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Credit, vacancies and unemployment fluctuations ☆

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Propagation in equilibrium models of search unemployment is altered when vacancy costs require some external financing on frictional credit markets. The easing of financing constraints during an expansion as firms accumulate net worth reduces the opportunity cost for resources allocated to job creation. The dynamics of market tightness are affected by (i) a cost channel, increasing the incentive to recruit for a given benefit from a new hire, and (ii) a wage channel, whereby firms' improved bargaining position limits the upward pressure of market tightness on wages. Agency related credit frictions endogenously generate persistence in the dynamics of labor-market tightness, and have a moderate endogenous effect on amplification.

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1. Introduction

The standard Mortensen and Pissarides (1994) search-and-matching model of equilibrium unemployment has been argued in many places to be inconsistent with key business cycle facts. In particular, it can explain neither the high volatilities of unemployment, vacancies and market tightness (Shimer, 2005), nor the persistence in the adjustment of these variables to exogenous shocks (Fujita and Ramey, 2007). Subsequent research has focused on whether the lack of internal propagation, both in terms of amplification and persistence, stems from the structure of the model itself or whether it is a question of setting an appropriate calibration.

Firms in these models must expend resources to fill job vacancies, a time-consuming process in the presence of search frictions on labor markets. Under Nash bargaining as a wage mechanism, wages absorb much of the change in the expected benefit to a new worker induced by fluctuations in labor productivity. As a result, Shimer (2005) argues, the incentive to post vacancies changes little over the business cycle. Quite naturally, subsequent research has focused on the dynamics of wages as a means of generating amplification of exogenous innovations. Such studies have either altered the particulars of the wage-determination mechanism (e.g., Shimer, 2004) or followed an alternative calibration strategy that results in

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a rigid wage (Hagedorn and Manovskii, 2008).[1] In order to address the second empirical shortcoming, the persistence of labor-market adjustments to productivity shocks, a second strand of research has focused on the structure of vacancy costs. Fujita and Ramey (2007), for example, develop a story about sunk costs to vacancy creation such that the strongest change in market tightness occurs several periods after the original shock. Their approach, however, does not generate additional amplification.[2]

This paper extends the baseline search-and-matching model of equilibrium unemployment by assuming that external finance must be called upon to fund part of a firm's vacancy costs, and that agency problems cause credit markets to be frictional. The thrust of this paper is to show that evolving conditions on credit markets over the business cycle change the opportunity cost for resources firms use to create new jobs in the face of small changes in the expected benefit to a new worker. This addresses, in part, the lack of persistence to productivity shocks outlined above and, when empirically documented time variation in both the costs of liquidation and rates of recovery on loans to U.S. firms is introduced into the model, can address the lack of amplification.[3] Acemoglu (2001) and Wasmer and Weil (2004) have shown that credit-market imperfections lead to higher equilibrium unemployment by restricting firm entry.[4] Petrosky-Nadeau and Wasmer (2013) show that the interactions between credit and labor-market frictions in Wasmer and Weil (2004) generate a financial multiplier analogous to that discussed in this paper. That is, the financial frictions introduce an essentially acyclical component to the cost of job creation. As pointed out by Pissarides (2009), this introduces additional rigidity in the cost of creating jobs over the business cycle and increases the elasticity of labor-market tightness to shocks. This paper, with an agency problem in credit markets rather than search frictions, contributes to making a broader case for the role credit-market imperfections play in understanding aggregate dynamics, in this instance operating through workers as opposed to investment flows (e.g., Kiyotaki and Moore, 1997; Bernanke et al., 1999).

The model developed in this paper works as follows. Due to a problem of costly state verification in lending relationships, firms write standard debt contracts (Gale and Hellwig, 1985; Williamson, 1987) to fund vacancies over accumulated assets. The higher shadow cost of external over internal funds increases the cost of vacancies, leading to a higher rate of equilibrium unemployment. However, the degree of agency costs is alleviated during economic upturns, both because of increased firm net worth, reducing their reliance on external funds, and an assumption of counter-cyclical liquidation costs. As discussed in detail in Section 2, there is extensive empirical evidence in corporate finance for time variation in both the costs of liquidation and rates of recovery on loans to U.S. firms. The model adopts the specifics of time variation in the costs from Livdan et al. (2009), allowing in addition for exogenous innovations interpreted as credit shocks. The elasticity of the costs is estimated on U.S. data on bond spreads, along with the process to productivity and credit-market shocks.

The shadow cost of resources allocated to job creation declines during expansion, and tightens during recessions. This opens two channels that alter the dynamics job vacancies in response to productivity shocks: (i) a cost channel, driving a time-varying wedge in the job-creation condition in which the lowered opportunity cost of resources allocated to job creation during an upturn increases the incentive to post vacancies; (ii) a wage channel – under Nash bargaining as a wage mechanism, the lowered opportunity cost of vacancies limits part of the upward pressure of market tightness on wages by improving firms' bargaining position. Note that this is an effect of frictional credit markets, not an inherent feature of the wage rule or a particular calibration of the model. This is operative only in the period an innovation occurs, is reversed by the changing conditions in the labor market, and results in a flexible aggregate wage. In addition, the opportunity cost for resources used for recruiting is distinct from the *fixed* unit cost of a job vacancy and the *average cost* of recruiting a worker, which is a function of the degree of congestion on labor markets. Just as in the canonical model, this average cost, which appears in the job-creation condition, will be procyclical. However, it will be more rigid due to the presence of a counter-cyclical premium on external funds. Finally, the progressive easing of financing constraints as firms accumulate assets induces persistence in the adjustments of labor-market variables to productivity shocks. Whereas in standard equilibrium-unemployment search models, or models with increased wage rigidity for that matter, the largest response of market tightness is contemporaneous to the exogenous shock, the height of the response in this setting is reached with a lag after the innovation.[5]

Section 3 details the model's quantitative results and sets them against a comparable framework without credit frictions. Conditional on productivity shocks being the only driving force, frictions in the credit market increase the volatility of

[1] Examples of alternative wage determination include a demand-game auction (Hall, 2005) or staggered wage contracting (Gertler and Trigari, 2009). In essence, Hagedorn and Manovskii's (2008) parametrization of the non-market activities' value and the relative Nash bargaining weight ensures that the wage is highly inelastic to its time-varying components, i.e. labor productivity and the degree of market tightness.

[2] Fujita and Ramey (2007) argue that by combining their modeling of job vacancies with Hagedorn and Manovskii's (2008) calibration, their model can address both issues pertaining to the propagation of productivity shocks. Alternative approaches to modeling vacancy costs include Yashiv (2006) and Rotemberg (2006) in which the cost of vacancies is a declining function of the number of vacancies a firm posts.

[3] This result is independent of whether external funding applies to recruiting costs alone or includes the wage bill. Results are available from the author upon request. Linking current costs to financial markets is also a features of bank-loan models, as in Christiano et al. (2005), or commercial debt models, as in Carlstrom and Fuerst (2000).

[4] Acemoglu (2001) provides evidence that credit-constrained industries have lower employment shares and Rendon (2001) finds that labor demand is both restricted and more elastic at credit-constrained firms.

[5] The staggered nature of wage contracts in Gertler and Trigari (2009) is an exception in this literature in that persistence to productivity shocks does arise.

labor-market tightness by a factor of 2.4. This amplification is achieved by both an endogenous change in agency costs, via the accumulation of net worth, and an exogenous variation in liquidation costs, as outlined above. Absent time variation in liquidations cost, frictions in the credit market increase the volatility of labor-market tightness by a factor of 1.9. The relative volatility of market tightness reaches 8.03 (against 15 in the data) compared to only 3.30 in the standard model with perfect credit markets. Allowing for credit shocks as well, the relative volatility of labor-market tightness increases to 14.99.[6] Section 3.4 follows the contributions of recent work such as Jermann and Quadrini (2012), and presents the effects of a large credit shock, a shock that causes a doubling of the premium on external funds. This leads to a 30% decline in the job-finding rate and an increase in the unemployment rate by just over two percentage points.

U.S. quarterly data on market tightness display a high degree of persistence, measured as positive auto-correlations in the growth rate of 0.67, 0.48 and 0.33 at the first, second and third lags respectively. Allowing for frictional credit markets can endogenously generate an auto-correlation of 0.26 at the first lag. Allowing for a cyclical recovery cost increases the auto-correlation at the first lag to 0.49. The model with perfect credit markets generates virtually no auto-correlation. This persistence is similar without or without time variation in the recovery rate. This criticism is akin to that advanced by Cogley and Nason (1995) about real business cycle (RBC) models' inability to generated persistence in the growth rate of output.

