An Equilibrium Asset Pricing Model with Labor Market Search

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Abstract

Search frictions in the labor market help explain the equity premium in the financial market. We embed the standard Diamond-Mortensen-Pissarides search framework into a stochastic general equilibrium production economy, in which the representative household has recursive Epstein-Zin preferences. With reasonable parameter values, the model reproduces an equity premium of 3.67% per annum with a low interest rate volatility of 1.44%. The equity premium is countercyclical, and is predictable with the vacancy-unemployment ratio in the model, a pattern we also confirm in the data. Crucially, for asset prices, large job destruction flows combined with search frictions create rare but deep crashes in the economy. As such, the search economy gives rise endogenously to the rare disaster risk à la Rietz (1988) and Barro (2006).

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1 Introduction

Asset pricing has focused on specifying preferences and cash flow dynamics that are necessary to reproduce the equity premium, its volatility, and its cyclical variation in the endowment economy (e.g., Campbell and Cochrane (1999) and Bansal and Yaron (2004)). Explaining the equity premium in the production economy with endogenous cash flows has proven more challenging. For the most part, the prior literature treats cash flows as dividends. However, wages comprise about two thirds of aggregate disposable income in the data, with dividends representing only a small fraction. As such, an equilibrium macroeconomic model of asset pricing should take the labor market seriously.

As a fundamental departure from the prior asset pricing literature, we tackle the equity premium puzzle by incorporating search frictions in the labor market (e.g., Diamond (1982), Mortensen (1982), and Pissarides (1985, 2000)) into an intertemporal general equilibrium production economy. With recursive Epstein and Zin (1989) preferences, a representative household pools incomes from its employed and unemployed members, and decides on optimal consumption and asset allocation. The unemployed members search for job vacancies posted by a representative firm. The rate at which a job vacancy is transformed into a filled position is affected by the degree of congestion in the labor market. The congestion is measured by labor market tightness, defined as the ratio of the number of job vacancies over the number of unemployed workers. Deviating from Walrasian equilibrium, search frictions create rents to be divided between the firm and the workers through wages, which are determined by the outcome of a generalized Nash bargaining process.

Our central message is that search frictions are important for understanding the equity premium in the production economy. With reasonable parameter values, the search economy generates an equity premium of 3.67% per annum and an average risk-free rate of 3.75%. The interest rate also has a low volatility of 1.44% per annum. However, the model produces a market volatility of 7.83%, which is too low compared with 12.94% in the data. Also, the equity premium is strongly countercyclical in the model. In particular, the vacancy-unemployment ratio forecasts stock market excess returns with a negative slope in the model, a pattern that we confirm in the data.

The model is also partially successful in replicating the cyclical behavior of unemployment, vacancies, and labor market tightness. In particular, the standard deviation of the vacancy-unemployment ratio is 0.16 in the model, albeit lower than 0.26 in the data. The model reproduces a Beveridge curve with a negative vacancy-unemployment correlation of −0.51. However, the magnitude of the correlation is lower than the correlation in the data, −0.91.

Why are search frictions important for asset prices? The challenge in reproducing the equity premium in the production economy is that the representative household can smooth consumption to alleviate the impact of shocks. In the standard production model, the amount of endogenous risk is too small (e.g., Rouwenhorst (1995) and Kaltenbrunner and Lochstoer (2010)). Swings in cyclical investment flows have little impact on the proportionally large capital stock. In contrast, job creation and job destruction flows are substantially larger than investment flows. In particular, the annual rate of capital depreciation is around 12%, but the annual job separation rate can be as high as 60% (e.g., Davis, Faberman, and Haltiwanger (2006)).

When combined with search frictions, such large job flows create rare but deep disasters. In the stationary distribution of the model, the unemployment rate is positively skewed with a long right tail. The mean unemployment rate is about 12%. The 2.5 and 5 percentiles are nearby: 7.44% and 7.81%, but the 95 and 97.5 percentiles are far from the mean: 21.51% and 29.10%, respectively. As a result, output and consumption in our production economy are negatively skewed with a long left tail, giving rise to rare disaster risk emphasized by Rietz (1988) and Barro (2006).

Through comparative statics, we find that a high value of unemployment benefits is critical for the search model to produce a high equity premium. Intuitively, a high value of unemployment benefits means that the wage is less elastic to aggregate productivity. With the procyclical covariation of the wage dampened, the procyclical covariation of the residual payments to shareholders ais magnified, thereby raising the equity premium. We also find that high vacancy costs and a low bargaining weight for the workers in the wage determination are necessary for the model's fit of asset pricing moments. Finally, consistent with Tallarini (2000), risk aversion only affects asset pricing moments, while leaving business cycle moments virtually unchanged in the search economy.

We connect the literature on asset pricing with production in financial economics and the search literature in labor economics. In finance, Rouwenhorst (1995) shows that the equity premium in the standard real business cycle framework is close to zero because of consumption smoothing. With habit formation, Jermann (1998) uses capital adjustment costs, and Boldrin, Christiano, and Fisher (2001) introduce across-sector immobility to reproduce a high equity premium in production economies. However, both models struggle with excessively volatile risk-free rates. Danthine and Donaldson (2002) and Uhlig (2007) show that wage rigidities are important for asset pricing in the production economy, a theme we also echo in the search model. While curing the excess risk-free rate volatility, Kaltenbrunner and Lochstoer (2010) show that a production economy with recursive preferences and capital adjustment costs still fails to reproduce a high equity premium.[1]

In the recent search literature in labor economics, Shimer (2005) argues that the standard search framework cannot explain the unemployment volatility in the data. Several authors including Hall (2005), Hagedorn and Manovskii (2008), and Gertler and Trigari (2009) show that wage rigidities go a long way toward resolving the Shimer puzzle. We introduce the search model into the asset pricing literature, and show that the exact mechanism also works to resolve the equity premium puzzle.

The rest of the paper is organized as follows. Section 2 constructs the model. Section 3 discusses the quantitative results under the benchmark calibration. Section 4 reports an extensive set of comparative statics. Finally, Section 5 concludes.

2 The Economy

To study the interaction between search frictions and asset prices, we embed the standard Diamond-Mortensen-Pissarides search model into an intertemporal general equilibrium production economy.

[1]However, Guvenen (2009) shows how to achieve this task with limit market participation.

2.1 Search and Matching

The model is populated by a representative firm that uses labor as the single productive input and a representative household. Following Merz (1995), we use the representative family construct, which implies perfect consumption insurance. In particular, the household has a continuum of employed workers and unemployed workers, which are representative of the population at large. The household pools their incomes together before choosing per capita consumption and asset holdings.

The representative firm posts a number of job vacancies, V_t, to attract unemployed workers, U_t, at the unit cost of κ. Vacancies are filled via a constant returns to scale matching function, $G(U_t, V_t)$. The matching function is specified as:

$$G(U_t, V_t) = \frac{U_t V_t}{(U_t^{\iota} + V_t^{\iota})^{1/\iota}}, \tag{1}$$

in which $\iota > 0$ is a constant parameter. This matching function from Den Haan, Ramey, and Watson (2000) has the desirable property that matching probabilities fall naturally between zero and one.

Specifically, define $\theta_t \equiv V_t/U_t$ as the vacancy-unemployment (V/U) ratio. The probability for an unemployed worker to find a job per unit of time (the job finding rate), denoted $f(\theta_t)$, is given by:

$$f(\theta_t) \equiv \frac{G(U_t, V_t)}{U_t} = \frac{1}{\left(1 + \theta_t^{-\iota}\right)^{1/\iota}}. \tag{2}$$

In addition, the probability for a vacancy to be filled per unit of time (the vacancy filling rate), denoted $q(\theta_t)$, is given by:

$$q(\theta_t) \equiv \frac{G(U_t, V_t)}{V_t} = \frac{1}{(1 + \theta_t^{\iota})^{1/\iota}}. \tag{3}$$

As such, $f(\theta_t) = \theta_t q(\theta_t)$. Also, $\partial q(\theta_t)/\partial \theta_t < 0$, meaning that an increase in the relative scarcity of unemployed workers relative to job vacancies makes it more difficult for a firm to fill a vacancy. In this sense, θ_t is a measure of labor market tightness from the perspective of the firm.

