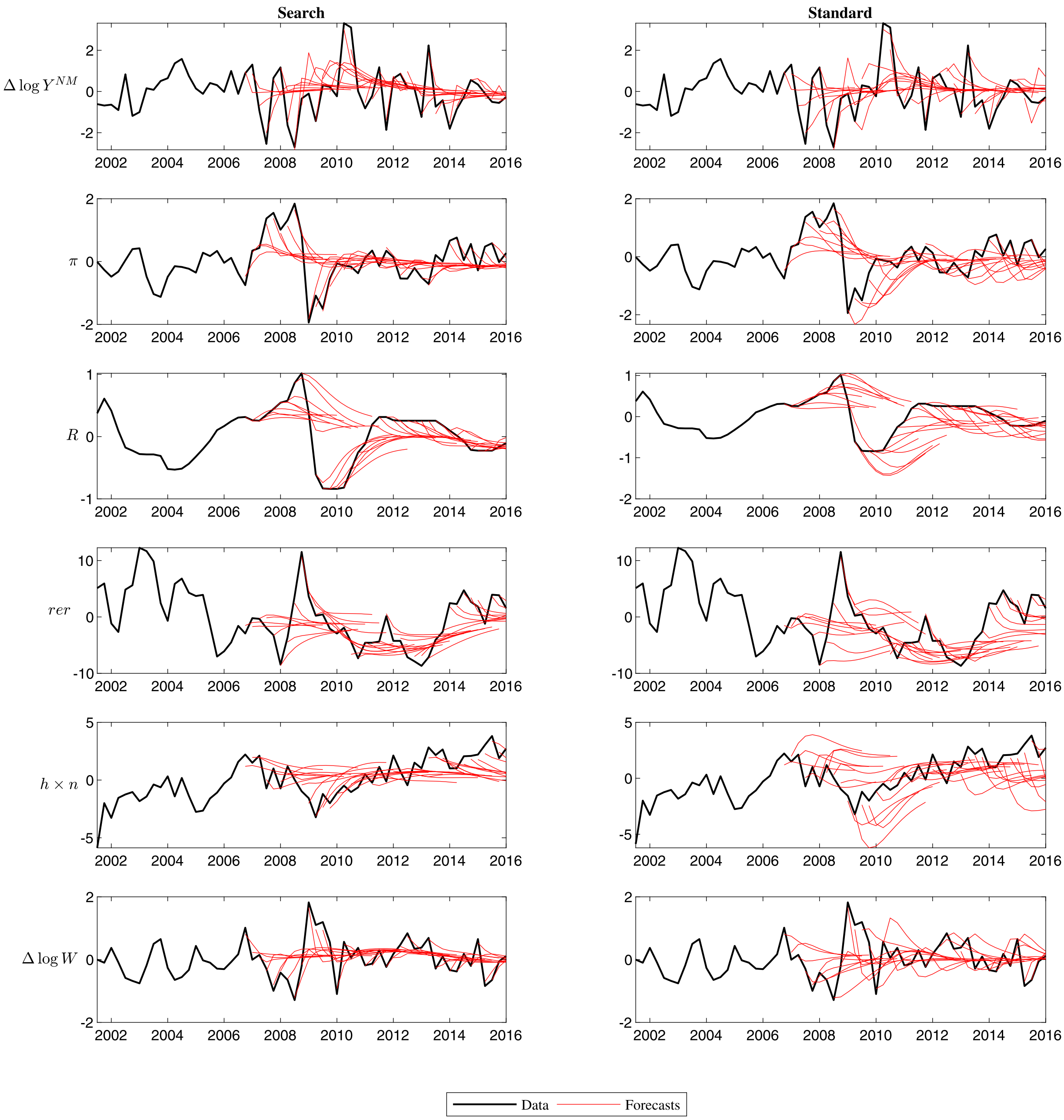

Fig. 4. Recursive out-of-sample forecasts. Note: The black thick lines show the observed data while the red thin lines show the recursive forecasts. The forecasts are based on recursive estimations of the posterior mode of each model. The first estimation sample is 2001Q3-2006Q4 and the last estimation sample is 2001Q3-2015Q1.

unimportant in the model with search and matching to explain the joint evolution of both labor market variables and other variables such as output and inflation.

However, unlike the main related study in the context of an NK-SOE model, i.e., Christiano et al. (2011), we find that basic foreign shocks (in particular foreign interest rate shocks and shocks to commodity export prices) are a very important driving force in the model with search frictions. Compared to the model of Christiano et al. (2011), we see the benefits of our approach mainly in its simplicity, being a relatively straightforward extension of an otherwise standard NK-SOE model to include search and matching with endogenous separations and staggered Nash wage bargaining.