2. Model

The model is populated by two types of agents: firms that produce using labor and households who decide on optimal consumption and purchase risky shares issued by a representative firm as well as a risk-free bond. The allocation of labor from households to firms involves a costly and time-consuming matching process, following the now common approach of Mortensen and Pissarides (1994), adapted to a representative household framework as in Merz (1995) or Andolfatto (1996). The additional assumption is that firms must seek external funds over accumulated assets to pay for current hiring through a lending relationship subject to a credit-market friction of the costly state-verification type. This incorporation of imperfect credit markets into a DSGE framework builds on work by Carlstrom and Fuerst (1997) with the canonical real business cycle model. The resulting debt contract is characterized by an optimal monitoring threshold and hiring.

2.1. Labor markets and households

Firms post job vacancies V_t to attract unemployed workers U_t at a unit cost of γ. Jobs are filled via a constant-return-to-scale matching function taking vacancies and unemployed workers $M(U_t, V_t)$. Define $\theta_t = \frac{V_t}{U_t}$ as labor-market tightness from the point of view of the firm, or the v–u ratio. The matching probabilities are $\frac{M(U_t,V_t)}{V_t} = p(\theta_t)$ and $\frac{M(U_t,V_t)}{U_t} = f(\theta_t)$ for firms and workers, respectively, with $\frac{\partial p(\theta_t)}{\partial \theta_t} < 0$ and $\frac{\partial f(\theta_t)}{\partial \theta_t} > 0$. Note that $f(\theta_t) = \theta_t p(\theta_t)$. Once matched, jobs are destroyed at the exogenous rate of δ per period. Thus, employment N_t and unemployment U_t evolve according to

$$N_{t+1} = (1-\delta)N_t + p(\theta_t)V_t, \tag{1}$$

$$U_{t+1} = \big(1 - f(\theta_t)\big)U_t + \delta N_t. \tag{2}$$

The household can buy risky shares issued by the representative firm as well as a risk-free bond. Let C_t denote consumption and χ_t denote the fraction of the household's wealth invested in the risky shares. Let r_t denote the risk-free interest rate, which is known at the beginning of period t, and r^f_{t+1} the return on firm shares. Let Π_t denote the household's financial wealth, and let $R^{\Pi}_{t+1} = \chi_t(1 + r^f_{t+1}) + (1-\chi_t)(1+r_t)$ be the return on wealth. The representative household, given existing rates of employment and unemployment, chooses optimal C_t and χ_t in order to maximize the value function[7]:

$$\mathcal{H}_t = \max_{C_t,\chi_t}\big[\mathcal{U}(C_t) + \beta E_t \mathcal{H}_{t+1}\big],$$

subject to the budget constraint

$$\frac{\Pi_{t+1}}{R^{\Pi}_{t+1}} = \Pi_t - C_t + W_t N_t + U_t b - T_t$$

and the laws of motion for matched labor (1) and unemployment (2). The government raises T_t in taxes to fund unemployment benefits $U_t b$, while employed workers earn the wage W_t. The household's dividend income, D_t, rebated lump sum

[6] Second moments correspond to Hodrick–Prescott filtered data. Time series cover the period 1977:1 to 2005:4. The standard model refers to the Mortensen–Pissarides model in a discrete-time setting, DSGE framework.

[7] As in Andolfatto (1996), each worker is a member of a household that offers perfect insurance against labor-market outcomes and is involved in a passive search process. Labor-force participation choices are not considered here, individuals are either employed or unemployed. See Garibaldi and Wasmer (2005) or Haefke and Reiter (2006) for models of labor-market participation. The household portfolio choice is as in Petrosky-Nadeau and Zhang (2013).

at the end of the period, is included in the current financial wealth, Π_t. Denoting the multiplier on the budget constraint with λ, the first-order condition for consumption is

$$\mathcal{U}_C(C_t) = \lambda_t, \tag{3}$$

while the first-order condition for wealth allocation implies a bond Euler equation:

$$1 = E_t\left[\frac{\lambda_{t+1}}{\lambda_t}(1+r_t)\right]. \tag{4}$$

2.2. Financial contract and hiring decisions

The decision problem of the firm with respect to hiring is divided into two steps. First, the firm decides on hiring ψ_t new workers, and each new worker will cost the firm Q_t. This price is determined in the second step in which a hiring department posts vacancies at unit cost γ to hire workers, and part of the cost is funded externally on a frictional credit market. We present the firm's hiring decision first and the hiring department's problem, which will determine the price Q_t, second.

The firm's problem is thus stated as:

$$J_t = \max_{\psi_t} X_t N_t - W_t N_t - Q_t \psi_t + \beta E_t \frac{\lambda_{t+1}}{\lambda_t} J_{t+1}$$
$$\text{subject to} \quad N_{t+1} = (1-\delta)N_t + \psi_t$$

with first-order condition for hiring:

$$Q_t = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} J_{N,t+1}$$

where the right-hand side is equal to the discounted expected marginal value of an additional employed worker. In order to derive the marginal value of a worker to the firm, $J_{N,t}$, differentiate the firm's value function with respect to N,

$$J_{N,t} = X_t - W_t + (1-\delta)\beta E_t \frac{\lambda_{t+1}}{\lambda_t} J_{N,t+1}.$$

The first term corresponds to the net return on an employee accruing to the firm, the difference between the productivity of labor and the wage. The final term captures the value of the continued relationship. Combining this with the previous equation yields a job-creation condition:

$$Q_t = \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\left[X_{t+1} - W_{t+1} + (1-\delta)Q_{t+1}\right]$$

in which we now determine the price of a hire Q_t, which can also be interpreted as the replacement cost of a unit of labor for the firm.

Firms go to financial markets to help fund hiring for next period labor. The informational assumptions are chosen to generate standard debt contracts, in the tradition of Gale and Hellwig (1985) and Williamson (1987), set in a quantitative macroeconomic framework as in Carlstrom and Fuerst (1997). The contracts are written on a competitive capital market (in the sense that there is a large number of atomistic lenders and firms) and lenders are assumed to hold sufficiently large and diversified portfolios to ensure perfect risk pooling, with the result that investors behave as if they were risk neutral. Repayment of the debt is assumed to occur within the period: the contract is negotiated at the beginning of the time period and resolved by the end of the same period.[8] The competitive pressure ensures that each lender–firm pair will write a contract that maximizes the expected value of the borrower subject to the constraint that the expected return to the lender cover the amount borrowed.

In order to show how the contract leads to a loan size linear in firm net worth, we will index individual firms by i for the moment, dropping the subscript in the remainder of the text. Each firm i borrows part of the job posting costs γV_{it} to hire $\psi_{it} = p(\theta_t)V_{it}$ workers. Each hired worker is valued Q_t to the firm, an aggregate price by assuming a recruiting department that could sell the hired worker to another firm, as could the lender in the case of default by the borrower. Assume that each firm draws an idiosyncratic productivity in the efficiency of its recruiting activities x, a random variable, i.i.d. across firms and time, drawn from a positive support with $E(x) = 1$, density $h(x)$ and distribution $H(x)$. The crucial assumption for the contractual problem is that agents have asymmetric information over the realization of the random variable x over the

[8] The present contract is written for intraperiod loans while Bernanke et al. (1999) consider interperiod contracts that take into account aggregate uncertainty. They show that the contract is similar in such a setting due to the assumption that the borrower is risk neutral. More precisely, is it the risk neutrality along with the linearity of the production function that implies a borrower's value function that is linear in wealth. As a consequence, the equilibrium conditions and the policy functions are similar.

duration of the contractual period. This state can only be observed by lenders at some resource cost which is modeled as a fraction μ_t of the value of a hire, and μ_t depends on the state of the economy as discussed next.

There is extensive evidence that both recovery rates and liquidation costs are time varying. Acharya et al. (2007) document how, when a firm's industry is in distress, the firm's financial instruments recover 10 to 15% less on a dollar than when the industry is healthy. Using data on defaulted firms in the U.S. over 1982–1999, they find a mean recovery rate of 51%, with a standard deviation of 36.58. Moreover, there is substantial variation in the recovery rate through time: The median recovery rate in 1990 was 34.14% while it was 73.71 % in 1997. A related observation is the negative correlation in the time series between recovery rates and the number of defaults. Frye (2000a, 2000b) finds bond recovery rates might decline 20–25% from a nominal average year in economic downturns, and makes similar observations for loan recovery rates. These findings were corroborated by Altman et al. (2005), who examine corporate bond recovery rates over 1982–2002.[9]

Levin et al. (2004), using firm-level data over the period 1997Q2 to 2003Q3, estimate the value of μ_t in this class of debt contracts consistent with the spread on corporate bonds. Their estimates reach a low of $\underline{\mu} = 0.07$ during the late 1990s expansion, and a high of $\overline{\mu} = 0.46$ during the 2001 recession. They argue this variation may capture the fact that the value of liquidated assets following bankruptcy is subject to strong illiquidity effects that are highly cyclical, implying a much greater cost of default to the lender during an economic downturn (Shleifer and Vishny, 1992; Pulvino, 1998; Ramey and Shapiro, 2001). Pulvino (1998), for example, finds that financially constrained airlines sell aircraft at a 14% discount to the average market price. However, these discounts exist only in times when the airline industry is depressed, not when it is booming.

