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Resurrecting the Participation Margin

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Abstract
This paper considers a real business cycle model with search frictions in the labor market and labor supply which is elastic along the participation margin. Previous authors have found that such models generate counterfactually procyclical unemployment and a positively-sloped Beveridge curve. This paper presents a calibrated model which succeeds at generating countercyclical unemployment and a negatively-sloped Beveridge curve despite the presence of a participation margin.

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1 Introduction

Recently, there has been renewed interest in the business cycle properties of models with search frictions and wage bargaining. Beginning with the seminal papers of Shimer (2005) and Hall (2005), a growing body of literature examines the ability of business cycle models with Mortensen-Pissarides search frictions to account for the cyclical variation of labor market variables. One striking feature of this literature is that all models assume that labor supply is inelastic.

Several attempts have been made to calibrate Real Business Cycle models with labor search frictions and labor supply which is elastic along the participation margin. However, previous authors have been unable to match key *qualitative* facts on the cyclical behavior of unemployment. Ravn (2008), Tripier (2003) and Veracierto (2008) all find that their models contradict the data by generating procyclical unemployment and a positively-sloped Beveridge curve (a positive correlation between unemployment and vacancies). This stark qualitative failure has arguably limited the use of search frictions in business cycle models.

The difficulty is simple but vexing: In response to a positive shock, some agents may wish to enter the labor market by commencing search, swelling the ranks of the unemployed. If the flow of workers from non-participation into search is large enough, then unemployment becomes procyclical and is positively correlated with the procyclical vacancies.

How to solve this conundrum? The key to ensuring that unemployment is countercyclical is that vacancies react more strongly to shocks than unemployment, so that tightness (the ratio of vacancies to unemployed) and job-finding rates (which are an increasing function of tightness) increase on impact. When job-finding rates increase sufficiently, the flows into unemployment from non-participation can be counterbalanced by flows out of unemployment into employment, guaranteeing that unemployment begins to drop soon after impact. Hence, the challenge is to ensure that flows into search/unemployment upon impact are small enough, while also generating vacancies that are sufficiently responsive to productivity shocks.

The key role for the elasticity of vacancies with respect to productivity is reminiscent of the challenge posed by the Shimer puzzle. As noted by Shimer (2005) and others, generating enough responsiveness in vacancies on impact of a productivity shock is also important for generating sufficient volatility in vacancies and tightness. In this sense, the quantitative Shimer puzzle and the qualitative procyclical unemployment puzzle are linked.

The main contribution of this paper is to show that a calibrated RBC model with search frictions and a participation margin is indeed able to generate both highly countercyclical unemployment rates and a negative correlation between unemployment and vacancies (a negatively sloped Beveridge curve). The key to success is a new calibration strategy. First, Ravn (2008), Tripier (2003) and Veracierto (2008) all choose the elasticity of labor supply to be either infinite or to match the relative volatility of employment. In contrast, I calibrate this elasticity to match the relative volatility of participation. In the body of the paper, I will show that the two calibration strategies are not equivalent, and explain why targeting the volatility of the participation rate is preferable.

This subtle but important difference in calibration strategies turns out to be crucial. The participation rate is only about 1/5 as volatile as GDP. The low volatility of the participation rate requires that labor supply elasticity be sufficiently low. Low labor supply elasticity implies that the flows of workers into and out of the labor force in reaction to shocks are relatively small. This guarantees that the response of unemployment on impact is relatively small. That labor supply elasticity along the participation margin turns out to be so low is an attractive feature of this calibration, as it corresponds to the low values typically found in microeconometric studies.

The second key element of the calibration strategy involves ensuring that vacancies are sufficiently elastic to productivity shocks. This part of the calibration follows Hagedorn and Manovskii (2008). Parameters are chosen so that the share of vacancy costs in national income and the wage elasticity of productivity match their value in the data, which generates wages that are sticky. The baseline calibration shares the Achilles heel of Hagedorn and Manovksii (2008)'s calibration, namely that the value of worker's surplus is very low. In contrast to Hagedorn and Manovskii (2008), however, my main qualitative results do not rely on extremely low values of worker's surpluses (or equivalently on extremely high replacement rates). In particular, the share of the wage from surplus can rise to more than 70%, while still ensuring that unemployment rates remain countercyclical. Similarly, the Beveridge curve remains negatively sloped, even if the surplus share of the wage is nearly 30%.

Ensuring that wages wages are sufficiently sticky (or using the small surplus calibration) is important only as a means to ensure that the incentives to create vacancies remain strong. Any other means of generating vacancies which respond sufficiently to shocks should also suffice for the purposes of this paper. Possible alternatives include on the job search as in Nagypal (2007) or downward-sloping labor demand as in Elsby and Michaels (2008).

A final important element of the calibration strategy involves time aggregation. The BLS measures unemployment by considering one reference week each month. Quarterly data is obtained by averaging these monthly observations. Hence, it is possible that a technology shock raises unemployment in the impact week or month, but that this is subsequently reversed. As a result, the procyclical impact reaction of unemployment would be washed out by subsequent countercyclical movements, so that unemployment is countercyclical in the quarterly average. I will find this to be the case.

To my knowledge, no other paper with homogeneous agents has been able to generate countercyclical unemployment and/or a negatively sloped Beveridge curve in RBC models with search frictions and a participation margin. One model assuming heterogeneous agents, Haefke and Reiter (2006), has also succeeded at this task. They allow for heterogeneous productivity in home production, combined with idiosyncratic productivity shocks. These two model elements also serve to restrict the flow of workers into unemployment due to a positive technology shock. However, the heterogeneity increases the complexity of their analysis considerably. In contrast, the model presented in the present paper is a standard RBC model with search frictions, and is highly tractable.

This paper also relates to an earlier literature which integrated search frictions into business cycle models. Merz (1995) and Andolfatto (1996) showed that business cycle models with search frictions could be quite successful at accounting for the cyclical properties of macro variables, as well as for the subset of the labor variables they considered. However, neither of these models allows for a participation margin. Merz (1995) also encounters the difficulty of a positively-sloped Beveridge curve when allowing for endogenous search intensity.

The paper is organized as follows: Section 2 presents the model, whose equilibrium is described in section 3. The calibration strategy is described in section 4, while quantitative results are presented in section 5. Section 6 concludes.

2 Model

This section presents the model. It is a standard real business cycle model, augmented by Mortensen-Pissarides labor market frictions and wage bargaining. Labor supply is elastic along the participation margin. The bargaining setup involves firms bargaining individually with each worker. Agents are risk averse and are organized into large households which provide full insurance against idiosyncratic consumption fluctuations. The production technology is Cobb-Douglas with labor and capital as inputs. This model can be seen as the natural extension of the RBC literature to allow for search frictions and decentralized wage bargaining. It is very similar to the models studied in Ravn (2008), Tripier (2003) and Veracierto (2008).

2.1 Household's Problem

The household chooses consumption c_t, investment in physical capital i_t and the fraction of household members engaged in search u_t to maximize its discounted expected utility, represented by the Bellman equation:

$$V(n_{t-1}, k_{t-1}) = \max_{c_t, i_t, u_t} \{u(c_t, l_t, u_t) + \beta E_t V(n_t, k_t)\} \tag{1}$$

subject to the large-family budget, time and transition constraints

$$\begin{aligned} w_t n_{t-1} + r_t k_{t-1} + \pi_t &\geq c_t + i_t & (2) \\ k_t &= (1-\delta) k_{t-1} + i_t & (3) \\ 1 &= n_{t-1} + u_t + l_t & (4) \\ n_t &= (1-\chi) n_{t-1} + f_t u_t & (5) \end{aligned}$$

The fraction n_{t-1} family members earn the wage w_t, while u_t are searching for work. The fraction l_t of household members do not participate in the labor market. The household owns the capital stock k_{t-1}, which it rents at market rate r_t to firms. Capital depreciates at constant rate δ. Due to search frictions in the labor market, the household's date t stock of employed workers n_{t-1} acts like a capital stock, which depreciates at the exogenous separation rate χ. Households cannot choose current period employment directly. Instead, they can invest in next period employment by sending workers into search, understanding that date t searching workers u_t will find jobs at (endogenous) rate f_t.

2.1.1 Specification of Utility

In the calibrated model, the utility function is specified as:

$$u(c_t, l_t, u_t) = \ln c_t + b u_t + \phi \frac{l_t^{1-\frac{1}{\nu}}}{1-\frac{1}{\nu}} \tag{6}$$

In models with inelastic labor supply and risk-neutral individual agents (cf. Pissarides (2000) or Shimer (2005)), the utility function is linear: $u(c_t) = c_t + bI_u$, where c_t is consumption of the market good, b is the non-market flow utility to unemployment and I_u is an indicator function that takes the value 1 when the agent is unemployed. Under the large family paradigm, the indicator is replaced by the fraction of family members who are searching u_t.

In addition, including the participation margin implies that one must model the utility from non-participation explicitly. In the specification used here, non-participants and searchers contribute to household utility in distinct ways. It is useful to think of the utility from non-participation as being derived from home production. Among all non-participants, 73.3% cite "taking care of house or family" as the reason for their non-participation[1]. Thus, it is fair to assume that home production is a major motivation for non-participation. The other major reasons cited by non-participants were being in education and being disabled or retired. Moreover, the work of Aguiar and Hurst (2005, 2007) emphasizes the importance of home production in the time use of retirees. Hence, it seems reasonable to think of the utility from non-participation as deriving from some home-produced goods or services. Under the utility function specified above, one can think of a linear production function (so that the amount of the home good produced is l_t) and power utility over consumption of the home good. The parameter ν would then represent the intertemporal elasticity of substitution over the home good, low values of ν indicating that households are reluctant to substitute the home good over time. Equivalently, ν is the intertemporal elasticity of substitution over time use, so that low values of ν indicate that households are reluctant to adjust the fraction of non-participants over time.[2] For brevity, I will refer to v as the participation elasticity in the remainder of the paper.

There is also good reason to think of b as a non-market leisure benefit rather than either an unemployment insurance payment in units of the market good or some contribution to home production[3]. First, the large family assumption ensures that consumption is perfectly insured against idiosyncratic unemployment risk, so that there is no rationale for unemployment insurance in this model. Moreover, in the US, relatively few unemployed workers receive rather modest benefits. According to data from the Department of Labor for 1967-2007, only 37.1% of unemployed workers received unemployment insurance payments, which replaced on average 35% of wages. Second, there is little evidence that unemployed workers contribute substantially to home production. According to data from the 2006 American Time Use Survey, conditional on having children under 18 in the household, employed and unemployed workers spent exactly the same amount of time engaged in childcare (328 minutes daily). Compared to the employed, the unemployed spent only 21 additional minutes on housework (135 versus 114 minutes daily), about the time it takes to wash the dishes. Job search activities filled only 20 minutes of the average day. The main activities for which the unemployed do use their extra time are sleep and leisure, primarily in the form of watching television[4]. Hence, it seems reasonable to

[1] Source: March 2008 Current Population Survey.