Once matched, jobs are destroyed at an exogenous and constant rate of s per period. As such, total employment, N_t, evolves as:

$$N_{t+1} = (1 - s)N_t + q(\theta_t)V_t. \tag{4}$$

We normalize the size of the work force to be one, meaning that $U_t = 1 - N_t$. As such, N_t and U_t can also be interpreted as the rates of employment and unemployment, respectively.

2.2 The Representative Firm

The firm faces aggregate productivity, X_t. The law of motion of $x_t \equiv \log(X_t)$ is given by:

$$x_{t+1} = \rho x_t + \sigma \epsilon_{t+1}, \tag{5}$$

in which $0 < \rho < 1$ is the persistence parameter, $\sigma > 0$ is the conditional volatility, and ϵ_{t+1} is an identically and independently distributed standard normal shock.

The firm uses labor as the only input to produce with a constant returns to scale production technology, $Y_t = X_t N_t$, in which Y_t is output. The dividend to the firm's shareholders is given by:

$$D_t = X_t N_t - W_t N_t - \kappa V_t, \tag{6}$$

in which W_t is the wage rate (to be determined later in Section 2.4).

Let $M_{t+\triangle t}$ be the representative household's stochastic discount factor from time t to $t + \triangle t$. Taking the matching probability $q(\theta_t)$ and the wage rate as given, the firm posts an optimal number of job vacancies to maximize the market value of equity, denoted S_t:

$$S_t = \max_{\{V_{t+\triangle t}, N_{t+\triangle t+1}\}_{\triangle t=0}^{\infty}} E_t \left[\sum_{\triangle t=0}^{\infty} M_{t+\triangle t}(X_{t+\triangle t} N_{t+\triangle t} - W_{t+\triangle t} N_{t+\triangle t} - \kappa V_{t+\triangle t}) \right], \tag{7}$$

subject to equation (4) and an irreversibility constraint on job creation:

$$q(\theta_t)V_t \geq 0. \tag{8}$$

Because $q(\theta_t) > 0$, this constraint is equivalent to $V_t \geq 0$. As such, the only source of job destruction in the model is the exogenous separation between the employed workers and the firm.

Let μ_t denote the Lagrange multiplier on the employment accumulation equation (4), and λ_t the Lagrange multiplier on the irreversibility constraint (8). The first-order conditions with respect to V_t and N_{t+1} in maximizing the equity value are given by, respectively:

$$\mu_t = \frac{\kappa}{q(\theta_t)} - \lambda_t, \tag{9}$$

$$\mu_t = E_t\left[M_{t+1}\left[X_{t+1} - W_{t+1} + (1-s)\mu_{t+1}\right]\right]. \tag{10}$$

Combining the two first-order conditions yields the intertemporal job creation condition:

$$\frac{\kappa}{q(\theta_t)} - \lambda_t = E_t\left[M_{t+1}\left[X_{t+1} - W_{t+1} + (1-s)\left(\frac{\kappa}{q(\theta_{t+1})} - \lambda_{t+1}\right)\right]\right]. \tag{11}$$

The optimal vacancy policy also satisfies the Kuhn-Tucker conditions:

$$q(\theta_t)V_t \geq 0, \lambda_t \geq 0, \tag{12}$$

$$\lambda_t q(\theta_t)V_t = 0. \tag{13}$$

When the firm posts vacancies, $V_t > 0$ and $\lambda_t = 0$. Equation (9) says that the marginal cost, κ, is equal to the marginal value of employment, μ_t, conditional on the probability of a successful match, $q(\theta_t)$. When the irreversibility constraint is binding, $V_t = 0$ and $\lambda_t > 0$. In addition, $\theta_t = V_t/U_t = 0$, and $q(\theta_t) = 1$ from equation (3). In this case, the marginal value of employment $\mu_t = \kappa - \lambda_t$. In all, $\kappa/q(\theta_t) - \lambda_t$ can be interpreted as the marginal cost of vacancy posting, taking into account the matching probability and the irreversibility constraint.

The intertemporal job creation condition (11) is intuitive. The marginal cost of vacancy posting at period t should be equal to the marginal benefit of vacancy posting at period $t+1$, discounted to period t with the stochastic discount factor. The marginal benefit includes the marginal product of labor, X_{t+1}, net of the wage rate, W_{t+1}, and the marginal value of employment, μ_{t+1}, which in turn equals the marginal cost of vacancy posting at $t+1$, net of separation.

Define the stock return as $R_{t+1} = S_{t+1}/(S_t - D_t)$ (S_t is the cum dividend equity value). The constant returns to scale assumption allows us to derive (see Appendix A for details):

$$R_{t+1} = \frac{X_{t+1} - W_{t+1} + (1-s)\left(\kappa/q(\theta_{t+1}) - \lambda_{t+1}\right)}{\kappa/q(\theta_t) - \lambda_t}. \tag{14}$$

As such, the stock return is the ratio of the marginal benefit of vacancy posting at period $t+1$ divided by the marginal cost of vacancy posting at period t.

2.3 The Representative Family

The representative household maximizes utility, denoted J_t, over consumption using the Epstein and Zin preferences. The household can buy risky shares on the representative firm's dividends and 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. The recursive utility function is given by:

$$J_t = \max_{\{C_t, \chi_t\}} \left[(1-\beta) C_t^{1-\frac{1}{\psi}} + \beta \left(E_t \left[J_{t+1}^{1-\gamma} \right] \right)^{\frac{1-1/\psi}{1-\gamma}} \right]^{\frac{1}{1-1/\psi}}, \tag{15}$$

in which β is time discount factor, ψ is the elasticity of intertemporal substitution, and γ is relative risk aversion. The Epstein-Zin preferences separate the elasticity of intertemporal substitution from the risk aversion. Intuitively, ψ measures the household's willingness to postpone consumption over time, and γ measures its aversion to atemporal risk across states. Separating the two parameters helps the model to produce a high equity premium and a low interest rate volatility simultaneously.

Tradeable assets consist of risky shares and a risk-free bond. Let R_{t+1}^f denote the risk-free interest rate (known at the beginning of period t) and R_{t+1}^{Π} the return on wealth, i.e., $R_{t+1}^{\Pi} = \chi_t R_{t+1} + (1-\chi_t) R_{t+1}^f$. Let Π_t denote the household's financial wealth, b the value of unemployment benefits, T_t the amount of taxes raised by the government to pay for the unemployment benefits in lump-sum rebates. We can write the representative household's budget constraint as:

$$\frac{\Pi_{t+1}}{R_{t+1}^{\Pi}} = \Pi_t - C_t + W_t N_t + U_t b - T_t. \tag{16}$$

Finally, the government balances its budget, meaning that $T_t = U_t b$.

The household's first order condition with respect to the fraction of wealth invested in the risky asset, χ_t, implies the fundamental equation of asset pricing:

$$1 = E_t[M_{t+1} R_{t+1}]. \tag{17}$$

In particular, the stochastic discount factor, M_{t+1}, is given by:

$$M_{t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\frac{1}{\psi}} \left(\frac{J_{t+1}}{E_t[J_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}} \right)^{\frac{1}{\psi}-\gamma}. \tag{18}$$

Finally, the risk-free rate is given by $R_{t+1}^f = 1/E_t[M_{t+1}]$ in equilibrium.

2.4 Wage Determination

The wage rate is determined endogenously as the outcome of a generalized Nash bargaining process between a worker and the firm. Let $0 < \eta < 1$ be the workers' relative bargaining weight. The wage equation, derived in details in Appendix B, is given by:

$$W_t = \eta[X_t + \kappa\theta_t] + (1-\eta)b. \tag{19}$$

The wage is increasing in productivity, X_t, and in labor market tightness, θ_t. Also, the workers' bargaining weight, η, affects the elasticity of the wage to productivity. The lower η is, the more the wage is tied with the constant unemployment benefit, b, inducing a higher degree of wage rigidity.