Livdan et al. (2009) use this evidence to parametrize time variation in liquidation costs, a well-established approach in corporate finance research (see Altman et al., 2005, for a survey). In their application with a collateral constraint similar to Kiyotaki and Moore (1997), a time-varying portion $s_0 e^{(x_t-1)s_1}$, with $0 < s_0 < 1$ and $s_1 > 0$, of the firm's capital can be used as collateral. Citing Hennessy and Whited's (2007) empirical evidence on liquidation costs, they set $s_0 = 0.85$ and the coefficient s_1 to 10.79, such that $s_0 e^{(x_t-1)s_1} = 0.70$ when productivity is one standard deviation below its long-run average. We adopt a similar specification here, setting $(1 - \mu_t) = s_{0t} e^{(x_t-1)s_1}$ and assume in addition the possibility of exogenous shocks to the level parameter s_{0t}, which may be interpreted as credit shocks. We implement a different strategy for the parameters s_0 and s_1. As detailed in the quantitative section below, the steady-state value of the level parameter s_0 will be set to match an observed premium on external funds, and the elasticity coefficient s_1 will be estimated using a U.S. time series for the bond spread.[10]

The timing of events in each period is as follows. Assume that hiring activities and related costs be paid before production occurs. All agents observe the aggregate state X_t and, given initial assets A_{it}, firms borrow $(\gamma V_{it} - A_{it})$ from financial markets to pay for period hiring. Lenders and borrowers agree on a contract specifying a cutoff productivity $\bar{x}_{it}$: If $x > \bar{x}_{it}$, the borrower pays the value $\bar{x}_{it} Q_t \psi_{it}$, a share of the value of hiring, and keeps the remaining value $(x - \bar{x}_{it}) Q_t \psi_{it}$. If $x < \bar{x}_{it}$, the borrower receives nothing and the lender claims the residual value net of the monitoring costs.

Define the expected gross share of returns going to the lender under the contract as

$$\Gamma(\bar{x}_{it}) = \int_0^{\bar{x}_{it}} x\, dH(x) + \int_{\bar{x}_{it}}^{\infty} \bar{x}_{it}\, dH(x),$$

noting that $\Gamma'(\bar{x}_{it}) = 1 - H(\bar{x}_{it}) > 0$ and $\Gamma''(\bar{x}_{it}) = -h(\bar{x}_{it}) < 0$, and the expected loss should there be monitoring as

$$\mu_t G(\bar{x}_{it}) = \mu_t \int_0^{\bar{x}_{it}} x\, dH(x)$$

with $G'(\bar{x}_{it}) = \bar{x}_{it} h(\bar{x}_{it})$. It is easy to see that the expected gross share to the lender will always be positive.[11] Given this set of definitions we can conveniently express the lender's participation constraint as $[\Gamma(\bar{x}_{it}) - \mu_t G(\bar{x}_{it})] Q_t \psi_{it} = (\gamma V_{it} - A_{it})$, which states that the return net of monitoring costs must equal the value of the loan.

We can now write the optimal incentive-compatible contracting problem with nonstochastic monitoring and repayment within the period. Vacancy postings V_{it} and the threshold $\bar{x}_{it}$ are chosen to maximize the expected value of the borrower subject to the lender's participation constraint:

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[9] The measure of annual bond recovery rates, a weighted average recovery of all corporate bond defaults where weights are based on the market value of defaulting debt, has a mean of 37%, with significant time variation. The rate was as low as 23.4% in 1990, rose to 54.2% in 1997, and was back down to 26.4% in 2000.

[10] An alternative modification to the setup in Carlstrom and Fuerst (1997), taken by Faia and Monacelli (2007), is to assume that the mean of the random variable x is increasing in aggregate productivity: $E(x|X_t) = X_t^{\vartheta}$, where $\vartheta > 1$. While an effective strategy to generate a counter-cyclical external-finance premium, this approach bears the unappealing effect of increasing the elasticity of effective TFP, now $X^{1+\vartheta}$, to exogenous productivity shocks. Thus, any amplification in their model is a conjunction of the increased variance of effective TFP and counter-cyclical external financing constraints. For a detailed analysis of the conditions under which credit-market frictions create a destabilizing financial accelerator, see House (2006).

[11] To do so, take the limits $\lim_{\bar{x}\to 0} \Gamma(\bar{x}) = \int_0^{\infty} \bar{x}\, dH(x) = 0$, $\lim_{\bar{x}\to\infty} \Gamma(x) = \int_0^{\infty} x\, dH(x) = 1 > 0$ and recall that $\Gamma(\bar{x})$ is strictly increasing and concave in $\bar{x}$. Note that the expected share of returns going to the borrower under the contract is $\Upsilon(\bar{x}) = \int_{\bar{x}}^{\infty} (x - \bar{x})\, dH(x)$. Note that $\Gamma(\bar{x}) + \Upsilon(\bar{x}) = 1$.

$$\max_{V_{it},\bar{x}_{it}} = \big[1-\Gamma(\bar{x}_{it})\big]Q_t p(\theta_t)V_{it}$$

$$\text{subject to}\quad \big[\Gamma(\bar{x}_{it})-\mu_t G(\bar{x}_{it})\big]Q_t p(\theta_t)V_{it} = (\gamma V_{it} - A_{it}).$$

The first-order conditions to this problem, calling ϕ_{it} the Lagrange multiplier on the lender's participation constraint, are:

$$(V_{it}):\quad \big[1-\Gamma(\bar{x}_{it})\big]Q_t p(\theta_t) + \phi_{it}\big[\big[\Gamma(\bar{x}_{it})-\mu_t G(\bar{x}_{it})\big]Q_t p(\theta_t) - \gamma\big] = 0, \tag{5}$$

$$(x_{it}):\quad -\Gamma'(\bar{x}_{it}) + \phi_{it}\big[\Gamma'(\bar{x}_{it}) - \mu_t G'(\bar{x}_{it})\big] = 0, \tag{6}$$

$$(\phi_{it}):\quad \big[\Gamma(\bar{x}_{it})-\mu_t G(\bar{x}_{it})\big]Q_t p(\theta_t)V_{it} - (\gamma V_{it} - A_{it}) = 0. \tag{7}$$

Given the assumptions on the functional forms, notably linearity in the hires production function and the monitoring technology, the distribution of assets among firms does not matter for the equilibrium. The see this, note that by (5) and (6) the cutoff threshold depends on aggregates Q_t and $p(\theta_t)$. Dropping firm subscripts on the cutoff $\bar{x}_t$, by Eq. (7), rearranged as $V_{it} = A_{it}/[\gamma - [\Gamma(\bar{x}_t) - \mu_t G(\bar{x}_t)]Q_t p(\theta_t)]$, vacancies are linear in the firm's net worth A_{it}. In other words, all firms choose the same ratio of vacancies to assets, allowing the model to remain in the representative-firm setting (cf., Carlstrom and Fuerst, 1997).

The price of a hire, Q_t, by Eqs. (5) and (6), can be expressed as:

$$Q_t = \frac{\gamma}{p(\theta_t)}\Phi_t$$

where $\Phi_t \equiv \phi_t/[1-\Gamma(\bar{x}_t) + \phi_t[\Gamma(\bar{x}_t) - \mu_t G(\bar{x}_t)]]$. As such, the value of a hired work is a function of the cost of a vacancy posting, the duration of searching to fill the position $p(\theta_t)$ and the terms of the financial contract through Φ_t.

The evolution of aggregate assets is given by $A_{t+1} = \varsigma[(X_t - W_t)N_t - [1-\Gamma(\bar{x}_t)]Q_t\psi_t]$, where the parameter $0<\varsigma<1$ ensures that self-financing does not occur, and rebated dividends are defined as $D_t = (1-\varsigma)[(X_t - W_t)N_t - [1-\Gamma(\bar{x}_t)]Q_t\psi_t]$.[12] Rearranging as

$$A_{t+1} = \varsigma\left[(X_t - W_t)N_t - \left(1 + \frac{\mu_t G(\bar{x}_t)Q_t\psi_t}{(\gamma V_t - A_t)}\right)(\gamma V_t - A_t)\right] \tag{8}$$

focuses on the premium associated with external funds, $\iota_t \equiv \frac{\mu_t G(\bar{x}_t)Q_t\psi_t}{(\gamma V_t - A_t)}$, which for any $\mu_t > 0$ is strictly positive.

