Price Rigidity and the Volatility of Vacancies and Unemployment*

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Abstract

The successful matching model developed by Mortensen and Pissarides seems to find its hardest task in explaining the cyclical movements of some key labor market variables such as the vacancy rate and the vacancy-unemployment ratio. Several authors have discussed mechanisms compatible with the matching technology that are able to deliver the kind of correlations observed in the data. In this paper we explore the contribution of price rigidity, within the framework of a full-blown SDGE model, to explain the dynamics of these variables. We find that price rigidity greatly improves the empirical performance of the model, making it capable of reproducing second moments of the data, in particular those related to the vacancy rate and market tightness. Other realistic features of these models, such as intertemporal substitution, endogenous match destruction and capital accumulation, do not seem to play a relevant role in a flexible price setting.

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1. Introduction

The Mortensen and Pissarides model provides an engaging explanation of the determinants of unemployment dynamics (see Mortensen and Pissarides, 1999, and the references therein). While the model has gained widespread acceptance as a theory of the Natural

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Rate of unemployment its implications for the dynamics of some key labor market variables at the business cycle frequency are less readily accepted. In a widely quoted paper, Shimer (2005) argues that the model is incapable of reproducing the volatility of unemployment, vacancies and the vacancy-unemployment (v/u) ratio observed in the data for a reasonable parameter calibration. This is most unfortunate, as the Mortensen and Pissarides model has become the workhorse for incorporating unemployment and labor market frictions in a coherent and yet tractable way in dynamic general equilibrium models. Several authors have followed different strategies to improve the ability of the model to match data moments. Mortensen and Nagypál (2005) find that a countercyclical endogenous separation rate amplifies the effects of productivity shocks on unemployment and vacancy creation, whereas for Hagedorn and Manovskii (2008) and Costain and Reiter (2008) generating sufficiently large cyclical fluctuations in unemployment and vacancies is mainly a matter of calibration[2]. One highly promising line of research emphasizes the role of wage rigidity as a means of overcoming the shortcomings of the basic model (see, for example, Shimer, 2004, Hall, 2005a, Gertler and Trigrari, 2006, Bodart, Pierrard and Sneessens, 2006, Blanchard and Galí, 2007, Gertler, Sala and Trigrari, 2008). More partircularly, Gertler and Trigari (2006) and Gertler, Sala and Trigrari (2008) find that nominal wage stickiness moderates the volatility of real wages, increasing the size of the fluctuations of labor market variables. Haefke, Sonntag and van Rens (2009) and Pissarides (2009) question this line of research. They argue that the theoretical model must allow for sticky wages in existing jobs while preserving the flexibiltiy of wages in new matches, that are observed to be very volatile, and that this form of wage rigidity cannot explain the unemployment volatility puzzle.

In this paper we take an alternative stance and approach the issue in a complementary way. Like Gertler and Trigari (2006) and den Haan, Ramey and Watson (2000), we argue that the model performance at business cycle frequency can be greatly improved by embedding the basic search and matching model in a broader general equilibrium framework, but we stick to the assumption of wage flexibility and explore other mechanisms instead, namely, endogenous separation rates, price rigidity, intertemporal substitution, capital and taxes. These seemingly unrelated features may have different or even offsetting effects on the ability of the model to match the data, but do, nonetheless, have something in common: they all bring the model closer to a state-of-the-art SDGE model and thus provide a richer framework to assess the usefulness of the search and matching

[2] Yashiv (2007) provides a more extensive survey of the literature.

structure to explain the data. Besides, each of these mechanisms is relevant on its own. Endogenous separation seems the right choice if we want to give firms an additional margin along which to optimize and adjust employment in the presence of technology shocks. Price rigidity might contribute to smoothing out the response of real wages. Real interest rate fluctuations affect the present value of future surpluses. Capital accumulation is a key component of a model of business cycle fluctuations and its interaction with the labor market cannot be ignored. Finally, distortionary taxes influence the response of investment and the net values of surpluses, thus affecting unemployment and vacancies.

Our main result is that price rigidity is crucial in order for the model to deliver the historical volatility of the vacancy rate and the unemployment-vacancy ratio. We see price rigidity as a mechanism akin to that of wage stickiness. Under price stickiness supply shocks generate large swings in the mark-up that greatly amplify fluctuations in the expected surplus of matches and the value of vacancies. Thus the incentive to post new vacancies becomes much more sensitive to variations in productivity than in a flexible price environment.

We also discuss the role of other model features. Among these only endogenous destruction makes a significant contribution to the volatility of labor market rates albeit taking the model farther away from the data. Endogenous separation moderates (enhances) match destruction following positive (negative) technology shocks, thus reducing the response of vacancy posting. Other additional features also help the model to predict higher volatility but they are less influential in qualitative terms than price rigidity.

The rest of the paper is organized as follows. In the second section we outline a general version of the model used in the paper. In the third section we present the empirical evidence and discuss calibration in detail. Section four presents the main results summarized above and the fifth section concludes.

2. The model

There are three types of agents in this economy: firms, workers and the government. Households maximize the discounted present value of expected utility operating in perfect capital markets. They offer labor and hold their wealth in bonds and capital. The productive sector is organized in three different levels: (1) firms in the wholesale sector (indexed by j) use labor and capital to produce a homogenous good that is sold in a competitive flexible price market; (2) the homogenous good is bought by firms (indexed by $\widetilde{j}$) and converted, without the use of any other input, into a firm-specific variety that is sold in a monopolistically competitive market, in which prices may not be flexible; (3) finally there is a competitive retail aggregator that buys differentiated varieties ($y_{\tilde{j}t}$) and sells a homogeneous final good (y_t) with flexible prices. Thus, the model embeds Mortensen and Pissarides trading technology in the labor market into a fairly general equilibrium model with capital and sticky prices. Therefore, our model extends den Haan, Ramey and Watson (2000) to an economy with sticky prices, and generalizes Walsh (2005) to an economy with capital.

2.1 Households

Households maximize the β discounted present value of the following utility function[3],

$$\overline{U}_{it}\left(c_{it}^{*}, A_i\right) = U\left(c_{it}^{*}\right) \tag{1}$$

where:

$$U_i\left(c_{it}^{*}\right) = \frac{\left(c_{it}^{*}\right)^{1-\sigma}}{1-\sigma} \tag{2}$$

$$c_{it}^{*} = \frac{c_{it}}{c_{it-1}^{h}} \tag{3}$$

and h is a parameter which if different from zero indicates the presence of consumption habits. The budget constraint is given by

$$\left(1+\tau_t^c\right)c_{it}+e_{it}+\frac{M_{it}}{P_t}+\frac{B_{it}}{P_t}=\begin{bmatrix} \chi_{it}y_{it}^{l}+\left(1-\tau_t^k\right)r_t k_{it-1}+ \\ \frac{M_{it-1}}{P_t}+\left(1+i_{t-1}\right)\frac{B_{it-1}}{P_t}+\int_0^1\frac{\Omega_{i\tilde{j}t}}{P_t}d\tilde{j} \\ +\left(1-\chi_{it}\right)\left(A+\tilde{g}^u\right)+g_t^s+\frac{M_{it}^s}{P_t}\end{bmatrix} \tag{4}$$

where c_{it} stands for real consumption, e_{it} for real investment, M_{it} represents money holdings, B_{it} bond holdings, r_t the real return on capital, i_t nominal interest rate, and $\Omega_{i\tilde{j}}$ is the share of profits from the $\tilde{j}th$ monopolistically competitive firm in the intermediate sector, that accrues to household i. A_i stands for the non-tradable units of consumption good produced at home when the worker in unemployed ($\chi_i = 0$), $\tilde{g}^u$ is the unemployment benefit, g_i^s is a lump sum transfer from the government, k_{it-1} is the stock of capital at the end of period $t-1$ held by household i, y_{it}^{l} represents household's real disposable labor income

[3] Notice that the specification of the utility function does not include hours worked. Sveen and Weinke (2008) consider a model with intensive margin of hours, and bargaining in wage and hours, to study the importance of different shocks in explaining the observed fluctuations in labor market variables. We take an alternative stand instead and look into the channels through which price rigidity can influence the labor market in a world with productivity shocks only.

(net of labor taxes, see the definition below) and M_{it}^{s} the monetary transfers from the government (in aggregate, $M_t^s = M_t - M_{t-1}$). The model has taxes on capital (τ_t^k) and labor (τ_t^w) incomes, and consumption (τ_t^c).

Money is required to make transactions,

$$P_t \left(1+\tau_t^c\right) c_{it} \leq M_{it-1} + M_{it}^s \tag{5}$$

and households accumulate capital for which they have to pay installation costs ϕ_t and then rent it to firms at rental cost r_t

$$k_{it} = \left(1-\delta\right) k_{it-1} + \phi_t k_{it-1} \tag{6}$$

where $\phi_t = \phi\left(\frac{e_{it}}{k_{it-1}}\right)$. We further assume that households are homogenous and that they pool their incomes at the end of the period (perfect risk sharing) regardless of their employment status. This makes the first order conditions symmetric across households:

$$\frac{c_t^{-\sigma}}{c_{t-1}^{h(1-\sigma)}} - E_t\beta h \frac{c_{t+1}^{1-\sigma}}{c_t^{h(1-\sigma)+1}} - \lambda_{1t}\left(1+\tau^c\right) - \lambda_{2t}\left(1+\tau^c\right) = 0 \tag{7}$$

$$\lambda_{1t} - \lambda_{3t}\phi' = 0 \tag{8}$$

$$\begin{aligned} &E_t\beta\lambda_{1t+1}\left(1-\tau_{t+1}^k\right) r_{t+1} - \lambda_{3t} + \\ &E_t\beta\lambda_{3t+1}\left[\left(1-\delta\right) + \phi_t - \phi_t' \tfrac{e_{t+1}}{k_t}\right] = 0 \end{aligned} \tag{9}$$

$$\lambda_{1t} - E_t\beta\lambda_{1t+1}\frac{P_t}{P_{t+1}} - E_t\beta\lambda_{2t+1}\frac{P_t}{P_{t+1}} = 0 \tag{10}$$

$$\lambda_{1t} - E_t\beta\lambda_{1t+1}\left(1+i_t\right)\frac{P_t}{P_{t+1}} = 0 \tag{11}$$

where λ_{1t+1} is the Lagrangian multiplier associated to the budget constraint, λ_{2t+1} is the Lagrangian multiplier associated to the CIA constraint and λ_{3t+1} is the Lagrangian multiplier associated to the law of motion of capital. Expressions (8)-(11) can be rearranged in a more familiar format

$$E_t\lambda_{2t+1} = i_t E_t \lambda_{1t+1} \tag{12}$$

$$\lambda_{1t}\beta^{-1} = (1+i_t)\,E_t\left(\lambda_{1t+1}\frac{P_t}{P_{t+1}}\right) \tag{13}$$

$$\frac{\lambda_{3t}}{\lambda_{1t}} = [\phi_t']^{-1} = q_t \tag{14}$$

$$q_t\beta^{-1}{=}E_t\left\{\frac{\lambda_{1t+1}}{\lambda_{1t}}\left(\left(1{-}\tau_t^k\right)r_{t+1}{+}q_{t+1}\left[(1{-}\delta)+\phi_t{-}\phi_t'\frac{e_{t+1}}{k_t}\right]\right)\right\} \tag{15}$$

where we express the ratio of shadow prices as the Tobin's q.

2.2 The competitive retail sector

There is a competitive retail aggregator that buys differentiated goods from firms in the intermediate sector and sells a homogeneous final good y_t at price P_t. Each variety $y_{\widetilde{j}t}$ is purchased at a price $P_{\widetilde{j}t}$. Profit maximization by the retailer implies

$$Max_{y_{\widetilde{j}t}}\left\{P_t y_t - \int P_{\widetilde{j}t} y_{\widetilde{j}t} d_{\widetilde{j}}\right\}$$

subject to,

$$y_t = \left[\int y_{\widetilde{j}t}^{(1-1/\theta)} d_{\widetilde{j}}\right]^{\frac{\theta}{\theta-1}} \tag{16}$$

where $\theta > 1$ is a parameter that can be expressed in terms of the elasticity of substitution between intermediate goods $\varkappa \geq 0$, as $\theta = (1+\varkappa)/\varkappa$.

The first order condition gives us the following expression for the demand of each variety:

$$y_{\widetilde{j}t} = \left(\frac{P_{\widetilde{j}t}}{P_t}\right)^{-\theta} y_t \tag{17}$$

Also from the zero profit condition of the aggregator the retailer's price is given by:

$$P_t = \left[\int_0^1 \left(P_{\widetilde{j}t}\right)^{1-\theta} d\widetilde{j}\right]^{\frac{1}{1-\theta}} \tag{18}$$

2.3 The monopolistically competitive intermediate sector

The monopolistically competitive intermediate sector is composed of $\widetilde{j} = 1, ...\widetilde{J}$ firms each of which buys the production of competitive wholesale firms at a common price P_t^w and sells a differentiated good at price $P_{\tilde{j}t}$ to the final competitive retailing sector described above.