[2] Alternatively, one can think of utility in the home good being linear (so that its elasticity of substitution is infinite), but its production being subject to decreasing returns to scale (for $\nu > 1$). Small values of ν would then indicate that the marginal product to home production of each additional non-participant is decreasing swiftly.

[3] An earlier version of this paper assumed b to be a transfer in units of the good. This transfer entered the household budget constraint, but not the utility function. Results are very similar and are available on request.

[4] The unemployed sleep 68 minutes per day more than the employed, and they enjoy 90 additional minutes of leisure, of which 56 minutes are spent watching television.

assume that the benefits from unemployment take the form of leisure rather than home production or units of the good.

2.1.2 Solution to the Household's Problem

The solution to the large family's problem takes the form of two Euler equations, which are derived in the Appendix.[5] The first is the standard Euler equation for consumption

$$1 = \beta E_t \left\{ \frac{u_{c,t+1}}{u_{c,t}} \left[r_{t+1} + 1 - \delta \right] \right\} \tag{7}$$

where $u_{c,t} \equiv u_c \left(c_t, l_t, u_t \right)$. The second Euler equation reflects the household's participation decision

$$u_{l,t} - u_{u,t} = f_t \beta E_t \left\{ w_{t+1} u_{c,t+1} - u_{l,t+1} + \frac{1-\chi}{f_{t+1}} \left[u_{l,t+1} - u_{u,t+1} \right] \right\} \tag{8}$$

The left-hand side of (8) reflects the marginal disutility to increasing the family's labor force participation, which involves shifting workers from non-participation into search. The right hand side captures the discounted marginal benefit to employment, scaled by the endogenous rate at which searching workers find jobs f_t.

2.2 Search and Matching in the Labor Market

The labor market is characterized by a standard search and matching framework. Aggregate stocks of unemployed workers U_t and vacancies V_t are converted into job matches by a constant returns to scale matching function $m \left(U_t, V_t \right) = s U_t^{\eta} V_t^{1-\eta}$. Defining labor market tightness as $\theta_t \equiv \frac{V_t}{U_t}$, the firm meets unemployed workers at rate $q_t = s \theta_t^{-\eta}$, while the unemployed workers meet vacancies at rate $f_t = s \theta_t^{1-\eta}$. Aggregate employment N_t evolves as

$$N_t = \left(1 - \chi \right) N_{t-1} + f_t U_t \tag{9}$$

where χ is the exogenous match destruction rate.

Workers are identical and bargaining is individual. Define $\widetilde{\beta}_{t+1} \equiv \beta \frac{u_{c,t+1}}{u_{c,t}}$ to be the households' stochastic discount factor. The household's surplus is derived in the Appendix from the Bellman equation (1) as the marginal value to the household of an additional employed worker[6]:

$$V_{n,t} = w_t u_{c,t} - u_{u,t} + \left(1 - \chi - f_t \right) \beta E_t \left[V_{n,t+1} \right] \tag{10}$$

[5] Both the household's optimization problem and its solution are very similar to those analyzed in Ravn (2008).

[6] The derivation of surplus is similar to that in Ravn (2008) or Trigari (2006).

Finally, worker's surplus in utility terms (10) can be converted into units of the good by dividing by the marginal utility of consumption $u_{c,t}$:

$$\frac{V_{n,t}}{u_{c,t}} = w_t - \frac{u_{u,t}}{u_{c,t}} + (1 - \chi - f_t) E_t \left[\widetilde{\beta}_{t+1} \frac{V_{n,t+1}}{u_{c,t+1}} \right] \tag{11}$$

2.3 Firm's Problem

There is a continuum of identical firms on the unit interval. Firms are perfectly competitive and produce using a constant returns to scale Cobb-Douglas technology.

Firms maximize the discounted value of future profits, and produce using labor and rented capital. They adjust employment by varying the number of workers rather than the number of hours per worker, consistent with stylized facts.

Firms face search frictions in the labor market, so that they cannot adjust employment in the current period. Employment is a state variable, and behaves like a capital stock. Firms can add to their future stock of employment capital by investing in current vacancies v_t, which cost κ each and are transformed into employed workers next period at the endogenous job-filling rate q_t. The firm's Bellman equation is:

$$J(n_{t-1}, z_t) = \max_{v_t, k_{t-1}} \left\{ y_t - w_t n_{t-1} - r_t k_{t-1} - \kappa v_t + E_t \left[\widetilde{\beta}_{t+1} J(n_t, z_{t+1}) \right] \right\} \tag{12}$$

subject to

$$\begin{aligned} \text{production function} &: & y_t &= A z_t n_{t-1}^{1-\alpha} k_{t-1}^{\alpha} & (13) \\ \text{transition function} &: & n_t &= (1-\chi) n_{t-1} + q_t v_t & (14) \\ \text{technology shock} &: & \ln z_t &= \rho \ln z_{t-1} + \varepsilon_t & (15) \end{aligned}$$

The following conditions for the firm's optimal factor choices are derived in the Appendix:

$$r_t = \alpha \frac{y_t}{k_{t-1}} \tag{16}$$

$$\frac{\kappa}{q_t} = E_t \left\{ \widetilde{\beta}_{t+1} \left[(1-\alpha) \frac{y_{t+1}}{n_t} - w_{t+1} + (1-\chi) \frac{\kappa}{q_{t+1}} \right] \right\} \tag{17}$$

Equation (17) equates the cost of searching for a worker $\frac{\kappa}{q_t}$ to the expected discounted benefits to hiring a worker. These benefits consist of the worker's marginal product net of the wage, plus a term which represents hiring costs that will be saved next period if the worker is not separated. In addition, it is useful to note that the firm's surplus under individual bargaining can be obtained from the envelope condition of the firm's problem

$$J_{n,t} = (1-\alpha)\frac{y_t}{n_{t-1}} - w_t + (1-\chi)\frac{\kappa}{q_t} \tag{18}$$

2.4 Individual Wage Bargaining

The key assumption of the individual bargaining framework is that firms cannot commit to long-term employment contracts, and may renegotiate wages with each worker at any time. This makes each worker effectively the marginal worker.[7] Hence, the firm's outside option is not remaining idle, but rather producing with one worker less, so that firm's surplus is the marginal value of a worker.

Individual bargaining is the appropriate bargaining setup when studying the business cycle properties of the US economy, because "Employment at will" is dominant in US labor markets. Under employment at will, both firms and workers can terminate the employment relationship at any time, without justification. As a result, wages can be renegotiated with any worker at any time, as assumed under individual bargaining.

The individual Nash bargaining problem maximizes the weighted sum of log surpluses

$$\max_{w_t} \mu \ln \frac{V_{n,t}}{u_{c,t}} + (1-\mu)\ln J_{n,t} \tag{19}$$

subject to firm surplus (18) and worker's surplus (11). Worker's bargaining power is given by μ.

Proposition 1 *The solution to the bargaining problem (19) subject to (18) and (11) is given by*

$$w_t = (1-\mu)\frac{u_{u,t}}{u_{c,t}} + \mu\left[(1-\alpha)\frac{y_t}{n_{t-1}} + \kappa\theta_t\right] \tag{20}$$

Proof *See the appendix.*

Equation (20) is the wage curve.

3 Equilibrium

An equilibrium is defined as sequences of prices and labor market tightnesses which solve the firm's, the household's and the bargaining problems and which let markets clear. The

[7]The individual bargaining framework was introduced in partial equilibrium by Stole and Zwiebel (1996), and extended to general equilibrium by Smith (1999) and Ebell and Haefke (2009).

solution satisfies the household's Euler equations (7) and (8), the household constraints (2)-(5), the firm's optimality conditions (16) and (17), the firm's constraints (13)-(15), the wage curve (20), the transition equation for aggregate unemployment (9) and appropriate market-clearing conditions.

This definition of equilibrium yields a system of fourteen equations in the fourteen unknowns $(n_t, l_t, k_t, f_t, q_t, \theta_t, u_t, v_t, w_t, y_t, c_t, i_t, r_t, z_t)$. The log-linearized system is solved by the method of undetermined coefficients, implemented using Uhlig (1999)'s toolkit. A list of all equations, both in levels and log-linearized, is provided in the Appendix.

4 Calibration

Period length is one week. There are fourteen parameters to pin down: the technology parameter A, the participation elasticity ν, the utility weight ϕ, matching elasticity η, vacancy costs κ, worker's bargaining power μ, the output elasticity of capital α, the flow utility to unemployment b, the depreciation rate δ, the match destruction rate χ, and the matching scale parameter s, the discount factor β and the two parameters of the productivity shock ρ and σ_ε.

The baseline calibration is summarized in Table 1.[8] The novel element of the baseline calibration strategy is the use of the relative volatility of the participation rate to pin down the participation elasticity ν. This strategy plays an important role in establishing the calibrated model's ability to generate countercyclical unemployment rates and a negatively sloped Beveridge curve, despite the presence of elastic labor supply along the participation margin.

The technology parameter A is normalized to one. The parameters of the weekly log productivity process are chosen to match the autocorrelation and volatility of output per worker in post-war quarterly US data. Choosing weekly autocorrelation $\rho_w = 0.9895$ and weekly standard deviation of the innovation $\sigma_{\varepsilon,w} = 0.34$ % leads to quarterly autocorrelation $\rho_q = 0.765$ and quarterly unconditional volatility $\sigma_{z,q} = 1.3$ %.[9] Matching elasticity η is set to 0.50, within the range reported in Petrongolo and Pissarides (2001). The discount factor β is chosen to match an annual risk-free rate $\widetilde{r} \equiv \frac{1}{\beta} - 1$ of 4%. The capital elasticity of output α is set at 0.36, a standard value. The depreciation rate for capital is chosen so that the investment share of income $\frac{i}{y} = 0.25$, its value in the post-war data reported by Francis and Ramey (2001). The weekly calibrated value of $\delta = 0.0019$ corresponds to an annual depreciation rate of about 9.0%. The weekly separation rate χ is set to 0.0081, which corresponds to the monthly rate of $\chi = 0.026$ estimated by Shimer (2005). Similarly, the target for the weekly job-finding rate f is 0.139, which corresponds

[8] A complete derivation of all calibrated parameters and the steady state is offered in the Appendix.

[9] These values are identical to those chosen in Hagedorn and Manovskii (2008).

to Shimer (2005)'s monthly value of 0.45. Together χ and f pin down the equilibrium unemployment rate $\widetilde{u} \equiv \frac{u}{u+n}$ via the Beveridge curve $\widetilde{u} = \frac{\chi}{\chi+f}$ at 5.5 %. The target for the job-filling rate q is that of Den Haan, Ramey and Watson (2000), who find q to be 0.71 monthly, corresponding to a weekly value of 0.266. Together, the targets for f and q pin down the steady-state labor market tightness as $\theta = \frac{f}{q} = 0.523$. The latter figure is in roughly line with the average tightness value in the data of 0.465, obtained using JOLTS data for December 2000 to June 2007. Together, the targets for q and f also pin down the scaling parameter of the matching function, which becomes $s = 0.192$.

