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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 extensive (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 does indeed generate 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 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. Veracierto (2002), Tripier (2003) and Ravn (2006) 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 failure has 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 between non-participation and search is large enough, then unemployment becomes procyclical and is positively correlated with the procyclical vacancies.

How to solve this conundrum? On impact of a technology shock, vacancies and unemployment both react positively. The key to ensuring that unemployment is countercyclical is that vacancies react more strongly than unemployment, so that tightness and job-finding rates increase on impact. When job-finding rates increase sufficiently, the flows into unemployment from non-participation can be counterbalanced by flows out of unemployment and into employment, guaranteeing that unemployment begins to drop soon after impact. Hence, the challenge is to generate vacancies that are sufficiently responsive to productivity shocks, while also ensuring that unemployment does not respond too strongly on impact.

This is reminiscent of the challenge posed by the Shimer puzzle. As noted by Shimer (2005) and many others, generating enough responsiveness in vacancies on impact of a productivity shock is important for generating sufficient volatility in vacancies and tightness. Indeed, in order to solve the *qualitative* procyclical unemployment puzzle, it will turn out to be important to address the *quantitative* Shimer puzzle. The converse of this statement is that models which do not address the Shimer puzzle, generating counterfactually low vacancy elasticities of productivity, will also tend to generate counterfactually pro- or acyclical unemployment. In this sense, the glass is half empty: adding a participation margin can be seen as deepening the Shimer puzzle. In another sense, however, the glass is half full: addressing the Shimer puzzle by whatever means one prefers will also help the model to generate strongly countercyclical unemployment. In this paper, I will a employ a straightforward (albeit not uncontroversial) means of generating sufficient responsiveness of vacancies to productivity, namely the Hagedorn and Manovskii (2008) calibration strategy. Other means of generating sufficient vacancy elasticity of productivity, such as those proposed by Mortensen and Nagypal (2007), should be easily substitutable.

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). This model will also turn out to generate substantial volatility and elasticity to productivity in the key labor market variables unemployment, vacancies and tightness. These qualitative and quantitative successes are important, because only a model which matches key qualitative and quantitative facts can be fruitfully used and developed further for theoretical and policy analysis.

The key to resurrecting the participation-search RBC model is a new calibration strategy. First, Ravn (2006), Tripier (2003) and Veracierto (2002) all choose the elasticity of labor supply to be either infinite or to match the volatility of employment. In contrast, I calibrate this elasticity to match the volatility of participation. In the body of the paper, I will show that the two calibration strategies are not equivalent, and explain why targetting the volatility of the participation rate is more appropriate.

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, near unity. It turns out that such a 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 turns out to be so low is an attractive feature of this calibration. Micro studies typically also find low elasticities.

The second key element of the calibration strategy involves the response of wages to productivity shocks. Parameters are chosen so that the wage elasticity of productivity matches its value in the data, and so that the share of vacancy costs in national income matches the data. These elements of the calibration strategy are due to Hagedorn and Manovskii (2008). Matching the cyclical variation in wages also helps in generating countercyclical unemployment rates and a negatively-sloped Beveridge curve. The reason is that if wages react too strongly to productivity shocks, the incentives to create vacancies are artificially low. When vacancies do respond sufficiently to shocks,however, then tightness and job-finding rates also react sufficiently so that the flows of workers out of unemployment and into employment are large enough to 'mop up' the inflows from non-participants. If job-finding rates increase sufficiently, then unemployment can begin to drop again soon after the impact of a positive technology shock.

A further 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, as demonstrated by impulse-response functions of unemployment.

The calibrated RBC model with search frictions presented here can also be used to gain a new perspective on the debate over whether or not Mortensen-Pissarides-style serach frictions can account well for the cyclical variation in labor market variables. Using differing calibration strategies, Shimer (2005) and Hagedorn and Manovskii (2008) find that the stylized version of the Mortensen-Pissarides model can explain either practically none or all of the cyclical variation in labor market variables, respectively.

The elastic labor supply model can only account for high volatility and elasticity to productivity of tightness when the model is also able to generate a negatively-sloped Beveridge curve. The reason is that a strong negative correlation between unemployment and volatilities is required to ensure that their ratio fluctuates sufficiently. Hence, targetting participation volatility rather than employment volatility when choosing the participation elasticity is important in generating sufficient variation in tightness to match the data.

To my knowledge, the only other paper which has been able to generate countercyclical unemployment in RBC models with search frictions and elastic labor supply is Haefke and Reiter (2006). 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 found 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 basic model. It is a standard real business cycle, augmented by labor market frictions and wage bargaining. Labor supply is elastic along the extensive (participation) margin. The bargaining setup involves firms bargaining individually with each worker. Agents are risk averse. The agents 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 similar to the models studied in Ravn (2006), Veracierto (2002) and Tripier (2004).

2.1 Household's Problem

Each household consists of a number of individuals which is large enough to guarantee perfect insurance over consumption. The household maximizes its discounted expected utility over consumption of market goods c_t and the fraction of non-participants l_t. The household's Bellman equation is:

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

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

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

The fraction n_{t-1} family members earn the wage w_t, while u_t are searching for work and obtain benefits b. 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. 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 employment directly. Instead, they can invest in employment by sending workers into search, understanding that date t searching workers u_t will find jobs at (endogenous) rate f_t.

The solution to the family's problem takes the form of two Euler equations, which are derived in the Appendix.[1] The first is the standard Euler equation for consumption

$$1 = \beta E_t \left\{ \frac{u_{c,t+1}}{u_{c,t}} \left[r_{t+1} + 1 - \delta \right] \right\} \tag{6}$$

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

$$u_{l,t} - bu_{c,t} = f_t \beta E_t \left\{ w_{t+1} u_{c,t+1} - u_{l,t+1} + \frac{1-\chi}{f_{t+1}} \left[u_{l,t+1} - bu_{c,t+1} \right] \right\} \tag{7}$$

The left-hand side of (7) reflects the marginal disutility to increasing the family's labor force participation, consisting of the loss in utility due to decreased l_t net of the gain to an increase in unemployment benefits. 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 $m(U_t, V_t) = sU_t^{\eta} V_t^{1-\eta}$. 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

$$N_t = (1-\chi) N_{t-1} + f_t U_t \tag{8}$$

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 its Bellman equation (1) as the marginal value to the household of an additional employed worker[2] $V_n(n_{t-1}, k_t)$:

$$V_{n,t} = w_t u_{c,t} - bu_{c,t} + (1 - \chi - f_t) \beta E_t \left[V_{n,t+1} \right] \tag{9}$$

Finally, worker's surplus in utility terms (9) can be converted into units of the good by

[1] Both the household's optimization problem and its solution are very similar to those analyzed in Ravn (2006).