Variety producers $y_{\tilde{j}t}$ set prices in a staggered fashion. Following Calvo (1983) only some firms set their prices optimally each period. Those firms that do not reset their prices optimally at t adjust them according to a simple indexation rule to catch up with lagged inflation. Thus, each period a proportion ω of firms simply set $P_{\tilde{j}t} = (1+\pi_{t-1})^{\varsigma} P_{\tilde{j}t-1}$ (with ς representing the degree of indexation and π_{t-1} the inflation rate in $t-1$). The fraction of firms (of measure $1-\omega$) that set the optimal price at t seek to maximize the present value of expected profits. Consequently, $1-\omega$ represents the probability of adjusting prices each period, whereas ω can be interpreted as a measure of price rigidity. Thus, the maximization problem of the representative variety producer can be written as:

$$\max_{P^*_{\tilde{j}t}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s}\omega^s \left[P^*_{\tilde{j}t}\overline{\pi}_{t+s}y_{\tilde{j}t+s} - P_{t+s}mc_{\tilde{j}t,t+s}y_{\tilde{j}t+s}\right] \tag{19}$$

subject to

$$y_{\tilde{j}t+s} = \left(P^*_{\tilde{j}t}\prod_{s'=1}^{s}\left(1+\pi_{t+s'-1}\right)^{\varsigma}\right)^{-\theta} P^{\theta}_{t+s}y_{t+s} \tag{20}$$

where $P^*_{\tilde{j}t}$ is the price set by the optimizing firm at time t, $mc_{\tilde{j}t,t+s} = \frac{P^w_{t+s}}{P_{t+s}} = \mu^{-1}_{t+s}$ represents the real marginal cost (inverse mark-up) borne at $t+j$ by the firm that last set its price in period t, P^w_{t+s} the price of the good produced by the whosale competitive sector, and $\Lambda_{t,t+s}$ is a price kernel which captures the marginal utility of an additional unit of profits accruing to households at $t+s$, i.e.,

$$\frac{E_t\Lambda_{t,t+s}}{E_t\Lambda_{t,t+s-1}} = \frac{E_t(\lambda_{1t+s}/P_{t+s})}{E_t(\lambda_{1t+s-1}/P_{t+s-1})} \tag{21}$$

The solution for this problem is

$$P^*_{\tilde{j}t} = \left(\frac{\theta}{\theta-1}\right)\frac{E_t\sum_{s=0}^{\infty}(\beta\omega)^s\Lambda_{t,t+s}\left[\mu^{-1}_{t+s}\left(P_{t+s}\right)^{\theta+1}y_{t+s}\left(\prod_{s'=1}^{s}\left(1+\pi_{t+s'-1}\right)^{\varsigma}\right)^{-\theta}\right]}{E_t\sum_{s=0}^{\infty}(\beta\omega)^s\Lambda_{t,t+s}\left[\left(P_{t+s}\right)^{\theta}y_{t+s}\left(\prod_{s'=1}^{s}\left(1+\pi_{t+s'-1}\right)^{\varsigma}\right)^{1-\theta}\right]} \tag{22}$$

Then, taking into account (18) and that θ is assumed time invariant, the corresponding aggregate price level in the retail sector is given by,

$$P_t = \left[\omega \left(P_{t-1}\pi_{t-1}^{\varsigma}\right)^{1-\theta} + (1-\omega)\left(P_t^*\right)^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{23}$$

2.4 The competitive wholesale sector

The competitive wholesale sector consists of $j = 1, ...J$ firms each selling a different quantity of a homogeneous good at the same price P_t^w to the monopolistically competitive intermediate sector. Firms in the perfectly competitive wholesale sector carry out the actual production using labor and capital. Each producer employs one worker and technology is given by,

$$y_{jt} = z_t a_{jt} k_{jt}^{\alpha} \tag{24}$$

where k_{jt} is the amount of capital (capital-labor ratio) optimally decided by the firm, z_t is a common aggregate AR(1) shock with root ρ_z and a_{jt} is a firm specific productivity shock that is independently and identically distributed over time and across firms. Both shocks have a mean of 1. Nominal income at t is $P_t^w y_{jt}$ but only becomes available in period $t+1$; thus, real income is given by $\frac{P_t^w}{P_{t+1}} y_{jt}$. Present value real income is given by,

$$\left(\frac{1}{1+i_t}\right)\frac{P_t^w}{P_t} y_{jt} = \left(\frac{1}{1+i_t}\right)\frac{z_t a_{jt} k_{jt}^{\alpha}}{\mu_t} \tag{25}$$

where $\mu \equiv \frac{P_t}{P_t^w}$ is the mark up and we have made use of the appropriate discount factor obtained from (11),

$$\beta E_t\left(\frac{\lambda_{1t+1}}{\lambda_{1t}}\frac{P_t}{P_{t+1}}\right) = \frac{1}{1+i_t} \equiv \frac{1}{R_t} \tag{26}$$

2.5 Bargaining

Let us normalize the population to 1. Matching and production take place in the wholesale sector. At the beginning of period t some workers and firms are matched while others are not. In particular, workers start period t either matched (n_t) or unmatched ($1 - n_t$). Some of these matches are destroyed throughout this period while others are created. Unmatched firms and those whose match is severed during that period decide whether or not to post a vacancy. This decision is studied later. Posted vacancies are visited randomly by unemployed workers and all visited vacancies are occupied so that a new match occurs.

In period t not all matches become productive. Before production takes place there is an exogenous probability ρ^x of the match being severed, so only $(1-\rho^x)n_t$ matches survive this exogenous selection. Surviving matches observe the realization of the random firm specific productivity shock a_{jt}. If a_{jt} is higher than some (endogenously set) threshold a'_{jt} the match becomes a productive firm, otherwise ($a_{jt} < a'_{jt}$) the match is (endogenously) severed with probability

$$\rho^n_{jt} = I(a'_{jt}) = \int_{-\infty}^{a'_{jt}} \varphi(a_{jt}) da_{jt} \tag{27}$$

so the match specific survival rate is given by $\rho^s_{jt} = \left(1\text{-}\rho_{jt}\right) = (1\text{-}\rho^x)\left(1\text{-}I\left(a'_{jt}\right)\right)$ where $\rho_{jt} = \rho^x + (1-\rho^x)\rho^n_{jt}$ is the proportion of matches that do not survive.

We define the number of workers that are unemployed during period t by means of $u_t \equiv (1-n_t) + \rho_t n_t$. Notice that this variable is neither the beginning nor the end of period unemployment rate but rather the number of workers that have been unemployed at some point during period t. These unemployed workers are actively looking for vacancies that will eventually become productive (if they ever do) in $t+1$. The number of new matches in period t is ϑ, so employment evolves according to:

$$n_{t+1} = (1-\rho_t)n_t + \vartheta \tag{28}$$

The number of matches in period t depends on the amount of vacancies posted and unemployed workers looking for jobs. The mapping from u_t and v_t into the number of matches is given by an aggregate matching function $\vartheta(u_t, v_t)$. The probability of a worker finding a job is given by

$$\rho^w_t = \frac{\vartheta(u_t, v_t)}{u_t} \tag{29}$$

and similarly, the probability of a firm with a posted vacancy actually finding a match is

$$\rho^f_t = \frac{\vartheta(u_t, v_t)}{v_t} \tag{30}$$

Let us look at the choices the firm makes throughout this process in more detail. When a vacancy is visited the job offer is accepted and the match produces $\widetilde{y}_{jt}$ with probability $1-\rho_{jt}$. With probability ρ_{jt} the match is severed. The joint payoff of this match is

$$\left(\frac{1}{1+i_t}\right)(1-\tau^w)\left[\frac{z_t a_{jt} k^\alpha_{jt}}{\mu_t} - r_t k_{jt}\right] + x_{jt} \tag{31}$$

where x_{jt} is the expected current value of future joint payoffs obtained if the relationship continues into the next period. A match continues if the expected payoff (31) compensates for the loss of alternative opportunities available to firms and workers. There are no alternative opportunities for firms and the alternative opportunities for workers are the current payoffs from being unemployed ($A + \tilde{g}^u$) plus the expected present value of worker's payoffs in future periods (w^u_{jt}, as defined below).

The threshold specific shock a'_{jt} below which existing matches do not produce satisfies

$$\left(\frac{1}{1+i_t}\right)(1-\tau^w)\left[\frac{z_t a'_{jt}\left(k'^*_{jt}\right)^\alpha}{\mu_t} - r_t k'^*_{jt}\right] + x_{jt} - (A + \tilde{g}^u) - w^u_{jt} = 0 \tag{32}$$

The capital level k'^*_{jt} represents the optimal value of capital if a'_{jt} had occurred. This optimal capital (labor ratio) is given by:

$$k'^*_{jt} = \left(\frac{\alpha z_t a'_{jt}}{\mu_t r_t}\right)^{\frac{1}{1-\alpha}} \tag{33}$$

If production takes place the firm chooses its capital optimally to satisfy,

$$\max_{k_{jt}} \left(\frac{1}{1+i_t}\right)(1-\tau^w)\left[\frac{z_t a_{jt} k^\alpha_{jt}}{\mu_t} - r_t k_{jt}\right] + x_{jt} \tag{34}$$

$$\frac{\alpha z_t a_{jt} k^{\alpha-1}_{jt}}{\mu_t} - r_t = 0 \rightarrow k^*_{jt} = \left(\frac{\alpha z_t a_{jt}}{\mu_t r_t}\right)^{\frac{1}{1-\alpha}} \tag{35}$$

Define $x^u_{jt} = x_{jt} - w^u_{jt}$ as the expected excess value of a match that continues into period $t+1$ and s_{jt+1} as the joint surplus of a match at the start of $t+1$, then for the optimal capital

$$s^*_{jt+1} \equiv \left(\frac{1}{1+i_{t+1}}\right)(1-\tau^w)\left[\frac{z_{t+1} a_{jt+1}\left(k^*_{jt+1}\right)^\alpha}{\mu_{t+1}} - r_{t+1} k^*_{jt+1}\right] - (A + \tilde{g}^u) + x^u_{jt+1} \tag{36}$$

The surplus is split among the worker and the firm according to the relative bargaining power of each side. In particular a proportion η of the surplus will be received by the worker, while the firm receives $1-\eta$ of the match surplus. An unemployed worker at t finds a match with probability ρ^w_t. With probability $1 - \rho^w_t(1 - \rho_{t+1})$ the worker either fails to make a match or makes a match that does not produce in $t+1$. In either case the worker only receives w^u_{t+1}. The expected discounted value net of taxes for an unmatched worker, and hence her relevant opportunity cost of being matched, is:[4]

$$w_t^u = \beta E_t \left(\frac{\lambda_{1t+1}}{\lambda_{1t}}\right) \left[\rho_t^w (1-\rho^x) \int_{a'_{jt+1}}^{a_{\max}} \eta s_{jt+1}^* \varphi(a_j) da_j + A + \widetilde{g}^u + w_{t+1}^u\right] \tag{37}$$

Existing matches produce in $t+1$ with probability $1-\rho_{t+1}$. The expected future joint payoffs of a worker and firm that remain matched in period t are:

$$x_t = \beta E_t \left(\frac{\lambda_{1t+1}}{\lambda_{1t}}\right) \left[(1-\rho^x) \int_{a'_{jt+1}}^{a_{\max}} s_{jt+1}^* \varphi(a_j) da_j + A + \widetilde{g}^u + w_{t+1}^u\right] \tag{38}$$

Therefore:

$$x_t^u \equiv x_t - w_t^u = \beta E_t \left(\frac{\lambda_{1t+1}}{\lambda_{1t}}\right) (1-\rho^x) \left[1-\eta\rho_t^w\right] \int_{a'_{jt+1}}^{a_{\max}} s_{jt+1}^* \varphi(a_j) da_j \tag{39}$$

Unmatched firms or those whose matches terminated may enter the labor market and post a vacancy. Posting a vacancy costs γ per period and the probability of filling a vacancy is ρ_t^f. Free entry ensures that

$$\beta E_t \left(\frac{\lambda_{1t+1}}{\lambda_{1t}}\right) \rho_t^f (1-\rho^x) \int_{a'_{jt+1}}^{a_{\max}} (1-\eta) s_{jt+1}^* \varphi(a_{jt}) da_j = \gamma \tag{40}$$

hence

$$x_t^u = \frac{\gamma\left[1-\eta\rho_t^w\right]}{\rho_t^f\,(1-\eta)} \tag{41}$$

Therefore, in equilibrium x^u increases with the cost of openning a vacancy (γ) and with the time the vacant is open ($1/\rho^f$), and it is decreasing in ρ^w, since this probability increases the expected value of being unemployed (w^u).

2.6 Aggregation

The economy-wide level of output can be obtained either by looking at production by the monopolistic firms ($\widetilde{j}$) or aggregating across all competitive productive units (j). To clarify the matter, consider the following relationships that hold in our model. The nominal value of total production can be expressed in terms of the different varieties:

$$P_t y_t = \int P_{\widetilde{j}t} y_{\widetilde{j}t} d_{\widetilde{j}} \tag{42}$$

[4] Note that recursivity in equation (37) implies a permanet flow of income from $\widetilde{g}^u$ that should be taken into account in the calibration.

which does not imply total output (y_t) being equal to the integral of varieties produced by monopolistic firms, $\int y_{\tilde{j}t} d_{\tilde{j}}$.

However, turning to the competitive wholesale sector, it is also true that

$$P_t^w y_t = \int P_t^w y_{jt} d_j \tag{43}$$

and thus

$$y_t = \int y_{jt} d_j \tag{44}$$

that implies

$$\int y_{jt} d_j = \left[\int y_{\tilde{j}t}^{(1-1/\theta)} d_{\tilde{j}} \right]^{\frac{\theta}{\theta-1}} \tag{45}$$

Total production therefore can be obtained by aggregating the output from the competitive wholesale firms.