2.3. Job creation under credit constraints

From the price of a hire $Q_t = \frac{\gamma}{p(\theta_t)}\Phi_t$, and making use of the household-bond Euler equation (4), we have a job-creation condition in the presence of financial frictions

$$\frac{\gamma\Phi_t}{p(\theta_t)} = \frac{1}{1+r_t}E_t\left[X_{t+1} - W_{t+1} + (1-\delta)\frac{\gamma\Phi_{t+1}}{p(\theta_{t+1})}\right] \tag{9}$$

equating the average cost of filling a vacancy to the discounted expected marginal value of an additional employed worker.

At this stage, it is useful to show how this setting with credit frictions compares to a standard search-and-matching model of equilibrium unemployment with perfect credit markets. Consider first the credit-constraint multiplier, Φ_t, on the cost side of the job-creation condition, which captures the cost of external over internal funds. This measure indicates how binding credit constraints are. In the absence of monitoring costs, the threshold $\bar{x}$ tends to the lower bound of its support. It is straightforward to show that $\frac{\partial\Phi_t}{\partial\bar{x}_t} > 0$, and that $\lim_{\bar{x}_t\to 0}\Phi_t = 1$. As a result, for any positive cost to monitoring, the presence of credit frictions drives up the average economic cost of filling a vacancy to $\frac{\gamma\Phi_t}{p(\theta_t)}$, as opposed to $\frac{\gamma}{p(\theta_t)}$. Significantly, for the purpose of this paper, an improvement in the state of credit markets, measured as a decrease in the tightness of the financial constraint Φ, is a decrease in the opportunity cost of resources allocated to job creation.

Second, in the absence of monitoring costs, the first-order condition (9) collapses to the standard job-creation condition in a stochastic discrete-time setting:

$$\frac{\gamma}{p(\theta_t)} = \frac{1}{1+r_t}E_t\left[X_{t+1} - W_{t+1} + (1-\delta)\frac{\gamma}{p(\theta_{t+1})}\right]. \tag{10}$$

The received argument for the lack of amplification of productivity shocks is easily understood by this job-creation condition equating the average cost of filling a vacancy to the expected benefit of a new job (see Shimer, 2005; Hall, 2005).

[12] The assumption of some depletion in the stock of assets is needed to rule out eventual self-financing. Carlstrom and Fuerst (1997) assume that consumers and entrepreneurs have different time-discount factors, while Bernanke et al. (1999) assume that a fraction of the entrepreneurial population exits every period consuming their assets on the way out. This paper assumes that firms retain a fraction of their earnings toward next period's assets while rebating the remaining to households as dividends.

A sudden rise in productivity, increasing the revenues generated by a job, increases the incentive to post vacancies. The same rise in productivity, however, leads to a rise in the wage which reduces the profits accruing to the firm. For most applications of the Nash bargaining solution, the wage is highly elastic to productivity such that the profits from a job for the firm are relatively inelastic to productivity shocks; as a consequence, so are vacancy postings. Quite naturally, a first response to this issue has been to induce greater wage rigidity by, for example, changing the structure of the model by settling on different wage-determination mechanisms.

There is, however, a second, overlooked, dampening mechanism built into the job-creation condition. The same event leading to a rise in the job-finding hazard for workers, and their ability to negotiate higher wages, also corresponds to an increase in the congestion facing firms on the labor market. In other words, each job vacancy faces a decreasing probability, $p(\theta_t)$, of being filled in a given unit of time. This increase in the average cost of hiring a worker further restricts firm entry, limiting the propagation of productivity shocks. Here, credit-market imperfections have the potential to amplify productivity shocks in a manner that is fundamentally different, operating through the cost side of the job-creation condition. Recall that in the presence of credit frictions the average economic cost to filling a vacancy is $\frac{\gamma \Phi_t}{p(\theta_t)}$, while in the model with perfect credit markets, this is $\frac{\gamma}{p(\theta_t)}$. The terms of the financial contract in effect drive a time-varying wedge on the cost side relative to the frictionless model. If these constraints are counter-cyclical, or Φ_t decreases during an economic upturn, there is a downward push on the opportunity cost of recruiting workers that increases the incentive for firms to post job vacancies independently of changes in the expected benefit of a new worker. The strong labor-market congestion effects imply that the average cost of recruiting, or the cost of a hire, remains procyclical. However, it becomes more rigid over the business cycle. The propagation induced by financial frictions studied in Petrosky-Nadeau and Wasmer (2013) operate by introducing a separable component K tied to financial intermediation to the average cost of job creation. This becomes $\frac{\gamma}{p(\theta_t)} + K$, a form advocated by Pissarides (2009) as a means of generating strong responses of labor-market tightness to changes in the expected benefit from hiring a worker.

2.4. Workers and wages

The model is fully described once the rule for wages is determined. In order to define the values of a job ($\mathcal{H}_N$) and unemployment ($\mathcal{H}_U$) to a worker, differentiate the household's value function with respect to N and U:

$$\mathcal{H}_{N,t} = \lambda_t W_t + \beta E_t\big[(1-\delta)\mathcal{H}_{N,t+1} + \delta \mathcal{H}_{U,t+1}\big],$$
$$\mathcal{H}_{U,t} = \lambda_t b + \beta E_t\big[\big(1-f(\theta_t)\big)\mathcal{H}_{U,t+1} + f(\theta_t)\mathcal{H}_{N,t+1}\big].$$

The current value of a job corresponds to the wage measured in utils and the discounted expected values of next period's state, which with probability $(1-\delta)$ remains employment. The value of unemployment is derived from the value of non-market activities, $\lambda_t b$, and the discounted expected value of next period's state, which with probability $f(\theta_t)$ is employment.

The surplus from a worker–firm match, defined as $S_t = J_{N,t} + \frac{\mathcal{H}_{N,t}-\mathcal{H}_{U,t}}{\lambda_t}$, is split under a generalization of Nash bargaining by choosing a wage that maximizes ${J_{N,t}}^{(1-\eta)}(\frac{\mathcal{H}_{N,t}-\mathcal{H}_{U,t}}{\lambda_t})^{\eta}$, where η is the worker's bargaining weight. Wages are negotiated at the beginning of the period once the aggregate state is observed, but before the firm draws an idiosyncratic productivity. The wage is not a function of the idiosyncratic productivity, lest it reveal the firm's productivity draw to creditors, but will reflect the terms faced by the firm on credit markets.[13] The first-order condition to this problem,

$$\eta J_{N,t} = (1-\eta)\left(\frac{\mathcal{H}_{N,t}-\mathcal{H}_{U,t}}{\lambda_t}\right)$$

describes a rule for sharing the joint surplus of the relationship. The resulting wage rule is

$$W_t = \eta[X_t + \gamma\theta_t\Phi_t] + (1-\eta)b. \tag{11}$$

As with the job-creation condition, when monitoring costs tend to 0, the wage rule (11) collapses to

$$W_t = \eta[X_t + \gamma\theta_t] + (1-\eta)b. \tag{12}$$

This is simply the wage rule in a search model of equilibrium unemployment without credit frictions, leading to the following proposition.

Proposition 1. *The canonical Mortensen–Pissarides search-and-matching model of equilibrium unemployment is a special case of the present model with frictional credit markets when the cost of monitoring tends to zero.*

[13] The study of possible separating equilibria on credit markets due to heterogeneous wages is beyond the scope of this paper. It is also assumed that wages cannot be renegotiated ex-post. The assumption of exogenous job destruction is related in that separation conditioned idiosyncratic productivity would also reveal firm specific information to lenders. Details on the derivation of the wage are presented in an appendix available upon request.

The steady-state and quantitative implications for the dynamics of labor markets are discussed in the next section. However, one important aspect of the modified wage rule is worth stressing here. A principal force in the cyclical properties of the wage rule is the term $\gamma\theta_t\Phi_t$, which (along with the value of non-market activities) captures the relative bargaining positions of workers and firms. During an upturn, labor-market tightness rises, making it more costly for firms to pull out of wage negotiations to search for another worker (recall that a rise in θ implies a drop in the probability of meeting a worker $p(\theta)$). In the presence of credit-market frictions, the opportunity cost of resources allocated to a job vacancy, $\gamma\Phi_t$, actually decreases during good times as conditions on credit markets improve; that is, $\Phi > 1$ and Φ tends to 1 as $\bar{x}$ tends to zero. The strengthened bargaining position of firms somewhat limits the upward pressure on wages stemming from the rise in market tightness. The end result is a dampening of the initial response of the wage to a productivity shock, as will be shown below.

2.5. Closing the model

From the household's budget constraint, it is straightforward to derive an aggregate resource constraint,

$$Y_t = C_t + \gamma\Phi_t V_t,$$

where $Y_t = X_t N_t$ and $\gamma\Phi_t V_t$ are job-creation costs augmented by the costs of credit-market imperfections.

The equilibrium of the model is then defined by Eqs. (3) and (4) from household optimization, a job-creation condition (9), the optimality condition for the threshold $\bar{x}_t$ in (5) and (6), the definition of market tightness, the lender's participation constraint, a wage rule (11), the aggregate resource constraint and laws of motion for asset accumulation and aggregate employment and unemployment.