2.5 Competitive Equilibrium

In equilibrium, the capital market clears. The risk-free asset is in zero net supply, and the household holds all the shares of the representative firm, $\chi_t = 1$. The return on wealth equals the return on the risky asset, $R_{t+1}^{\Pi} = R_{t+1}$, and the household's wealth equals the equity value of the firm, $\Pi_t = S_t$. In addition, the goods market clearing condition implies the aggregate resource constraint:

$$C_t + \kappa V_t = X_t N_t. \tag{20}$$

The competitive equilibrium consists of vacancy, $V^\star(N_t, x_t) \geq 0$, multiplier, $\lambda^\star(N_t, x_t) \geq 0$, consumption, $C^\star(N_t, x_t)$, and indirect utility, $J^\star(N_t, x_t)$, such that (i) $V^\star(N_t, x_t)$ and $\lambda^\star(N_t, x_t)$ satisfy the intertemporal job creation condition (11) and the Kuhn-Tucker condition (13), while taking the stochastic discount factor (18) and the wage equation (19) as given; (ii) $C^\star(N_t, x_t)$ and $J^\star(N_t, x_t)$ satisfy the intertemporal consumption-portfolio choice condition (17), in which the stock return is given by equation (14); and (iii) the goods market clears as in equation (20).

3 Quantitative Results

We calibrate the model in Section 3.1, examine the theoretical properties of the model's solution in Section 3.2, and present the quantitative results from the model in Section 3.3.

3.1 Calibration

We calibrate the model in monthly frequency. Table 1 lists the parameter values in the benchmark calibration. Following Gertler and Trigari (2009), we set the time discount factor, β, to be $0.99^{1/3}$, and the persistence of the aggregate productivity, ρ, to be $0.95^{1/3} = 0.983$. We choose the conditional volatility of the log aggregate productivity, σ, to be 0.0077 to target the standard deviation of output growth in the data. Following Bansal and Yaron (2004), we set the relative risk aversion, γ, to be 10, and the elasticity of intertemporal substitution, ψ, to be 1.5.

For the labor market parameters, we begin with the matching function, $G(U_t, V_t)$. Den Haan, Ramey, and Watson (2000) estimate the average monthly job filling rate to be $\bar{q} = 0.71$, and the average monthly job finding rate in the United States to be $\bar{f} = 0.45$ (see also Shimer (2005)). The constant returns to scale property of the matching function implies that the long-run average labor market tightness is around $\bar{\theta} = \bar{f}/\bar{q} = 0.634$. This value helps pin down the constant parameter in the matching function, ι. Specifically, evaluating equation (3) at the long run average yields: $0.71 = (1 + 0.634^\iota)^{-1/\iota}$, which in turn implies $\iota = 1.29$.

The average rate of unemployment for the United States over the 1920–2009 period is approx-

Table 1 : Parameter Values in the Benchmark Calibration

All the model parameters are calibrated at the monthly frequency.

Parameters	Value	Source
The rate of time preference, β	$0.99^{1/3}$	Gertler and Trigari (2009)
Relative risk aversion, γ	10	Bansal and Yaron (2004)
The elasticity of intertemporal substitution, ψ	1.5	Bansal and Yaron (2004)
Aggregate productivity persistence, ρ	0.983	Gertler and Trigari (2009)
Conditional volatility of productivity shocks, σ	0.0077	Gertler and Trigari (2009)
Worker's bargaining weight, η	0.10	Hagedorn and Manovskii (2008)
Value of unemployment benefit, b	0.85	Hagedorn and Manovskii (2008)
Job destruction rate, s	0.05	Andolfatto (1996)
Elasticity of the matching function w.r.t. θ, ι	1.290	Den Haan, Ramey, and Watson (2000)
Cost of vacancy, κ	0.975	Job creation condition in steady state

imately 7%. However, important flows in and out of nonparticipation in the labor force as well as discouraged workers not accounted for in the pool of individuals seeking employment suggest that the unemployment rate should be calibrated higher in the model. As such, we adopt the target average unemployment rate of $\bar{U} = 10\%$, which lies within the range between 7% in Gertler and Trigari (2009) and 12% in Krause and Lubik (2007). This target pins down the monthly job separation rate s. In particular, the steady state labor market flows condition, $s(1 - \bar{U}) = \bar{f}\bar{U}$, sets $s = 0.05$. This value of s, which is also used by Andolfatto (1996), is close to the estimate of 0.053 from Clark (1990), and is within the range of estimates from Davis, Faberman, and Haltiwanger (2006).

The value of unemployment benefits, b, measures the total value of leisure, home production, and unemployment insurance. Hagedorn and Manovskii (2008) argue that in a perfect competitive labor market, b should equal the value of employment. In the long run, the average marginal product of labor is unity, to which b should be close. Following Hagedorn and Manovskii, we choose a relatively high value for $b = 0.85$, and a relatively low value for the workers' bargaining weight, $\eta = 0.10$. Doing so helps the model to match the volatility of labor market tightness and the elasticity of wage to productivity in the data. Intuitively, by limiting the response of the marginal cost of production to shocks, wage rigidity increases the sensitivity of the marginal profits to shocks.

Finally, with all the other parameters determined, we pin down the vacancy cost parameter, κ, by evaluating the job creation condition (11) at the steady state.[2] This strategy yields $\kappa = 0.975$.

3.2 Theoretical Properties of the Model's Solution

Armed with the calibrated parameters, we solve for the competitive equilibrium using a nonlinear projection algorithm with parameterized expectations (see Appendix C for details). Before studying the model's quantitative results, we first examine qualitative properties of the model's solution on the two-dimensional grid of N_t and x_t. (Additional qualitative results are in Appendix C.3.)

Panel A of Figure 1 shows that, sensibly, labor market tightness, θ_t, is increasing in employment, N_t, and in aggregate productivity, x_t. The labor market is tighter from the perspective of the firm when there are fewer unemployed workers searching for jobs (N_t is high), and when the demand for workers is high (x_t is high). Panel B confirms that congestion in the labor market is most severe in the states with high N_t and high x_t. In particular, the vacancy fill rate, $q(\theta_t)$, is the lowest in these states, but hits the maximum of unity in the low N_t and low x_t states.

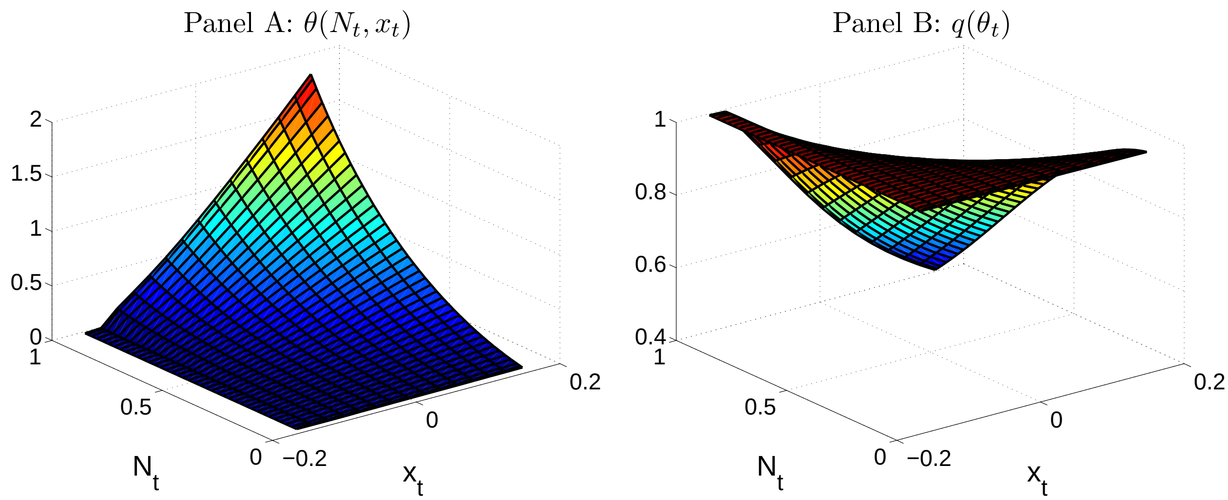
From Panel A of Figure 2, the optimal vacancy, V_t, is procyclical (increasing with aggregate productivity), and is hump-shaped in employment, N_t. Intuitively, operating profits, $X_t N_t - W_t N_t$, increase with aggregate productivity, implying that the firm posts more vacancies in good times. Conditional on X_t, low states of N_t mean low operating profits. As such, the firm posts fewer vacancies to avoid high vacancy costs. At the other extreme, although high states of N_t mean high operating profits, these states also imply more congestion and low vacancy filling rates, $q(\theta_t)$, which the firm takes as given. The congestion deters the firm from posting more vacancies.