Due to the presence of the match idiosyncratic shock, aggregation requires a double integral, one for all possible realizations of the specific shock and the other for all firms that actually produce. The result of the latter integral gives the number of active matches $(1-\rho_t)n_t$, whereas the former integral can be interpreted as the average realization of the shock. Therefore aggregate output net of vacancy costs of the wholesale sector is obtained from:

$$y_t = (1-\rho_t) n_t z_t \int_{a_t'}^{a_{\max}} a_t \left(k_{jt}^*\right)^{\alpha} \frac{\varphi(a_t)}{1 - I\left(a_t'\right)} da_t \tag{46}$$

or,

$$y_t{=}(1{-}\rho^x) n_t z_t \left(\frac{\alpha z_t}{\mu_t r_t}\right)^{\frac{\alpha}{1-\alpha}} \int_{a_t'}^{a_{\max}} a_t^{\left(\frac{1}{1-\alpha}\right)} \varphi(a_t) da_t \tag{47}$$

where we have considered that the distribution function for a_j is common across firms and independent over time. The aggregate resources constraint establishes that

$$c_t + e_t + g_t^c + \gamma v_t = y_t \tag{48}$$

Aggregation also implies that the average optimal capital and the average joint surplus of the match at the start of $t+1$ can be represented as:

$$k_t^* = \int_{a_t'}^{a_{\max}} k_{jt}^* \frac{\varphi(a_t)}{1 - I(a_t')} da_t \tag{49}$$

$$s_{t+1}^{*}=\int_{a'_{t+1}}^{a_{\max}} s_{jt+1}^{*}\frac{\varphi(a_t)}{1-I(a'_{t+1})}da_t \tag{50}$$

Hence, aggregate capital k_{t-1} is given by

$$(1-\rho_t)\,n_t k_t^{*}=k_{t-1} \tag{51}$$

From (35) and (49), aggregated output (46) can also be written as

$$y_t=\frac{(1-\rho_t)n_t\mu_t r_t}{\alpha}k_t^{*} \tag{52}$$

Using this expression for aggregate output, the aggregate income that workers receive from firms is given by

$$y_t^{l}=(1-\tau^{w})\left(\frac{(1-\rho_t)n_t\mu_t r_t k_t^{*}}{\alpha}-r_t k_{t-1}\right)-\gamma v_t \tag{53}$$

whereas the aggregate resource constraint is

$$c_t+e_t+g_t^{c}+\gamma v_t=y_t+A\rho_t n_t \tag{54}$$

2.7 Government

Tax revenues are defined as:

$$t_t=\tau_t^{c}c_t+\tau_t^{k}r_t k_{t-1}+\tau_t^{w}\left(\frac{(1-\rho_t)n_t\mu_t r_t k_t^{*}}{\alpha}-r_t k_{t-1}\right) \tag{55}$$

The budget constraint in real terms for the government is defined by:

$$\frac{M_t}{P_t}+\frac{B_t}{P_t}=(1+i_{t-1})\,\frac{B_{t-1}}{P_t}=g_t^{c}+g_t^{s}+g^{u}u_t+\frac{M_{t-1}}{P_t}+\frac{M_t^{s}}{P_t}-t_t \tag{56}$$

where g_t^{c} represents public consumption. That can be simplified to,

$$b_t-(1+i_{t-1})\,\frac{b_{t-1}}{\pi_t}=g_t^{c}+g_t^{s}+g^{u}u_t-t_t \tag{57}$$

where $b_t=\frac{B_t}{P_t}$ and $\pi_t=\frac{P_t}{P_{t-1}}$.

It is necessary to specify both a fiscal rule and a monetary rule to close the model. As shown by Leeper (1991), fiscal rules avoid explosive paths of public debt and, more specifically, as in Andrés and Doménech (2006), we assume that only public transfers react to deviations from a debt objective, having no effects on other variables in the model:

$$g_t^s = g_{t-1}^s + \psi_1^s \left[\overline{\left(\frac{b}{y}\right)} - \left(\frac{b_t}{y_t}\right) \right] \tag{58}$$

In the same vein, in order to rule out non-stationary paths of inflation we also assume that the nominal interest rate is set as a function of the output gap and the deviation of inflation with respect to a target inflation rate $\overline{\pi}$:

$$i_t = \rho_i i_{t-1} + (1-\rho_i) \left[\rho_\pi (\pi_t - \overline{\pi_t}) + \rho_y (y_t - \overline{y}) + \overline{i} \right] \tag{59}$$

3. Calibration

The quantitative implications of the model are derived by simulating of a numerical solution of the steady state as well as of the log-linearized system (see Appendixes 1 to 3). Parameter values are chosen so that the baseline solution replicates the steady state U.S. economy. The calibrated parameters and exogenous variables appear in Table 1 and the implied steady state in Table 2. The calibration strategy begins by solving for separation rate $\overline{\rho}$, the rate of unemployed workers looking for a job $\overline{u}$, the vacancy rate $\overline{v}$, the specific productivity threshold $\overline{a}'$, and ν_0, the scale parameter in the matching function, using the steady-state equations (see Appendix 2). We need to choose the steady-state values of some endogenous variables to obtain these five unknown variables. Thus the employment rate, $\overline{n}$, has been set to the sample average, 0.9433 and the mean quarterly separation rate is approximately 0.09 (as in Hall, 2005). Consistent with these values the average rate of workers looking for a job within each quarter is $\overline{u} = 0.141$ and the condition $\overline{\rho n} = \overline{u \rho}^w$ implies a value of $\overline{\rho}^w$ equal to 0.6. This value of $\overline{\rho}^w$ is consistent with our definition of the unemployment rate $\overline{u}$ and corresponds to a value of 1.479 of the quarterly job-finding rate consistent with the average US unemployment rate, slightly higher than the value of 1.35 estimated by Shimer (2005). Also from the steady-state condition $\overline{\rho}^f \overline{v} = \overline{\rho}^w \overline{u}$ and using data from JOLTS in which the average 2001:1-2004:3 ratio $\overline{v}/(1-\overline{n})$ equals 0.58, we obtain $\overline{v} = 0.033$ and $\overline{\rho}^f = 2.58$, which implies that a vacancy is open on average for 5 weeks. We assume that $\rho^x = 0.072$ which implies that the exogenous separation rate is 80 per cent of the total separation rate, a value between that assumed by den Haan, Ramey and Watson (2000) but smaller than that used by Hall (2005b), who suggests that the total separation rate is almost completely acyclical. Finally, we assume that $\{a_t\}$ follows a log normal distribution with standard deviation of 0.10, the same as den Haan, Ramey and

Watson (2000). We set the share of the match surplus that the worker receives (η) equal to 2/3, between 0.5 (Walsh, 2005) and 0.72 (Shimer, 2005), and the elasticity of matching with respect to vacancies, ν, at 0.4. With these numbers, equations (2.3) and (2.5) imply that $\nu_0 = 1.075$ and $\overline{a}' = 0.8133$.

Preference parameters are set to conventional values. more specifically, we take the following parameters from Walsh (2005): the discount rate ($\beta = 0.989$), the risk aversion ($\sigma = 2$), the elasticity of demand for differentiated goods ($\theta = 11$) and habits ($h = 0.78$). The elasticity of demand for the differentiated retail goods implies a steady state mark-up $\overline{\mu}$ value of 1.1:

$$\overline{\mu} = \frac{\theta}{\theta - 1} \tag{60}$$

The elasticity of output to private capital (α) is set to 0.4 and we consider a standard value for the depreciation rate (δ) of 0.02. Capital adjustment costs are assumed to satisfy the following properties: $\phi^{-1}(\delta) = \delta$ and $\phi'\left(\frac{\overline{e}}{\overline{k}}\right) = 1$. Therefore, in the steady state, equation (2.9) implies $\overline{q} = 1$, which allows equations (2.19) and (2.8) to be rewritten as:

$$\overline{e} = \delta\overline{k} \tag{61}$$

$$1 = \beta\left(1 - \overline{\tau}^k\right)\overline{r} + \beta(1 - \delta) \tag{62}$$

so the rental cost of capital is given by

$$\overline{r} = \frac{1 - \beta(1 - \delta)}{\beta\left(1 - \overline{\tau}^k\right)} \tag{63}$$

Capital adjustment costs ($\Phi = \phi''(\overline{e/k})$) are equal to -0.25 as in Bernanke, Gertler and Gilchrist (1999). Since the discount factor (β) is 0.989, following Christiano and Eichenbaum (1992), equation (2.7) implies a steady-state value of $\bar{i}$

$$\bar{i} = \frac{\overline{\pi}}{\beta} - 1 \tag{64}$$

The values of $\overline{a}'$, $\bar{i}$, $\overline{r}$ and $\overline{\mu}$ can be plugged in equation (2.13) and (2.11) to obtain the steady-state value for the optimal individual capital demand

$$\overline{k'}^* = \left(\frac{\alpha\overline{a'}}{\overline{\mu}\overline{r}}\right)^{\frac{1}{1-\alpha}} \tag{65}$$

and optimal average capital

$$\overline{k}^{*} = \frac{1}{\left(1 - I\left(\overline{a'}\right)\right)} \left(\frac{\alpha}{\overline{\mu r}}\right)^{\frac{1}{1-\alpha}} \int_{\overline{a'}}^{a_{\max}} a^{\frac{1}{1-\alpha}} \varphi(a) da \tag{66}$$

whereas steady-state aggregate capital stock is calculated from (2.12) as

$$\left(1 - \overline{\rho}\right) \overline{n}\overline{k}^{*} = \overline{k} \tag{67}$$

Given the steady state value for $\overline{n}$, $\overline{k}^{*}$, $\overline{\rho}$, $\overline{\mu}$, $\overline{r}$ and the parameters γ and α, expression (2.18) gives the steady-state value of output $\overline{y}$. Government consumption ($\overline{g}^{c}/\overline{y}$) and goverment investment ($\overline{g}^{p}/\overline{y}$) are set to historical average values. Capital and consumption tax rates have been taken from Boscá, García and Taguas (2005), whereas τ^{w} has been calibrated to obtain a debt-to-GDP ratio equal to 2 on a quarterly basis. For simplicity, unemployment benefits are assumed to be equal to the replacement rate times the average labor income:

$$\overline{g}^{u} = \overline{rr}\frac{\overline{y}^{l}}{\overline{n}} \tag{68}$$

where $\overline{rr} = 0.26$, taken from the average value from 1960 to 1995 in Blanchard and Wolfers (2000). Then, using the approximation (68), equations (2.14), (2.15), (2.16), (2.23) can be solved simultaneously for the four unknowns A, $\overline{x}^{u}$, $\overline{s}^{*}$, $\overline{y}^{l}$. Once we have the value of A, the steady-state equation (2.17) allows us to obtain the cost of vacancies γ. We calibrate transfers $\overline{g}^{s}$ assuming that total transfers are 15.5 per cent of GDP, that is

$$\frac{g^{u}\overline{u} + \overline{g}^{s}}{\overline{y}} = \frac{\overline{rr}\frac{\overline{y}^{l}}{\overline{n}}\overline{u} + \overline{g}^{s}}{\overline{y}} = 0.155 \tag{69}$$

and hence:

$$\frac{\overline{g}^{s}}{\overline{y}} = 0.155 - \overline{rr}\frac{\overline{y}^{l}}{\overline{yn}}\overline{u} \tag{70}$$

Since the steady-state investment is given by equation (61), the aggregate resource constraint (2.20) enables us to obtain private consumption $\overline{c}$, making it possible to solve for $\overline{\lambda_1}$ in expression (2.21) and $\overline{m}$ in expression (2.22). Finally, $\overline{t}$ and $\overline{b}$ can be solved recursively in equations (2.24) and (2.25).

TABLE 1 — PARAMETER VALUES

ν_0	1.075	γ	0.339	ω	0.650
ρ^x	0.072	h	0.780	ς	0.400
β	0.989	$\overline{g}^c/\overline{y}$	0.150	Φ	-0.25
δ	0.020	$\overline{g}^s/\overline{y}$	0.141	ρ_i	0.750
θ	11	$\overline{g}^p/\overline{y}$	0.035	ρ_π	1.500
$\alpha = \nu$	0.400	τ^w	0.327	ρ_y	0.000
$\overline{rr}$	0.260	τ^k	0.350	σ_a	0.100
σ	2.000	τ^c	0.100	σ_z	1.340
A	0.856	η	0.666	ρ_z	0.471

TABLE 2 — STEADY STATE

$\overline{\rho}$	0.090	$\overline{r}$	0.048	$\overline{\lambda}$	0.078
$\overline{u}$	0.141	$\overline{q}$	1.000	$\overline{m}/\overline{y}$	0.715
$\overline{v}$	0.033	$\overline{\mu}$	1.100	$\overline{x}^u/\overline{y}$	0.070
$\overline{a}'$	0.813	$\overline{k}^*/\overline{y}$	8.848	$\overline{s}^*/\overline{y}$	0.130
$\overline{n}$	0.943	$\overline{k}/\overline{y}$	7.594	$\overline{b}/\overline{y}$	2.400
$\overline{\rho}^f$	2.581	$\overline{y}$	3.386	$\overline{k'}^*/\overline{y}$	6.142
$\overline{\rho}^w$	0.600	$\overline{e}/\overline{y}$	0.152	$\overline{y}^l/\overline{y}$	0.424
$\overline{i}$	0.011	$\overline{c}/\overline{y}$	0.681	$\overline{\pi}$	1.000

Surplus (s^*) and labour income (y^l) are net of taxes

Some relevant parameters cannot be obtained from the steady-state relationships. Thus, we adopt a value of 0.65 for ω (the share of firms that do not set their prices optimally), close to empirical estimates of the average duration of price stickiness (Gali and Gertler, 1999, Sbordone, 2002), whereas we take an intermediate value ($\varsigma = 0.4$) for inflation indexation. For the fiscal rule, we assume that $\psi_1^s = 0.4$. The parameters in the interest rule are standard in the literature: $\rho_i = 0.75$, $\rho_\pi = 1.50$ and $\rho_y = 0$. Finally the standard deviation of productivity shocks (σ_z) and their autocorrelation parameter (ρ_z) are calibrated to reproduce the average historical volatility and autocorrelation of the US output gap.

The model with transitory supply shocks (that is, shocks in z_t) has been simulated 1000 times, with 260 observations in each simulation. We take the last 160 quarters and compute the averages over the 1000 simulations of the standard deviation of each variable (x) relative to that of output (σ_x/σ_y, except for GDP which is just σ_y), the first-order autocorrelation (ρ_x) and the contemporaneous correlation with output (ρ_{xy}) of each variable.

These moments are compared with basic labor market statisitics of the US business cycles from 1951:1 to 2005:3. The data source is basically the same as in Shimer (2005). We use FRED Economic Data from the Federal Reserve Bank of St. Louis for unemployment, the help wanted index (for vacancies) and civilian employment. As the frequency of these data is monthly, we compact the data set by taking quarterly averages. Real quarterly GDP (billions of chained 2000 dollars) is obtained from the Bureau of Economic Analysis of the Department of Commerce. We take logs of these quarterly variables and obtain their cyclical components using the Hodrick-Prescott filter with a smoothing parameter equal to 1600.[5]

4. Results

The results discussed in this section can be explained with the help of two crucial expressions in the model: the free entry condition for posting vacancies, equation (40), and the related definition of the surplus, equation (36). Figure 1 represents the free entry condition as a negative function of vacancies, holding the rest of the implied variables constant. Vacancies enter this expression through the probability of filling a vacancy $\rho_t^f = \vartheta(\frac{u_t}{v_t}, 1)$, whereas changes in other variables shift the curve thus affecting the equilibrium or the impact response and volatility of the vacancy rate. For instance, for a given number of vacancies, an increase in unemployment shifts the curve upwards increasing the number of posted vacancies. The volatility of the vacancy rate depends on the interaction of all these variables in general equilibrium.