I follow Hagedorn and Manovskii (2008) in estimating that hiring a worker costs 7.6 % of the worker's annual wage[10]. This yields a share of vacancy costs in national income of $\Pi_v = 1.6\%$[11]. $\Pi_v = \chi \frac{\kappa}{q} \frac{n}{y}$ pins down vacancy posting costs κ[12].

Next, worker's bargaining power μ is chosen so that wages respond to technology shocks in a way that matches the data. The baseline calibration chooses μ to match the wage elasticity of productivity, which has been estimated to be $\varepsilon_{w,z} = 0.449$ by Hagedorn and Manovskii (2008)[13]. Choosing $\mu = 0.026$ achieves this target. Although Haefke, et. al. (2008) report higher point estimates for the wage elasticity of productivity, their standard errors are so large that their estimates for the wage elasticity of labor productivity still lie within about one standard error of the baseline target used here.[14] Due to the controversy surrounding these estimates, I will allow the target for $\varepsilon_{w,z}$ to vary widely from the baseline when reporting the results.

Now, one can use the steady-state versions of labor demand (17) and the wage curve (20) to obtain an equation which relates the benefit to unemployment b to parameters, and steady state variables:

$$b = \left[(1-\alpha) \frac{y}{n} - \frac{1}{1-\mu} \frac{\kappa}{q} (\widetilde{r} + \chi) - \frac{\mu}{1-\mu} \kappa \theta \right] \frac{1}{c}$$

[10] In Hagedorn and Manovskii (2008), labor costs are 4.5% of quarterly wages, corresponding to 1.1 % of annual wages, while capital costs are 6.5 % of annual wages.

[11] If hiring a worker costs 0.076 of annual wages, then $\frac{\kappa}{q} = 0.076 \cdot w_A$. The income share becomes:

$$\Pi_v = \kappa \frac{v}{y_A} = \chi_A \cdot \frac{\kappa}{q} \frac{n}{y_A} = \chi_A \cdot 0.076 \cdot \Pi_n$$

Using that $\chi_A = 1 - (1 - \chi_W)^{48} = 0.323$ is the annual probability of being separated, and that labour share of income is 0.64 yields $\Pi_v = 1.57$ %.

[12] Note that $\frac{n}{y}$ is pinned down by $\frac{y}{n} = A \frac{k}{n}^{\alpha}$, where capital intensity comes from the consumption Euler equation in the steady state: $\frac{k}{n} = \left(\frac{A\alpha}{r}\right)^{1/(1-\alpha)}$.

[13] The model's wage elasticity of productivity is obtained, following Hagedorn and Manovskii (2008), by regressing the model-generated wages on model-generated labor productivity $\frac{y_t}{n_t}$.

[14] Haefke, et. al. (2008) use CPS data on job-movers and find an OLS point estimate of $\varepsilon_{w,z} = 0.94$ with a standard error of 0.44. When controlling for the differing industry composition of new jobs versus all jobs, the OLS point estimate drops to 0.73 with a standard error of 0.48. Hagedorn and Manovskii (2008) use PSID data and obtain a point estimate of $\varepsilon_{w,z} = 0.449$ with a standard error of 0.042.

where c, $\frac{y}{n}$ and θ can be calculated using the parameters which have already been pinned down. The replacement rate $\frac{b}{w}$ is not meaningful under the utility function (6).[15] Instead, I report the fraction of the wage which is due to reservation utility in the steady state: $\frac{(1-\mu)bc}{w} = 0.96$, so that worker's surplus makes up about 4% of the steady state wage. This low value has been criticized as being unrealistic, since it would seem to give workers little incentive to work rather than be unemployed. In the model presented here, however, the relevant decision is participation versus non-participation, not unemployment versus employment. Nonetheless, as indicated above, I will allow the target for $\varepsilon_{w,z}$ (and hence the fraction of the wage due to surplus) to vary widely when analyzing the results in the following section.

Finally, the utility parameters ϕ and ν remain to be set. The participation elasticity ν is set so that the volatility of the participation rate matches the data. Targeting a relative volatility of participation of $\frac{\sigma_p}{\sigma_y} = 0.20$ results in a participation elasticity of $\nu = 0.768$. One can read the resulting partial elasticity of participation with respect to technology shocks off the model's recursive law of motion. In the baseline model a 1% increase in TFP leads to a 0.34 % increase in labor force participation. This is in line with numerous microeconometric estimates for labor supply elasticity which are smaller than unity. The weight on utility from the non-participants ϕ is chosen so that the steady-state fraction $1 - l$ of family members who participate in the labor market matches the average rate of labor market participation in the US from 1964 to 2006 at 64%. Setting $\phi = 0.37$ achieves this target.

5 Results

Results of the baseline calibration are presented in Tables 2, 3 and 5. The results of the weekly calibration have been aggregated to a quarterly frequency, so that they can be compared to the quarterly data. In what follows, I will first discuss the model's success at generating countercyclical unemployment and a negatively sloped Beveridge curve despite labor supply which is elastic along the participation margin. Next, the impact of elastic labor supply on the ability of the model to account for the volatilities and elasticities of labor market variables with respect to productivity is discussed.

5.1 Countercyclical Unemployment

The baseline calibration generates unemployment rates $\widetilde{u}_t$ which are almost exactly as countercyclical as in the data, $\rho_{\text{model}}(\widetilde{u}, y) = -0.87$ versus $\rho_{\text{data}}(\widetilde{u}, y) = -0.88$. The

[15] This is because the wage is denominated in terms of the consumption good, while b is not.

calibrated model also generates a negatively sloped Beveridge curve, although the contemporaneous correlation between unemployment and vacancies $\rho_{\text{model}}(\widetilde{u}, v) = -0.44$ falls short of its value in the data $\rho_{\text{data}}(\widetilde{u}, v) = -0.97$. The mere fact that model unemployment rates are strongly countercyclical and the model Beveridge curve negatively sloped is surprising. Previous authors studying RBC models with search frictions and elastic labor supply along the participation margin (Ravn (2008), Tripier (2003) and Veracierto (2008)) have consistently found their models to generate procyclical unemployment and a positively sloped Beveridge curve, contradicting the stylized facts.

The calibrated model presented in this paper is able to succeed at generating countercyclical unemployment rates and a negatively sloped Beveridge curve due to three elements of the calibration: low intertemporal substitution elasticity over time use ν, the low bargaining power μ (i.e. matching a wage elasticity of productivity smaller than unity a la Hagedorn and Manovskii, 2008) and the weekly calibration. In what follows, I discuss each of these factors in detail.

5.1.1 Targeting Participation Volatility

The first reason that the model presented here succeeds at generating countercyclical unemployment and a negatively-sloped Beveridge curve is the calibration strategy for the participation elasticity parameter ν. In the baseline calibration, I choose ν to match the relative volatility of the participation rate $\frac{\sigma_p}{\sigma_y} = 0.20$, leading to $\nu = 0.768$. In contrast, Ravn (2008), Tripier (2003) and Veracierto (2008) have all chosen higher values for ν. Ravn (2008) focuses on utility functions that are linear in non-participation, and hence are characterized by infinite elasticity. Veracierto (2008) sets the participation elasticity parameter to match the relative volatility of employment $\frac{\sigma_n}{\sigma_y}$. Tripier (2003) reports results to one calibration in which participation is infinitely elastic, and two in which he chooses participation elasticity to match employment volatility, corresponding to a value of ν of about 3. Figure 1 shows the impact of varying the participation elasticity ν on the key correlations of the unemployment rate $\widetilde{u}$ with vacancies, output and employment. Clearly, increasing ν makes the calibrated model less successful at matching these key correlations, underlining its importance.

Why does the low participation elasticity implied by targeting $\frac{\sigma_p}{\sigma_y}$ help to generate countercyclical unemployment and a negatively-sloped Beveridge curve? To understand this, compare impulse-response functions for the low-elasticity case (the baseline, $\nu = 0.768$) and a high-elasticity case ($\nu = 5.0$), shown in Figures 2 and 3 respectively. In both cases, vacancies respond to a positive productivity shock by increasing sharply.[16]

[16] The high elasticity of vacancies to productivity shocks is due to the small surplus calibration (i.e. choosing the bargaining power to match the wage elasticity of productivity), and will be discussed in the next sub-section.

In the low-elasticity baseline, relatively few workers enter search from non-participation in response to the positive productivity shock, so that the uptick in unemployment on impact is modest. The strong response of vacancies, coupled with the modest response of unemployment rates, lead tightness and job-finding rates to increase strongly in the baseline case. The strong increase on impact in job-finding rates ensures that the unemployed workers find jobs quickly, so that unemployment begins to decline about 4 weeks after the shock. As a result, quarterly unemployment rates are quite countercyclical, and the correlation between unemployment rates and vacancies is negative.

In the high elasticity case of Figure 3, in contrast, relatively many workers respond to the positive productivity shock by entering search from non-participation, as is reflected in the large downward movement of non-participation. As a result, the uptick in unemployment on impact is nearly as large as the surge in vacancies. Not only does this generate a positive correlation between the unemployment rate and vacancies ($\rho\left(\widetilde{u},v\right)=0.70$), it also leads to only modest increases in tightness and job-finding rates. The combination of a larger increase in unemployment rates coupled with a smaller increase in job-finding rates makes it more difficult for the impact on unemployment to be reversed. In particular, it now takes two months for unemployment rates to decline in response to the positive productivity shock, making unemployment less countercyclical ($\rho\left(\widetilde{u},y\right)=-0.32$) than in the baseline.

The cost of targeting participation volatility rather than employment volatility (as in Veracierto, 2008 or Tripier, 2003) is of course that the model is not able to match employment volatility perfectly. Figure 4 shows relative employment and participation volatilities as a function of the participation elasticity ν. The fact that relative participation volatility $\frac{\sigma_p}{\sigma_y}$ is more sensitive to ν implies that matching this target exactly comes at a smaller cost in terms of distance between the model and data relative employment volatilities than vice-versa.[17]

Another way of seeing why the difference between targeting participation and employment volatility is important is by doing a bit of volatility accounting. First, note that participation p_t is equal to the sum of employment h_t and unemployment u_t.[18] As a result, the variance of log deviations of the participation rate is given as

$$p^2\left(\frac{\sigma_p}{\sigma_y}\right)^2=u^2\left(\frac{\sigma_u}{\sigma_y}\right)^2+n^2\left(\frac{\sigma_n}{\sigma_y}\right)^2+2nu\cdot\rho\left(u,n\right)\frac{\sigma_u}{\sigma_y}\frac{\sigma_n}{\sigma_y} \tag{21}$$

Matching the relative volatility of the participation rate $\frac{\sigma_p}{\sigma_y}$ would only be equivalent to

[17] Indeed, Veracierto (2008) matches relative employment volatility exactly, but reports a model-generated relative participation volatility of 0.58.