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

dividing by the marginal utility of consumption $u_{c,t}$:

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

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. Firms produce using labor and rented capital. Firms adjust employment by varying the number of workers rather than the number of hours per worker. This is the appropriate margin, since about 2/3 of the fluctuations in employment can be attributed to the extensive margin.[3]

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 much as a capital stock. Firms can add to their future stock of employment capital by investing in current vacancies v_t, which are transformed into employed workers next period at the endogenous job-filling rate q_t. The firm's Bellman equation is:

$$J(n_{t-1}, z_t) = \max_{v_t, k_{t-1}} \left\{ y_t - w_t n_{t-1} - r_t k_{t-1} - \kappa v_t + E_t \left[\widetilde{\beta}_{t+1} J(n_t, z_{t+1}) \right] \right\} \tag{11}$$

subject to

$$\begin{aligned} \text{production function} &: & y_t &= A z_t n_{t-1}^{1-\alpha} k_{t-1}^{\alpha} && (12) \\ \text{transition function} &: & n_t &= (1-\chi)\, n_{t-1} + q_t v_t && (13) \\ \text{technology shock} &: & \ln z_t &= \rho \ln z_{t-1} + \varepsilon_t && (14) \end{aligned}$$

It is straightforward to derive the following conditions for the firm's optimal factor choices:

$$r_t = \alpha \frac{y_t}{k_{t-1}} \tag{15}$$

$$\frac{\kappa}{q_t} = E_t \left\{ \widetilde{\beta}_{t+1} \left[(1-\alpha) \frac{y_{t+1}}{n_t} - w_{t+1} + (1-\chi) \frac{\kappa}{q_{t+1}} \right] \right\} \tag{16}$$

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

$$J_{n,t} = (1-\alpha) \frac{y_t}{n_{t-1}} - w_t + (1-\chi) \frac{\kappa}{q_t} \tag{17}$$

[3] cf. Hansen (1985), whose results can also be replicated with more recent data.

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.[4] 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. "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.

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

$$\max_{w_t} \mu \ln \frac{V_{n,t}}{u_{c,t}} + (1-\mu) \ln J_{n,t} \tag{18}$$

subject to firm surplus (17) and worker's surplus (10). Worker's bargaining power is given by μ.

Proposition 1 *The solution to the bargaining problem (18) subject to (17) and (10) is given by*

$$w_t = (1-\mu)\, b + \mu \left[(1-\alpha) \frac{y_t}{n_{t-1}} + \kappa \theta_t \right] \tag{19}$$

Proof *See the appendix.*

Equation (19) 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 solution satisifes the household's Euler equations (6) and (7), the household constraints (2)-(5), the firm's optimality conditions (15) and (16), the wage curve (19), the transition equation for aggregate unemployment (8) 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's toolkit.

[4] The individual bargaining framework was introduced by Stole and Zwiebel (1996).

4 Calibration

The specification of the utility function is standard:

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

so that ν is the intertemporal elasticity of substitution for leisure.

Period length is one week. There are fourteen parameters to pin down: the technology parameter A, the intertemporal elasticity of substitution over time use ν, the weight on non-participants' time in the utility function ϕ, the matching elasticity η, vacancy costs κ, worker's bargaining power μ, the output elasticity of capital α, the utility coefficient on 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.

I consider four calibrations. The choices for the subset of parameters $(A, \eta, \alpha, \delta, \chi, s, \beta, \rho, \sigma_\varepsilon)$ are common to all of these and are reported in Table 1a. 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 $\sigma_{z,q} = 1.3$ %.[5] 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 of 4%. 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 $\delta = 0.0022$ corresponds to an annual depreciation rate of 10.0%. 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 to Shimer (2005)'s monthly value of 0.45. Together χ and f pin down the equilibrium unemployment rate $\frac{u}{u+n}$ 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 $\theta = \frac{f}{q} = 0.523$.[6] 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,

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

[6] At monthly frequency, the tightness target is $\theta = \frac{f_m}{q_m} = 0.634$, which corresponds to the monthly target in Hagedorn and Manovskii (2008). Labor market tightness is not invariant to frequency when calculated as $\theta = \frac{f}{q}$. The reason is that the weekly job-finding rate f_w is obtained from the monthly rate f_m as $1 - f_w = (1 - f_m)^{\frac{1}{4}}$. Analogously, the weekly job-filling rate q_w is the solution to $1 - q_w = (1 - q_m)^{\frac{1}{4}}$.

the targets for q and f also pin down the scaling parameter of the matching function, which becomes $s = 0.175$.

The target for the labor share is $\Pi_n = 0.64$, as implied by national accounts data. Factor shares add up to one, so that $\Pi_n + \Pi_k + \Pi_v = 1$, where Π_v is the share of vacancy costs in national income. The capital elasticity of output α is determined as $\Pi_k = \alpha$.

4.1 Baseline

The baseline calibration is summarized in Table 1a. The key element of the baseline calibration strategy is the use of the cyclical variation in the participation rate to pin down the elasticity of labor supply ν. This is a novel calibration strategy, and plays an important role in establishing the 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. Otherwise, the calibration is similar to that of Hagedorn and Manovskii (2008).

I follow Hagedorn and Manovskii (2008) in estimating that hiring a worker costs 7.6 % of the worker's annual wage[7]. This yields a share of vacancy costs in national income of $\Pi_v = 1.57\%$[8]. $\Pi_v = \chi \frac{\kappa}{q} \frac{n}{y}$ pins down vacancy posting costs κ[9]. 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 targets the point estimate of the wage elasticity of labor productivity reported by Hagedorn and Manovskii (2008), $\varepsilon_{w,z} = 0.449$. Choosing $\mu = 0.103$ achieves this target, and leads to a relative volatility of wages to output $\sigma_{w/y} = \frac{\sigma_w}{\sigma_y} = 0.424$, very close to the value of 0.42 from the data. The model's value for $\varepsilon_{w,z}$ is also within about one standard error of the point estimates reported in Haefke, et. al. (2007).[10]

As a result,

$$\theta_w = \frac{f_w}{q_w} = \frac{1-(1-f_m)^{\frac{1}{4}}}{1-(1-q_m)^{\frac{1}{4}}}$$

which is clearly distinct from $\theta_m = \frac{f_m}{q_m}$.