3. Propagation properties of financial and labor-market frictions

Before discussing some of the steady-state labor-market implications of credit-market frictions in this setting, the assumptions on functional forms and calibration are presented in detail. The model is then solved by computing the unique rational-expectations solution for a log-linearization around the deterministic steady state, and the dynamics are evaluated with a series of unconditional second moments and impulse-response functions. The performance of the model is assessed by presenting results for a standard labor-search model with perfect credit markets as a basis for comparison and by performing a series a sensitivity analyses to key parameters.

3.1. Functional forms and calibration

The basic unit of time is a quarter.[14] The discount factor, $\beta = 0.992$, is set to match an average annual real yield on a risk-free 3-month treasury bill of 3.3%. Period utility in household preferences is defined as $\mathcal{U}(C) = \log C$. Following much of the real business cycle literature incorporating search-and-matching frictions, aggregate technology is assumed stationary and to evolve according to

$$\log X_t = \rho_X \log X_{t-1} + \varepsilon_t^X,$$

with $\varepsilon_t^X \sim \mathcal{N}(0, \sigma_X^2)$ and $0 < \rho_X < 1$. The level parameter in the recovery rate, $s_{0,t}$, follows an AR(1) process,

$$\log s_{0,t} = (1 - \rho_{s_0}) \log \bar{s}_0 + \rho_{s_0} \log s_{0,t-1} + \varepsilon_t^{s_0},$$

with $\rho_{s_0} \in (0,1)$ and $\varepsilon_t^{s_0} \sim \mathcal{N}(0, \sigma_{s_0}^2)$.

Several authors have argued that the targeted steady-state rate of unemployment should include more than the rate of workers counted as unemployed as the model does not account for nonparticipation. Krause and Lubik (2007), for example, choose an unemployment rate of 12%, above the average rate observed for the United States. The benchmark calibration, however, will target an 8% unemployment rate, a midpoint between the later authors and the post-war average of 5.6% for the U.S. This is achieved by adjusting the level parameter ξ in the matching function. According to the study by Barron et al. (1997), the average cost of time spent hiring one worker is approximately 3% of quarterly hours, and up to 4.5% if it is assumed that hiring is done by supervisors with higher wages (Silva and Toledo, 2009). The unit cost of job vacancies is set to $\gamma = 0.14$ such that the cost of vacancies, $\gamma V/(WN)$, is 3%. Finally, the quarterly rate of job separation is set to 6%, corresponding to the evidence presented in Davis et al. (2006).

The matching technology in the labor market is assumed to be Cobb–Douglas: $M(U,V) = \xi U^{\epsilon} V^{1-\epsilon}$, with $0 < \epsilon < 1$ and $\xi > 0$. The elasticity of the labor-matching function, ϵ, is set to 0.72, corresponding to the estimate in Shimer (2005). The household's bargaining weight in wage negotiations, η, is set to 0.5. This midpoint is chosen to strike a balance between the extremes advocated in the literature. The value of non-market activities is set to $b = 0.71$. Mulligan (2012) estimates

[14] The results are invariant to the frequency. An appendix reproducing the results when the basic unit of time is a month is available from the author upon request.

a median replacement rate for the U.S. of 63%, covering the variety of income support programs available to U.S. workers. Allowing for the value of leisure and other non-market activities, this parameterization follows the value for b of 0.71 derived in Hall and Milgrom (2008).

The standard deviation of idiosyncratic productivity shocks x, assumed to follow a log-normal distribution with mean $E(x) = 1$ – i.e., $\log(x) \sim \mathcal{N}(-\frac{\sigma^2_{\log(x)}}{2}, \sigma^2_{\log(x)})$ – and the parameter ς in the asset-accumulation equation are set jointly to match two observations: (i) a steady-state quarterly default rate, $H(\bar{x})$, of 1.5%, drawing on the empirical evidence in Lee and Mukoyama (2008) and similar to the values reported in both Carlstrom and Fuerst (1997) and Bernanke et al. (1999) and; (ii) a steady-state proportion of externally funded vacancy costs of one third. We target a conservative value relative to measures in Devereux and Schiantarelli (1989) and Buera and Shin (2008) who report nearly one half of firms' current expenditure being financed externally. Christiano et al. (2005), by comparison, assume that all current costs, in their case the entire wage bill, must be financed through bank loans. This calibration results in values of $\sigma_x = 0.01$ and $\varsigma = 0.98$. Finally, the level parameter is set to $s_0 = 0.90$, such that the premium on external funds at a steady state equals 70 basis points. By comparison, Carlstrom and Fuerst (1997) set $\mu = 0.25$.

The parameters for the exogenous processes, along with the elasticity parameter s_1, are obtained by estimating a log-linear approximation of the model by maximum likelihood on U.S. data. The series employed are real GDP per capita and the bond spread over 1951:I to 2011:I.[15] The parameter estimates for aggregate productivity are similar to those obtained by comparable real business cycle studies, with a persistence parameter $\rho_X = 0.975$ and standard deviation of the innovations of 0.009. The process for credit shocks is less persistent with $\rho_{s_0} = 0.95$, and $\sigma^2_{s_0} = 0.16$. The coefficient s_1, is estimated to be $s_1 = 8.57$, whereas the unestimated value in Livdan et al. (2009) is 10.79.

3.2. Steady-state implications

Proposition 2. *There exists a unique steady-state equilibrium in which the rate of unemployment is strictly increasing in the resource cost of monitoring, μ.*

Proof. The job-creation condition in the presence of credit constraints can express the wage as a decreasing function of market tightness,

$$W = 1 - \left(\frac{1}{\beta} - (1-\delta)\right)\frac{\gamma\Phi}{p(\theta)},$$

where aggregate productivity has been normalized to 1. Relative to the case with perfect credit markets, the additional cost induced by the need for external funds implies a steeper curve by the factor $\Phi > 1$, with Φ strictly increasing in $\bar{x}$ and $\lim_{\bar{x}\to 0}\Phi = 1$. Fig. 1 plots the job-creation curve in (θ, W) space for the model with (solid line) and without (dashed line) credit frictions. The wage rule in the presence of credit frictions, $W = \eta(1 + \gamma\Phi\theta) + (1-\eta)b$, has a slope greater than in the absence of credit-market friction by the same factor $\Phi > 1$. This captures the greater opportunity cost for a match to the firm that workers can exploit and, conditional on $(\eta + (1-\eta)b) < 1$, the intersection of the wage rule and job-creation condition is unique.

Combined, the two labor-market equilibrium conditions, job creation and the wage rule, pin down the equilibrium market tightness $\tilde{\theta}$ as

$$\gamma\left(\frac{(r+\delta)}{\xi}\tilde{\theta}^{\epsilon} + \eta\tilde{\theta}\right)\Phi = (1-\eta)[1-b],$$

where $\Phi \geqslant 1$. In the absence of credit frictions this is given by

$$\gamma\left(\frac{r+\delta}{\xi}\theta^{*\epsilon} + \eta\theta^{*}\right) = (1-\eta)[1-b],$$

where θ^* denotes the equilibrium market tightness in the frictionless case. $\tilde{\theta} < \theta^*$ follows from the fact that $\Phi > 1$ for any strictly positive value of the monitoring cost, μ. To see the effect of an increase in μ on market tightness, note that $\partial\Phi/\partial\mu > 0$. As a result, an increase in monitoring costs leads to a decrease in equilibrium labor-market tightness which, through the Beveridge relationship $U = \frac{\delta}{\delta + f(\theta)}$, implies a greater steady-state rate of unemployment.[16] This insight is similar to that in Acemoglu (2001) and Wasmer and Weil (2004): Credit friction restricts firm entry on labor markets. Comparing steady states, credit-market imperfections have a negligible impact on the unemployment rate. Removing all frictions reduces the steady-state rate of unemployment from 8% to 7.9%. Moreover, increasing the resource cost of monitoring and

[15] The time series used are: real U.S. GDP, billions of chained 2005 dollars, FRED II I.D. GDPC96, civilian noninstitutional population, thousands, FRED II I.D. CNP16OV, and Moody's seasoned Aaa and Baa corporate bond yields, FRED II I.D.s AAA and BAA. The implementation borrows from the algorithm provided by Chris Otrok.

[16] The effect on the equilibrium wage is ambiguous as higher recruiting costs both lowers job offers and affects the threat point in wage bargaining to the advantage of workers.