[18] In the log-linearized model, this corresponds to $p\widehat{p}_t=u\widehat{u}_t+h\widehat{h}_t$, where p is the steady-state participation rate and $\widehat{p}_t$ is the log-deviation.

matching the relative volatility of employment $\frac{\sigma_n}{\sigma_y}$ if both models generated the same relative unemployment volatility and the same correlation between unemployment and employment $\rho(u, n)$.[19] Otherwise, the two calibration strategies yield different results. From Figure 1, it is easy to see that the baseline calibration does much better at matching the correlation between the unemployment rate and employment, making it easier to reconcile the relative volatilities in equation (21).

5.1.2 Wage Elasticity

A second important element of the calibration strategy is the use of a small surplus calibration following Hagedorn and Manovskii (2008), which chooses worker's bargaining power μ to match the wage elasticity of productivity $\varepsilon_{w,z}$. Figure 5 summarizes the behavior of key calibrations when the wage elasticity of productivity is varied[20]. The model wage elasticity of productivity $\varepsilon_{w,z}$ can be increased quite substantially from its baseline value of 0.449 to about 0.70, while still generating strongly countercyclical unemployment ($\rho(\widetilde{u}, y) = -0.79$) and a negatively sloped Beveridge curve ($\rho(\widetilde{u}, v) = -0.27$)[21]. As $\varepsilon_{w,z}$ approaches unity, however, the performance of the calibrated model deteriorates rapidly: unemployment becomes nearly acyclical and the Beveridge curve becomes strongly positively sloped.

Why is it important that wage elasticities remain below unity to generate countercyclical unemployment and a negatively sloped Beveridge curve? The key is the calibrated model's ability to generate vacancies which react strongly enough to productivity shocks. To see this, compare two sets of impulse responses which differ only according to their wage elasticity. Figure 2 presents the baseline, while Figure 6 presents a high wage elasticity case with $\mu = 0.50$ and $\varepsilon_{w,z} = 0.96$. In the baseline case of Figure 2, vacancies increase much more strongly to the positive productivity shock than does unemployment. As a result, tightness and job-finding rates also increase strongly, so that the positive impact reaction of unemployment is quickly reversed, allowing unemployment to remain countercyclical on average.

When the wage elasticity of productivity is increased to near unity, however, as in Figure 6, this mechanism breaks down. When wages react nearly one for one to a productivity shock, there is little increase in surplus for firms, and vacancies do not increase much more than unemployment. This leads to a positive correlation between the unemployment rate and vacancies ($\rho(\widetilde{u}, v) = 0.59$). Also, the increases in tightness and

[19] The steady state values of employment n, unemployment u and participation p are matched exactly in all calibrations.

[20] Figure 5 was generated by varying the target for the wage elasticity of productivity, but maintaining all other targets.

[21] When the wage elasticity of productivity is $\varepsilon_{w,z} = 0.70$, 15% of the wage is derived from match surplus.

job-finding rates are also very small, so that it takes about twice as long for the flows into search (i.e. the initial upward tick in unemployment) to be counterbalanced by flows out of search and into employment. This leads to a lower degree of countercyclicality in the unemployment rate ($\rho(\widetilde{u}, y) = -0.27$).

The calibration strategy of Hagedorn and Manovskii (2008) has come under strong criticism due to the high replacement rates it implies. As mentioned in Section 4, the replacement rate $\frac{b}{w}$ is meaningless in the model presented here. As an alternative, I report the steady state share of the wage which is due to reservation utility $\frac{b(1-\mu)c}{w}$. Figure 7 shows the behavior of key correlations as functions of this alternative measure to the replacement rate. Clearly, the calibrated model can still generate strongly countercyclical unemployment and a negatively sloped Beveridge curve, even if the share of surplus in the wage rises to about 25%. Moreover, unemployment remains countercyclical, even if the wage share of surplus is allowed to increase to 70% or more. This implies that the calibrated model's main results - the ability to generate countercyclical unemployment and a negatively sloped Beveridge curve - do not rest solely on extremely small surpluses.

5.1.3 Time Aggregation

Another reason that the calibrated model succeeds at generating realistic behavior of unemployment has to do with time aggregation and data collection. The BLS samples unemployment and vacancies for one reference week each month.[22] That is, subjects are asked whether they were searching for work not during the entire month, but only during the reference week. As a result, it is possible that a worker enters the labor force between reference weeks, searches for up to 3 weeks, finds a job, and is never recorded as unemployed. This is especially relevant in good times, when job-finding rates are high.[23]

In addition, since productivity data is available quarterly, one can only assess the cyclical behavior of unemployment at a quarterly frequency. The quarterly data is obtained as an average of monthly values. Hence, a small upward tick in monthly unemployment on impact of a positive technology shock would be averaged with the lagged downward movements in subsequent months. As a result, the average unemployment rate over the quarter might respond negatively to a positive productivity shock, despite an uptick in the impact month.

To address these issues, the baseline calibration has a weekly frequency. The weekly results are then aggregated to a quarterly frequency by taking averages, the quarterly series are HP-filtered, and then the correlations, standard deviations and impulse-responses are calculated.

[22] I refer here to collection procedures for the Current Population Survey, described on the BLS website under www.bls.gov/cps/cps_htgm.htm.

[23] Hagedorn and Manovskii (2008) make a very similar point, and also implement a weekly calibration.

To examine the impact of the weekly versus the equivalent quarterly calibration, results of the latter are presented in Table 6 and Figure 8. The quarterly impulse-responses of Figure 8 show that vacancies, unemployment rates, tightness and job-finding rates react in fundamentally the same way as in the weekly calibration. The impact of a positive technology shock is greater on vacancies than on unemployment, so that tightness and job-finding rates increase on impact. As a result, enough searchers find jobs immediately, and the unemployment rate already begins to decline one quarter after impact. Although the contemporaneous quarterly correlation between GDP and the unemployment rate in the baseline is of relatively small magnitude at -0.45, the lagged quarterly correlation between y_t and $\widetilde{u}_{t+1}$ is highly negative at -0.89. Similarly, the contemporaneous correlation between the unemployment rate and vacancies is positive, but the lagged correlation is highly negative at -0.70. Aggregating up to a biannual or annual frequency would hence cause the contemporaneous correlations with the unemployment rate to be (more strongly) negative, in the same way that aggregating from weekly to quarterly did.

5.2 The Shimer Puzzle

Finally, given the recent literature on the Shimer (2005) puzzle, it seems sensible to report on the ability of the model to account for the behavior of labor market variables over the cycle. In a framework with inelastic labor supply, it is well known that the small surplus calibration of Hagedorn and Manovskii (2008) is able to match the raw volatilities of unemployment, vacancies and tightness relative to productivity in the data reported in Table 4. The question is whether these results carry over to the case with elastic labor supply. Results for the baseline calibration are presented in Table 5. Clearly, introducing even a modest amount of participation elasticity diminishes the ability of the small surplus calibration to match the raw volatilities of key labor market variables.

Figure 9 shows the impact of increasing the target wage elasticity of productivity on the relative volatilities of unemployment, vacancies and tightness. Not surprisingly, the relative volatilities are decreasing in $\varepsilon_{w,z}$. Figure 10 shows the impact of increasing the increasing the participation elasticity parameter ν (i.e. target relative volatility of participation) on these key labor market volatilities. It is interesting to note that the ability of the calibrated model to account for highly volatile labor market tightness disappears as participation becomes more elastic. The reason is that in the high participation elasticity case (see the impulse-responses of Figure 3), both vacancies and unemployment rise sharply in response to a positive productivity shock. This implies that their ratio, labor market tightness θ, responds only very weakly to the productivity shock, so that the volatility of tightness remains quite low.

Mortensen and Nagypal (2007) and Pissarides (2007) argue that it is more appropriate to convert the raw volatilities into elasticities, to account for the fact that labor productivity is not the only source of cyclical variation. In the data, the elasticity of a labor market variable x with respect to productivity z is obtained as $\varepsilon_{x,z} = \frac{\sigma_x}{\sigma_z}\rho_{x,z}$.[24] The results of calculating the elasticities of labor market variables with respect to productivity in the same way in both the model and the data are presented in Table 7.

5.3 The "Consumption-Tightness Puzzle"

In recent work, Ravn (2008) presents an analytic approach to the "Shimer Puzzle". He derives a closed form relationship relating the amount of volatility in tightness that can be generated to the model's consumption volatility and parameters. In the appendix, I derive the corresponding consumption-tightness expression for the model presented here

$$\kappa\theta_t = \frac{1-\mu}{\mu}\left(\phi l_t^{-\frac{1}{\nu}} - b\right) c_t \tag{22}$$

compared to the consumption-tightness relationship in Ravn (2008)[25]:

$$\kappa\theta_t = \frac{1-\mu}{\mu}\left(\phi - b\right) c_t \tag{23}$$

Comparing (22) to (23) highlights that the two models are very similar. The crucial difference is the specification of the utility function. Ravn (2008) assumes utility which is linear in leisure, so that labor supply over the participation margin is infinitely elastic, while I allow for finite participation elasticity ν. Indeed, equation (22) corresponds to (23) for the special case in which labor supply elasticity is infinite ($\upsilon \to \infty$). Log-linearizing

[24] I follow Mortensen and Nagypal (2007) and Pissarides (2007) in using the data correlations reported in Shimer (2005). These are reproduced in the final column of Table 4.

[25] Ravn's original utility function is:

$$u = \ln c_t + H\left(1-s-l_t\right) n_t + H\left(1-s\right) u_t + H\left(1\right)\left(1-n_t-u_t\right)$$

where l_t are hours worked by the n_t employed family members, u_t is the share of searchers, $(1-n_t-u_t)$ is the share of non-participants and $H(1)$ and $H(1-s)$ are constants. I have adapted Ravn (2006)'s notation to mine. Renaming the constants as $H(1) = \phi$, $H(1-s) = b$

$$u\left(c_t, u_t, n_t\right) = \ln c_t + f\left(l_t\right) n_t + b u_t + \phi\left(1-n_t-u_t\right)$$

Ravn's original consumption-tightness equation under log utility in consumption is

$$\theta_t = \frac{\alpha}{1-\alpha}\frac{H(1)-H(1-s)}{\kappa}c_t$$

where α is the firm's bargaining power. Noting that in my model firm's bargaining power is $1-\mu$ yields

$$\theta_t = \frac{1-\mu}{\mu}\frac{\phi-b}{\kappa}c_t$$

both sides of (22) and (23) respectively yields:

$$\widehat{\theta}_t = -\frac{1}{\nu}\frac{\phi l^{-\frac{1}{\nu}}}{\phi l^{-\frac{1}{\nu}} - b}\widehat{l}_t + \widehat{c}_t \tag{24}$$

$$\widehat{\theta}_t = \widehat{c}_t \tag{25}$$

where variables with hats are log-deviations from the steady state $\widehat{x}_t = \ln \frac{x_t}{x}$ and I have used the steady state versions of (22) and (23) to simplify some parameters. Hence, the variance of tightness, consumption and non-participation over the cycle are are related as:

$$\sigma_\theta = \sqrt{\left(\frac{1}{\nu}\frac{\phi l^{-\frac{1}{\nu}}}{\phi l^{-\frac{1}{\nu}} - b}\right)^2 \sigma_l^2 - 2\left(\frac{1}{\nu}\frac{\phi l^{-\frac{1}{\nu}}}{\phi l^{-\frac{1}{\nu}} - b}\right)\sigma_{l,c}^2 + \sigma_c^2} \tag{26}$$

where $\sigma_x^2 \equiv var\left(\widehat{x}_t\right)$ and $\sigma_{l,c}^2 \equiv cov\left(\widehat{c}_t, \widehat{l}_t\right)$. Note that taking the limit as $\nu \to \infty$ yields the tight relationship between tightness and consumption volatilities derived in Ravn (2008): $\sigma_\theta = \sigma_c$.