Panel B shows that the dynamics of dividend are more complex. First, the dividend dynamics are closely related to the vacancy dynamics. When x_t is high, dividend shows a U-shape in employment, N_t. Dividend is positive and procyclical when N_t is around its long run average (close to

[2]Specifically, after we substitute the wage equation (19), the job creation condition at the steady state becomes: $\frac{1}{\beta}\frac{\kappa}{\bar{q}} = \bar{X} - \eta(\bar{X} + \kappa\bar{\theta}) - (1-\eta)b + (1-s)\frac{\kappa}{\bar{q}}$, in which $\bar{X} = 1$. Solving for κ yields: $\kappa = \frac{(\bar{X}-b)(1-\eta)\bar{q}}{1/\beta-(1-s)+\eta\bar{\theta}\bar{q}}$.

Figure 1 : Labor Market Tightness and the Vacancy Filling Rate

We plot labor market tightness, $\theta(N_t, x_t)$, and the vacancy filling rate, $q(\theta_t)$ on the N_t-x_t grid.

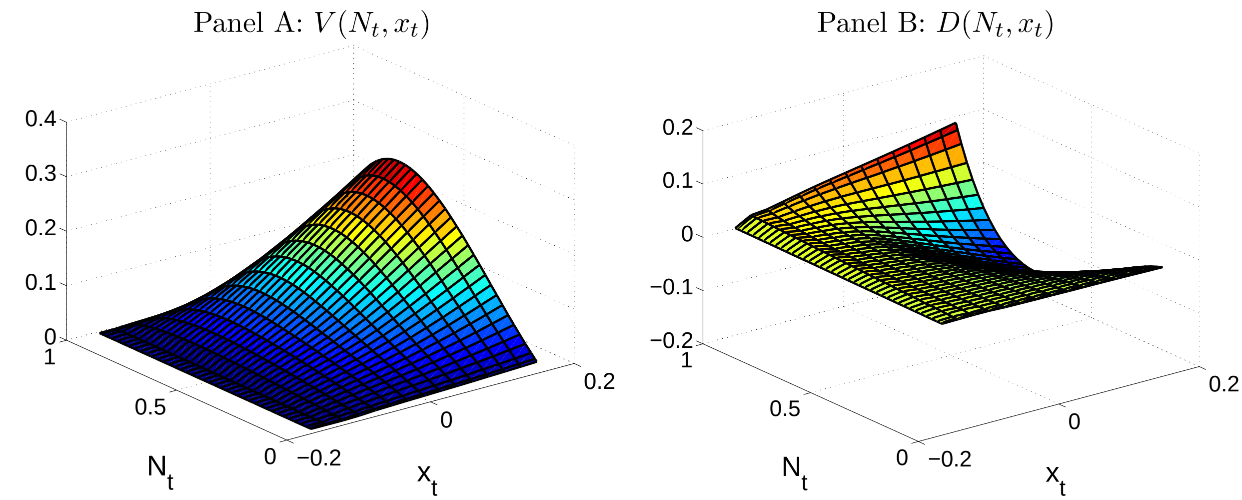


0.90). However, dividend can be negative and countercyclical when N_t is in the middle range on the grid. The absolute values of negative dividends can be seen as positive equity issues in the model. The countercyclicality of dividend is the mirror image of the procyclicality of vacancy because the firm posts more vacancies in the middle range of the N_t grid.

Panel A of Figure 3 plots the multiplier on the irreversibility constraint, λ_t. We observe that λ_t is strongly countercyclical: λ_t equals zero for most values of x_t, but increases rapidly as x_t approaches its lowest level. The multiplier is also convex in employment, N_t: λ_t is flat across most values of N_t, but rises with an increasing speed as N_t approaches zero. To obtain some intuition, Panel B plots the conditional expectation, denoted $\mathcal{E}(N_t, x_t)$, which is defined as the right-hand side of equation (11), $E_t\left[M_{t+1}\left[X_{t+1} - W_{t+1} + (1-s)\left(\frac{\kappa}{q(\theta_{t+1})} - \lambda_{t+1}\right)\right]\right]$. As noted, when the irreversibility constraint is binding, $V_t = 0, \theta_t = 0$, and $q(\theta_t) = 1$. As such, $\lambda_t = \kappa - \mathcal{E}(N_t, x_t)$. From Panel B, $\mathcal{E}(N_t, x_t)$ is increasing in both N_t and x_t. More important, $\mathcal{E}(N_t, x_t)$ shows strong nonlinearity as it drops swiftly as the economy approaches the lowest levels of N_t and x_t simultaneously. This nonlinearity is a natural result of the nonlinear stochastic discount factor, M_{t+1}. As consumption

Figure 2 : Vacancy and Dividend

We plot the optimal vacancy, $V(N_t, x_t)$, and dividend, $D(N_t, x_t)$, on the grid of N_t and x_t.



approaches zero, marginal utility blows up, causing $\mathcal{E}(N_t, x_t)$ to drop and λ_t to rise precipitously.

Figure 4 reports two key financial moments: the equity risk premium and the conditional market volatility. Both moments exhibit similar dynamic patterns as the multiplier on the irreversibility constraint, λ_t. In particular, both moments are strongly countercyclical, and are largely convex in employment as it approaches zero. Intuitively, the irreversibility constraint binds only in bad times. The binding constraint prevents the household from smoothing consumption, giving rise to high risk and high risk premiums. Conversely, the irreversibility constraint does not bind in good times, consumption is smooth, giving rise to low risk and low risk premiums.

3.3 Quantitative Results

Before evaluating the model's quantitative performance, we first examine its stationary distribution.

Stationary Distribution

We simulate 1,006,000 monthly periods from the model. The initial condition consists of a value of zero for aggregate productivity, x_t, and a value of 0.90 for employment, N_t. We discard the first

Figure 3 : The Multiplier on the Irreversibility Constraint of Vacancy and the Conditional Expectation in the Intertemporal Job Creation Condition

On the N_t-x_t grid, we plot the multiplier on the irreversibility constraint on vacancy, $\lambda(N_t, x_t)$, and the conditional expectation defined as the right-hand side of equation (11), $\mathcal{E}(N_t, x_t)$.

Panel A: $\lambda(N_t, x_t)$ Panel B: $\mathcal{E}(N_t, x_t)$

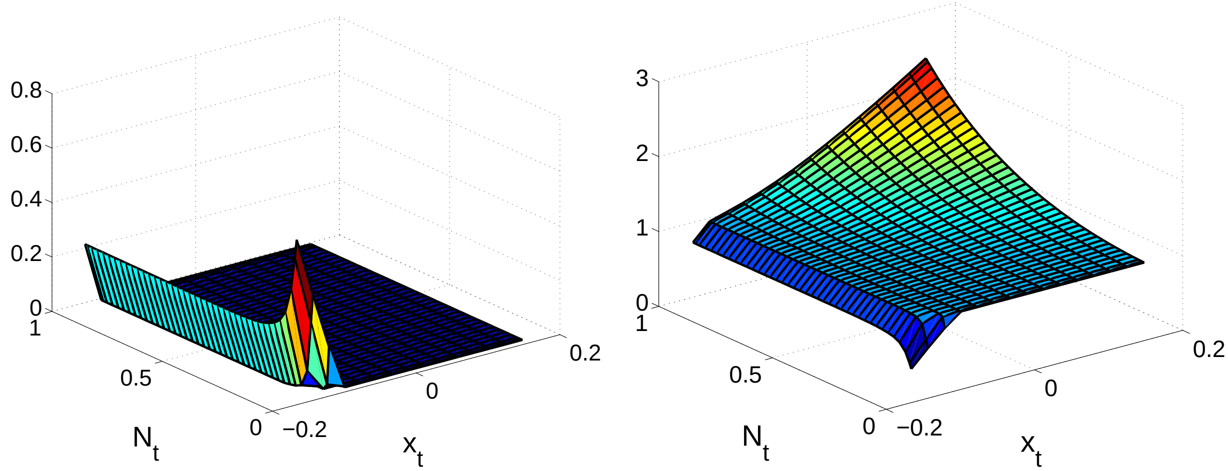
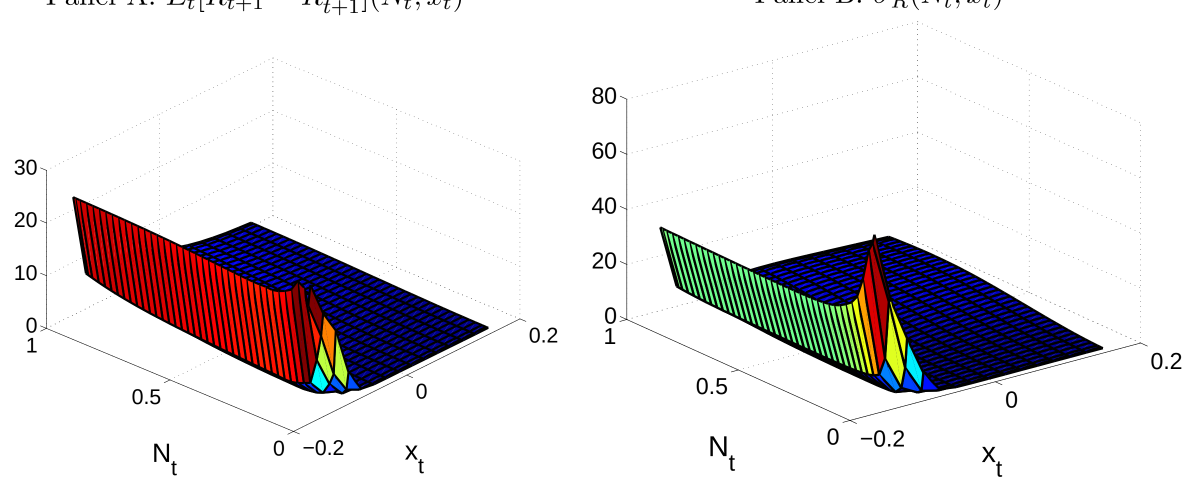