[7] 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.

[8] 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 $\Pi_v = 1.57$ %.

[9] 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: $\frac{k}{n} = \left(\frac{A\alpha}{r}\right)^{1/(1-\alpha)}$.

[10] Haefke, et. al. (2007) 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

Now, one can use the steady-state versions of labor demand (16) and the wage curve (19) to obtain an equation which relates the benefit to unemployment b to parameters and steady-state tightness θ (recall that θ was pinned down by targets for f and q):

$$b = (1-\alpha)\frac{y}{n} - \frac{\mu}{1-\mu}\kappa\theta - \frac{1}{1-\mu}\frac{\kappa}{q}(r+\chi)$$

Finally, the utility parameters ϕ and ν remain to be set. 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 $\phi = 0.516$ achieves this target. The participation elasticity ν is set so that the volatility of the participation rate matches the data. Targetting a relative volatility of participation of $\sigma_{p/y} = 0.20$ results in an intertemporal elasticity of substitution over time use of $\nu = 1.045$. One can read the corresponding 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 0.285 % increase in labor force participation. This is in line with numerous microeconometric estimates for labor supply elasticity which are smaller than unity[11].

4.2 Hagedorn/Manovskii, Target $\sigma_{n/y}$

Next, I also examine a calibration which differs from the baseline only in its calibration strategy for labor supply elasticity ν. Rather than targetting participation volatility, this alternative targets employment volatility, as in the work of previous authors. A much higher value of $\nu = 4.9$ is needed to ensure that employment is about 60% as volatile as output.

4.3 Traditional

Results from traditional calibrations are reported in Table 1b. The traditional calibrations choose bargaining power μ and the replacement rate b/w in the standard way, as advocated by Shimer (2005). Now, $\mu = \eta = 0.50$, so that the Hosios condition is satisfied[12]. The replacement rate is set at $\frac{b}{w} = 0.40$. This implies a value of $\kappa = 6.69$ for vacancy costs, leading to a higher share of vacancy costs in national income than in the baseline calibration of $\Pi_v = 2.07$. The weight on leisure in utility ϕ is again chosen so that in steady-state, 64% of agents participate in the labor market. A value of $\phi = 0.27$ achieves this target.

(2008) use PSID data and obtain a point estimate of $\varepsilon_{w,z} = 0.449$ with a standard error of 0.042.

[11] In principle, one could also use microeconometric estimates of partcipation elasticity as calibration targets.

[12] Shimer (2005) actually uses $\eta = \mu = 0.72$, but most of the literature takes $\eta = \mu = 0.50$.

I examine two versions of the traditional calibration, which differ only in the choice of target for labor supply elasticity, ν. When the target is participation volatility, as in the baseline, a low value of $\nu = 0.63$ is required to ensure that participation is one-fifth as volatile as output. When the target is employment volatility, as in previous authors' work, a high value of $\nu = 5.04$ yields employment that is about 60% as volatile as output.

5 Results

Results of the baseline calibration are presented in Table 2. 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 extensive margin. Next, the impact of elastic labor supply on the ability of the model to account for the volatility of labor market variables over the cycle is discussed.

5.1 Countercyclical Unemployment

The baseline calibration generates unemployment which is nearly as countercyclical as in the data, $\rho_{\text{model}}(u, y) = -0.82$ versus $\rho_{\text{data}}(u, y) = -0.88$. It also generates a negatively sloped Beveridge curve, although the contemporaneous correlation between unemployment and vacancies $\rho_{\text{model}}(u, v) = -0.43$ falls somewhat short of its value in the data $\rho_{\text{data}}(u, v) = -0.97$. The mere fact that model unemployment is 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 (Veracierto (2002), Tripier (2003) and Ravn (2005)) have consistently found their models to generate procyclical unemployment and a positively sloped Beveridge curve, contradicting the stylized facts.

The model presented here succeeds for two reasons: the calibration strategy and time aggregation. In what follows, I discuss each of these factors in detail.

5.1.1 Targetting 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 labor supply elasticity. In the baseline calibration, I choose ν so as to match the relative volatility of the participation rate $\sigma_{p/y} = 0.20$, leading to a moderate degree of participation elasticity ν in the baseline model, namely 1.045. In contrast, Veracierto (2002), Tripier (2003) and Ravn (2006) have all chosen higher values for ν. Ravn (2006) focuses on utility functions that are linear in leisure, and hence are characterized by infinitely elastic labor supplies. Veracierto (2002) calibrates ν to match the volatility of *employment* rather than participation, resulting in a more elastic labor supply in his model.[13] Table 2 compares the results of the baseline calibration, in which ν is chosen to match participation volatility, with the results of an otherwise identical calibration in which ν is chosen to match employment volatility. Targetting $\sigma_{n/y}$ leads to a much higher value for ν of nearly 5. Clearly, the high labor supply elasticity version fails badly at matching the key correlations of unemployment with output, vacancies and employment. It generates unemployment which is slightly procyclical, and a strongly positively sloped Beveridge curve, both in marked contrast to the strongly countercyclical unemployment and strongly negatively sloped Beveridge curve in the data.

Why does the low labor supply elasticity implied by targetting $\sigma_{p/y}$ help to generate countercyclical unemployment and a negatively-sloped Beveridge curve? To see this, compare impulse-response functions for the low-elasticity scenario (targetting $\sigma_{p/y}$) and and the high-elasticity scenario (targetting $\sigma_{n/y}$), shown in Figures 1 and 2 respectively. When participation is very elastic, the response of unemployment to a technology shock is large and positive on impact, as agents respond to the increased wages and increased probability of job-finding by streaming into search (unemployment). When participation is less elastic, the initial impact of a technology shock on unemployment is still positive, but smaller, because of agents' lower willingness to substitute over time uses, putting a brake on the flows into search. As a result of the small increase in unemployment, combined with a strong increase in vacancies, tightness and hence job-finding rates increase strongly in Figure 1. The increased job-finding rates ensure that the inflows of searching workers are 'mopped up' quickly and transit into employment, so that net inflows of workers to unemployment become negative within one month. In addition, the quick reversal of unemployment's behavior, coupled with an increase in tightness, help keep the Beveridge curve negatively sloped.