The consumption-tightness relationship of equation (26) provides an analytic basis for the simulation results presented above. According to (26), three parameters are important in generating high volatility of tightness despite a low volatility of consumption: participation elasticity ν, flow utility to unemployment b, and the utility weight on the home good ϕ. Due to the negative correlation between log-deviations in consumption and non-participation in the data[26], large values of the coefficient $\frac{1}{\nu}\frac{\phi l^{-\frac{1}{\nu}}}{\phi l^{-\frac{1}{\nu}} - b}$ unambiguously increase the wedge between σ_θ and σ_c generated by the model. As a result, low participation elasticity ν makes tightness more volatile for given consumption volatility, corresponding to the simulation results of Figure 10.

In addition, the gap between the steady state marginal utilities to non-participation $\phi l^{-\frac{1}{\nu}}$ and to search b is crucial for the ability of the model to generate very volatile labor market tightness. Taking the steady state of the household's participation Euler equation (8) and rearranging yields:

$$\frac{\phi l^{-\frac{1}{\nu}} - b}{\phi l^{-\frac{1}{\nu}}} = \frac{f}{\widetilde{r} + \chi}\left(\frac{w/c}{\phi l^{-\frac{1}{\nu}}} - 1\right)$$

Now it is the ratio between the marginal utility to obtaining the wage $\frac{w}{c}$ and the marginal utility to non-participation (home production) $\phi l^{-\frac{1}{\nu}}$ which must be near unity in order to generate highly volatile tightness. This reflects that the key decision is whether to participate or not. That is, the closer agents are to being indifferent between being

[26] Ravn (2008) reports a correlation in the data between participation and consumption of 0.27, so that the correlation between non-participation and consumption must be negative. In the model, the correlation between c_t and l_t is indeed negative, taking the value -0.58.

employed and not participating at all, the greater is the ability of the model to amplify consumption fluctuations into tightness volatility.

6 Conclusions

The main contribution of this paper is to demonstrate that a business cycle model with labor search frictions and a participation margin can indeed give qualitatively and quantitatively sensible results. The calibrated model succeeds at generating countercyclical unemployment and a negatively-sloped Beveridge curve, despite the presence of elastic labor supply along the extensive (participation) margin. The key to success is a small surplus calibration strategy that chooses participation elasticity so as to match the volatility of the participation rate and that uses a small surplus calibration to ensure that vacancies are sufficiently responsive to productivity shocks.

Table 1

Baeline Calibration (Weekly)

Parameter	Baseline Value	Parameter	Baseline Value
A	1.0	δ	0.0019
ρ	0.9895	s	0.192
σ_ε	0.34	κ	8.28
η	0.50	μ	0.026
χ	0.0081	b	1.38
β	0.9992	ν	0.768
α	0.36	ϕ	0.37

Table 2

Baseline Results: Business Cycle

Relative Volatility $\frac{\sigma_x}{\sigma_y}$	Data	Model	Correlations $\rho(x, y)$	Data	Model
Output	1.00	1.00	Output	1.00	1.00
Consumption	0.57	0.21	Consumption	0.80	0.73
Investment	4.28	3.25	Investment	0.91	0.99
Capital	0.43	0.25	Capital	0.05	0.17
Employment	0.57	0.42	Employment	0.81	0.98
Participation	0.20	0.20	Participation	0.39	0.97
Productivity	0.63	0.73	Productivity	0.84	0.99

Table 2: Data values are those reported in Veracierto (2008) for quarterly US data, 1967:1 to 1999:4.

Table 3

Baseline Results: Key Unemployment Correlations

x		$\rho(y, \widetilde{u})$	$\rho(v, \widetilde{u})$	$\rho(n, \widetilde{u})$
Data		-0.88	-0.97	-0.95
Model	Baseline	-0.87	-0.44	-0.93

Table 3: Data correlations are based upon quarterly BLS data from 1964 Q1-2005 Q4 which has been HP-filtered using Ravn and Uhlig (2002)'s optimal parameter value for quarterly data of 1600. Each simulated time series of 1800 weeks (37.5 years) is aggregated to quarterly frequency, and then model correlations are calculated as averages over 50 simulated time series.

Table 4

Shimer's summary statistics, quarterly US data, 1951-2003

x		$\widetilde{u}$	v	$v/\widetilde{u}$	f	z
Standard deviation		0.190	0.202	0.382	0.118	0.020
Relative Std. deviation $\frac{\sigma_x}{\sigma_z}$		**9.5**	**10.1**	**19.1**	**5.9**	**1.0**
Autocorrelation		0.936	0.940	0.941	0.908	0.878
Correlation matrix	$\widetilde{u}$	1	-0.894	-0.971	-0.949	-0.408
	v	–	1	0.975	0.897	0.364
	$v/\widetilde{u}$	–	–	1	0.948	0.396
	f	–	–	–	1	0.396
	z	–	–	–	–	1

Table 4: Source: Shimer (2005, Table 1), augmented by own calculations of the relative standard deviations $\frac{\sigma_x}{\sigma_z}$.

Table 5

Baseline Results: Cyclicality of Labor Market Variables

x		$\widetilde{u}$	v	$v/\widetilde{u}$	f	z
Relative Std deviation $\frac{\sigma_x}{\sigma_z}$		**5.8**	**8.7**	**12.4**	**6.1**	**1.0**
Autocorrelation		0.72	0.50	0.74	0.74	0.75
Correlation matrix	$\widetilde{u}$	1	-0.44	-0.77	-0.77	-0.81
	v	–	1	0.91	0.91	0.86
	$v/\widetilde{u}$	–	–	1	1.00	0.99
	f	–	–	–	1	0.99
	z	–	–	–	–	1

Table 5: All variables reported are log deviations from an HP trend.

Table 6

Key Unemployment Correlations: Quarterly Calibration

x			$\rho(y, \widetilde{u})$	$\rho(v, \widetilde{u})$	$\rho(n, \widetilde{u})$
Data			-0.88	-0.97	-0.95
Model	baseline	quarterly	-0.45	0.41	-0.20

Table 6: Data correlations are based upon quarterly BLS data from 1964 Q1-2005 Q4 which has been HP-filtered using Ravn and Uhlig (2002)'s optimal parameter value for quarterly data of 1600. Model correlations are calculated as averages over 100 simulated quarterly time series of 150 quarters (37.5 years).

Table 7

Elasticities of Labor Market Variables

	$\varepsilon_{\widetilde{u},z}$	$\varepsilon_{v,z}$	$\varepsilon_{\theta,z}$
Data	-3.88	3.68	7.56
Baseline	-2.37	3.17	7.48

Table 7: Elasticities calculated as $\varepsilon_{x,z} = \frac{\sigma_x}{\sigma_z}\rho_{x,z}$, where $\rho_{x,z}$ is the correlation in the data, as suggested by Mortensen and Nagypal (2007).

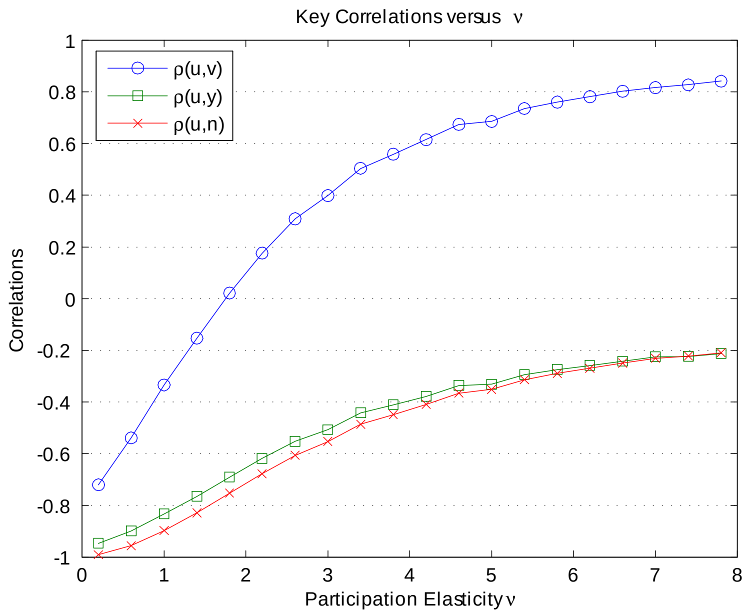

Figure 1: Correlations between unemployment rates and vacancies, output and employment respectively, plotted as functions of the participation elasticity ν. Varying ν implies that the relative volatility of participation will deviate from its baseline target value. All other baseline calibration targets are maintained.

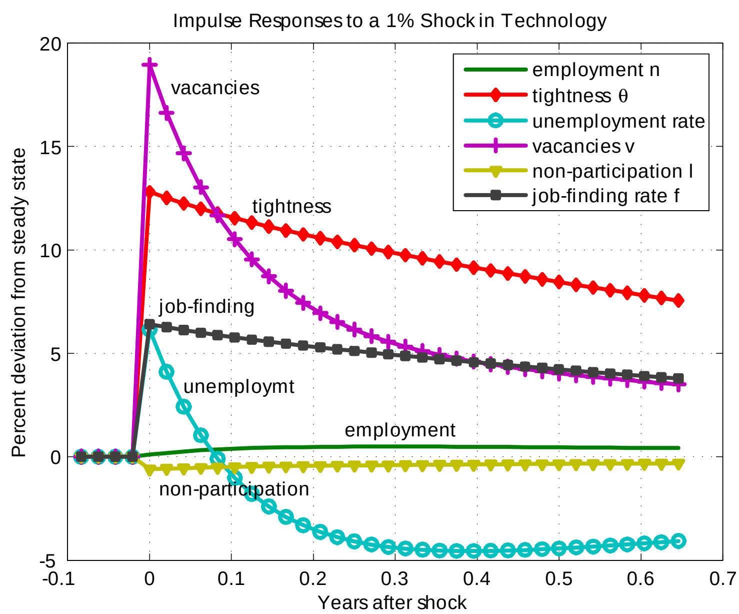

Figure 2: Impulse-responses to a 1% shock to productivity in the baseline calibration.