Figure 4 : The Equity Risk Premium and the Conditional Market Volatility

On the N_t-x_t grid, we plot the conditional equity risk premium, $E_t[R_{t+1} - R^f_{t+1}](N_t, x_t)$, and the conditional market volatility, $\sigma_R(N_t, x_t)$, both of which are in annualized percent.

Panel A: $E_t[R_{t+1} - R^f_{t+1}](N_t, x_t)$ Panel B: $\sigma_R(N_t, x_t)$



6,000 periods, and treat the remaining one million months as from the model's stationary distribution. Figure 5 reports the empirical cumulative distribution functions ($ECDF$) and simulated paths for unemployment, output, and consumption. (Appendix C.3 reports additional $ECDF$s.)

Most important, the economy shows infrequent but deep crashes. From Panels A and B, unemployment, U_t, is positively skewed with a long right tail. The mean unemployment rate is 12.14%, the median is 10.29%, and the skewness coefficient is 5.09. (Although we target an unemployment rate of 10% in the calibration, the skewed distribution of U_t implies that its mean is slightly above its median around 10%.) The 2.5 and 5 percentiles are close to the median: 7.44% and 7.81%, respectively. In contrast, the 95 and 97.5 percentiles are far away from the median: 21.51% and 29.10%, respectively. As a mirror image, the employment rate, $N_t = 1 - U_t$, is negatively skewed with a long left tail. As a result, output and consumption also exhibit infrequent but severe disasters (see Panels C to F). With small probabilities, the economy falls off the cliff in simulations, exhibiting the behavior modeled by Rietz (1988) and Barro (2006).

The disasters reflect in asset prices as rare upward spikes in the equity premium. From Figure 6, the stationary distribution of the equity premium is positively skewed with a long right tail. The mean equity premium is 3.87% per annum, and its 2.5 and 97.5 percentiles are 1.86% and 5.40%, respectively. With small probabilities the equity premium can reach very high levels. In particular, the 99.99 and 99.995 percentiles of its stationary distribution are 15.51% and 21.12%, respectively.

Unconditional Financial Moments

Panel A of Table 2 reports the standard deviation and autocorrelations of (log) consumption growth and (log) output growth, as well as unconditional financial moments in the data. Consumption is annual real personal consumption expenditures and output is annual real gross domestic product from 1929 to 2010 from Bureau of Economic Analysis at U.S. Department of Commerce. The annual consumption growth in the data has a volatility of 3.04%, and a first-order autocorrelation of 0.38. The autocorrelation drops to 0.08 at the two-year horizon, and turns negative, -0.21, at the

Figure 5 : Empirical Stationary Distribution of the Model: Unemployment, Output, and Consumption

We simulate 1,006,000 monthly periods from the model, discard the first 6,000 periods, and treat the remaining one million months as forming the model's stationary distribution. In Panels A, C, and E, we plot the empirical cumulative distribution functions, $ECDF(\cdot)$, for unemployment, output, and consumption. In Panels B, D, and F, we plot their simulated paths.

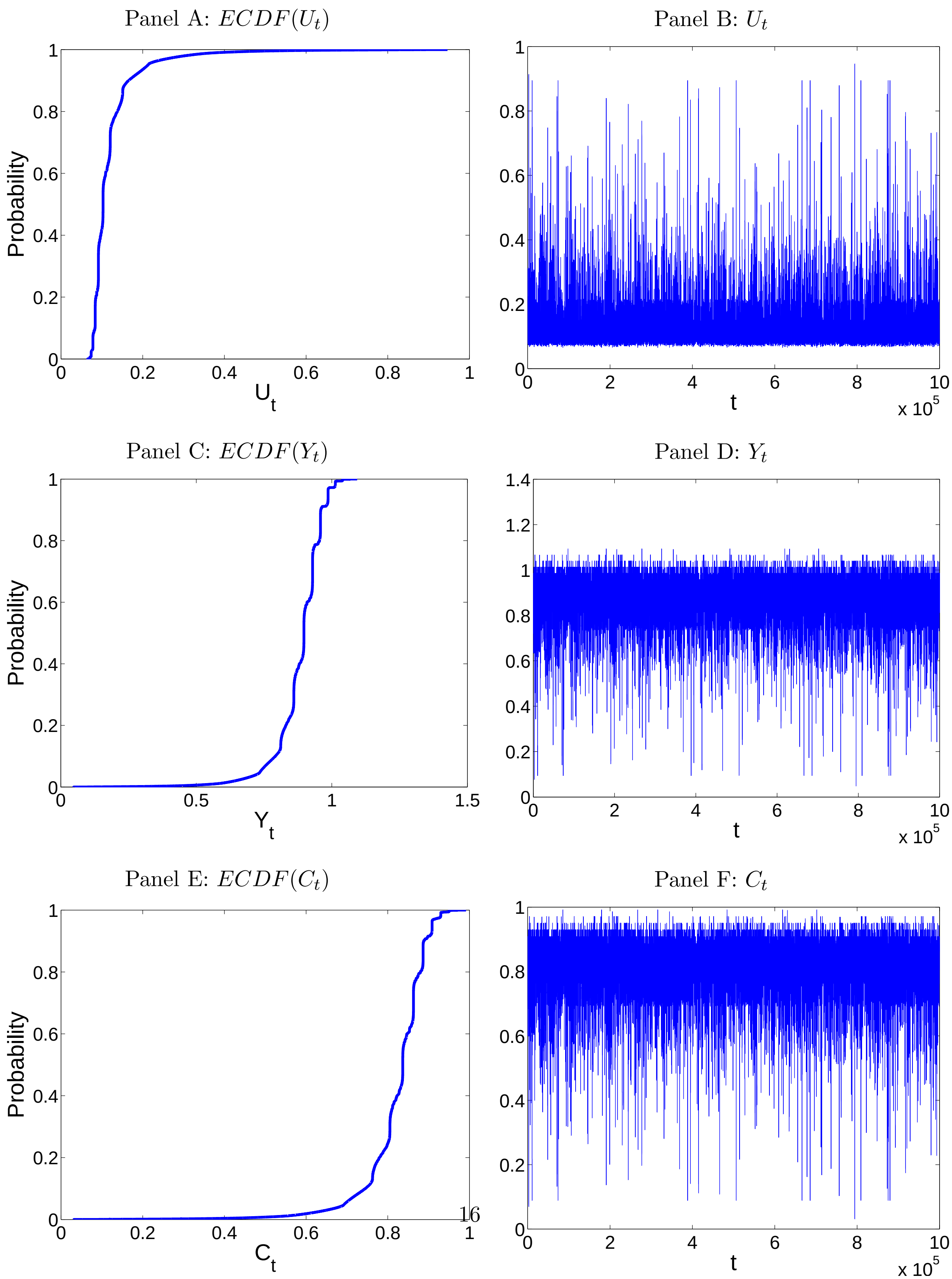
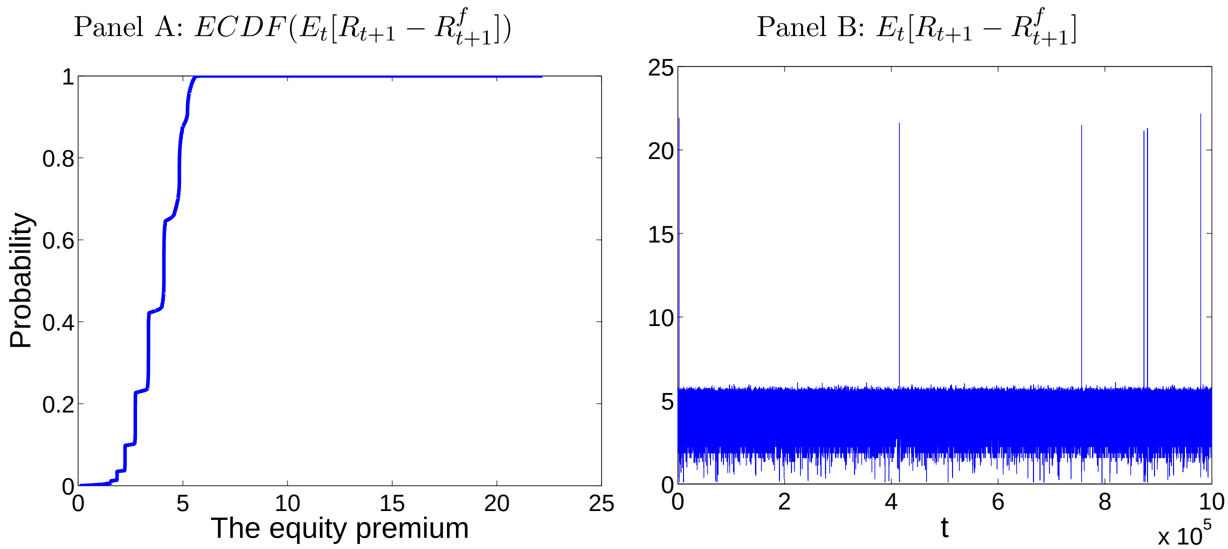