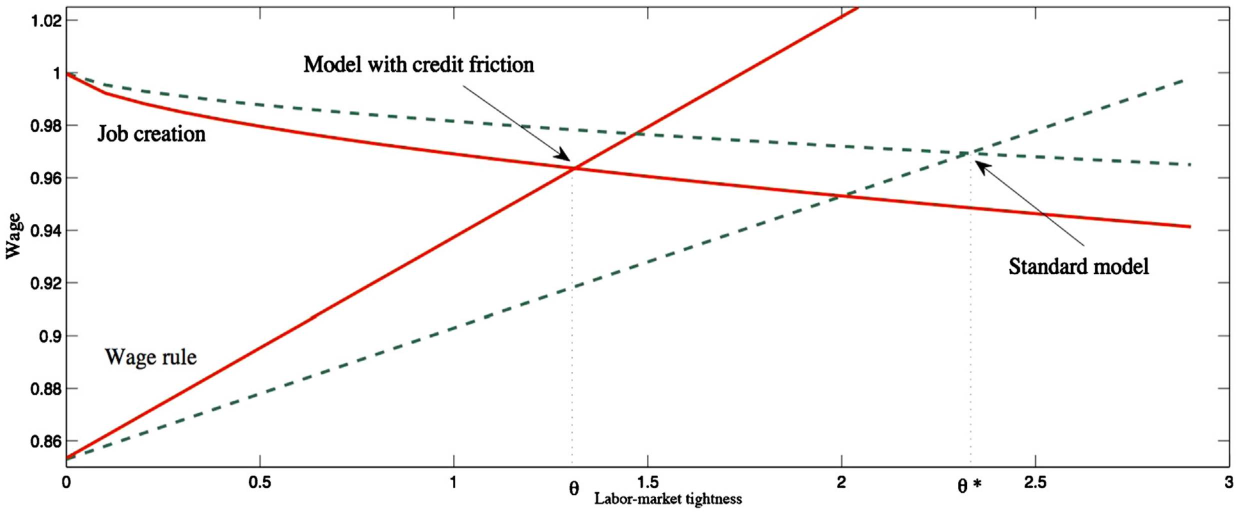

Fig. 1. Steady-state labor-market equilibrium.

steady-state default rate such that the premium reaches 1.5% only increases the unemployment rate to 8.1%. Therefore, the impact of financial frictions in the long run in this setup are modest. As the next sections will show, this need not be the case in the short run. □

3.3. Dynamic results: productivity shocks

The first set of results assumes productivity shocks are the only driving force. The results for the model with both productivity and credit shocks are presented in Section 3.4.

The known weaknesses of the Mortensen–Pissarides framework in generating sufficient internal propagation of exogenous shocks to productivity are summarized in Table 1. This table reports the Hodrick–Prescott filtered standard deviation relative to aggregate output of variables central to the labor market, along with their contemporaneous correlation with the cyclical component of aggregate output. The first columns set the performance of the standard labor-search model against moments from U.S. data and highlight its shortcomings in terms of amplification. The relative volatility of market tightness generated by the standard model is only 21% of that in the data. The dismal performance of the model extends to job vacancies which have a relative volatility of 8.83 in the data and 2.61 in the standard model. The performance in terms of unemployment or employment is hardly any better: The model generates a relative standard deviation for unemployment of 1.13 against a relative standard deviation of 6.83 in the data.

The second significant shortcoming concerns the persistence in the adjustment to exogenous shocks. Evidence uncovered from reduced-form VARs shows that market tightness (and vacancies) have a sluggish response to productivity shocks, peaking several quarters after the innovation (see Fujita and Ramey, 2007). The last three rows of Table 1 report another measure of this persistence, the auto-correlation in the growth rate of market tightness. The data are characterized by a high degree of positive auto-correlation at the first three lags while the standard search model generates virtually no persistence. With regard to output growth, the standard search model does generate some persistence, essentially due to the predetermined nature of employment. However, fluctuations in the later are too weak for the model to be consistent with the data.[17]

3.3.1. Amplification and persistence under imperfect credit markets

We begin by examining, in Fig. 2, the responses of vacancies and market tightness to a positive productivity shock in the standard labor-search model (i.e., when $\mu_t = 0\ \forall t$, dashed line), and proposed model under two scenarios. The impulse responses with circled lines are for a model with a fixed recovery rate (setting $s_1 = 0$). The solid lines are the responses for the model with a cyclical recovery rate μ_t. The introduction of credit frictions yields two improvements. First, the responses are amplified, and more so with a cyclical recovery rate. Second, the responses are persistent, or the adjustment to the exogenous innovation is “sluggish.” The response of vacancies and market tightness peak with a lag after the innovation to productivity.

The unconditional second moments for the proposed model are presented in the last columns of Table 1. The relative volatility of job vacancies in the model with cyclical recovery costs is 5.99, and 4.77 when $s_1 = 0$. This comes relatively

[17] Andolfatto’s (1996) work incorporating search on labor markets in this class of models shows that the persistence problem can be resolved for certain labor-market parametrizations.

Table 1
Unconditional second moments.

1977:1–2005:4	U.S. data		Labor, no credit friction $\mu_t = 0$		Labor and credit friction Fixed μ		Labor and credit friction Cyclical μ_t	
Variable	a	b	a	b	a	b	a	b
U	6.83	−0.88	1.13	−0.74	2.17	−0.64	2.81	−0.72
V	8.83	0.89	2.61	0.94	4.77	0.84	5.99	0.93
θ	15.41	0.90	3.30	0.99	6.25	0.86	8.03	0.95
N	0.48	0.82	0.10	0.74	0.19	0.64	0.25	0.72
ν	θ	Y	θ	Y	θ	Y	θ	Y
$\text{corr}(\Delta\nu, \Delta\nu_{-1})$	0.67	0.26	0.02	0.07	0.26	0.03	0.49	0.10
$\text{corr}(\Delta\nu, \Delta\nu_{-2})$	0.48	0.23	0.00	0.01	0.01	0.13	0.01	0.15
$\text{corr}(\Delta\nu, \Delta\nu_{-3})$	0.33	0.08	0.00	0.00	0.00	0.03	0.00	0.03

a: standard deviation relative to output; b: contemporaneous correlation with output. All moments but growth rate are Hodrick–Prescott filtered; Data sources: BLS, BEA.

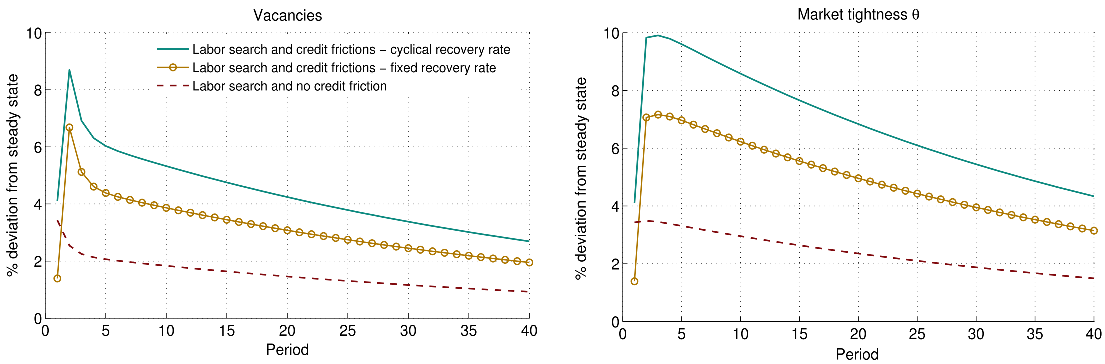

Fig. 2. IRF to a positive productivity shock, job vacancies and labor-market tightness.

close to the empirical value of 8.83 in a model in which productivity is the only driving force. The increase in the relative volatility of market tightness is equally large, rising to 8.03. This is an increase by a factor of 1.9 to 2.4 relative to the model with perfect credit markets, depending on whether recovery costs are fixed or allowed to fluctuate exogenously with changes in aggregate productivity. This is more moderate than the amplification of labor-market tightness found in Petrosky-Nadeau and Wasmer (2013). In that model, with search frictions in the labor and credit markets, the resulting financial accelerator is found to range from 5 to 8. The environment, however, does not generate endogenous persistence in labor-market variables, a feature of the present model discussed next.

In terms of persistence, deviations in market tightness peak a quarter after the shock. More precisely, the model generates elevated positive auto-correlations in the growth rate of market tightness, close to the data at the first lag but decaying too rapidly at the second and third (see the last three rows of Table 1). Credit-market frictions endogenously increase the first-order auto-correlation in the growth rate of labor-market tightness from 0.02 to 0.26. Allowing for exogenous cyclical fluctuations in μ_t increases the auto-correlation further, to 0.49 compared to 0.67 in the data.

The dynamics of the cost and wage channels of propagation, outlined earlier, help to understand these results. As the previous section discussed, both depend on the evolution of the shadow price of external versus internal funds. The first panel of Fig. 3 plots the response of the measure of credit constraints, Φ_t, against the same expansionary shock to productivity. When the cost of recovery is fixed, Φ_t does not react on impact. A counter-cyclical μ_t allows the constraint to be relaxed on impact. The accumulation of assets pushes the constraint to its lowest level with a lag. The effect on the job-creation condition is not strongest, therefore, contemporaneously to the productivity shock, as in the case of the standard model with prefect credit markets, and illustrated in Fig. 2.