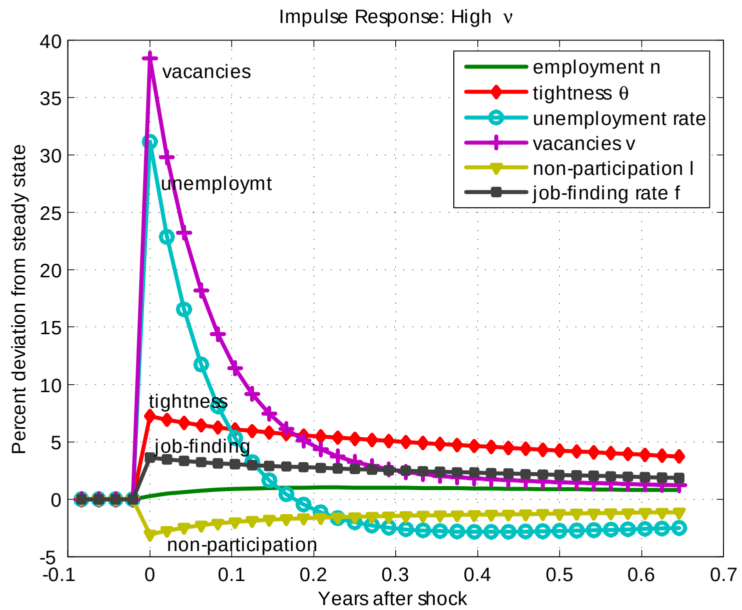

Figure 3: Impulse-responses to a 1% shock to productivity, high participation elasticity $\nu = 5.0$, all other baseline calibration targets maintained.

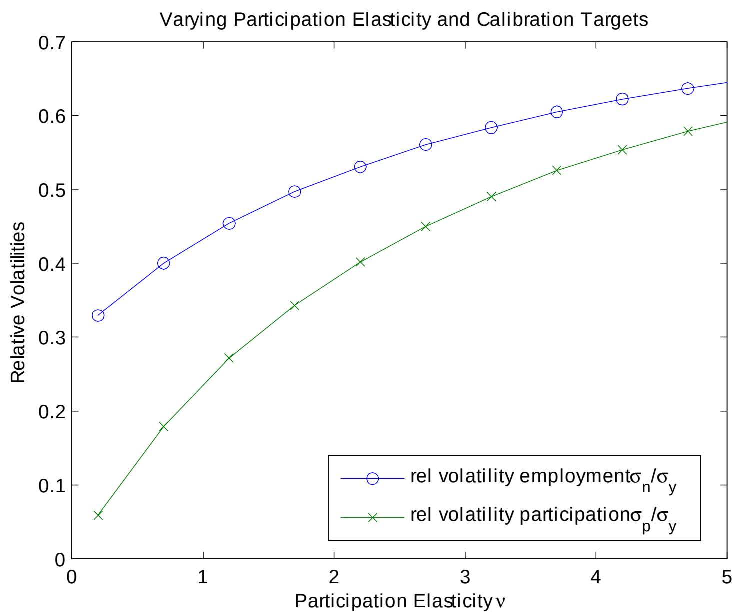

Figure 4: Impact of varying participation elasticity ν on relative volatilities of participation and employment. All other baseline calibration targets are maintained.

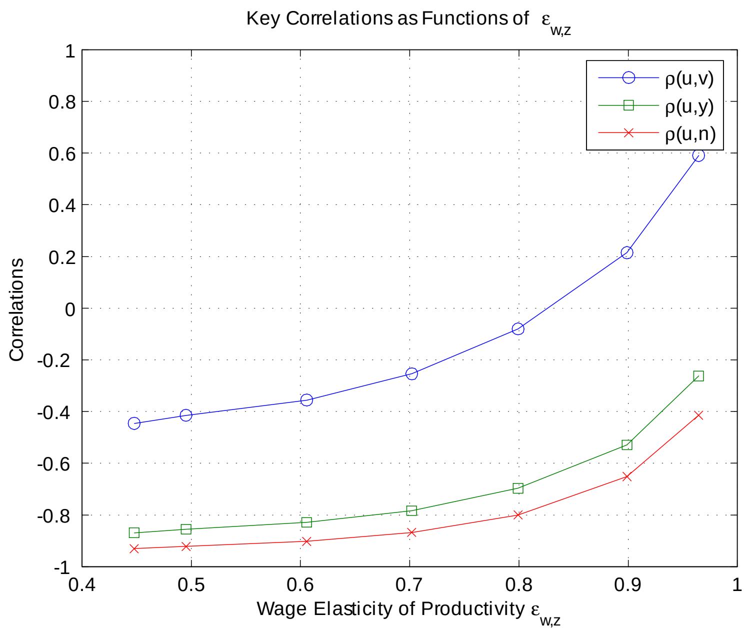

Figure 5: Key correlations as functions of the target wage elasticity of productivity $\varepsilon_{w,z}$. All other baseline calibration targets are maintained.

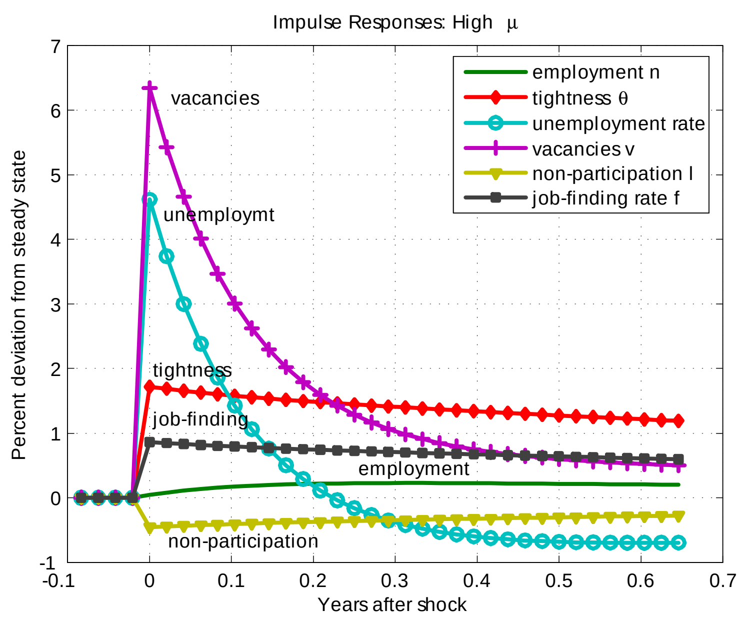

Figure 6: Impulse-responses to a 1% shock to productivity, high wage elasticity of productivity $\varepsilon_{w,z} = 0.96$ (worker's bargaining power $\mu = 0.5$), all other baseline calibration targets maintained.

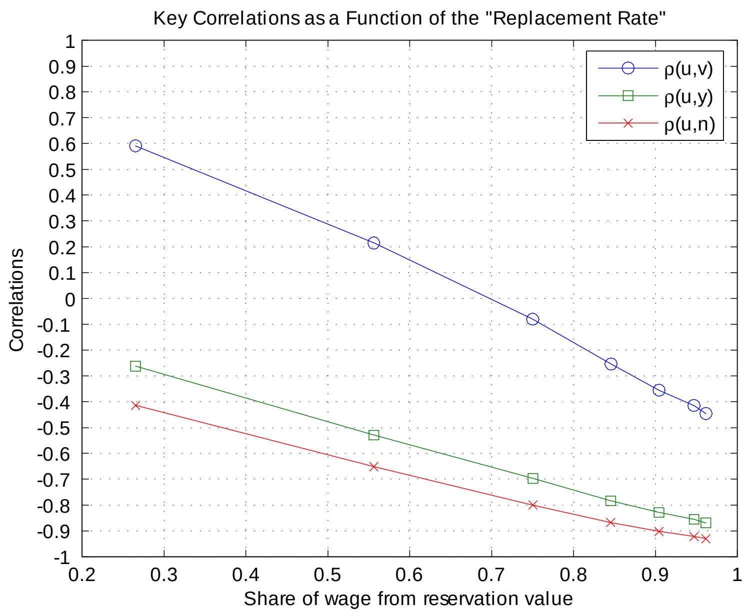

Figure 7: Correlations between unemployment rates and vacancies, output and employment respectively, plotted as functions of the share of the wage which derives from reservation utility $\frac{b(1-\mu)c}{w}$. The wage elasticity of productivity will deviate from its baseline value, but all other baseline calibration targets are maintained.

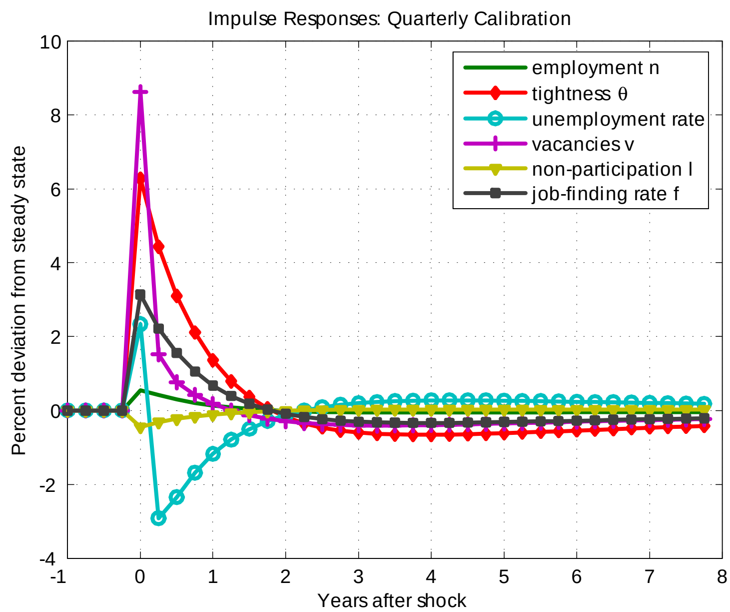

Figure 8: Impulse-responses to a 1% shock to productivity, baseline calibration but at quarterly frequency.