Figure 6 : Empirical Stationary Distribution of the Model: The Equity Premium

We simulate 1,006,000 monthly periods from the model, discard the first 6,000 periods, and treat the remaining one million months as from the model's stationary distribution. Panel A plots the empirical cumulative distribution function, $ECDF$, and Panel B plots the simulated path for the equity premium, $E_t[R_{t+1} - R^f_{t+1}]$.



three-year horizon. The annual output growth has a volatility of 4.93%, and a high first-order autocorrelation of 0.54. The autocorrelation drops to 0.18 at the two-year horizon, and turns negative afterward: −0.18 at the three-year horizon and −0.23 at the five-year horizon.

We obtain monthly series of the value-weighted market returns including all NYSE, Amex, and Nasdaq stocks, one-month Treasury bill rates, and inflation rates (the rates of change in Consumer Price Index) from Center for Research in Security Prices (CRSP). The sample is from January 1926 to December 2010 (1,020 months). The mean of real interest rates (one-month Treasury bill rates minus inflation rates) is 0.59% per annum, and the annualized volatility is 1.87%. The equity premium (the average of the value-weighted market returns in excess of one-month Treasury bill rates) in the 1926–2010 sample is 7.45% per annum. Because we do not model financial leverage, we adjust the equity premium in the data for leverage before matching with the equity premium implied from the model. Frank and Goyal (2008) report that the aggregate market leverage ratio of U.S. corporations is fairly stable around 0.32. As such, we calculate the leverage-adjusted equity

Table 2 : Unconditional Financial Moments

In Panel A, consumption is annual real personal consumption expenditures (series PCECCA), and output is annual real gross domestic product (series GDPCA) from 1929 to 2010 (82 annual observations) from Bureau of Economic Analysis at U.S. Department of Commerce. σ_C is the volatility of log consumption growth, and σ_Y is the volatility of log output growth. Both volatilities are in percent. $\rho_C(j)$ and $\rho_Y(j)$, for $j = 1, 2, 3$, and 5, are the j-th order autocorrelations of log consumption growth and log output growth, respectively. We obtain monthly series from January 1926 to December 2010 (1,020 monthly observations) for the value-weighted market index returns including dividends, one-month Treasury bill rates, and the rates of change in Consumer Price Index (inflation rates) from CRSP. $E[R-R^f]$ is the average (in annualized percent) of the value-weighted market returns in excess of the one-month Treasury bill rates, adjusted for the long-term market leverage rate of 0.32 reported by Frank and Goyal (2008). (The leverage-adjusted average $E[R-R^f]$ is the unadjusted average times 0.68.) $E[R^f]$ and σ_{Rf} are the mean and volatility, both of which are in annualized percent, of real interest rates, defined as the one-month Treasury bill rates in excess of the inflation rates. σ_R is the volatility (in annualized percent) of the leverage-weighted average of the value-weighted market returns in excess of the inflation rates and the real interest rates. In Panel B, we simulate 1,000 artificial samples, each of which has 1,020 monthly observations, from the model in Section 2. In each artificial sample, we calculate the mean market excess return, $E[R-R^f]$, the volatility of the market return, σ_R, as well as the mean, $E[R^f]$, and volatility, σ_{Rf}, of the real interest rate. All these moments are in annualized percent. We also time-aggregate the first 984 monthly observations of consumption and output into 82 annual observations in each sample, and then calculate the volatilities and autocorrelations of log consumption growth and log output growth. We report the mean and the 5 and 95 percentiles across the 1,000 simulations. The p-values are the percentages with which a given model moment is larger than its data moment.

	Panel A: Data	Panel B: Model			
		Mean	5%	95%	p-value
σ_C	3.036	4.643	2.691	8.473	0.846
$\rho_C(1)$	0.383	0.243	0.013	0.530	0.168
$\rho_C(2)$	0.081	−0.131	−0.328	0.110	0.068
$\rho_C(3)$	−0.206	−0.135	−0.346	0.111	0.697
$\rho_C(5)$	0.062	−0.082	−0.301	0.140	0.145
σ_Y	4.933	4.945	3.024	8.639	0.342
$\rho_Y(1)$	0.543	0.236	0.018	0.521	0.038
$\rho_Y(2)$	0.178	−0.127	−0.324	0.112	0.025
$\rho_Y(3)$	−0.179	−0.131	−0.337	0.113	0.636
$\rho_Y(5)$	−0.227	−0.082	−0.295	0.135	0.866
$E[R-R^f]$	5.066	3.669	2.951	4.324	0.000
$E[R^f]$	0.588	3.751	3.235	4.143	1.000
σ_R	12.942	7.829	7.147	8.572	0.000
σ_{Rf}	1.872	1.439	0.928	2.267	0.125

premium as $(1-0.32) \times 7.45\% = 5.07\%$ per annum. The annualized volatility of the market returns in excess of inflation rates is 18.95%. Adjusting for leverage (taking the leverage-weighted average of real market returns and real interest rates) yields an annualized volatility of 12.94%.[3]

Panel B of Table 2 reports the model moments. From the initial condition of zero for aggregate productivity, x_t, and 0.90 for employment, N_t, we first simulate the economy for 6,000 monthly periods to reach its stationary distribution. We then repeatedly simulate 1,000 artificial samples, each with 1,020 months. On each artificial sample, we calculate the annualized monthly averages of the equity premium and the real interest rate, as well as the annualized monthly volatilities of the market returns and the real interest rate. We also take the first 984 monthly observations of consumption and output, and time-aggregate them into 82 annual observations. (We add up 12 monthly observations within a given year, and treat the sum as that year's annual observation.) For each data moment, we report the average as well as the 5 and 95 percentiles across the 1,000 simulations. The p-values are the frequencies with which a given model moment is larger than its data counterpart.