The wage channel is illustrated in the second panel of Fig. 3. Following an innovation to productivity, wages do not initially respond as strongly as in the standard model, increasing progressively for several quarters. This contributes to the elasticity of the initial response of market tightness and vacancies to a productivity shock. As market tightness continues to rise more that the reduction in the tightness of the credit-market constraint, the wage peaks after a few quarters. Indeed, this flexible wage has an elasticity with respect to labor productivity of 0.90. As such, the wage effect is operative only contemporaneously to the productivity shock. The continued rise in market tightness, even as the wage is increasing, leads to the conclusion that the cost channel is largely dominant in the propagation of productivity shocks. This reinforces the main argument that evolving conditions on credit markets contribute to fluctuations on labor markets through the change in the opportunity of resources used by firms to create jobs.

The assumption of a time-varying recovery rate can be evaluated by examining its implication for the dynamics of the external-finance premium. The last panel of Fig. 3 plots the response of the annualized premium, ι_t, relative to its

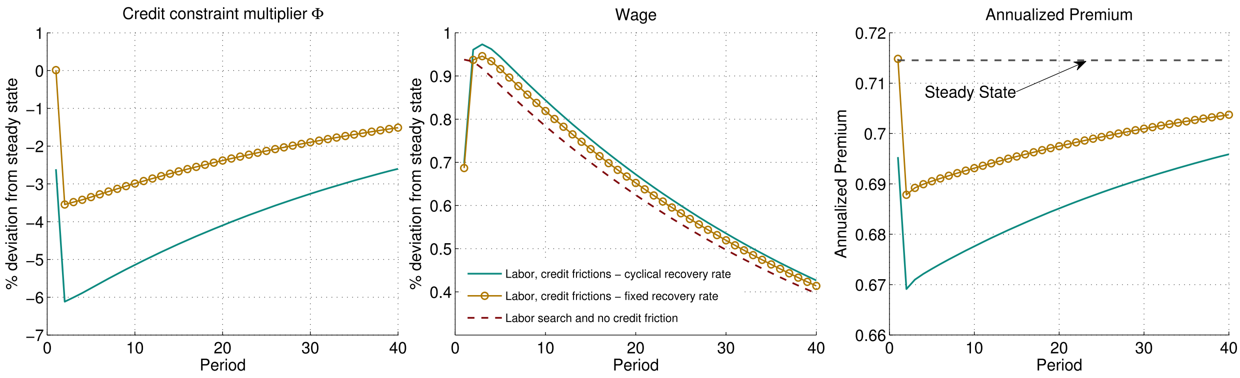

Fig. 3. IRFs to a positive productivity shock, credit-market constraints, wage and premium.

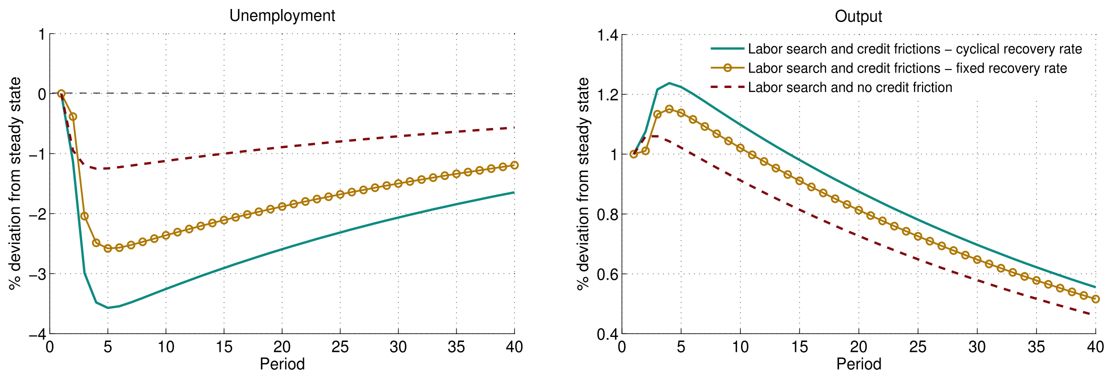

Fig. 4. IRFs to a positive productivity shock, unemployment and output.

steady-state level. The premium's does not react on impact with the μ is fixed, and declines moderately when μ_t is counter-cyclical. However, the average cost of recruiting, $\gamma \Phi_t / p(\theta_t)$, remains procyclical.

Fig. 4 plots the responses of unemployment and output to a positive productivity shock, illustrating the full impact of these financial factors on aggregate activity. The strong rise in hirings leads to a deep and prolonged drop in the unemployment rate. It immediately follows that output continues to expand several quarters after the innovation. The standard deviation of aggregate unemployment reaches 2.81, up from 1.13 for the model with perfect credit markets. Although a significant improvement upon the standard model, this still falls short of the data, and the magnitude of the response of employment is insufficient to generate the degree of persistence in output growth seen in the data.

3.3.2. The Beveridge curve and cross-correlations

One concern for extensions to the standard framework is the violation of a robust empirical observation of a strong negative correlation between unemployment and vacancies, the Beveridge curve. This occurs, for instance, when allowing jobs to end endogenously as in Mortensen and Pissarides (1994). Table 2 presents the contemporaneous cross-correlations of key labor-market variables in the data and generated by the models. In this respect, the proposed model offers a moderate improvement on the standard search model of equilibrium unemployment, generating a correlation between unemployment and vacancies of −0.57 and −0.61 in the models with fixed and cyclical μ_t, respectively. This gain is due to the appearance of a positive short run auto-correlation in the growth rate of job vacancies.

The data are also characterized by a very strong negative correlation between the unemployment rate and the measure of labor-market tightness, with a contemporaneous correlation of −0.97. The presence of credit frictions, by inducing persistence in the adjustment of market tightness that mirrors that of unemployment, brings the correlation closer to the data at −0.81 in the scenario with a cyclical recovery rate, and −0.77 when μ is fixed. By extension, the proposed model also improves on the correlation between the unemployment and job-finding rates.

Finally, the proposed model is able to reduce the correlation between unemployment and labor productivity to −0.57 in the scenario with a cyclical recovery rate, and −0.51 when μ is fixed. This is relatively close to a correlation of −0.42 in the data. This can be understood from the fact that credit-market imperfections, which amplify movements in unemployment that peak several quarters after labor productivity, increase the disconnect between the two variables. Both models fall short, however, of being consistent with the correlations between labor productivity and vacancies or market tightness, which are mildly positively correlated in the data.

Table 2
Labor-market cross-correlations.

	U.S. data					Labor search, no credit friction – $\mu_t = 0$				
	U	V	θ	$f(\theta)$	Y/N	U	V	θ	$f(\theta)$	Y/N
U	1.00	−0.89	−0.97	−0.95	−0.41	1.00	−0.47	−0.71	−0.71	−0.69
V	–	1.00	0.98	0.90	0.36	–	1.00	0.95	0.95	0.96
θ	–	–	1.00	0.95	0.40	–	–	1.00	1.00	0.99
$f(\theta)$	–	–	–	1.00	0.40	–	–	–	1.00	0.99
Y/N	–	–	–	–	1.00	–	–	–	–	1.00
	Labor and credit frictions – fixed μ					Labor and credit frictions – cyclical μ_t				
	U	V	θ	$f(\theta)$	Y/N	U	V	θ	$f(\theta)$	Y/N
U	1.00	−0.57	−0.77	−0.77	−0.51	1.00	−0.61	−0.81	−0.81	−0.57
V	–	1.00	0.96	0.96	0.82	–	1.00	0.96	0.96	0.93
θ	–	–	1.00	1.00	0.81	–	–	1.00	1.00	0.89
$f(\theta)$	–	–	–	1.00	0.81	–	–	–	1.00	0.89
Y/N	–	–	–	–	1.00	–	–	–	–	1.00

All moments are Hodrick–Prescott filtered; Data sources: BLS, BEA and Fujita and Ramey (2007).

Table 3
Robustness to credit and labor-market parametrization.