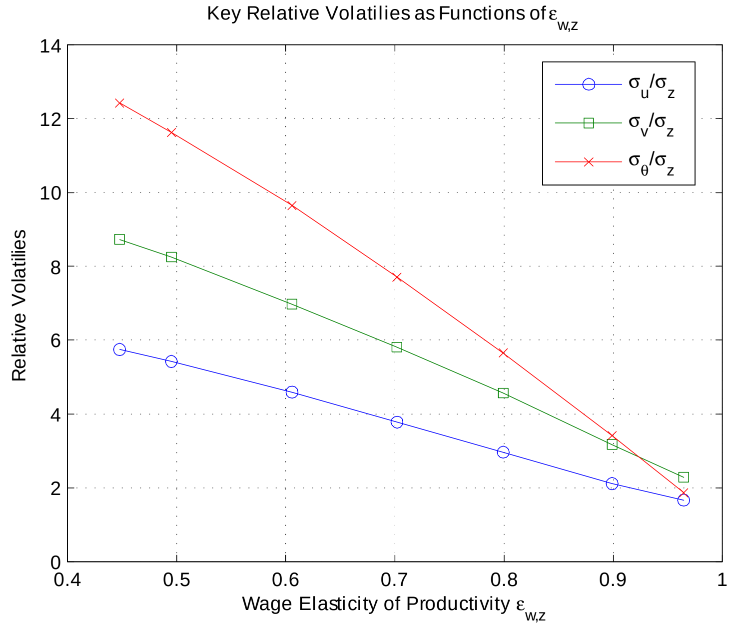

Figure 9: Sensitivity of key relative labor market volatilities to wage elasticity of productivity $\varepsilon_{w,z}$. Weekly calibration, all other baseline calibration targets maintained.

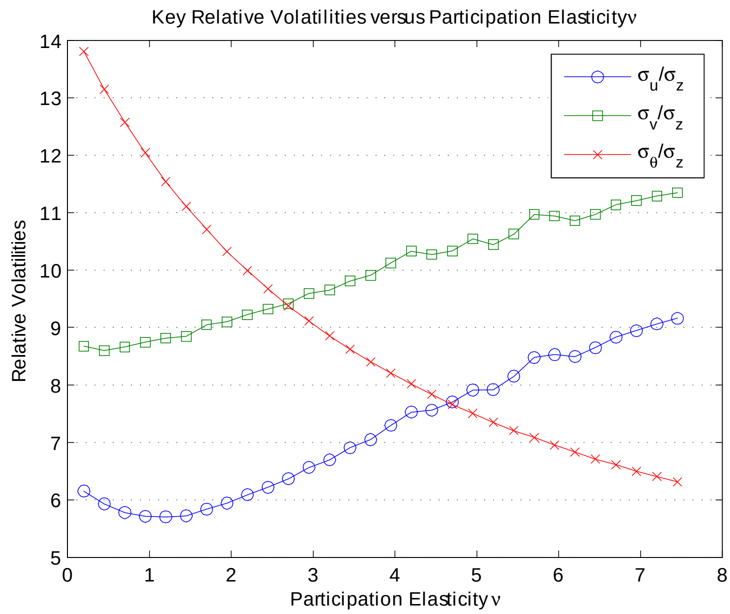

Figure 10: Sensitivity of key relative labor market volatilities to participation elasticity ν. Weekly calibration, all other baseline calibration targets maintained.

Appendices

A Solving the Household's Optimization Problem

The household's optimization problem is given by (1) subject to (2)-(5). Substituting the constraints (3)-(5) into (1) yields

$$V\left(n_{t-1},k_{t-1}\right)=\max_{c_t,i_t,u_t}\left\{\begin{array}{c} u\left[c_t,\underbrace{1-n_{t-1}-u_t}_{l_t},u_t\right] \\ +\beta E_t V\left[\underbrace{\left(1-\chi\right)n_{t-1}+f_t u_t}_{n_t},\underbrace{\left(1-\delta\right)k_{t-1}+i_t}_{k_t}\right]\end{array}\right\} \tag{27}$$

subject to

$$w_t n_{t-1}+r_t k_{t-1}+\pi_t\geq c_t+i_t \tag{28}$$

The first order conditions are

$$\begin{aligned} \text{FOC } c_t &: \quad u_c\left(c_t,l_t,u_t\right)=\lambda_t && (29)\\ \text{FOC } u_t &: \quad u_l\left(c_t,l_t,u_t\right)=u_u\left(c_t,l_t,u_t\right)+f_t\beta E_t\left[V_n\left(n_t,k_t\right)\right] && (30)\\ \text{FOC } i_t &: \quad \beta E_t\left[V_k\left(n_t,k_t\right)\right]=\lambda_t && (31)\end{aligned}$$

where λ_t is the multiplier on the budget constraint (28). The envelope conditions for the two state variables n_{t-1} and k_{t-1} are:

$$\begin{aligned} V_n\left(n_{t-1},k_{t-1}\right) &= w_t\lambda_t-u_l\left(c_t,l_t,u_t\right)+\left(1-\chi\right)\beta E_t\left[V_n\left(n_t,k_t\right)\right] && (32)\\ V_k\left(n_{t-1},k_{t-1}\right) &= \left(1-\delta\right)\beta E_t\left[V_k\left(n_t,k_t\right)\right]+\lambda_t r_t && (33)\end{aligned}$$

Substituting (29) and (30) into (32) yields (8). Substituting (29) and (31) into (33) yields (7).

B Deriving Worker's Surplus

The marginal value to the household of an additional employed worker at date t is given by the envelope condition (32)

$$V_{n,t}=w_t u_{c,t}-u_{l,t}+\left(1-\chi\right)\beta E_t\left[V_{n,t+1}\right]$$

where $V_{n,t} \equiv V_n(n_{t-1}, k_{t-1})$ and the first order condition (29) has been used to substitute out for λ_t. Similarly, the marginal value to the household of an additional unemployed worker at date t is given by the household's first order condition for u_t (30)

$$V_{u,t} = -u_{l,t} + u_{u,t} + f_t \beta E_t [V_{n,t+1}] = 0$$

As a result, the household's surplus to employment is

$$V_{n,t} - V_{u,t} = w_t u_{c,t} - u_{u,t} + (1 - \chi - f_t) \beta E_t [V_{n,t+1}]$$

Using that at the optimum $V_{u,t} = 0$ yields (10).

C Solving the Firm's Problem

The firm's optimization problem is (12) subject to (13)-(15). The first order condition with respect to capital k_{t-1} is the standard optimality condition relating the rental rate on capital to its marginal product: $r_t = \alpha \frac{y_t}{k_{t-1}}$. The first order condition with respect to vacancies v_t is:

$$\frac{\kappa}{q_t} = E_t \left[\widetilde{\beta}_{t+1} J_n(n_t, z_{t+1}) \right] \tag{34}$$

According to (34), firms choose vacancies so that the cost of hiring a worker $\frac{\kappa}{q_t}$ is equal to the expected discounted marginal value of a worker to the firm. The envelope condition with respect to the firm's state variable n_{t-1} is given by (18). Combining (18) with (34) yields the firm's Euler equation for optimal labor choice (17).

D Deriving the Wage Curve

Proof of Proposition 1: *The first order condition of the bargaining problem (19) subject to (18) and (11) is:*

$$\frac{V_{n,t}}{u_{c,t}} = \frac{\mu}{1-\mu} J_{n,t} \tag{35}$$

Substitute into (35) from (18) to obtain

$$\frac{V_{n,t}}{u_{c,t}} = \frac{\mu}{1-\mu} \left[(1-\alpha) \frac{y_t}{n_{t-1}} - w_t + (1-\chi) \frac{\kappa}{q_t} \right] \tag{36}$$

Now taking (36) ahead one period and multiplying both sides by $\widetilde{\beta}_{t+1}$ yields a closed form expression for future workers surplus:

$$E_t \left\{ \widetilde{\beta}_{t+1} \frac{V_{n,t+1}}{u_{c,t+1}} \right\} = \frac{\mu}{1-\mu} E_t \left\{ \widetilde{\beta}_{t+1} \left[(1-\alpha) \frac{y_{t+1}}{n_t} - w_{t+1} + (1-\chi) \frac{\kappa}{q_{t+1}} \right] \right\} \tag{37}$$

Next, can use firm's optimality condition for labor (17) to obtain

$$E_t \left\{ \widetilde{\beta}_{t+1} \frac{V_{n,t+1}}{u_{c,t+1}} \right\} = \frac{\mu}{1-\mu} \frac{\kappa}{q_t} \tag{38}$$

Future surplus depends only upon aggregate variables. The reason is that the expected worker's surplus is a search rent, whose value depends only upon the cost of searching for a new worker $\frac{\kappa}{q_t}$. Finally, substitute (11), (18) and (38) into the wage bargain (35) to obtain the wage curve (20). Q.E.D.

E Consumption-Tightness Relationship

This derivation follows Ravn (2008) closely. Begin with the first order condition of the wage bargaining problem (35), take it ahead by one period and multiply both sides by β and $\frac{1}{u_{c,t}}$ to obtain

$$\mu E \left[\widetilde{\beta}_{t+1} J_{n,t+1} \right] = (1-\mu) \frac{1}{u_{c,t}} \beta E \left[V_{n,t+1} \right]$$

Now, use the first order condition for the household (30) to substitute out for $\beta E \left[V_{n,t+1} \right]$, and also use (34) to substitute out for $E_t \left[\widetilde{\beta}_{t+1} J_{n,t+1} \right]$. This yields

$$\kappa \theta_t = \frac{1-\mu}{\mu} \cdot \frac{u_{l,t} - u_{u,t}}{u_{c,t}}$$

Using the utility function $u(c_t, l_t) = \log c_t + \phi \frac{l_t^{1-\frac{1}{\nu}}}{1-\frac{1}{\nu}} + b u_t$ leads immediately to (22).

F List of Equilibrium Equations

1. consumption Euler

$$1 = \beta E_t \left\{ \frac{c_t}{c_{t+1}} \left[r_{t+1} + 1 - \delta \right] \right\}$$

2. participation Euler

$$\phi l_t^{-\frac{1}{\nu}} - b = \beta f_t E_t \left\{ \frac{w_{t+1}}{c_{t+1}} - \phi l_{t+1}^{-\frac{1}{\nu}} + \left(\frac{1-\chi}{f_{t+1}} \right) \left[\phi l_{t+1}^{-\frac{1}{\nu}} - b \right] \right\}$$

3. optimal labor choice

$$\frac{\kappa}{q_t} = \beta E_t \left\{ \frac{c_t}{c_{t+1}} \left[(1-\alpha) \frac{y_{t+1}}{n_t} - w_{t+1} + (1-\chi) \frac{\kappa}{q_{t+1}} \right] \right\}$$

4. wage curve

$$w_t = (1-\mu) b c_t + \mu \left[(1-\alpha) \frac{y_t}{n_{t-1}} + \kappa \theta_t \right]$$

5. budget constraint

$$y_t = c_t + i_t + \kappa v_t$$

6. transition capital

$$k_t = (1-\delta) k_{t-1} + i_t$$

7. household time constraint

$$1 = n_{t-1} + u_t + l_t$$

8. transition labor

$$n_t = (1-\chi) n_{t-1} + f_t u_t$$

9. production function

$$y_t = A z_t n_{t-1}^{1-\alpha} k_{t-1}^{\alpha}$$

10. optimal capital choice

$$r_t = \alpha \frac{y_t}{k_{t-1}}$$

11. tightness

$$\theta_t = \frac{v_t}{u_t}$$

12. job-filling

$$q_t = m \theta_t^{-\eta}$$

13. job-finding

$$f_t = m \theta_t^{1-\eta}$$

14. technology

$$z_t = \rho z_{t-1} + \varepsilon_t$$

G Log-linearized Equations

1. consumption Euler

$$E_t\left\{(\widehat{c}_t-\widehat{c}_{t+1})+\beta r\widehat{r}_{t+1}\right\}=0$$