Overall, our results point to the usefulness of a search and matching specification for medium-scale NK-SOE models. These results may be of special interest to economic modelers at central banks and other policy institutions who seek to improve the specification of DSGE models used for policy analysis and forecasting.

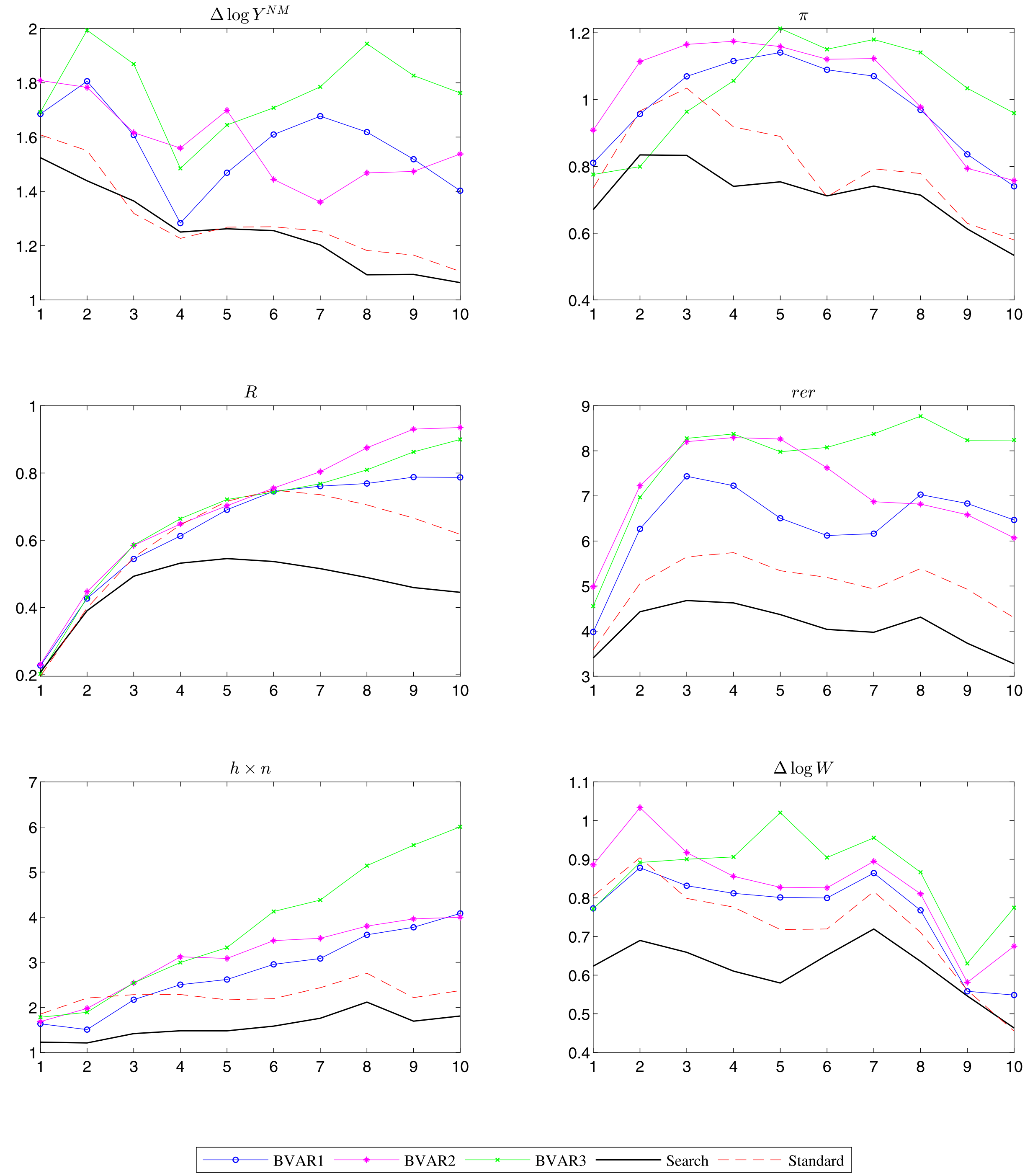

Fig. 5. Root mean squared errors of out-of-sample forecasts. Note: See Fig. 4. BVAR1 includes real non-mining GDP growth, inflation, the monetary policy rate, the real exchange rate, total hours worked and real wage growth. BVAR2 includes the variables from BVAR1 plus the growth rates of real private consumption and investment, and real government consumption. BVAR3 includes the variables from BVAR1 plus commercial partners' real GDP, the foreign interest rate, the copper price, and commercial partners' inflation. The variable transformations for the BVARs are the same as those adopted for the estimation of the DSGE models.

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