In contrast, in the high labor supply elasticity scenario of Figure 2, flows into unemployment upon impact are nearly has high as the increases in vacancies. As a result, tightness and job-finding rates do not increase much, so that job-seekers transit to employment at a lower rate. It then takes nearly half a year for the inflows into unemployment to become negative. Not only does this lead to procyclical unemployment, but the strong correlation between unemployment and vacancies leads to a strongly positively-sloped Beveridge curve.

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

[13] Tripier (2003) reports results to one calibration in which labor supply is infinitely elastic, and one in which he chooses labor supply elasticity to match employment volatility, as in Veracierto (2002).

that participation p_t is equal to the sum of employment h_t and unemployment u_t.[14] As a result, the variance of the participation rate is given as

$$p^2\sigma_p^2 = u^2\sigma_u^2 + h^2\sigma_h^2 + 2hu \cdot cov\left(\widehat{u}_t, \widehat{h}_t\right)$$

Matching the volatility of the participation rate σ_p would only be equivalent to matching the volatility of employment σ_h if both models generated the same unemployment volatility σ_u and the same covariance of unemployment and employment $cov\left(\widehat{u}_t, \widehat{h}_t\right)$. Otherwise, the two calibration strategies yield different results.

The volatilities of unemployment generated by the alternative participation and employment volatility targets are reasonably similar and roughly in line with the data (details further below). However, the correlation between unemployment and employment generated by the two targets varies considerably. In the data, this correlation is strongly negative at $\rho_{u,h} = -0.95$. Figure 3 shows that targetting participation rate volatility leads to almost as strong a negative correlation between unemployment and employment, as in the data ($\rho_{u,h}$ (model) $= -0.89$). In contrast, targetting employment volatility causes unemployment and employment to be somewhat positively correlated in the model. Hence, targetting the employment volatility is equivalent to targeting much too high a volatility in the participation rate. Indeed, Veracierto (2002) also finds that his model generates volatility of the participation rate that is nearly three times as large as that observed in the data.[15] Figure 4 shows how the key correlations with unemployment vary with participation volatility.

In addition, participation volatility σ_p is much more sensitive to labor supply elasticity ν than employment volatility σ_h, as can be seen from Figure 5. This implies that calibrating to σ_p leads to a smaller deviation from σ_n than vice-versa.

5.1.2 Wage Elasticity

A second important element of the calibration strategy is the wage elasticity of productivity. This elasticity is important in respect to its ability to generate vacancies which react strongly enough to productivity shocks. Recalling the impulse-response functions discussed in the previous subsection, the key to generating countercyclical unemployment is that vacancies react more strongly than unemployment on impact of a technology shock, so that tightness increases. Only if tightness increases do job-finding rates increase, so that the flows into search can be counterbalanced by flows out of search and into employ-

[14] 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.

[15] Here, I refer to Table 6 in Veracierto (2002), which gives the results of the Mortensen-Pissarides search model.

ment.

Figure 6 examines the impact of increasing the implied wage elasticity of productivity in the model on key variables.[16] 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, a strong negative correlation between unemployment and employment, and a (slightly) negatively sloped Beveridge curve. As $\varepsilon_{w,z}$ approaches 1, however, model performance deteriorates.

Another way of examining the role of wage elasticity is to compare the results from the Hagedorn and Manovskii (2008)-style baseline calibrations to the traditional calibrations. The main distinction between these two sets of calibrations is the implied wage elasticity of productivity, which approaches unity in the traditional calibrations. From the results reported in Table 2, one can see that neither traditional calibration is able to generate enough countercyclical movement in unemployment or a negatively sloped Beveridge curve. The traditional calibration which targets participation volatility does perform somewhat better, leading to somewhat countercyclical unemployment with $\rho(u, y) = -0.22$.

5.1.3 Time Aggregation

Another reason that our 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.[17] 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.[18]

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 unemployment on impact of a positive technology shock would be averaged with the lagged downward movements in unemployment. 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, I calibrate the model to weekly data, aggregate the results to a quarterly frequency by taking averages, HP-filter the quarterly series, and then calculate

[16] Figure 6 was generated by increasing worker's bargaining power and abandoning the target $\sigma_{w/y} = 0.42$, while maintaining all other calibration targets.

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

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

the correlations and the standard deviations. Table 3 compares the weekly results to the results of equivalent quarterly calibrations. While the frequency of the calibration does not have much impact on results under the employment volatility target, it is important under the participation volatility target. The reason is simple. The quarterly impulse-responses of Figure 7 show that vacancies, unemployment, 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 unemployment already begins to decline one quarter after impact. Although the contemporaneous quarterly correlation between GDP and unemployment is of relatively small magnitude at -0.21, the lagged quarterly correlation between y_t and u_{t+1} is highly negative at -0.83. Aggregating up to a biannual or annual frequency would cause the positive impact of technology on unemployment to be reversed, in the same way that aggregating from weekly to quarterly did.

5.2 Volatilities of Unemployment and Vacancies

Finally, I discuss the ability of the model to account for the volatilities of labor market variables over the cycle. In a framework with inelastic labor supply, Hagedorn and Manovskii (2008) are able to match the raw volatilities of unemployment, vacancies and tightness relative to productivity reported in Table 4. Elastic labor supply makes it more difficult for the model to generate highly volatile labor market variables. The quantitative question is: How much of the volatility of labor market variables in the data can be accounted for by a full RBC model with elastic labor supply?

Results on the cyclicality of labor market variables in the baseline calibration are presented in Tables 5 and 6. Even the moderate degree of labor supply elasticity in the baseline calibration does decrease the ability of Mortensen-Pissarides search frictions to match the raw volatilities of unemployment and vacancies noticeably. Still, the model with elastic labor supply is able to account for nearly 80% of the relative volatility of vacancies, while generating about 60% as much volatility in unemployment as in the data.

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 labor productivity p is obtained as $\varepsilon_{x,p} = \frac{\sigma_x}{\sigma_p}\rho_{x,p}$. In the model, I obtain estimates for $\varepsilon_{x,p}$ by regressing the relevant labor market variable x on labor productivity, defined as output per worker. The results are presented in Table 6.