2. participation Euler

$$0=\frac{\phi}{\nu}l^{-\frac{1}{\nu}}\widehat{l}_t-\frac{b}{c}\widehat{c}_t+E_t\left\{\begin{array}{c}\beta\left[f\frac{w}{c}+\phi l^{-\frac{1}{\nu}}(1-\chi-f)-(1-\chi)\frac{b}{c}\right]\widehat{f}_t+\beta f\frac{w}{c}\widehat{w}_{t+1}\\+\beta\frac{1}{c}\left[(1-\chi)b-fw\right]\widehat{c}_{t+1}-\beta(1-\chi)\left(\phi l^{-\frac{1}{\nu}}-\frac{b}{c}\right)\widehat{f}_{t+1}\\-\beta\frac{\phi}{\nu}l^{-\frac{1}{\nu}}(1-\chi-f)\widehat{l}_{t+1}\end{array}\right\}$$

3. optimal labor choice

$$0=\frac{\kappa}{q}\widehat{q}_t+E_t\left\{\begin{array}{c}\beta\left[(1-\alpha)\frac{y}{h}-w+(1-\chi)\frac{\kappa}{q}\right](\widehat{c}_t-\widehat{c}_{t+1})\\+\beta(1-\alpha)\frac{y}{n}(\widehat{y}_{t+1}-\widehat{n}_t)-\beta w\widehat{w}_{t+1}-\beta(1-\chi)\frac{\kappa}{q}\widehat{q}_{t+1}\end{array}\right\}$$

4. wage curve

$$-w\widehat{w}_t+(1-\mu)bc\widehat{c}_t+\mu(1-\alpha)\frac{y}{n}(\widehat{y}_t-\widehat{n}_{t-1})+\mu\kappa\theta\widehat{\theta}_t=0$$

5. budget constraint

$$y\widehat{y}_t-c\widehat{c}_t-v\kappa\widehat{v}_t-i\widehat{i}_t=0$$

6. transition capital

$$-\widehat{k}_t+(1-\delta)\widehat{k}_{t-1}+\delta\widehat{i}_t=0$$

7. household time constraint

$$n\widehat{n}_{t-1}+u\widehat{u}_t+l\widehat{l}_t=0$$

8. transition labor

$$-n\widehat{n}_t+(1-\chi)n\widehat{n}_{t-1}+fu\left(\widehat{f}_t+\widehat{u}_t\right)=0$$

9. production function

$$\widehat{y}_t-z_t-\alpha\widehat{k}_{t-1}-(1-\alpha)\widehat{n}_{t-1}=0$$

10. optimal capital choice

$$\widehat{y}_t-\widehat{k}_{t-1}-\widehat{r}_t=0$$

11. tightness

$$\widehat{\theta}_t-\widehat{v}_t+\widehat{u}_t=0$$

12. job-filling

$$\widehat{q}_t + \eta \widehat{\theta}_t = 0$$

13. job-finding

$$\widehat{f}_t - (1-\eta)\,\widehat{\theta}_t = 0$$

14. technology

$$z_t = \rho z_{t-1} + \varepsilon_t$$

This is a system of 14 linear equations in the 14 unknowns $\left(\widehat{n}_t, \widehat{l}_t, \widehat{k}_t, \widehat{f}_t, \widehat{q}_t, \widehat{\theta}_t, \widehat{u}_t, \widehat{v}_t, \widehat{w}_t, \widehat{y}_t, \widehat{c}_t, \widehat{i}_t, z_t, \widehat{r}_t\right)$.

H Calibration

H.1 Steady State

As usual, the calibration relies primarily on using steady-state equations to pin down parameters. The steady state versions of all equilibrium equations are listed here. The first group are those equations related to the household's problem (1) subject to (2)-(5) and its solution (7) and (8).

$$\text{Consumption Euler} : \frac{1}{\beta} - 1 = r - \delta \equiv \widetilde{r} \tag{39}$$

$$\text{Labor Euler} : \phi l^{-\frac{1}{\nu}} = \frac{\widetilde{r} + \chi}{\widetilde{r} + \chi + f} b + \frac{f}{\widetilde{r} + \chi + f} \frac{w}{c} \tag{40}$$

$$\text{Capital accumulation} : i = \delta k \tag{41}$$

$$\text{Household budget} : wn + rk + \pi = c + i \tag{42}$$

$$\text{Time} : 1 = n + u + l \tag{43}$$

$$\text{Household transition labor} : \chi n = fu \tag{44}$$

The second group are those equations related to the firm's problem (12) subject to (13)-(15) and its solution (16) and (17).

$$\text{Firm's capital optimality} : r = \alpha \frac{y}{k} \tag{45}$$

$$\text{Firm's labor optimality} : \frac{\kappa}{q}(\widetilde{r} + \chi) = (1-\alpha)\frac{y}{n} - w \tag{46}$$

$$\text{Production function} : y = A n^{1-\alpha} k^{\alpha} \tag{47}$$

$$\text{Firm's transition labor} : v = \frac{\chi}{q} n \tag{48}$$

Finally, there are the expressions for the bargained wage (20):

$$w = (1-\mu)\, bc + \mu \left[(1-\alpha) \frac{y}{n} + \kappa\theta \right] \tag{49}$$

and the resource constraint (market clearing in the goods market)

$$c + i + \kappa v = y \tag{50}$$

Note that the resource constraint and the household budget constraint (42) coincide if profits are given by $\pi = y - rk - wn - \kappa v$.

H.2 Baseline Parameters

The calibration is weekly. There are 14 parameters.

1. **Technology level** A**:** First, normalize $A = 1$.

2. A number of parameters are taken directly from the data:

$$\begin{aligned} \text{Autocorrelation of shocks} &: \; \rho = 0.9895 \\ \text{Std deviation of } \varepsilon_t &: \; \sigma_\varepsilon = 0.34\ \% \\ \text{Matching elasticity} &: \; \eta = 0.50 \\ \text{Separation rate} &: \; \chi = 0.0081 \end{aligned}$$

3. **Capital elasticity of output** α is set to 0.36, a standard value.

4. **Discount factor** β**:** The target is that the riskfree interest rate $\widetilde{r} \equiv \frac{1}{\beta} - 1$ be 4% per annum. This yields

$$(1+\widetilde{r})^{48} = 1.04$$

so that weekly $\widetilde{r} = 0.00082$ and $\beta = 0.9992$.

5. **Depreciation rate** δ**:** By (41), $\frac{i}{y} = \delta \frac{k}{y}$. By (45): $\frac{k}{y} = \frac{\alpha}{r}$, so that $\frac{i}{y} = \delta \frac{\alpha}{r}$. By (39) $\widetilde{r} + \delta = r$, so that $\delta = \frac{i}{y} \frac{\widetilde{r}+\delta}{\alpha}$. Solving for δ and using the target $\frac{i}{y} = 0.25$ yields:

$$\delta = \frac{\frac{i}{y}\widetilde{r}}{\alpha - \frac{i}{y}} = 0.0019$$

As a result, the **weekly steady state capital rental rate** becomes $r = \delta + \widetilde{r} = 0.0027$.

6. **Scaling of matching function** s: First, note that the targets for the job-finding rate f and the job-filling rate q pin down steady-state tightness θ due to $\theta = \frac{f}{q} = 0.523$. Now, s can be obtained from

$$f = s\theta^{1-\eta}$$

so that $s = 0.192$.

7. **Vacancy costs** κ: Now the target for the share of vacancy costs in national income $\Pi_v \equiv \frac{\kappa v}{y}$ can be used to pin down κ. Using (48) to substitute out for v and solving for κ yields:

$$\kappa = \Pi_v \frac{q}{\chi} \frac{y}{n}$$

To obtain $\frac{y}{n}$ use that $\frac{y}{n} = A\left(\frac{k}{n}\right)^{\alpha}$ and $\frac{y}{k} = A\left(\frac{k}{n}\right)^{\alpha-1} = \frac{r}{\alpha}$ so that $\frac{k}{n} = \left(\frac{A\alpha}{r}\right)^{\frac{1}{1-\alpha}}$ and $\frac{y}{n} = A\left(\frac{A\alpha}{r}\right)^{\frac{\alpha}{1-\alpha}} = 15.76$. As a result, $\kappa = 8.28$.

8. **Worker's bargaining power** μ is chosen numerically, by iterating over possible values of μ until the wage elasticity of productivity is $\varepsilon_{w,z} = 0.449$. This leads to $\mu = 0.026$.

9. To continue with the calibration, it is necessary to use the steady state values of several variables.

   (a) The Beveridge curve (44) together with the time constraint (43) yields:

   $$u = \frac{\chi}{f}(1 - l - u) = 0.0352$$

   u is the fraction of household/population members which is unemployed.

   (b) Use the time constraint and the share of non-participants $l = 0.36$ to obtain the employment to population ratio $h = 1 - u - l = 0.605$. The steady state unemployment rate (as a share of participants) is $\widetilde{u} \equiv \frac{u}{n+u} = 5.5\%$.

   (c) The **steady-state wage** w can be calculated from (46) as $w = 9.81$.

   (d) To find steady-state consumption c, divide both sides of the steady-state resource constraint (50) by n to obtain $\frac{c}{n} = \frac{y}{n} - \delta\frac{k}{n} - \kappa\frac{v}{n}$. It has already been established that $\frac{k}{n} = \left(\frac{A\alpha}{r}\right)^{\frac{1}{1-\alpha}}$ and that $\frac{y}{n} = A\left(\frac{k}{n}\right)^{\alpha}$. By (48), $\frac{v}{n} = \frac{\chi}{q}$. Substituting into the equation for $\frac{c}{n}$ yields $\frac{c}{n} = 11.57$. Finally, one can obtain **steady-state consumption** $c = n\frac{c}{n} = 6.995$.

10. **Unemployment benefit** b can be obtained from the wage curve (49):

$$w = (1 - \mu) bc + \mu \left[(1 - \alpha) \frac{y}{n} + \kappa \theta \right]$$

Solving for b yields that $b = 1.38$.

11. **Intertemporal substitution elasticity** ν is chosen numerically, by iterating over possible values of ν until the volatility of the participation rate relative to output $\frac{\sigma_p}{\sigma_y}$ matches 0.20, its value in the data. This yields $\nu = 0.768$.

12. **Weight on leisure in utility** ϕ: Finally, use the household's labor Euler equation (40) and the target for non-participation $l = 0.36$ to pin down ϕ as

$$\phi l^{-\frac{1}{\nu}} = \frac{f}{\widetilde{r} + f + \chi} \frac{w}{c} + \frac{\widetilde{r} + \chi}{\widetilde{r} + f + \chi} b$$

which yields $\phi = 0.370$.

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