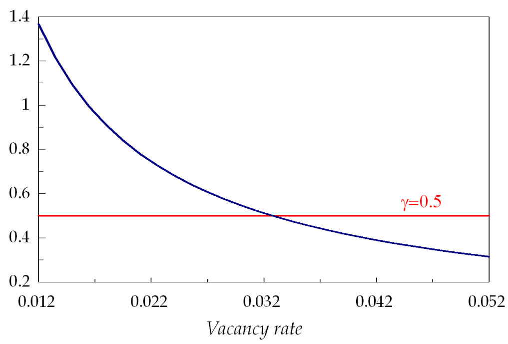

Figure 1: *Free entry condition*

Expressions (40) and (36) contain the main parameters that determine the volatility of labor market variables and have been the subject of much discussion in this literature.

[5] We have checked that we obtain the same results as in Shimer (2005) if the analysed period dates from 1951:1 to 2003(4) and the smoothing parameter is 100000.

The value of non-market activities A and $\widetilde{g}^{u}$ (inside x^{u}_{jt+1}) on the one hand, and the bargaining power of workers η, on the other, are the key parameters in the calibration discussion for Hagedorn and Manovskii (2008) and Costain and Reiter (2008). More specifically, the expression (40) can be rewritten in terms of the survival rate (1-ρ^{x}) $\left(1\text{-}I\left(a'_{jt}\right)\right)$ as:

$$\beta E_t\left(\frac{\lambda_{1t+1}}{\lambda_{1t}}\right)\rho^{f}_{t}(1-\rho^{x})\left(1-I\left(a'_{jt}\right)\right)\int_{a'_{t+1}}^{a_{\max}}(1-\eta)s^{*}_{jt+1}\frac{\varphi(a)}{\left(1-I\left(a'_{jt}\right)\right)}da=\gamma \tag{71}$$

We can get a glimpse of the main mechanisms behind the volatility of labor market variables with the help of equations (71) and (36). A positive shock to aggregate productivity (z_t) increases the surplus and shifts the free entry condition upwards in Figure 1, increasing the optimal vacancy rate. If the change in vacancy posting is small, so is the volatility of the vacancy rate. Some authors have proposed alternative models of wage determination as a means of increasing the proportion of the observed volatility of labor market variables that the model is able to explain, while the importance of the price formation mechanism has gone quite unnoticed. Gertler and Trigari (2006) have looked at the role of wage rigidity, whereas Costain and Reiter (2008) have allowed for countercyclical movements in η. With flexible prices the mark-up $\mu_t=\frac{P_t}{P^{w}_{t}}$ barely responds to technology shocks, while with some degree of price stickiness, the mark-up increases sharply on impact (due to a fall in P^{w}_{t} not compensated by a fall in P_t) and adjusts thereafter. Thus, price inertia induces an expected fall in the mark-up that gives an additional impulse to the surplus at $t+1$ and hence to the optimal vacancy rate.

Endogenous destruction also matters through the effect of a'_{t+1} in equation (71). A decrease in a'_{jt}, as a consequence of a positive shock in productivity, affects the survival rate as well as the average surplus measured by the integral in the above expression. Furthermore, the volatility of vacancies will depend on how much the general equilibrium real interest rate $\frac{\lambda_{1t+1}}{\lambda_{1t}}$ varies after a positive productivity shock. Capital, in turn, enters (36), reducing surplus in levels and therefore making the free entry condition more sensitive to shocks. Taxes affect both the net surplus as well as the dynamics of investment and vacancy posting. We show the effects of these mechanisms in detail in the fourth appendix.

The simulation results of the general model in the previous sections appear in the last column of Table 3, along with the empirical evidence for the United States (first column) and the results for the simplest version of our model (column 3), which is comparable to Shimer's (2005). The last row displays the steady-state values of some relevant variables related to the calibration of each model: the ratio of the surplus to the output

$(\frac{\bar{s}^*}{(1-\tau^w)\bar{y}})$, the net flow surplus enjoyed by an employed worker $(\frac{\frac{\bar{y}^l}{n}-(A+\tilde{g}^u)}{A+\tilde{g}^u})$, the worker's bargaining power (η), and the worker's value of non-market activities (A). The replacement rate rr is held constant at 0.26 across all experiments.

The model in column (2) is a particular case of the model described in Section 2 that assumes perfect competition in the goods market and price flexibility, with neither capital nor government so that consumption smoothing is not possible and in which job destruction is completely exogenous. Hereafter we refer to this specification as Shimer's model In column (2) we present the results of this model using Shimer's calibration for vacancy posting cost ($\gamma = 0.213$), the rate of discount ($1/\beta = 1.012$), utility from leisure (A $= 0.4$), the separation rate ($\rho = 0.1$), worker's bargaining power ($\eta = 0.72$, also equal to the matching elasticity with respect to u) and the scale parameter in the matching function ($\nu_0 = 1.355$); we also set the variance and autocorrelation of technology shocks (σ_z and ρ_z) at the values needed to reproduce second GDP moments. The results in column (2) corroborate Shimer's results: the basic search and matching model generates relative volatilities of unemployment and vacancies which are respectively 19 and 7.5 times smaller than those observed in the data.

Shimer's calibration applied to the model in column (2) leads to some unrealistic steady-state values. Both the implicit flow arrival rate of job offers ($\bar{\rho}^w = 1.34$) and the employment rate ($\bar{n} = 1.03$) are far from our benchmark calibration. Also, as Costain and Reiter (2008) point out, there is a relatively large match surplus calibrated in Shimer's model. Thus, in column (3) we use an alternative calibration for the same basic model. In particular, we choose a set of parameters so that the steady-state values are compatible with those corresponding to the general model. This means the same $\bar{\rho}^w$, $\bar{n}$, $\bar{\rho}^f$, $\bar{u}$ and $\bar{v}$ as in the benchmark model in column (5). Also the value of A is set so that the basic model reproduces the surplus/GDP ratio of the benchmark model, as reflected at the bottom of the table.

The results in column (3) contain a clear message: the poor performance of Shimer's model was, to a certain extent, driven by a calibration that does not reproduce the main observed first moments in general equilibrium. This also confirms previous findings in the literature (such as those of Costain and Reiter, 2008, and Hagedorn and Manovskii, 2008) that point out that the size of the match surplus is vital for increasing volatilities. This is indeed the case for the unemployment rate but also, albeit to a lesser extent, for the vacancy rate and the probability of finding a job.

We next proceed to assess the extent to which price rigidity contributes to improve the explanatory power of the model with regard the main US labour market moments.[6] To ascertain the role of this particular feature we compare volatilities across models that share the other key parameters. First, to make sure that we control for the amount of variability in our simulated variables, we calibrate all models to replicate the observed standard deviation and autocorrelation of GDP in the U.S. Second, all our models imply the same-steady state value for the key parameters and ratios in the process of wage bargaining

Column (4) presents the results of our general model described above assuming price flexibility. This model incorporates a number of mechanisms with respect to the basic model in column (3): endogenous job destruction, intertemporal substitution, habits, capital and taxes. The joint effect of all these channels is a reduction to half the vacancy volatility, whereas the volatility of unemployment remains basically unaltered. As a result, market tightness becomes less volatile. [7]

In column (5) we augment the model with price stickiness ($\omega = 0.65$) and indexation ($\varsigma = 0.4$) and calibrate it to fit the volatility of output and to maintain the main steady-state labor market ratios: $\frac{\bar{s}^*}{\bar{y}}$, $\frac{\frac{\bar{y}^l}{n} - (A+\tilde{g}^u)}{A+\tilde{g}^u}$, $\bar{n}, \bar{v}, \bar{u}, \eta, A, \bar{\rho}^f, \bar{\rho}^w$. The direct consequence of allowing for price rigidity is a sharp increase in the volatilities of all labor market variables that particularly affects the vacancy rate. The greatest change affects the volatility of vacancies that is almost four times higher than that obtained in the flex-price model in column (4). Once a realistic degree of price stickiness is allowed for, the model comes very close to replicate the volatility of the market tightness and job finding rate observed in the data. Interestingly, the pattern of correlations between unemployment and vancacies with output implies a negative correlation between unemployment and vacancies (i.e. a negatively sloped Beveridge curve). Notice moreover that the ratio $\frac{\frac{\bar{y}^l}{n} - (A+\tilde{g}^u)}{A+\tilde{g}^u}$ increases in the benchmark model with respect to the basic recalibrated model in column (3). This is relevant since some authors have criticized the choice of a small surplus gain of being employed as a means of obtaining highly volatile labour market rates.[8] The numbers in the

[6] We focus in all the variables implied by the Shimer's puzzle, namely unemployment, vacancies, the market tightness ratio, and the job-finding rate. However, we have also checked the ability of the model to capture other dimensions of the business cycle and found that the model does fairly well in matching the observed correlation of output with consumption and investment as well as the volatility if these variables. The model does less well in accounting for other labor market moments that have been recently studied by Galí and Gambetti (2009) and Barnichon (2009), among others. These authors conclude that these dynamics require extensions of the search and matching models that are beyond the scope of this paper. In any case, we find that price rigidity also has some, albeit smaller, effect on these moments.

[7] The detailed analysis of the impact of each of these mechanisms on the relevant volatilities is left to Appendix 4.

[8] Mortensen and Nagypál (2005) estimates this flow surplus at 2.8 per cent in the Hagedorn and Monovskii

TABLE 3 — MAIN RESULTS

		US	Basic model Shimer	Basic model (recalibrated)	Benchmark model (flexible prices)	Benchmark model (sticky prices)
		(1)	(2)	(3)	(4)	(5)
$\widehat{y}_t$	σ_y	1.58	1.58	1.58	1.58	1.58
	ρ_y	0.84	0.84	0.84	0.84	0.84
$\ln u_t$	σ_u/σ_y	7.83	0.41	7.96	7.65	8.05
	ρ_u	0.87	0.70	0.80	0.85	0.86
	$\sigma_{u,y}$	-0.84	-0.83	-0.99	-0.99	-0.97
$\ln v_t$	σ_v/σ_y	8.85	1.18	5.30	2.44	8.94
	ρ_v	0.91	0.68	0.30	0.18	0.20
	$\sigma_{v,y}$	0.90	0.97	0.66	0.51	0.50
$\ln \frac{v_t}{u_t}$	σ_{vu}/σ_y	16.33	1.49	12.37	9.09	13.71
	ρ_{vu}	0.90	0.83	0.62	0.72	0.60
	$\sigma_{vu,y}$	0.89	0.99	0.92	0.97	0.89
ρ^w	σ_{ρ^w}/σ_y	4.86	0.42	3.85	2.80	4.22
	ρ_{ρ^w}	0.91	0.83	0.62	0.72	0.60
	$\sigma_{\rho^w,y}$		0.99	0.92	0.98	0.90
$\frac{\bar{s}^*}{(1-\tau^w)\bar{y}}$			0.67	0.19	0.19	0.19
$\frac{\frac{\bar{y}^l}{n}-(A+\bar{g}^u)}{A+\bar{g}^u}$			1.10	0.12	0.67	0.67
η			0.72	0.67	0.67	0.67
A			0.40	0.91	0.86	0.86

σ_y: Stand. deviation y; ρ_y: First order autocorr. y; $\sigma_{y,z}$: cross corr. y, z.

table indicate that this critique does not apply to our results.

A closer look at the entry condition helps to clarify the economics of the contribution of price rigidity to the increase in volatilities. Substituting out the first order conditions of households into (40) we obtain:

$$E_t\left(\frac{P_{t+1}}{P_t}\frac{1}{1+i_t}\right)\rho_t^f(1-\rho^x)\int_{a'_{t+1}}^{a_{\max}}(1-\eta)s^*_{jt+1}\varphi(a)da=\gamma \tag{72}$$

After a positive technology shock the left hand side of (72) shifts upwards, thus increasing the amount of vacancies posted in period t in Figure 1. Apart from the real interest rate, two components of this equation are influenced by the degree of price stickiness in the

(2005) calibration, more than twenty times smaller than in our benchmark model.