The baseline calibration of the elastic labor supply RBC model with search frictions leads to an elasticity of unemployment with respect to productivity of $\varepsilon_{u,p} = -3.44$, which quite close to that the estimate from the data of -3.88. The model's estimate of the elasticity of vacancies with respect to productivity even overshoots the value in the data, at $\varepsilon_{v,p} = 5.51$ versus the data value of 3.68.[19]

How well the elastic labor supply model does at accounting for the elasticity of tightness to productivity depends crucially on the calibration target for ν. When the preferred participation volatility target is used, the model generates a somewhat higher elasticity of tightness in the model at $\varepsilon_{\theta,p} = 8.95$ than in the data at 7.56. When the employment volatility target is used, however, the model generated elasticity of tightness is much too low at $\varepsilon_{\theta,p} = 1.19$. The reason is that the participation target ensures that unemployment and vacancies are negatively correlated, which of course leads to greater variation in their ratio.

Interestingly, the employment target also leads to much lower elasticities of unemployment and vacancies with respect to productivity. Nonetheless, the employment target calibration is indeed able to generate significant *volatility* in u and v: unemployment is about 6.9 times as volatile as productivity, while vacancies are about 7.5 times as volatile as productivity. This is mainly due to the low correlation between productivity and these labor market variables ($\rho(u,p) = 0.14$ and $\rho(v,p) = 0.36$)[20].

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 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.

[19] Hagedorn and Manovskii (2008)'s inelastic labor supply model overshoots even more strongly on these elasticities, as noted in Mortensen and Nagypal (2007).

[20] Recall that the elasticity is the product of the relative volatility and the correlation with productivity, $\varepsilon_{x,p} = \frac{\sigma_x}{\sigma_p}\rho(x,p)$.

Table 1a
Baseline Calibration Weekly

Parameter	Value	Target
A	1.0	normalization
ρ	0.9895	data
σ_{ε}	0.34	data
η	0.50	data
χ	0.0081	data
β	$0.99^{1/12}$	$\widetilde{r} = 4.0$ % ann
δ	0.0022	$\frac{i}{y} = 0.25$
α	0.344	$\Pi_k = 0.344$
s	0.175	$f = 0.139$
ϕ	0.516	$l = 0.64$
ν	1.045 4.9	$\sigma_{p/y} = 0.20$ $\sigma_{n/y} = 0.60$
μ	0.103	$\varepsilon_{w,z} = 0.449$
κ	5.08	$\Pi_v = 0.0157$
$\frac{b}{w}$	0.949	$q = 0.266$

Table 1b
Traditional Calibration Weekly

Parameter	Value	Target
ϕ	0.27	$l = 0.64$
ν	0.63 5.04	$\sigma_{p/y} = 0.20$ $\sigma_{n/y} = 0.60$
κ	6.69	$\frac{b}{w} = 0.40$
μ	0.50	Hosios $\eta = \mu$

Table 2

Baseline Results

x		$\rho(y,u)$	$\rho(v,u)$	$\rho(n,u)$
Data		-0.88	-0.97	-0.95
Model	Baseline	-0.82	-0.43	-0.89
	HM, target $\sigma_{n/y}$	0.02	0.98	-0.01
	trad, target $\sigma_{n/y}$	-0.01	0.96	-0.04
	trad, target $\sigma_{p/y}$	-0.22	0.64	-0.36

Correlations are based upon quarterly BLS data from 1964 Q1-2005 Q4 which has been HP-filtered using Ravn and Uhlig (2004)'s optimal parameter value for quarterly data of 1600.

Table 3

Weekly vs Quarterly

x			$\rho(y,u)$	$\rho(v,u)$	$\rho(n,u)$
Data			-0.88	-0.97	-0.95
Model	Baseline	weekly	-0.82	-0.43	-0.89
		quarterly	-0.15	0.68	0.00
	trad, target $\sigma_{p/y}$	weekly	-0.22	0.64	-0.36
		quarterly	0.19	0.95	0.29
	HM, target $\sigma_{n/y}$	weekly	0.02	0.98	-0.01
		quarterly	0.05	0.99	0.39
	trad, target $\sigma_{n/y}$	weekly	-0.01	0.96	-0.04
		quarterly	0.09	1.00	0.42

Table 4

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

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

All variables reported are log deviations from an HP trend with smoothing parameter 10^5. *Source*: Shimer (2005, Table 1), augmented by own calculations of the relative standard deviations $\frac{\sigma_x}{\sigma_p}$.

Table 5

Baseline Results

x		u	v	v/u	f	p
Relative Std deviation $\frac{\sigma_x}{\sigma_p}$		**5.6**	**7.9**	**11.5**	**5.6**	**1.0**
Autocorrelation		0.75	0.52	0.76	0.77	0.75
Correlation matrix	u	1	−0.43	−0.78	−0.78	−0.73
	v	–	1	0.90	0.90	0.92
	v/u	–	–	1	1.00	0.99
	f	–	–	–	1	0.99
	p	–	–	–	–	1

All variables reported are log deviations from an HP trend with smoothing parameter 10^5.

Table 6

Elasticities of Labor Market Variables

	$\varepsilon_{u,p}$	$\varepsilon_{v,p}$	$\varepsilon_{\theta,p}$
Data	−3.88	3.68	7.56
Baseline	−3.44	5.51	8.95
HM, target $\sigma_{n/y}$	0.42	1.61	1.19

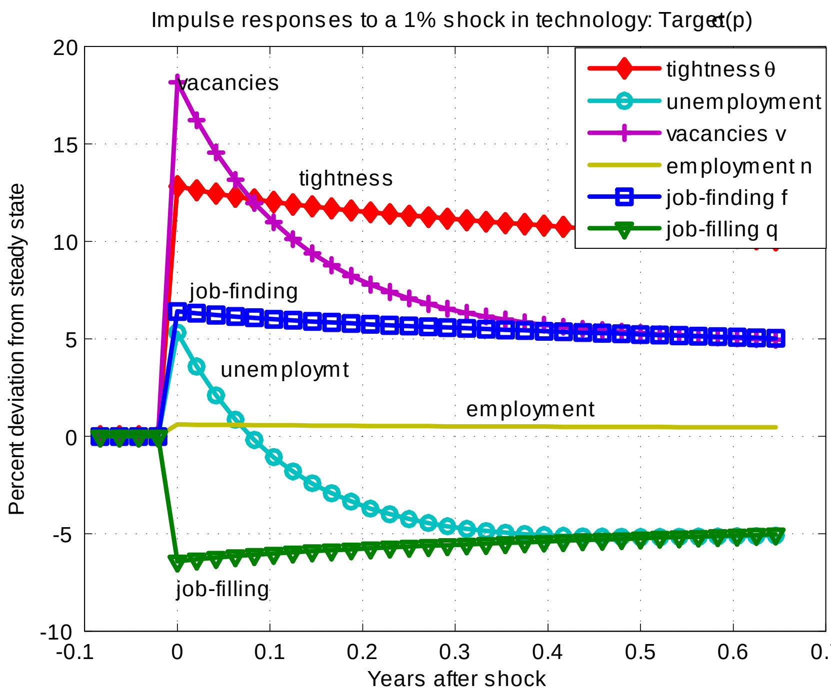

Figure 1: Low participation elasticity scenario, $\nu = 1.045$ to match participation volatility $\sigma_{p/y} = 0.20$.