	Baseline		Credit market						Labor market			
			Increased recovery rate		Increased elasticity s_1		Increased variance of x		Wage barg. $\eta = 2/3$		Unemp. flow $b = 0.5$	
	a	b	a	b	a	b	a	b	a	b	a	b
U	2.81	−0.72	2.62	−0.74	3.60	−0.79	3.87	−0.75	2.91	−0.71	2.33	−0.71
V	5.99	0.93	5.59	0.94	7.66	0.95	8.38	0.87	7.15	0.86	4.50	0.94
θ	8.03	0.95	7.50	0.96	10.26	0.99	11.08	0.92	9.04	0.91	6.29	0.94
ν	θ	Y	θ	Y	θ	Y	θ	Y	θ	Y	θ	Y
corr$(\Delta\nu, \Delta\nu_{-1})$	0.49	0.10	0.51	0.11	0.49	0.20	0.35	0.11	0.34	0.09	0.50	0.07
corr$(\Delta\nu, \Delta\nu_{-2})$	0.01	0.15	0.01	0.12	0.01	0.17	0.01	0.25	0.01	0.22	0.01	0.09
corr$(\Delta\nu, \Delta\nu_{-3})$	0.00	0.03	0.00	0.02	0.00	0.03	0.00	0.06	0.00	0.09	0.00	0.00

a: Standard deviation relative to output; b: contemporaneous correlation with output. All moments, but growth rates, are Hodrick–Prescott filtered.

3.3.3. *Robustness to the calibration of the credit market*

This section examines the behavior of the model along the dimension of the credit-market calibration. The first columns of Table 3 present the effects of increasing the recovery rate to $s_0 = 0.91$ such that the premium declines to 30 basis points. Increasing the level of the recovery rate reduces the degree of credit-market friction. A lower premium on external funds results in a relative volatility of the v–u ratio of 7.50, compared to 8.03 in the baseline.

Next, we present the sensitivity of results to increasing in the responsiveness of the costs to monitoring to changes in aggregate conditions, setting $s_1 = 20$. Increasing this elasticity from 8.5 to 20 increases the relative standard deviation of labor-market tightness from 8.03 to 10.26, and has little noticeable effect on the persistence of the growth rate of the v–u ratio.

Finally, the fourth pair of columns in Table 2 presents the results from increasing the dispersion in firm idiosyncratic draws x from $\sigma_x = 0.01$ to $\sigma_x = 0.02$. Although such a change has little effect on the level of the premium, it significantly alters its elasticity to productivity shocks. As a result, the relative standard deviation of labor-market tightness increases to 11.08. However, there is less persistence in the response of labor-market variables. The first auto-correlation of the growth rate of θ_t decreases from 0.49 to 0.35.

3.3.4. *Sensitivity to the calibration of the labor market*

This section presents the sensitivity of the main results to changes in labor-market-specific parameters. The consequences of changing the value of the bargaining weight, η, and the value of non-market activities, b, are presented in the last columns of Table 3.

Increasing the worker's bargaining weight $\eta = 2/3$ somewhat increases the volatility of labor-market variables, the relative volatility of θ increases to 9.04, and reduces their persistence. The auto-correlation for market tightness declines from 0.49 to 0.34.

The last columns of Table 3 present the results for $b = 0.5$. As expected, increasing the size of the labor surplus reduces the responsiveness of the profits from labor, and hence the incentives to hire, to changes in labor productivity. However, this has no discernible effect on the persistence generated by the presence of credit-market frictions.

Table 4
Unconditional second moments – credit shocks.

Variable:	Baseline model		Estimated model with credit shocks		Contemporaneous cross-correlations:					
	a	b	a	b		U	V	θ	$f(\theta)$	Y/N
U	2.81	−0.72	5.15	−0.67	U	1.00	−0.50	−0.73	−0.73	−0.29
V	5.99	0.93	11.74	0.90	V	–	1.00	0.95	0.95	0.43
θ	8.03	0.95	14.99	0.91	θ	–	–	1.00	1.00	0.44
ν	θ	Y	θ	Y	$f(\theta)$	–	–	–	1.00	0.44
$corr(\Delta\nu, \Delta\nu_{-1})$	0.49	0.10	0.10	0.12	Y/N	–	–	–	1.00	
$corr(\Delta\nu, \Delta\nu_{-2})$	0.01	0.15	0.00	0.13						
$corr(\Delta\nu, \Delta\nu_{-3})$	0.00	0.03	0.00	0.02						

a: Standard deviation relative to output; b: contemporaneous correlation with output. All moments, but growth rates, are Hodrick–Prescott filtered.

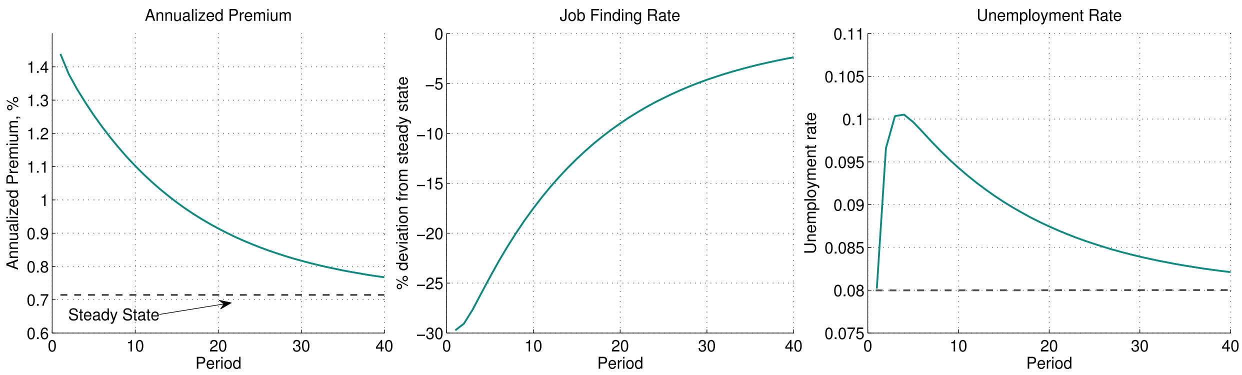

Fig. 5. Response to a negative credit shock.

3.4. Credit shocks

The introduction of credit-market frictions in conjunction with search-and-matching frictions in the labor market allows the model to consider, in addition, the possibility of the importance of shocks to credit markets as a driving force for fluctuations. That is, this section presents the results for a model with both productivity and credit shocks estimated on U.S. time series for aggregate GDP and bond spreads.

Table 4 presents the business-cycle moment of labor-market variables for the model with productivity shocks only and the model augmented with credit shocks. The extension to exogenous credit shocks brings the model, in terms of the volatility of the v–u ratio, close to the data, and somewhat overshoots the relative volatility of job vacancies. There is little change with respect to the cross-correlations, presented in the last columns. However, credit shock significantly reduces the measure of persistence. The auto-correlation in the growth rate of labor-market tightness declines to 0.1 at the first lag.

In light of the recent financial crisis, the model is used to evaluate the effect of a negative shock to credit markets that causes a doubling of the external-finance premium. The results of this large, 2-standard-deviation shock are presented in Fig. 5. The first panel plots the response of the external-finance premium, which returns to its steady state after just over five years. The second panel plots the response of the job-finding rate, which declines by 30%. Its incidence on unemployment is plotted in the last panel. The unemployment rate peaks at over 10%, just over a year after the shock to the credit market. This is comparable to recent research, such as Jermann and Quadrini (2012), into the effect of credit shocks for business cycle fluctuations, although with a particular focus on the dynamics of the labor market (see also Monacelli et al., 2012).

4. Conclusion

It has been argued that the standard search-and-matching model of equilibrium unemployment cannot generate sufficient propagation: Productivity shocks, by inducing a rise in wages, have little effect on firm profits from a new employee and, hence, on the incentive to post job vacancies. This paper has shown that when vacancies must be funded in part on frictional credit markets, agency problems can lead to higher, time-varying, opportunity costs of the resources involved that alter the dynamics of job vacancies following shocks to productivity. In the quantitative exercise, agency problems in the credit market endogenously generate persistence in job vacancies and labor-market tightness. The inclusion of exogenously counter-cyclical recovery costs, estimated on U.S. data, brings the model closer to the data in terms of amplification, and persistence. The paper thus concludes that the dynamics of the opportunity cost of resources allocated to recruiting workers are an essential element in understanding the cyclical behavior of job creation and the dynamics of the labor market, echoing the conclusions in Fujita and Ramey (2007) and Pissarides (2009). The originality here is that these costs evolve as a function of credit-market conditions. While the study of the macroeconomic consequences of credit-market imperfections has generally focused on their consequences for capital investment – e.g., models of financial intermediation and agency costs by Bernanke et al. (1999) or Kiyotaki and Moore (1997) – this paper corroborates the finding in Petrosky-Nadeau and Wasmer (2013) that their implications for labor markets should not be overlooked.

The results suggest avenues for subsequent research. If hiring is conditional on the state of credit markets, it may be that worker flows, as opposed to investment in new capital goods, are an alternative channel for the transmission of monetary policy shocks that affect the cost of credit. This avenue seems particularly promising: The propagation mechanism in the paper can be interpreted as increasing the rigidity of the firm's marginal cost to changes in production. Often referred to in the New Keynesian literature as a greater degree of real rigidity, this property is known to be essential for understanding the dynamics of inflation and for allowing any significant scope to monetary policy.

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