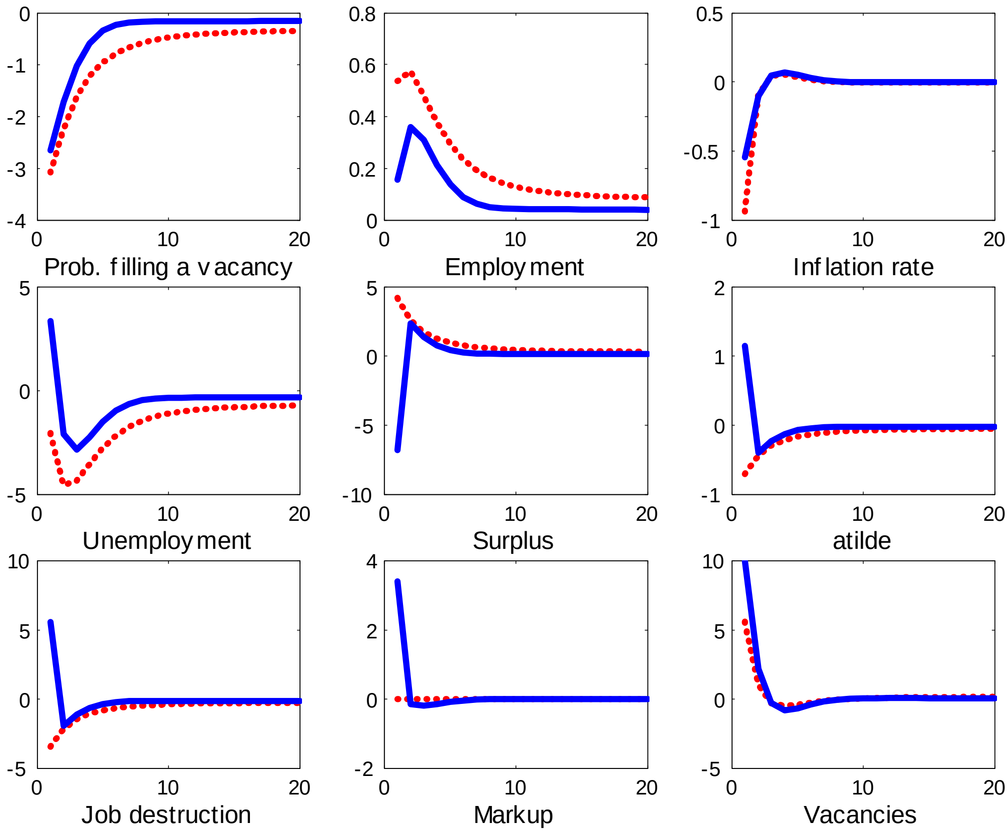

Figure 2: *Impulse-responses to a one percent technology shock for the sticky prices model (solid blue line) and for the flexible prices model (dotted red line).*

model. First, the mark-up ($\mu_t = P_t/P_t^w$) increases on impact, due to the downward rigidity of P_t. Once the downward adjustment of prices is underway, μ_{t+1} is expected to fall. The cyclical response of the mark-up is more intense the stronger the degree of price rigidity and hence the response of s_{t+1}^* is also more pronounced. Thus, price rigidity affects positively the correlation between the shock and the surplus. Second, the sharp increase in μ_t pushes the optimal threshold value a'_{jt} up in (32) and, as a consequence, endogenous destruction rises and unemployment increases. More unemployment reduces labor market tightness increasing the probability (in relative terms) of filling a vacancy ρ_t^f. These two effects reinforce each other and induce an upward shift on the left hand side of (72) that is larger the higher the degree of price stickiness. Thus the volatilities of vacancies and unemployment increase as prices become more rigid. All these effects are reflected in Figure 2 that displays the IR functions for the benchmark model with price rigidity and

TABLE 4 - THE IMPORTANCE OF PRICE RIGIDITY

Distortionary taxes			No					
Capital			No				Yes	
Habits			No		Yes		Yes	
Price rigidity			No	Yes	No	Yes	No	Yes
		US	(2)	(3)	(4)	(5)	(6)	(7)
$\widehat{y}_t$	σ_y	1.58	1.58	1.58	1.58	1.58	1.58	1.58
	ρ_y	0.84	0.91	0.91	0.91	0.91	0.84	0.84
$\ln u_t$	σ_u/σ_y	7.83	10.71	9.95	11.23	9.56	7.26	7.23
	ρ_u	0.87	0.91	0.94	0.89	0.94	0.86	0.87
	$\sigma_{u,y}$	-0.84	-0.99	-0.99	-0.99	-0.99	-0.99	-0.98
$\ln v_t$	σ_v/σ_y	8.85	1.53	5.04	1.92	4.19	2.22	6.50
	ρ_v	0.91	0.32	0.22	0.45	0.38	0.19	0.18
	$\sigma_{v,y}$	0.90	0.46	0.20	0.35	0.19	0.52	0.50
$\ln \frac{v_t}{u_t}$	σ_{vu}/σ_y	16.33	11.46	12.14	12.16	11.26	8.54	11.29
	ρ_{vu}	0.90	0.87	0.84	0.85	0.90	0.74	0.62
	$\sigma_{vu,y}$	0.89	0.99	0.89	0.97	0.91	0.98	0.91
ρ^w	σ_{ρ^w}/σ_y	4.86	3.10	3.31	3.27	3.07	2.64	3.50
	ρ_{ρ^w}	0.91	0.87	0.83	0.85	0.90	0.74	0.61
	$\sigma_{\rho^w,y}$		0.99	0.89	0.97	0.91	0.98	0.92
$\frac{\bar{s}^*}{(1-\tau^w)\bar{y}}$			0.19	0.19	0.19	0.19	0.19	0.19
$\frac{\frac{\bar{y}^l}{n}-(A+\tilde{g}^u)}{A+\tilde{g}^u}$			0.38	0.38	0.38	0.38	0.67	0.67
η			0.67	0.67	0.67	0.67	0.67	0.67
A			0.60	0.60	0.60	0.60	1.70	1.70

σ_y: Stand. deviation y; ρ_y: First order autocorr. y; $\sigma_{y,z}$: cross corr. y, z.

for the benchmark model with flexible prices.

The channel just described hinges crucially on the dynamics of the technology shock. When this shock is very persistent, the downward movement of μ_{t+1} after a positive innovation at t is dampened by an upward reaction following the positive realization of z_{t+1}. Models with high price inertia require low values of ρ_z to match the volatility of GDP. Thus, to isolate the role of price stickiness we have repeated our analysis in models with low and high shock persistence. In both cases the volatility of vacancies increases significantly with price stickiness although this increase is more pronounced in models in which shocks to productivity are less persistent.

Finally, to gauge the sensitivity of our previous results, in Table 4 we show the effects of price stickiness in three alternative settings:[9] a model with no distortionary taxes, no capital and no habits in columns (2) and (3); a model with no distortionary taxes, no capital but with habits in consumption in columns (4) and (5); and a model of no distortionary taxes with capital and habits in columns (6) and (7).[10] The sensitivity analysis in Table 4 confirms our main result: regardless of other model features, price stickiness always induces a small change in the volatility of unemployment but considerably boosts the volatility of vacancies.[11]

5. Concluding Remarks

In the standard search and matching model, the equilibrium unemployment rate depends crucially on the number of vacancies posted, which in turn depends on the expected present value of the vacancy posting firm. Three key components of this expected value are the probability of a vacancy being filled, the expected surplus of the vacancy and the discount rate. These three components are model-specific and vary to make vacancy posting more or less responsive to a total factor productivity shock. Shimer (2005) looked at the business cycle implications of search and matching frictions and showed that the volatilities of vacancies and unemployment (as well as the vacancy to unemployment ratio) predicted by the basic model are far lower than those observed in US data.

In this paper we have proposed a more general neo-keynesian dynamic general equilibrium model whose empirical predictions match the empirical evidence remarkably well. More specifically, the model predicts a relative (to output) volatility of vacancies, un-

[9] Here we only present the robustness of our results to the presence of the other features of the model. We have also found that the main finding of the paper, namely the role of price stickiness as a mechanism to amplify fluctuations in vacancies, is robust to a wide range of values of two key parameters of the model: the replacement rate and the value for home production. The tables summarizing the results of these exercises are displayed in Appendix 5.

[10] The model without capital cannot reproduce the observed persistence of output, even when the common productivity shock is assumed to be white noise. This is because the autocorrelation induced by the law of motion of employment is very high and firms cannot substitute away from employment when they cannot use capital, so the simulated persistence of the output chosen in columns (4) and (5) is the maximum of the minimum simulated autocorrelation coefficient reachable by each of the models with no capital.

[11] Krause and Lubik (2007) find that a search model with price rigidity explains a small proportion of the observed voaltility of vacancies in the US; however, they do not analyze the role of price inertia in detail. Since our calibration differs from theirs' in the value of the unemploymnet (employment) rate, we have checked the sensitivity of our results with respect to variations in this rate(s). We find that as we increase (decrease) the steady state unemployment (employment) rate to make it closer to 0.12 (0.88), which is the value chosen by Kraus and Lubik, the relative standard deviation of vacancies falls. Thus, low volatilities in their paper seem to be mostly driven by that calibration strategy. As a further check of our results we find that even if we stick to their calibration, increasing price rigidity doubles the predicted volatility of vacancies.

employment and the v/u ratio that matches those observed in the data almost perfectly. The model also explains autocorrelations and cross correlations among variables well, although the implied persistence of vacancies is somewhat low, a result that can be improved with nominal wage rigidities as in Gertler and Trigari (2006) or convex hiring costs as in Yashiv (2006).

The main result of the paper is that price stickiness turns out to be of paramount importance to increase labor market variability in line with that observed in the data. This is particularly the case for the vacancy rate and the unemployment/vacancy ratio. Price rigidity has a direct effect on all the components of the free entry condition and has proved to be very significant in quantitative terms. In this sense, we see our results as akin to those emphasizing the importance of wage stickiness as a way of improving the empirical performance of matching models. The combination of wage and price stickiness seems a natural extension aimed at both further improving empirical relevance of the model and also assessing the relative importance of different sources of nominal inertia for the purpose at hand. We also find that, compared with the importance of price rigidities, neither endogenous destruction, nor intertemporal substitution, habits, capital or taxes contribute very much towards explaining the cyclical performance of the labor market.

Although we have chosen to frame our work in a strand of the literature that focuses only on technology shocks (as in the Shimer's original paper) to identify an economic mechanism able to boost the fluctuations in the labor market, we are not claiming that technology shocks are the only source of dynamics in the data. There are other equally reasonable strategies to solve the Shimer's puzzle on the volatility of vacancies and unemployment. One such strategy emphasizes the role played by other shocks (Krause and Lubick, 2007, Sveen and Weinke, 2008 or Barnichon, 2007). It is beyond the scope of the paper to pursue this interesting line of research.

A final comment on calibration is pertinent here. Our empirical analysis has been ushered in by a thorough calibration exercise based on a careful analysis of the existing literature on the issue, as well as on the basic steady-state variables for the US economy. The main result in our paper, namely the importance of price rigidity when explaining labor market volatilities, is robust to reasonable changes in calibration values. However, we have also verified that some predictions of the basic Mortensen and Pissarides model might be sensitive to the choice of some key parameter values. This leads us to believe that more research is needed on this matter and, more specifically, an in-depth econometric analysis is called for to obtain a better empirical counterpart of some of the parameters used in this literature. This is next on the research agenda.

6. References

Andrés, J. and R. Doménech (2006): “Automatic Stabilizers, Fiscal Rules and Macroeconomic Stability”. *European Economic Review*, 50(6), 1487-1506.

Barnichon, R. (2007): "The Shimer Puzzle and the Correct Identification of Productivity Shocks". CEP Discussion Papers dp0823, Centre for Economic Performance, LSE

Barnichon, R. (2009): ˇProductivity, Aggregate Demand and Unemployment Fluctuationsı. Finance and Economics Discussion Series (FEDS). Federal Reserve Board, Washington, D.C. Staff Working Paper 2008-47.

Bernanke, B. S., M. Gertler and S. Gilchrist (1999): “The Financial Accelerator in a Quantitative Business Cycle Framework”, in J. B. Taylor and M. Woodford (eds.)., *Handbook of Macroeconomics*, Volume 3, 1341-93.

Blanchard, O. and J. Galí (2007): “A New Keynesian Model with Unemployment”. Kiel Working Papers 1335, Kiel Institute for the World Economy.

Blanchard, O. and J. Wolfers (2000): “The Role of Shocks and Institutions in the Rise of European Unemployment: The Aggregate Evidenceı, *The Economic Journal*, 110, C1–33.

Bodart, V., O. Pierrard and H. R. Sneessens (2006): “Calvo Wages in a Search Unemployment Model”. IZA Discussion Papers 2521, Institute for the Study of Labor (IZA).

Boscá, J.E., García, J. R. and Taguas, D. (2005): “Tipos Efectivos de Gravamen y Convergencia Fiscal en la OCDE: 1965-2001ı. *Hacienda Pública Española*, 174 (3), 119-141.

Calvo, G. (1983): “Staggered Prices in a Utility Maximizing Framework”. *Journal of Monetary Economics*, 12(3), 383-98.

Costain, J. S. and M. Reiter (2008): "Business Cycles, Unemployment Insurance, and the Calibration of Matching Models". *Journal of Economic Dynamics and Control*, 32 (4), 1120-1155.

den Haan, W., G. Ramey, and J. Watson (2000): “Job Destruction and Propagation of Shocks”. *American Economic Review*, 90(3), 482-98.

Galí, J. (1994): “Government Size and Macroeconomic Stability”. *European Economic Review*, 38(1), 117-132.

Galí, J. and M. Gertler (1999): “Inflation Dynamics: A Structural Econometric Analysis”. *Journal of Monetary Economics*, 44, 195-222.

Galí, J. and L. Gambetti (2009): ˇOn the Sources of the Great Moderationı. *American Economic Journal: Macroeconomics*. Vol. 1(1), 26-57.

Gertler, M. and A. Trigari (2006): “Unemployment Fluctuations with Staggered Nash Wage Bargaining”. NBER Working Paper No. 12498.

Gertler, M., L. Sala and A. Trigari (2008): “An Estimated Monetary DSGE Model with Unemployment and Staggered Nominal Wage Bargaining”. *Journal of Money, Credit and Banking*, vol. 40(8), 1713-1764.

Haefke, C., M. Sonntag and T. van Rens (2009): “Wage Rigidity and Job Creation”. Kiel Working Papers, 1504, Kiel Institute for the World Economy.

Hagedorn, M. and I. Manovskii (2008): “The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited”. *American Economic Review*, 98(4), 1692-1706..

Hall, R. (2005a): “Employment Fluctuations with Equilibium Wage Stickiness”, *American Economic*

Review, 95 (March), 50-65.

Hall, R. (2005b): "Job Loss, Job Finding, and Unemployment in the U.S. Economy over the Past Fifty Years". NBER Working Paper No. 11678.

Krause, M. U. and T. A. Lubik (2007): "The (ir)relevance of real wage rigidity in the New Keynesian model with search frictions". *Journal of Monetary Economics*, 54, 706-727.

Leeper, E. (1991): "Equilibria under 'Active' and 'Passive' Monetary and Fiscal Policies". *Journal of Monetary Economics*, 27, 129-147.

Mortensen D. T. and É. Nagypál (2005): "More on Unemployment and Vacancy Fluctuations". NBER Working Paper No. 11692.