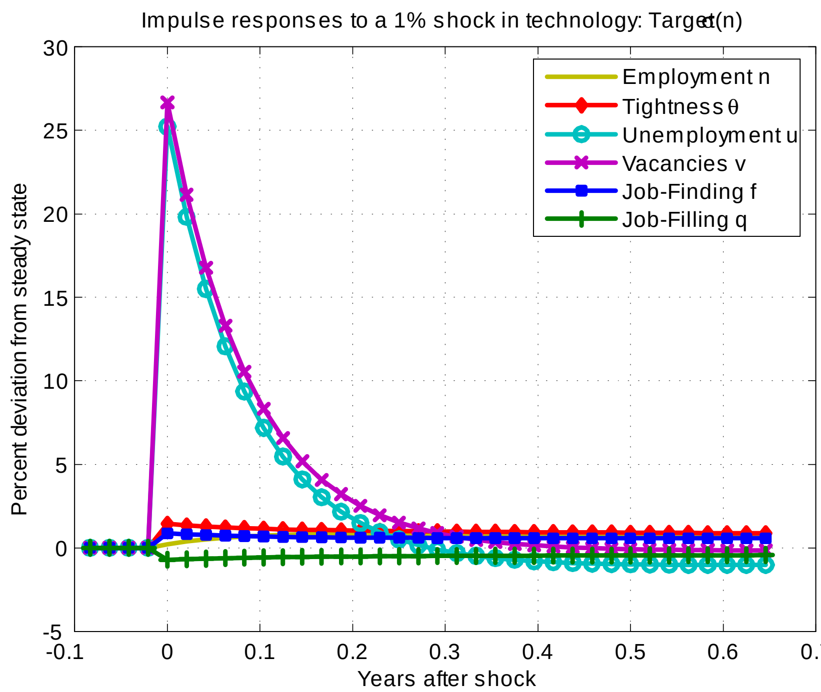

Figure 2: High participation elasticity scenario, $\nu = 4.9$ to match employment volatility $\sigma_{n/y} = 0.60$.

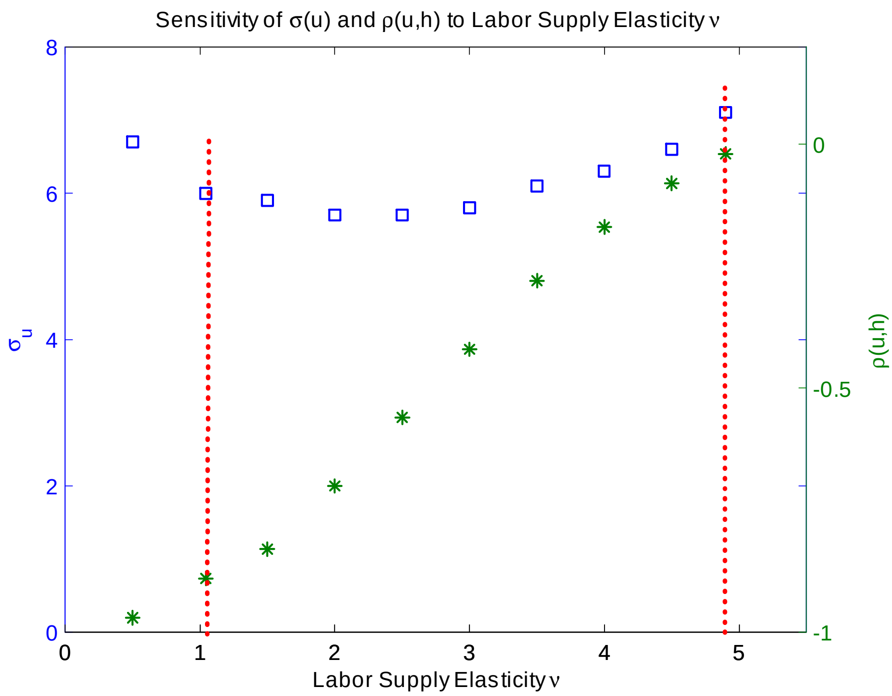

Figure 3: Plot of $\rho\left(u,h\right)$ (stars) and σ_u (squares) versus participation elasticity ν. Vertical lines indicate the calibrated values for ν when targetting $\sigma_{p/y}$ and $\sigma_{n/y}$.

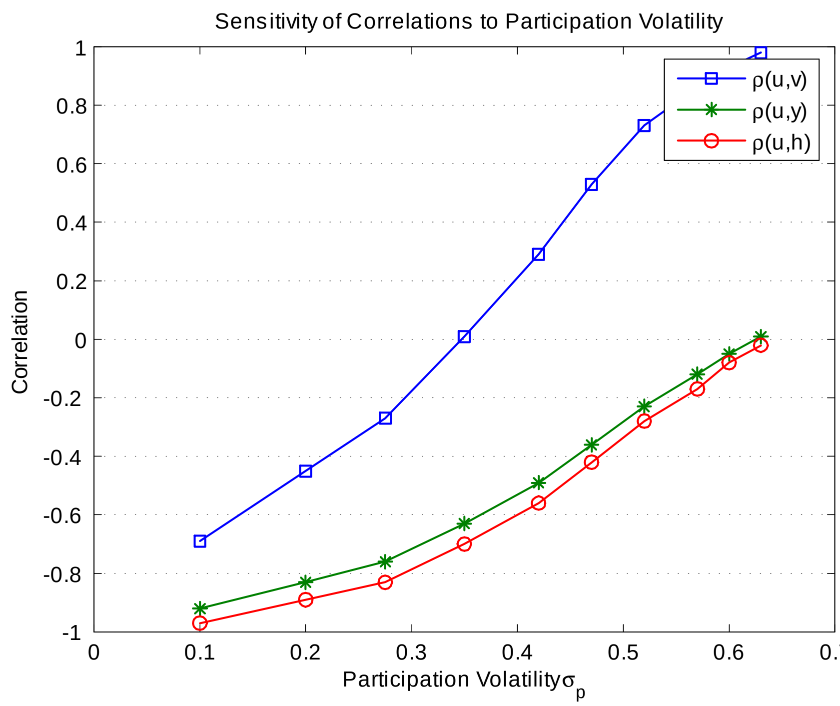

Figure 4: Sensitivity of unemployment correlations to targetted $\sigma_{p/y}$. Weekly calibration, all remaining calibration targets maintained.