Because we target the (log) output growth volatility (σ_Y) in calibration, the model implied σ_Y is 4.95% per annum, which is fairly close to 4.93% in the data. The model also reproduces a positive first-order autocorrelation of 0.24 for the output growth, but its magnitude is substantially lower than 0.54 in the data. As such, the propagation mechanism in the model is weaker than what we observe in the data. The model also predicts a consumption growth volatility of 4.64% per annum, which is higher than 3.04% in the data. However, this data moment lies within the 90% confidence interval of the model's bootstrapped distribution. The model also implies a positive first-order autocorrelation of 0.24 for consumption growth. The model's performance in matching unconditional financial moments seems fair. The equity premium is 3.67% per annum, and the market volatility is 7.83%. The real interest rate is on average 3.75% per annum, and its volatility is 1.44%.

[3] Albeit simple, our leverage adjustment for the equity premium and the volatility of real market returns is crude. The aggregate debt of U.S. corporations is risky, but our adjustment implicitly assumes that the debt is riskless. However, modeling risky debt in our framework would take us too far afield.

Labor Market Moments

In Panel A of Table 3, we update Hagedorn and Manovskii's (2008) Table 3 using a sample from January 1951 to June 2006. We obtain seasonally adjusted monthly unemployment (thousands of persons 16 years of age and older) from the Bureau of Labor Statistics (BLS) at U.S. Department of Labor, and seasonally adjusted help wanted advertising index from the Conference Board. We take quarterly averages of the monthly series to obtain quarterly observations. The average labor productivity is seasonally adjusted real average output per person in the nonfarm business sector from BLS.

Hagedorn and Manovskii (2008) report all variables in logs as deviations from the Hodrick-Prescott (1997, HP) trend with a smoothing parameter of 1,600. In contrast, we detrend all variables as the HP-filtered cyclical component of proportional deviations from the mean with the same smoothing parameter.[4] We do not use log deviations because vacancies can be zero in the model's simulations when the irreversibility constraint is binding. In the data, the two detrending methods yield quantitatively similar results, which are in turn similar to Hagedorn and Manovskii's Table 3. In particular, the standard deviation of the V/U ratio is 0.255, and the V/U ratio is also procyclical with a positive correlation of 0.299 with the labor productivity in the data. Finally, vacancy and unemployment are negatively correlated, with a coefficient of -0.913.

To examine the model's performance in matching labor moments in Panel A of Table 3, we simulate 1,000 artificial samples, each with 666 months. We take the quarterly averages of the monthly unemployment U, vacancy, V, and labor productivity X to obtain 222 quarterly observations for each series. We then implement the same empirical procedures as in Panel A on the artificial data, and report the cross-simulation averages (and standard deviations) for the model moments.

Panel B reports the model's quantitative fit for the labor moments. The model implies a standard deviation of 0.16 for the V/U ratio, which is lower than 0.26 in the data. The bootstrapped

[4]Specifically, for a variable X, the HP-filtered cyclical component of proportional deviations from the mean is calculated as $(X - \bar{X})/\bar{X} - \text{HP}((X - \bar{X})/\bar{X}, 1600)$, in which $\bar{X}$ is the mean of X, and $\text{HP}((X - \bar{X})/\bar{X}, 1600)$ is the HP trend of $(X - \bar{X})/\bar{X}$ with a smoothing parameter of 1,600.

Table 3 : Labor Market Moments

In Panel A, seasonally adjusted monthly unemployment (U, thousands of persons 16 years of age and older) is from the Bureau of Labor Statistics. The seasonally adjusted help wanted advertising index, V, is from the Conference Board. The series are monthly from January 1951 to June 2006 (666 months). Both U and V are converted to quarterly averages of monthly series. The average labor productivity, X, is seasonally adjusted real average output per person in the nonfarm business sector from the Bureau of Labor Statistics. All variables are in hpfiltered proportional deviations from the mean with a smoothing parameter of 1,600. For example, for the variable X, its cyclical component is calculated as $(X - \bar{X})/\bar{X} - \text{HP}((X - \bar{X})/\bar{X}, 1600)$, in which $\bar{X}$ is the mean of X, and $\text{HP}((X - \bar{X})/\bar{X}, 1600)$ is the HP trend of $(X - \bar{X})/\bar{X}$ with a smoothing parameter of 1,600. In Panel B, we simulate 1,000 artificial samples, each of which has 666 monthly observations. We take the quarterly averages of monthly U, V, and X to convert to 222 quarterly observations, and implement the same empirical procedures as in Panel A on these quarterly series. We report the cross-simulation averages and standard deviations (in parentheses) for all the model moments.

Panel A: Data

	U	V	V/U	X	
Standard deviation	0.119	0.134	0.255	0.012	
Quarterly autocorrelation	0.902	0.922	0.889	0.761	
	1	−0.913	−0.801	−0.224	U
Correlation matrix		1	0.865	0.388	V
			1	0.299	V/U
				1	X

Panel B: Model

	U	V	V/U	X	
Standard deviation	0.143	0.095	0.158	0.016	
	(0.051)	(0.019)	(0.030)	(0.002)	
Quarterly autocorrelation	0.879	0.617	0.804	0.773	
	(0.040)	(0.066)	(0.036)	(0.040)	
	1	−0.510	−0.704	−0.655	U
		(0.081)	(0.116)	(0.128)	
Correlation matrix		1	0.857	0.915	V
			(0.055)	(0.023)	
			1	0.988	V/U
				(0.018)	
				1	X

standard deviation of this model moment is 0.03. As such, the data moment is more than three standard deviations away from the model moment. The standard deviations of U and V in the model are 0.14 and 0.10, which are close to 0.12 and 0.13 in the data, respectively. The model also generates a Beveridge curve with a negative U-V correlation of -0.51. However, its magnitude is lower than -0.91 in the data. Finally, the correlation between V_t/U_t and the labor productivity is 0.99 in the model, which is substantially higher than 0.30 in the data.

The model implies an average unemployment rate of 0.12, an job finding rate of 0.42, a vacancy filling rate of 0.73, and an average V/U ratio of 0.61 (untabulated). These moments are close to those in the data. Hagedorn and Manovskii (2008) report the elasticity of wage to labor productivity to be 0.45, while taking log deviations of wage and productivity from their HP trends with a smoothing parameter of 1,600. Using the same procedure, we calculate this elasticity to be 0.71 in the model with a cross-simulation standard deviation of 0.03. This higher elasticity is not surprising because we use less extreme parameter values for the value of unemployment benefits, b, and the workers' bargaining power, η, than those used by Hagedorn and Manovskii.

The Linkage between the Labor Market and the Financial Market

The equity premium is time-varying and countercyclical in the data (e.g., Lettau and Ludvigson (2001)). Because vacancy is procyclical and unemployment is countercyclical, labor market tightness (the V/U ratio) exhibits strong procyclical movements (e.g., Shimer (2005), see also Panel A of Table 3). As such, labor market tightness should forecast stock market excess returns with a negative slope. Panel A of Table 4 documents such predictability in the data.[5]

Specifically, we perform monthly long-horizon regressions of log excess returns on the CRSP value-weighted market returns, $\sum_{h=1}^{H} R_{t+3+h} - R^f_{t+3+h}$, in which $H = 1, 3, 6, 12, 24$, and 36 is the forecast horizon in months. When $H > 1$, we use overlapping monthly observations of H-period

[5]In related work, Chen and Zhang (2011) document that payroll growth forecasts market excess returns with a negative slope at business cycle frequencies in the U.S. data.

Table 4 : Long-Horizon Regressions of Market Excess Returns on Labor Market Tightness

Panel A reports long-horizon regressions of log excess returns on the value-weighted market index from CRSP, $\sum_{h=1}^{H} R_{t+3+h} - R^f_{t+3+h}$, in which H is the forecast horizon in months. The regressors are two-month lagged values of the V/U ratio. We report the ordinary least squares estimate of the slopes (Slope), the Newey-West corrected t-statistics (t_{NW}), and the adjusted R^2s. The seasonally adjusted monthly unemployment (U, thousands of persons 16 years of age and older) is from the Bureau of Labor Statistics, and the seasonally adjusted help wanted advertising index (V) is from the Conference Board. The sample is from January 1951 to June 2006 (666 monthly observations). We multiply the V/U series by 50 so that its mean is 0.622, close to that in the model. In Panel B, we simulate 1,000 artificial samples, each of which has 666 monthly observations. On each sample we implement the same empirical procedures as in Panel A, and report the cross-simulation averages and standard deviations (in parentheses) for all the model moments.