Mortensen, D. T. and C. A. Pissarides (1999): "Job Reallocation, Employment Fluctuations and Unemployment", in J.B. Taylor and M. Woodford (eds.), *Handbook of Macroeconomics*, Volume 1, 1171-1228.

Pissarides, C. (2009): "The Unemployment Volatility Puzzle: Is Wage Stickiness the Answer?". *Econometrica*, vol. 77(5), 1339-1369.

Sbordone, A.M. (2002): "Prices and Unit Labor Costs: A New Test of Price Stickiness". *Journal of Monetary Economics,* 49 (2), 265–292.

Shimer, R. (2004): "The Consequences Of Rigid Wages In Search Models". *Journal of the European Economic Association*, 2(2–3), 469–79.

Shimer, R. (2005): "The Cyclical Behavior of Equilibrium Unemployment and Vacancies", *American Economic Review,* 95 (March), 25-49.

Sveen, T. and L. Weinke (2008): "New Keynesian perspectives on labor market dynamics". *Journal of Monetary Economics*, 55, 921-930.

Trigari, A. (2004): "Equilibrium Unemployment, Job Flows and Inflation Dynamics". ECB Working Paper Series No. 304.

Walsh, C.E. (2005): "Labor Market Search, Sticky Prices, and Interest Rate Policies". *Review of Economic Dynamics*, 8, 829–849.

Yashiv, E. (2006): "Evaluating the Performance of the Search and Matching Model". *European Economic Review*, 50(4), 909-936.

Yashiv, E. (2007): "Labor search and matching in macroeconomics". *European Economic Review*, 51(8), 1859-1895.

Appendix 1: Equilibrium (not to be published)

The dynamic equilibrium is defined by the following equations:

$$y_t = \frac{(1-\rho_t)n_t\mu_t r_t}{\alpha}k_t^* \tag{1.1}$$

$$c_t + e_t + g_t^c + \gamma v_t = y_t + A\rho_t n_t \tag{1.2}$$

$$\frac{c_t^{-\sigma}}{c_{t-1}^{h(1-\sigma)}} - E_t\beta h \frac{c_{t+1}^{1-\sigma}}{c_t^{h(1-\sigma)+1}} - \lambda_{1t}\left(1+\tau^c\right) - \lambda_{2t}\left(1+\tau^c\right) = 0 \tag{1.3}$$

$$E_t\lambda_{2t+1} = i_t E_t \lambda_{1t+1} \tag{1.4}$$

$$\lambda_{1t}\beta^{-1} = (1+i_t)\, E_t\left(\lambda_{1t+1}\frac{P_t}{P_{t+1}}\right) \tag{1.5}$$

$$P_t\left(1+\tau_t^c\right)c_t = M_t \tag{1.6}$$

$$k_t = (1-\delta)\,k_{t-1} + \phi\left(\frac{e_t}{k_{t-1}}\right)k_{t-1} \tag{1.7}$$

$$\left[\phi'\left\{\frac{e_t}{k_{t-1}}\right\}\right]^{-1} = q_t \tag{1.8}$$

$$q_t\beta^{-1} = E_t\left[\frac{\lambda_{1t+1}}{\lambda_{1t}}\left(\begin{array}{c}\left(1-\tau_t^k\right)r_{t+1} + \\ q_{t+1}\left[(1-\delta) + \phi\left\{\frac{e_{t+1}}{k_t}\right\} - \phi'\left\{\frac{e_{t+1}}{k_t}\right\}\frac{e_{t+1}}{k_t}\right]\end{array}\right)\right] \tag{1.9}$$

$$P_t^* = \left(\frac{\theta}{\theta-1}\right)\frac{E_t\sum_{s=0}^{\infty}\omega^s\Lambda_{t,t+s}\left[\mu_{t+s}^{-1}\left(P_{t+s}\right)^{\theta+1}c_{t+s}\right]}{E_t\sum_{s=0}^{\infty}\omega^s\Lambda_{t,t+s}\left[\left(P_{t+s}\right)^{\theta}c_{t+s}\right]} \tag{1.10}$$

$$P_t^{1-\theta} = (1-\omega)\, P_t^{*1-\theta} + \omega P_{t-1}^{1-\theta} \tag{1.11}$$

$$k_{jt}^{*} = \left(\frac{\alpha z_t a_{jt}}{\mu_t r_t}\right)^{\frac{1}{1-\alpha}} \tag{1.12}$$

$$\left(\frac{1}{1+i_t}\right)(1-\tau^w)\left[\frac{z_t \widetilde{a}_t\,(k_t'^{*})^{\alpha}}{\mu_t} - r_t k_t'^{*}\right] + x_t^u - (A+\widetilde{g}^u) = 0 \tag{1.13}$$

$$\rho_t^n = \int_{-\infty}^{\widetilde{a}_t} \varphi(a_t)\,da \tag{1.14}$$

$$\rho_t = \rho^x + (1-\rho^x)\,\rho_t^n \tag{1.15}$$

$$\rho_t^s = 1 - \rho_t \tag{1.16}$$

$$s_{jt+1}^{*} \equiv \frac{1-\tau^w}{1+i_{t+1}}\left[\frac{z_{t+1} a_{jt+1}\left(k_{jt+1}^{*}\right)^{\alpha}}{\mu_{t+1}} - r_{t+1} k_{jt+1}^{*}\right] - (A+\widetilde{g}^u) + x_{jt+1}^u \tag{1.17}$$

$$s_{t+1}^{*} = (1-\tau^w)\,\frac{1-\alpha}{(1+i_{t+1})\alpha} r_{t+1} k_{t+1}^{*} - (A+\widetilde{g}^u) + x_{t+1}^u \tag{1.18}$$

$$x_t^u \equiv \beta E_t\left(\frac{\lambda_{1t+1}}{\lambda_{1t}}\right)(1-\rho)\,[1-\eta\rho_t^w]\, s_{t+1}^{*} \tag{1.19}$$

$$x_t^u = \frac{\gamma\,[1-\eta\rho_t^w]}{\rho_t^f\,(1-\eta)} \tag{1.20}$$

$$y_t^l = (1-\tau^w)\left(\frac{(1-\rho_t) n_t \mu_t r_t k_t^{*}}{\alpha} - r_t k_{t-1}\right) - \gamma v_t \tag{1.21}$$

$$u_t = 1 - (1 - \rho_t)\, n_t \tag{1.22}$$

$$\rho_t^w = \frac{\vartheta(u_t, v_t)}{u_t} \tag{1.23}$$

$$\rho_t^f = \frac{\vartheta(u_t, v_t)}{v_t} \tag{1.24}$$

$$n_{t+1} = (1 - \rho_t) n_t + \vartheta(u_t, v_t) \tag{1.25}$$

$$(1 - \rho_t)\, n_t k_t^* = k_{t-1} \tag{1.26}$$

$$i_t = \rho_i i_{t-1} + (1 - \rho_i)\left[\rho_\pi(\pi_t - \overline{\pi_t}) + \rho_y\,(\widehat{y}_t) + \bar{i}\right] \tag{1.27}$$

$$t_t = \tau_t^c c_t + \tau_t^k r_t k_{t-1} + \tau_t^w \left(\frac{(1 - \rho_t) n_t \mu_t r_t k_t^*}{\alpha} - r_t k_{t-1}\right) \tag{1.28}$$

$$b_t - (1 + i_{t-1})\,\frac{b_{t-1}}{\pi_t} = g_t^c + g_t^s + g^u u_t - t_t \tag{1.29}$$

$$g_t^\varphi = g_{t-1}^\varphi + \psi_1^\varphi \left[\overline{\left(\frac{b}{y}\right)} - \left(\frac{b_t}{y_t}\right)\right] + \psi_2^\varphi \left[\left(\frac{b_{t-1}}{y_{t-1}}\right) - \left(\frac{b_t}{y_t}\right)\right] \tag{1.30}$$

$$\frac{E_t \Lambda_{t,t+s}}{E_t \Lambda_{t,t+s-1}} = \frac{E_t(\lambda_{1t+s}/P_{t+s})}{E_t(\lambda_{1t+s-1}/P_{t+s-1})} \tag{1.31}$$

$$k_t^* = \int_{a_t'}^{a_{\max}} k_{jt}^* \frac{\varphi(a)}{1-\Phi(a')} da = \tag{32}$$

$$\left(\frac{\alpha z_t}{\mu_t r_t}\right)^{\frac{1}{1-\alpha}} \int_{a_t'}^{a_{\max}} \frac{a_t^{\frac{1}{1-\alpha}} \varphi(a)}{1-I(a_t')} da$$

$$k_t'^* = \left(\frac{\alpha z_t a_t'}{\mu_t r_t}\right)^{\frac{1}{1-\alpha}} \tag{1.33}$$

$$\pi_t = \frac{P_{t+1}}{P_t} \tag{1.34}$$

Endogenous variables:c_t, e_t, y_t, λ_{1t}, i_t, r_t, v_t, u_t, a_t', n_t, k_{jt}^*, π_t, M_t, P_t, q_t, P_t^*, Λ_t, μ_t, x_t^u, ρ_t^n, ρ_t, ρ_t^w, ρ_t^f, ρ_t^s, t_t, b_t, g_t^{φ}, k_t, y_t^l, k_t^*, $k_t'^*$,.s_{jt+1}^*, s_{t+1}^*

(33 equations=33 variables)

Appendix 2: The steady-state model (not to be published)

From (1.22):

$$\overline{u} = 1 - (1-\overline{\rho})\,\overline{n} \tag{2.1}$$

From (1.25):

$$\overline{\rho n} = \vartheta(\overline{u}, \overline{v}) \equiv \nu_0 \overline{v}^{\nu} \overline{u}^{1-\nu} \tag{2.2}$$

From (1.23):

$$\overline{\rho}^w = \frac{\vartheta(\overline{u}, \overline{v})}{\overline{u}} \tag{2.3}$$

From (1.24):

$$\overline{\rho}^f = \frac{\vartheta(\overline{u}, \overline{v})}{\overline{v}} \tag{2.4}$$

From (1.14) and (1.15):

$$\overline{\rho} = \rho^x + (1-\rho^x)\, I\left(a'\right) \tag{2.5}$$

From (1.16):

$$\overline{\rho}^s = 1 - \overline{\rho} \tag{2.6}$$

From (1.5):

$$\beta = \frac{\overline{\pi}}{1+\overline{i}} \tag{2.7}$$

From (1.9):

$$\overline{q}\beta^{-1} = \left(\left(1-\overline{\tau}^{k}\right)\overline{r} + \overline{q}\left[(1-\delta) + \phi\left\{\frac{\overline{e}}{\overline{\overline{k}}}\right\} - \phi'\left\{\frac{\overline{e}}{\overline{\overline{k}}}\right\}\frac{\overline{e}}{\overline{\overline{k}}}\right]\right) \tag{2.8}$$

From (1.8):

$$\left[\phi'\left\{\frac{\overline{e}}{\overline{\overline{k}}}\right\}\right]^{-1} = \overline{q} \tag{2.9}$$

From (1.10):

$$\left(\frac{\theta}{\theta-1}\right) = \overline{\mu} \tag{2.10}$$

From (1.32):

$$\overline{k}^{*} = \frac{1}{\left(1-I\left(\overline{a'}\right)\right)}\left(\frac{\alpha}{\overline{\mu r}}\right)^{\frac{1}{1-\alpha}}\int_{\overline{a'}}^{a_{\max}} a^{\frac{1}{1-\alpha}}\varphi(a)da \tag{2.11}$$

From (1.26):

$$(1-\overline{\rho})\,\overline{n}\overline{k}^{*} = \overline{k} \tag{2.12}$$

From (1.33):

$$\overline{k'}^{*} = \left(\frac{\alpha\overline{a'}}{\overline{\mu r}}\right)^{\frac{1}{1-\alpha}} \tag{2.13}$$

From (1.19)[12]:

$$\overline{x}^u = \beta\left(1-\rho^x\right)\left[1-\eta\overline{\rho}^w\right]\overline{s}^* \tag{2.14}$$

From (1.13):

$$\overline{x}^u = A + g^u - \frac{1-\overline{\tau}^w}{1+\overline{i}}\left[\frac{\overline{a'}\left(\overline{k'}^*\right)^\alpha}{\overline{\mu}} - \overline{r}\overline{k'}^*\right] \tag{2.15}$$

From (1.18):

$$\overline{s}^* = \frac{1-\tau^w}{1+\overline{i}}\frac{1-\alpha}{\alpha}\overline{r}\overline{k}^* - \left(A+g^u\right) + \overline{x}^u \tag{2.16}$$

From (1.20):

$$A + g^u - \frac{1-\tau^w}{1+\overline{i}}\left(\frac{a'\overline{k'}^{*\alpha}}{\overline{\mu}} - \overline{r}\overline{k'}^*\right) = \frac{\gamma\left[1-\overline{\rho}^w\eta\right]}{\left(1-\eta\right)\overline{\rho}^f} \tag{2.17}$$

From (1.1):

$$\overline{y} = \frac{(1-\overline{\rho})\overline{n}\overline{\mu}\overline{r}}{\alpha}\overline{k}^* \tag{2.18}$$

From (1.7):

$$\frac{\overline{e}}{\overline{k}} = \phi^{-1}\left(\delta\right) \tag{2.19}$$

From (1.2):

$$\overline{c} + \overline{e} + \overline{g}^c + \gamma\overline{v} = \overline{y} + A\overline{\rho}\overline{n} \tag{2.20}$$

[12] The steady-state expected present value of income coming from $\tilde{g}^u$ can be obtained from 37 as:

$$\left[1+\beta\left(1-\rho^w\left(1-\rho^x\right)\right)+\beta^2\left(1-\rho^w\left(1-\rho^x\right)\right)^2+\beta^3\left(1-\rho^w\left(1-\rho^x\right)\right)^3 \ldots\right]\tilde{g}^u$$

We wish to calibrate $\tilde{g}^u$ so that the observed unemployment benefits $\left(g^u\right)$ is received for only two consecutive periods:

$$\left[1+\beta\left(1-\rho^w\left(1-\rho^x\right)\right)\right]g^u = \left[\frac{1}{1-\beta\left(1-\rho^w\left(1-\rho^x\right)\right)}\right]\tilde{g}^u$$