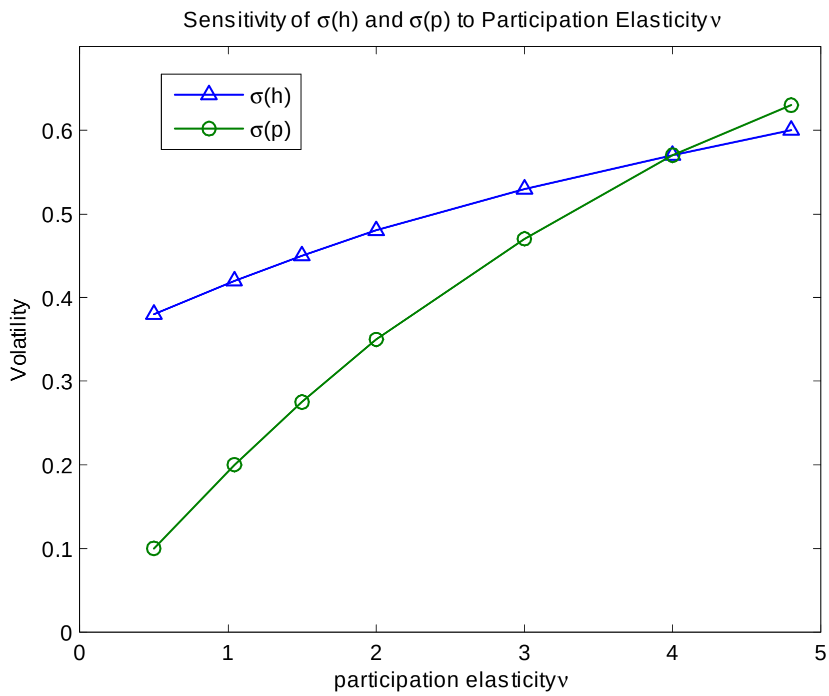

Figure 5: Sensitivity of implied values for relative employment and participation volatilities when participation elasticity ν is varied.

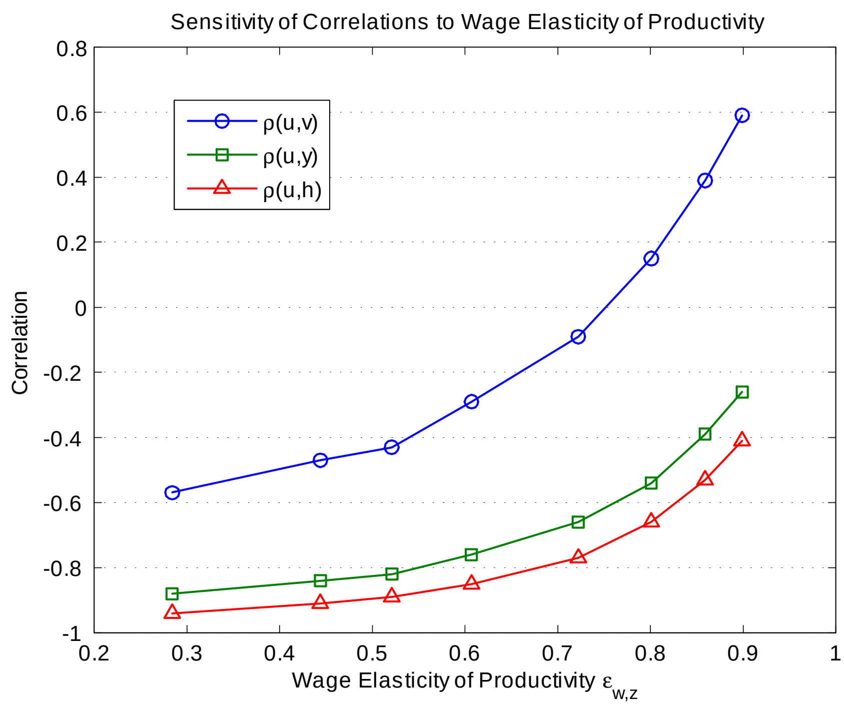

Figure 6: Sensitivity of unemployment correlations to targetted $\sigma_{p/y}$. Weekly calibration, all remaining calibration targets maintained.

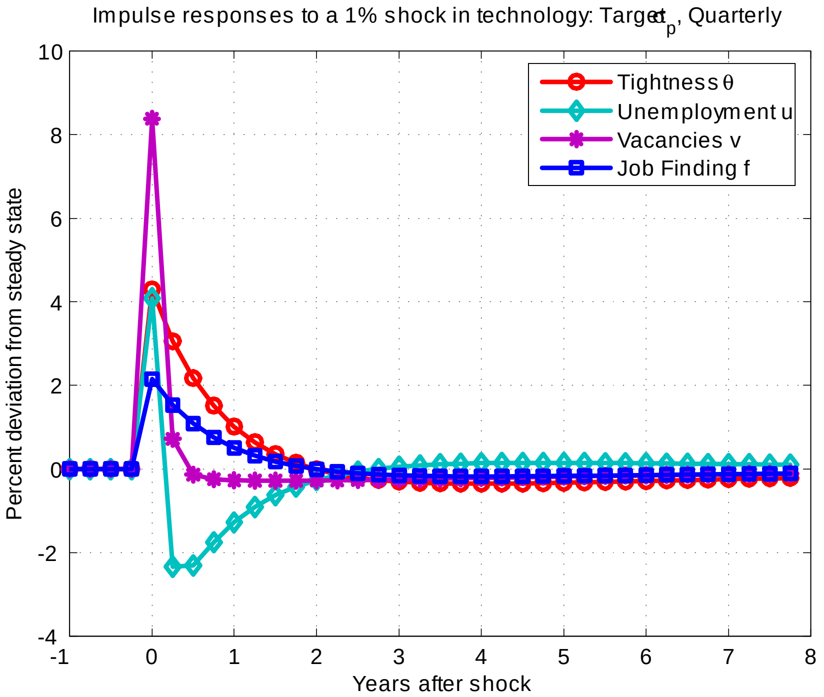

Figure 7: Quarterly impulse responses, low participation elasticity scenario, ν chosen to match participation volatility $\sigma_{p/y} = 0.20$.

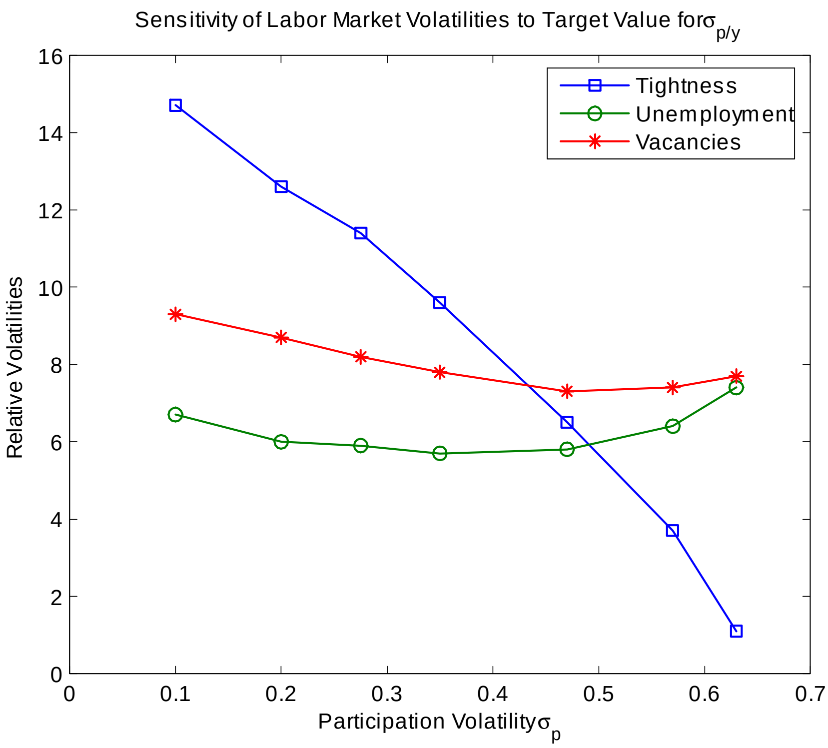

Figure 8: Sensitivity of volatilities of key labor market variables to the targetted participation volatility $\sigma_{p/y}$. Weekly calibration, all remaining calibration targets maintained.

Appendices

A Solving the Household's Optimization Problem

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

$$V\left(n_{t-1}, k_{t-1}\right) = \max_{c_t, i_t, u_t} \left\{ \begin{array}{c} u\left[c_t, \underbrace{1 - n_{t-1} - u_t}_{l_t}\right] \\ +\beta E_t V\left[\underbrace{\left(1-\chi\right) n_{t-1} + f_t u_t}_{n_t}, \underbrace{\left(1-\delta\right) k_{t-1} + i_t}_{k_t}\right] \end{array} \right\} \tag{20}$$

subject to

$$w_t n_{t-1} + b u_t + r_t k_{t-1} + \pi_t \geq c_t + i_t \tag{21}$$

The first order conditions are

$$\text{FOC } c_t \quad : \quad u_c\left(c_t, l_t\right) = \lambda_t \tag{22}$$

$$\text{FOC } u_t \quad : \quad u_l\left(c_t, l_t\right) = b\lambda_t + f_t \beta E_t\left[V_n\left(n_t, k_t\right)\right] \tag{23}$$

$$\text{FOC } i_t \quad : \quad \beta E_t\left[V_k\left(n_t, k_t\right)\right] = \lambda_t \tag{24}$$

where λ_t is the multiplier on the budget constraint (21). The envelope conditions for the two state variables n_{t-1} and k_{t-1} are:

$$V_n\left(n_{t-1}, k_{t-1}\right) = w_t \lambda_t - u_l\left(c_t, l_t\right) + \left(1-\chi\right)\beta E_t\left[V_n\left(n_t, k_t\right)\right] \tag{25}$$

$$V_k\left(n_{t-1}, k_{t-1}\right) = \left(1-\delta\right)\beta E_t\left[V_k\left(n_t, k_t\right)\right] + \lambda_t r_t \tag{26}$$

Substituting (22) and (23) into the envelope for n_{t-1} yields (7). Substituting (22) and (24) into (26) yields (6).

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 (25)

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

where $V_{n,t} \equiv V_n(n_{t-1}, k_{t-1})$ and the first order condition (22) 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 (23)

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

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

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

Using that at the optimum $V_{u,t} = 0$ yields (9).

C Deriving the Wage Curve

Proof of Proposition 1: *The first order condition of the bargaining problem (18) subject to (17) and (10) is:*

$$\frac{V_{n,t}}{u_{c,t}} = \frac{\mu}{1-\mu} J_{n,t} \tag{27}$$

Substitute into (27) from (17) to obtain

$$\frac{V_{n,t}}{u_{c,t}} = \frac{\mu}{1-\mu} \left[(1-\alpha) \frac{y_t}{n_{t-1}} - w_t + (1-\chi) \frac{\kappa}{q_t} \right] \tag{28}$$

Now taking (28) ahead one period and multiplying both sides by $\widetilde{\beta}_{t+1}$ yields a closed form expression for future workers surplus:

$$E_t \left\{ \widetilde{\beta}_{t+1} \frac{V_{n,t+1}}{u_{c,t+1}} \right\} = \frac{\mu}{1-\mu} E_t \left\{ \widetilde{\beta}_{t+1} \left[(1-\alpha) \frac{y_{t+1}}{n_t} - w_{t+1} + (1-\chi) \frac{\kappa}{q_{t+1}} \right] \right\} \tag{29}$$

Next, can use firm's optimality condition for labor (16) to obtain

$$E_t \left\{ \widetilde{\beta}_{t+1} \frac{V_{n,t+1}}{u_{c,t+1}} \right\} = \frac{\mu}{1-\mu} \frac{\kappa}{q_t} \tag{30}$$

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 (10), (17) and (30) into the wage bargain (27) to obtain the wage curve (19). Q.E.D.

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