Therfore

$$\tilde{g}^u = \left(1-\left[\beta\left(1-\rho^w\left(1-\rho^x\right)\right)\right]^2\right)g^u$$

From (1.3) and (1.4):

$$\left(1+\overline{\tau}^{c}\right)\left(1+\overline{i}\right)\overline{\lambda}_{1}=\left(1-\beta h\right)\frac{\overline{c}^{\sigma(h-1)}}{\overline{c}^{h}} \tag{2.21}$$

From (1.6):

$$\left(1+\overline{\tau}^{c}\right)\overline{c}=\frac{\overline{M}}{\overline{P}} \tag{2.22}$$

From (1.21):

$$\overline{y^{l}}=\left(1-\tau^{w}\right)\left(\overline{y}-\overline{r}\overline{k}\right)-\gamma\overline{v} \tag{2.23}$$

From (1.28):

$$\overline{t}=\overline{\tau}^{c}\overline{c}+\overline{\tau}^{k}\overline{r}\overline{k}+\overline{\tau}^{w}\left(\overline{y}-r\overline{k}\right) \tag{2.24}$$

From (1.29):

$$\overline{g}^{c}+\overline{g}^{s}+g^{u}\overline{u}+\overline{i}\overline{b}=\overline{t} \tag{2.25}$$

Exogenous variables: $\overline{\pi}$ and $\overline{\tau}^{c}$, $\overline{\tau}^{k}$, $\overline{\tau}^{w}$, $\overline{g}^{c}$, $\overline{g}^{s}$, $\overline{g}^{u}$. Endogenous:$\overline{c}$, $\overline{e}$, $\overline{y}$, $\overline{\lambda}_{1}$, $\overline{i}$, $\overline{r}$, $\overline{v}$, $\overline{u}$, a', $\overline{n}$, $\overline{m}$, $\overline{q}$, $\overline{\mu}$, $\overline{x}^{u}$, $\overline{\rho}$, $\overline{s}^{*}$, $\overline{\rho}^{w}$, $\overline{\rho}^{f}$, $\overline{y}^{l}$, $\overline{t}$, $\overline{b}$, $\overline{k}$, $\overline{k'}^{*}$, $\overline{k}^{*}$, $\overline{\rho}^{s}$ (25 endogenous=25 equations)

Appendix 3: Log-linearized model (not to be published)

Let $\widehat{x}$ be the variable to tell us how much x differs from its steady-state value and define $R_t \equiv 1+i_t$.

From (1.13):

$$\begin{aligned}
\widehat{a'_t} \quad = \quad & \left(\frac{\overline{i}}{1+\overline{i}}\right)\left(\frac{\overline{R}(A+g^{u}-\overline{x}^{u})}{\overline{R}(A+g^{u}-\overline{x}^{u})+(1-\tau^{w})\overline{r}\overline{k'}^{*}}\right)\widehat{i}_t-\widehat{z}_t+\widehat{\mu}_t \\
& -\left(\alpha-\frac{(1-\tau^{w})\overline{r}\overline{k'}^{*}}{(1-\tau^{w})\overline{r}\overline{k'}^{*}+\overline{R}(A+g^{u}-\overline{x}^{u})}\right)\widehat{k'}^{*}_{t} \\
& +\left(\frac{(1-\tau^{w})\overline{r}\overline{k'}^{*}}{(1-\tau^{w})\overline{r}\overline{k'}^{*}+\overline{R}(A+g^{u}-\overline{x}^{u})}\right)\widehat{r}_t \\
& -\left(\frac{\overline{R}\overline{x}^{u}}{\overline{R}(A+g^{u}-\overline{x}^{u})+(1-\tau^{w})\overline{r}\overline{k'}^{*}}\right)\widehat{x}^{u}_{t}
\end{aligned} \tag{3.1}$$

From (1.14):

$$\widehat{\rho}_t^n = \frac{\varphi(\overline{a'})\overline{a'}}{I\left(\overline{a'}\right)}\widehat{a'}_t \tag{3.2}$$

From (1.15):

$$\widehat{\rho}_t = \left[\frac{(1-\rho^x)\,\overline{\rho}^n}{\overline{\rho}}\right]\widehat{\rho}_t^n \tag{3.3}$$

From (1.16):

$$\widehat{\rho}_t^s = \frac{-\overline{\rho}}{1-\overline{\rho}}\widehat{\rho}_t \tag{3.4}$$

From (1.25):

$$\widehat{n}_{t+1} = (1-\overline{\rho})\widehat{n}_t - \overline{\rho}\widehat{\rho}_t + \overline{\rho}^w\frac{\overline{v}^\nu}{\overline{u}^\nu+\overline{v}^\nu}\frac{\overline{u}}{\overline{n}}\widehat{u}_t + \overline{\rho}^f\frac{\overline{u}^\nu}{\overline{u}^\nu+\overline{v}^\nu}\frac{\overline{v}}{\overline{n}}\widehat{v}_t \tag{3.5}$$

From (1.22):

$$\widehat{u}_t = -\left(1-\overline{\rho}\right)\frac{\overline{n}}{\overline{u}}\widehat{n}_t + \overline{\rho}\frac{\overline{n}}{\overline{u}}\widehat{\rho}_t \tag{3.6}$$

From (1.24):

$$\widehat{\rho}_t^f = \frac{\overline{v}^\nu}{\overline{u}^\nu+\overline{v}^\nu}\left(\widehat{u}_t - \widehat{v}_t\right) \tag{3.7}$$

From (1.23):

$$\widehat{\rho}_t^w = \frac{\overline{u}^\nu}{\overline{u}^\nu+\overline{v}^\nu}\left(\widehat{v}_t - \widehat{u}_t\right) \tag{3.8}$$

From (1.20):

$$\widehat{x}_t^u + \widehat{\rho}_t^f = -\frac{\eta\overline{\rho}^w}{1-\eta\overline{\rho}^w}\widehat{\rho}_t^w \tag{3.9}$$

From (1.1):

$$\widehat{y}_t = \widehat{n}_t - \left(\frac{\overline{\rho}}{1-\overline{\rho}}\right)\widehat{\rho}_t + \widehat{\mu}_t + \widehat{r}_t + \widehat{k}_t^* \tag{3.10}$$

From (1.19):

$$\begin{aligned}\widehat{x}_t^u \quad &= \quad E_t\widehat{\lambda}_{t+1} - \widehat{\lambda}_t + E_t\widehat{s}_{t+1}^* \\ &\quad -\frac{\eta\overline{\rho}^w}{1-\eta\overline{\rho}^w}\widehat{\rho}_t^w - \frac{\overline{\rho}}{1-\overline{\rho}}E_t\widehat{\rho}_{t+1}\end{aligned} \tag{3.11}$$

From (1.18):

$$\widehat{s}_t^* = \left(\frac{1-\alpha}{\alpha}\right)\frac{(1-\tau^w)\overline{r}\overline{k}^*}{\overline{R}\overline{s}^*}\left(\widehat{k}_t^* + \widehat{r}_t - \frac{\overline{i}}{1+\overline{i}}\widehat{i}_t\right) + \frac{\overline{x}^u}{\overline{s}^*} \tag{3.12}$$

From (1.2):

$$\widehat{y}_t = \frac{\overline{c}}{\overline{y}}\widehat{c}_t + \frac{\overline{e}}{\overline{y}}\widehat{e}_t + \frac{\overline{g}}{\overline{y}}\widehat{g}_t^c + \frac{\gamma\overline{v}}{\overline{y}}\widehat{v}_t - \frac{A\overline{\rho n}}{\overline{y}}(\widehat{\rho}_t + \widehat{n}_t) \tag{3.13}$$

From (1.5):

$$\widehat{\lambda}_{1t} = \frac{\overline{i}}{(1+\overline{i})}\widehat{i}_t + E_t\left(\widehat{\lambda}_{1t+1} - \widehat{\pi}_{t+1}\right) \tag{3.14}$$

From (1.6):

$$\widehat{M}_t = \widehat{P}_t + \widehat{c}_t \tag{3.15}$$

From (1.7):

$$\widehat{k}_t = \left(1 - \frac{\overline{e}}{\overline{k}}\right)\widehat{k}_{t-1} + \frac{\overline{e}}{\overline{k}}\widehat{e}_t \tag{3.16}$$

From (1.8):

$$\widehat{q}_t = \phi''\frac{\overline{e}}{\overline{k}}\left(\widehat{k}_{t-1} - \widehat{e}_t\right) \tag{3.17}$$

From (1.9):

$$\begin{aligned}\widehat{q}_t \quad = \quad & E_t\left(\widehat{\lambda}_{1t+1} - \widehat{\lambda}_{1t}\right) + \beta\overline{r}\left(1 - \overline{\tau}^k\right)E_t\widehat{r}_{t+1} + \\ & \beta\left(1 - \frac{\overline{e}}{\overline{k}}\right)E_t\widehat{q}_{t+1} - \beta\left(\frac{\overline{e}}{\overline{k}}\right)^2\phi''E_t\left(\widehat{e}_{t+1} - \widehat{k}_t\right)\end{aligned} \tag{3.18}$$

From (1.11):

$$E_t\widehat{P}_{t+1}^* = \frac{1}{(1-\omega)}E_t\left(\widehat{P}_{t+1} - \widehat{P}_t\right) + \widehat{P}_t \tag{3.19}$$

From (1.27):

$$\overline{i}\widehat{i}_t = \rho_i\overline{i}\widehat{i}_{t-1} + (1-\rho_i)\,\rho_\pi\overline{\pi}\widehat{\pi}_t + (1-\rho_i)\,\rho_y\overline{y}\widehat{y}_t \tag{3.20}$$

Fom (1.10):

$$\widehat{P}_t^* = \beta\omega E_t\widehat{P}_{t+1}^* + (1-\beta\omega)\left(\widehat{P}_t - \widehat{\mu}_t\right) \tag{3.21}$$

From (1.31):

$$E_t\widehat{\Lambda}_{t+1} = \widehat{\Lambda}_t + E_t\left(\widehat{\lambda}_{1t+1} - \widehat{\lambda}_{1t}\right) - E_t\left(\widehat{P}_{t+1} - \widehat{P}_t\right) \tag{3.22}$$

From (1.3) and (1.4):

$$\begin{aligned}\widehat{\lambda}_{1t} \quad = \quad & \frac{\beta h(1+h\,(1-\sigma))-\sigma}{1-\beta h}\widehat{c}_t - \frac{h\,(1-\sigma)}{1-\beta h}\widehat{c}_{t-1} \\ & -\frac{\beta h\,(1-\sigma)}{1-\beta h}E_t\widehat{c}_{t+1} - \frac{\bar{i}}{1+\bar{i}}\widehat{i}_{t-1}\end{aligned} \tag{3.23}$$

From (1.21):

$$\widehat{y}_t^l = \frac{(1-\tau^w)\left(\frac{\overline{\mu}}{\alpha}-1\right)\overline{r}\overline{k}}{\overline{y}^l}\left[\frac{\overline{\mu}}{\overline{\mu}-\alpha}\widehat{\mu}_t + \widehat{r}_t + \widehat{k}_{t-1}\right] - \left(\frac{\gamma\overline{v}}{\overline{y}^l}\right)\widehat{v}_t \tag{3.24}$$

From (1.26):

$$\widehat{k}_{t-1} = \widehat{n}_t - \frac{\overline{\rho}}{1-\overline{\rho}}\widehat{\rho}_t + \widehat{k}_t^* \tag{3.25}$$

New Phillips curve:

$$\widehat{\pi}_t = \frac{\beta}{1+\varsigma\beta}E_t\widehat{\pi}_{t+1} - \frac{(1-\beta\omega)\,(1-\omega)}{\omega(1+\varsigma\beta)}\widehat{\mu}_t + \frac{\varsigma}{1+\varsigma\beta}\widehat{\pi}_{t-1} \tag{3.26}$$

From (1.28):

$$\widehat{t}_t = \frac{\overline{\tau}^c\overline{c}}{\overline{t}}\widehat{c}_t + \frac{\overline{r}\overline{k}}{\overline{t}}\left(\overline{\tau}^k + \frac{\overline{\tau}^w}{\alpha}\mu - \overline{\tau}^w\right)\left(\widehat{k}_{t-1} + \widehat{r}_r\right) + \frac{\overline{\tau}^w\overline{\mu}\overline{r}\overline{k}}{\alpha\overline{t}}\widehat{\mu}_t \tag{3.27}$$

From (1.30):

$$\overline{g}^\varphi\widehat{g}_t^\varphi = \overline{g}^\varphi\widehat{g}_{t-1}^\varphi + \left(\frac{\overline{b}}{y}\right)\left(\psi_1^\varphi + \psi_2^\varphi\right)\left(\widehat{y}_t - \widehat{b}_t\right) + \psi_2^\varphi\left(\frac{\overline{b}}{y}\right)\left(\widehat{b}_{t-1} - \widehat{y}_{t-1}\right) \tag{3.28}$$

From (1.29):

$$\overline{t}\widehat{t}_t = \overline{g}^c\widehat{g}_t^c + \overline{g}^s\widehat{g}_t^s + g^u\overline{u}\widehat{u}_t + \frac{\overline{b}}{\overline{\pi}}\overline{i}\widehat{i}_{t-1} - \frac{\overline{b}}{\overline{\pi}}\left(1+\overline{i}\right)\widehat{\pi}_t + \frac{\overline{b}}{\overline{\pi}}\left(1+\overline{i}\right)\widehat{b}_{t-1} - \overline{b}\widehat{b}_t \tag{3.29}$$

From (1.32):

$$\widehat{k}_t^* = \left(\frac{1}{1-\alpha}\right)\left(\widehat{z}_t - \widehat{\mu}_t - \widehat{r}_t\right) - \Psi(\overline{a'})\widehat{a'}_t \tag{3.30}$$

where:

$$\Psi(\overline{a'}) = \overline{a'}\varphi(\overline{a'}) \left[\frac{1}{1 - I\left(\overline{a'}\right)} - \frac{\left(\overline{a'}\right)^{\left(\frac{1}{1-\alpha}\right)}}{\int_{\overline{a'}}^{a_{\max}} (a)^{\left(\frac{1}{1-\alpha}\right)} \varphi(a) da} \right] \tag{3.31}$$

From (1.33):

$$\widehat{k'}_t^* = \left(\frac{1}{1-\alpha}\right) \left(\widehat{z}_t + \widehat{a'}_t - \widehat{\mu}_t - \widehat{r}_t\right) \tag{3.32}$$

Appendix 4: Endogenous job destruction, intertemporal substitution, habits, capital and taxes

There are many differences between our benchmark model and the basic model, making it difficult to gauge the contribution of the different components of the model to explaining the improvement in empirical performance. This appendix explores these mechanisms in detail, by taking each of them at a time from the basic to the more general specification in a setting without price rigidity. Given the complexity of the model and the lack of an analytical solution, this can only be achieved by relying on numerical simulations and analyzing the sensitivity of the results in each particular case.

Table A4.1 contains the results for six different models. Given that the simulated persistence of the output in some models without capital is always higher than that actually observed, we have re-calibrated the corresponding coefficient of the productivity shock in all the models to match an autocorrelation of 0.91 for output. This is higher than the observed figure, but as the aim of the exercise is to study how cyclical properties of the labor market change as we enrich the model, we preferred to maintain this moment constant to facilitate comparability across models. However, it is important to note that this strategy means that the persistence and volatility of the common productivity shock is now different across models, thus creating an additional margin affecting the results.

The main message from Table A4.1 is that adding other mechanisms but price rigidity does not contribute towards raising the volatility of vacancies. Quite the opposite, some of them seem to work in the wrong direction. Thus, column (2) corresponds to a model without price rigidity, endogenous job destruction, intertemporal substitution, habits, capital or taxes. This is equivalent to our basic model in Table 3, although with a slightly different output persistence.[13] In column (3) we introduce endogenous destruction (that amounts to 1.8 per cent in steady state, representing 20 per cent of the total quarterly separation rate). Compared with the results in column (2) this model predicts a lower volatility in vacancies and unemployment. In column (4), we then embed the matching mechanism in a dynamic model in which agents make their intertemporal decisions operating through a perfect financial market. As we can see, this model does a worse job of fitting the relative volatility of u (increasing it) and v (lowering it). The presence of habits ($h = 0.78$) in column (5) seems to improve the performance of the model regarding the volatility of vacancies, but further pushes up the volatility of unemployment. Column (6) introduces capital, which leads to a sharp fall in the volatility of unemployment, making the relative

[13] As commented before, the higher the persistence of the productivity shock, the lower the volatility of vacancies.

standard deviation of unemployment closer to that actually observed. Finally, in column (7) taxes are considered, without adding too much in terms of volatilities in a model of flexible prices.

Table A4.2 shows how the results would change for the case in which the productivity shock has the same volatility and persistence than our benchmark model with price rigidity. Qualitatively, the message learnt from changing the model in the flexible prices case is the same: enriching the model does not add too much towards explaining the cyclical performance in the labor market, although in this case the gap between the observed and simulated volatilities for unemployment and vacancies widens as a consequence of intertemporal substitution.

TABLE A4.1 VOLATILITIES ACROSS MODELS
Same persistence and volatility in output

Price rigidity			No					
Endogenous destruction			No	Yes				
General equilibrium			No		Yes			
Habits			No			Yes		
Capital			No				Yes	
Distortionary taxes			No					Yes
		US	(2)	(3)	(4)	(5)	(6)	(7)
$\widehat{y}_t$	σ_y	1.58	1.58	1.58	1.58	1.58	1.58	1.58
	ρ_y	0.84	0.91	0.91	0.91	0.91	0.91	0.91
$\ln u_t$	σ_u/σ_y	7.83	8.86	8.23	10.71	11.23	7.49	7.78
	ρ_u	0.87	0.88	0.89	0.91	0.89	0.92	0.91
	$\sigma_{u,y}$	-0.84	-0.99	-0.99	-0.99	-0.99	-0.99	-0.99
$\ln v_t$	σ_v/σ_y	8.85	4.93	3.72	1.53	1.92	1.88	2.04
	ρ_v	0.91	0.46	0.43	0.32	0.45	0.32	0.31
	$\sigma_{v,y}$	0.90	0.68	0.66	0.46	0.35	0.57	0.55
$\ln \frac{v_t}{u_t}$	σ_{vu}/σ_y	16.33	13.01	11.17	11.46	12.16	8.66	9.05
	ρ_{vu}	0.90	0.76	0.78	0.87	0.85	0.85	0.83
	$\sigma_{vu,y}$	0.89	0.93	0.95	0.99	0.97	0.99	0.98
ρ^w	σ_{ρ^w}/σ_y	4.86	4.03	3.47	3.10	3.27	2.66	2.77
	ρ_{ρ^w}	0.91	0.76	0.78	0.87	0.85	0.84	0.83
	$\sigma_{\rho^w,y}$		0.93	0.95	0.99	0.97	0.99	0.98
$\frac{\overline{s}^*}{(1-\tau^w)\overline{y}}$			0.19	0.19	0.19	0.19	0.19	0.19
$\frac{\frac{\overline{y}^l}{n}-(A+\widetilde{g}^u)}{A+\widetilde{g}^u}$			0.12	0.12	0.38	0.38	0.67	0.67
η			0.67	0.67	0.67	0.67	0.67	0.67
A			0.91	0.95	0.60	0.60	1.70	0.86

TABLE A4.2 VOLATILITIES ACROSS MODELS
Same persistence and volatility in the shock

Price rigidity			No						
Endogenous destruction			No	Yes					
General equilibrium			No		Yes				
Habits			No			Yes			
Capital			No				Yes		
Distortionary taxes			No						Yes
		US	(2)	(3)	(4)	(5)	(6)	(7)
$\widehat{y}_t$	σ_y	1.58	1.90	4.02	10.46	13.47	2.15	2.29
	ρ_y	0.84	0.72	0.69	0.95	0.95	0.63	0.66
$\ln u_t$	σ_u/σ_y	7.83	6.51	6.45	15.49	12.94	6.26	7.06
	ρ_u	0.87	0.70	0.69	0.76	0.74	0.71	0.71
	$\sigma_{u,y}$	-0.84	-0.99	-0.98	-0.42	-0.33	-0.99	-0.99
$\ln v_t$	σ_v/σ_y	8.85	5.13	3.81	1.61	2.05	2.32	2.70
	ρ_v	0.91	0.14	0.07	0.53	0.67	-0.02	-0.02
	$\sigma_{v,y}$	0.90	0.70	0.64	0.46	0.35	0.49	0.49
$\ln \frac{v_t}{u_t}$	σ_{vu}/σ_y	16.33	10.79	9.27	15.89	13.40	7.46	8.57
	ρ_{vu}	0.90	0.46	0.46	0.76	0.74	0.50	0.50
	$\sigma_{vu,y}$	0.89	0.93	0.94	0.46	0.37	0.98	0.97
ρ^w	σ_{ρ^w}/σ_y	4.86	3.36	2.74	3.16	3.25	2.30	2.60
	ρ_{ρ^w}	0.91	0.46	0.46	0.92	0.92	0.49	0.49
	$\sigma_{\rho^w,y}$		0.93	0.95	0.99	0.97	0.98	0.97
$\frac{\bar{s}^*}{\bar{y}}$			0.19	0.19	0.19	0.19	0.19	0.19
$\frac{\eta\bar{s}^*}{A-\bar{x}^u}$			0.12	0.12	0.38	0.38	0.67	0.67
η			0.67	0.67	0.67	0.67	0.67	0.67
A			0.91	0.95	0.60	0.60	1.70	0.86

Appendix 5: Sensitivity analysis for unemployment benefits and the value of home production

As we explained in the paper, we have carried out a careful calibration exercise through the paper in order to obtain an accurate steady state for the model. Moreover, we have taken into account the Hagedord and Manovskii - Costain and Reiter's critique by holding constant the steady-state values for some relevant variables across different experiments.

In this appendix we perform a sensitivity analysis of our results to changes on the home production value (A) and the replacement rate (rr) parameters. The results are summarized in Tables A5.1 and A5.2. The conclusion of this exercise is that our main result of price stickiness as a mechanism to amplify fluctuations in vacancies is robust to a wide range of values of these two parameters.

Both parameters have important effects on the steady state values for the labor market. Thus, we stick on an interval of values for both of them consistent with reasonable steady states for the labor market variables, in particular the employment/unemployment rate. The intervals considered for the sensitivity analysis are then $[0.78, 0.93]$ for A, including the benchmark vale of 0.86, and $[0.20, 0.32]$ for rr, including the benchmark value of 0.26. These values imply that the simulated unemployment rate ranges from 10 per cent $[A = 0.93$ or $rr = 0.32]$ to 3 per cent $[A = 0.78$ or $rr = 0.20]$, around the benchmark value of 6.

Columns (1) to (3) present the USdata and the results for the complete model in Table 3 of our paper. In columns (4) and (5) we increase the value for home production (Table A5.1) and the replacement rate (Table A5.2). The last two columns reduce the value for home production (Table A5.1) and the replacement rate (Table A5.2). Because home production and unemployment benefits play the same role in the model, the results in both tables are very similar, reinforcing the robustness of our results to variations in these two parameters.

TABLE A5.1 BENCHMARK MODEL
SENSITIVITY ANALYSIS (CHANGE IN THE HOME PRODUCTION VALUE)

		(1)	(2)	(3)	(4)	(5)	(6)	(7)
			No	Yes	No	Yes	No	Yes
		US	(A =0.86)	(A =0.86)	(A =0.93)	(A =0.93)	(A =0.78)	(A =0.78)
$\widehat{y}_t$	σ_y	1.58	1.58	1.58	2.12	1.73	1.26	1.62
	ρ_y	0.84	0.84	0.84	0.86	0.88	0.82	0.77
$\ln u_t$	σ_u/σ_y	7.83	7.65	8.05	5.62	5.37	8.78	12.10
	ρ_u	0.87	0.85	0.86	0.86	0.87	0.83	0.78
	$\sigma_{u,y}$	-0.84	-0.99	-0.97	-0.99	-0.97	-0.99	-0.98
$\ln v_t$	σ_v/σ_y	8.85	2.44	8.94	1.79	6.59	3.11	9.43
	ρ_v	0.91	0.18	0.20	0.17	0.23	0.25	0.16
	$\sigma_{v,y}$	0.90	0.51	0.50	0.42	0.40	0.70	0.62
$\ln \frac{v_t}{u_t}$	σ_{vu}/σ_y	16.33	9.09	13.71	6.58	9.25	11.10	19.10
	ρ_{vu}	0.90	0.72	0.60	0.72	0.62	0.72	0.55
	$\sigma_{vu,y}$	0.89	0.97	0.89	0.96	0.85	0.98	0.93
ρ^w	σ_{ρ^w}/σ_y	4.86	2.80	4.22	2.29	3.26	2.94	4.93
	ρ_{ρ^w}	0.91	0.72	0.60	0.72	0.62	0.71	0.55
	$\sigma_{\rho^w,y}$		0.98	0.90	0.97	0.85	0.98	0.93
$\frac{\overline{s}^*}{(1-\tau^w)\overline{y}}$			0.19	0.19	0.18	0.18	0.22	0.22
$\frac{\frac{\overline{y}^l}{n}-(A+\widetilde{g}^u)}{A+\widetilde{g}^u}$			0.67	0.67	0.46	0.46	0.86	0.86
η			0.67	0.67	0.67	0.67	0.67	0.67
A			0.86	0.86	0.93	0.93	0.78	0.78
rr			0.26	0.26	0.26	0.26	0.26	0.26

TABLE A5.2 BENCHMARK MODEL
SENSITIVITY ANALYSIS (CHANGE IN THE REPLACEMENT RATE)

		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Price rigidity			No	Yes	No	Yes	No	Yes
		US	(rr=0.26)	(rr=0.26)	(rr=0.32)	(rr=0.32)	(rr=0.20)	(rr=0.20)
$\widehat{y}_t$	σ_y	1.58	1.58	1.58	2.13	1.73	1.21	1.66
	ρ_y	0.84	0.84	0.84	0.86	0.88	0.81	0.75
$\ln u_t$	σ_u/σ_y	7.83	7.65	8.05	5.60	5.32	9.01	13.79
	ρ_u	0.87	0.85	0.86	0.86	0.87	0.83	0.74
	$\sigma_{u,y}$	-0.84	-0.99	-0.97	-0.99	-0.97	-0.99	-0.98
$\ln v_t$	σ_v/σ_y	8.85	2.44	8.94	1.79	6.41	3.20	9.32
	ρ_v	0.91	0.18	0.20	0.17	0.24	0.27	0.14
	$\sigma_{v,y}$	0.90	0.51	0.50	0.42	0.42	0.73	0.64
$\ln \frac{v_t}{u_t}$	σ_{vu}/σ_y	16.33	9.09	13.71	6.56	9.07	11.49	20.89
	ρ_{vu}	0.90	0.72	0.60	0.72	0.63	0.71	0.53
	$\sigma_{vu,y}$	0.89	0.97	0.89	0.96	0.86	0.98	0.93
ρ^w	σ_{ρ^w}/σ_y	4.86	2.80	4.22	2.28	3.20	2.90	5.07
	ρ_{ρ^w}	0.91	0.72	0.60	0.72	0.63	0.71	0.53
	$\sigma_{\rho^w,y}$		0.98	0.90	0.97	0.86	0.99	0.93
$\frac{\bar{s}^*}{(1-\tau^w)\bar{y}}$			0.19	0.19	0.18	0.18	0.23	0.23
$\frac{\frac{\bar{y}^l}{n}-(A+\tilde{g}^u)}{A+\tilde{g}^u}$			0.67	0.67	0.55	0.55	0.73	0.73
η			0.67	0.67	0.67	0.67	0.67	0.67
A			0.86	0.86	0.86	0.86	0.86	0.86
rr			0.26	0.26	0.32	0.32	0.20	0.20