	Forecast horizon (H) in months					
	1	3	6	12	24	36
	Panel A: Data					
Slope	−1.425	−4.203	−7.298	−10.312	−9.015	−10.156
t_{NW}	−2.575	−2.552	−2.264	−1.704	−0.970	−0.861
Adjusted R^2	0.950	2.598	3.782	3.672	1.533	1.405
	Panel B: Model					
Slope	−0.758	−2.231	−4.321	−8.108	−14.407	−19.463
	(0.456)	(1.329)	(2.553)	(4.767)	(8.282)	(10.866)
t_{NW}	−1.929	−2.021	−2.131	−2.377	−2.977	−3.503
	(0.850)	(0.903)	(0.977)	(1.161)	(1.555)	(1.889)
Adjusted R^2	0.555	1.628	3.130	5.859	10.419	14.142
	(0.433)	(1.245)	(2.361)	(4.375)	(7.575)	(10.013)

holding returns. The regressors are *two*-month lagged values of labor market tightness.[6] The BLS takes less than one week to release monthly employment and unemployment data. The Conference Board takes about one month to release monthly help wanted advertising index data.[7] We impose the two-month lag between labor market tightness and market excess returns to guard against look-ahead bias in predictive regressions. Also, to make the regression slopes comparable to those in the model, we also scale the V/U series in the data by multiplying it by 50. As a result, its average is 0.62, close to the average of 0.61 in the model. This scaling is necessary because the

[6] Per our timing convention, returns such as R_{t+1} are observed at the end of period t, but labor market tightness, V_t/U_t, is observed at the beginning of period t, even though V_t occurs during the course of period t.

[7] We verify this practice through a private correspondence with the Conference Board staff.

vacancy and unemployment series in the data have different units.

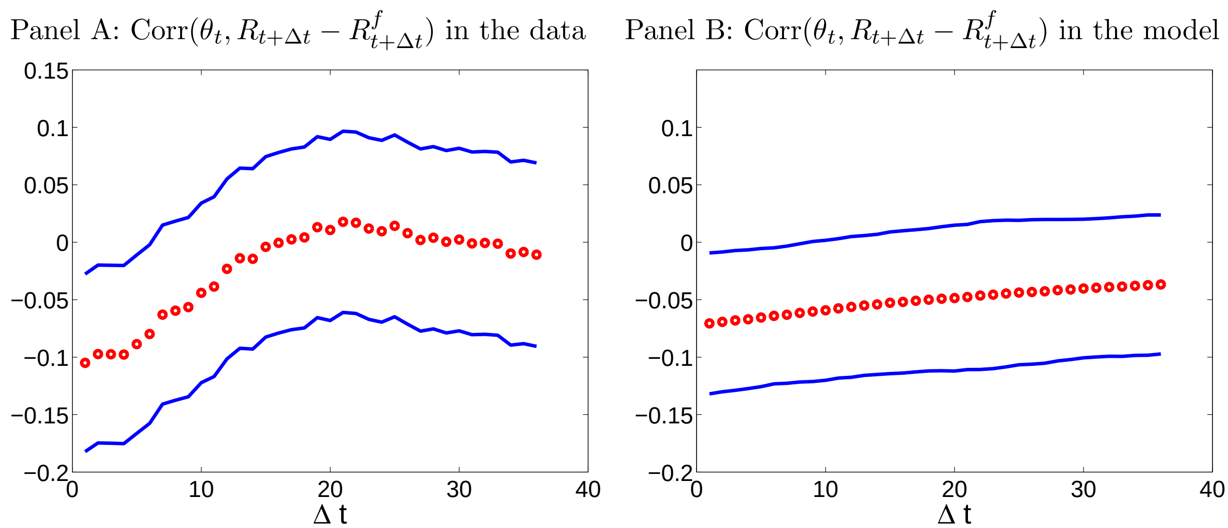
Panel A of Table 4 shows that labor market tightness is a reliable negative forecaster of market excess returns at business cycle frequencies. In forecasting two-month ahead market returns, the slope is -1.42, which is more than 2.5 standard errors from zero. The standard errors are adjusted for heteroscedasticity and autocorrelations of 12 lags per Newey and West (1987). Also, the adjusted R^2 is close to 1%. The slopes remain significant at the three-month and six-month horizons, but become insignificant afterward. In particular, the slopes at the two-year and three-year horizons are within one standard error of zero. The adjusted R^2 peaks at 3.78% at the six-month horizon, and declines to 3.67% at the one-year horizon and further to 1.41% at the three-year horizon.

Panel B of Table 4 reports the model's fit for the predictive regressions. Consistent with the data, the model predicts that labor market tightness forecasts market excess returns with a negative slope. In particular, at the one-month horizon, the predictive slope is -0.76 with a t-statistic of -1.93. At the six-month horizon, the slope is -4.32 with a t-statistic of -2.13. The slopes in the model are smaller in magnitude than those in the data because the equity premium in the model is lower. However, the model implies a stronger predictive power for labor market tightness than that in the data. Both the t-statistics and the adjusted R^2s increase monotonically with the forecast horizon. In contrast, both measures peak at the six-month horizon in the data.

Panel A of Figure 7 provides further evidence on time-varying risk premiums. The panel plots the cross-correlations (and their two standard errors bounds) between labor market tightness, θ_t, and stock market excess returns, $R_{t+\triangle t} - R^f_{t+\triangle t}$, for $\triangle t = 1, 2, \ldots, 36$ in the data. No overlapping observations are used in calculating these cross-correlations. We observe that the correlations are negative and significant for $\triangle t$ up to six months. Panel B plots the cross-correlations and their two standard deviations bounds from the model's bootstrapped distribution. Although the cross-correlations are insignificant beyond the seven-month horizon, they decay more slowly to zero over the forecast horizon than those in the data. The pattern is consistent with Panel B of Table 4,

Figure 7 : Cross-Correlations between Labor Market Tightness and Future Market Excess Returns

We report the cross-correlations between labor market tightness, θ_t, and stock market excess returns, $R_{t+\triangle t}-R^f_{t+\triangle t}$, for $\triangle t = 1, 2, \ldots, 36$, both in the data (Panel A) and in the model (Panel B). In Panel A, θ_t is the seasonally adjusted help wanted advertising index from the Conference Board divided by the seasonally adjusted monthly unemployment (thousands of persons 16 years of age and older) from the BLS. The sample is from January 1951 to June 2006. The stock market excess returns are the CRSP value-weighted market returns in excess of one-month Treasury bill rates. The two standard errors bounds for the cross-correlations are also plotted. In Panel B, we simulate 1,000 artificial samples, each of which has 666 monthly observations. On each artificial sample, we calculate the cross-correlations between θ_t and $R_{t+\triangle t} - R^f_{t+\triangle t}$, and plot the cross-simulation averaged correlations and their two cross-simulation standard errors bounds.



which shows that the predictive power of θ_t in the model increases over the forecast horizon.

4 What Drives the Equity Risk Premium?

To understand the driving forces behind the equity premium in the model, we conduct an extensive set of comparative statics by varying the model's key parameters.

4.1 The Value of Unemployment Benefits

We reduce the value of unemployment benefits, b, from 0.85 in the benchmark calibration to 0.40, which is the value used in Shimer (2005). All the other parameters are fixed. Because unemployment is less valuable to workers, the average unemployment rate drops to 5.46%. A lower b also means that, from equation (19), wage is more sensitive to exogenous shocks. In particular, the wage elasticity to labor productivity increases to 0.80 from 0.71 in the benchmark calibration.

Figure 8 reports the stationary distribution from the low-b economy. Unlike the benchmark economy, the low-b economy exhibits no disasters. The unemployment rate varies within a narrow range between 5.2% and 5.8%. Neither output nor consumption has a long left tail in its empirical cumulative distribution function. The equity premium hovers within a narrow range around 0.09% per annum, and shows no upward spikes. Figure 9 reports the equity premium and the market volatility on the grid of employment and aggregate productivity. Comparing Figures 4 and 9 shows that the low-b economy produces substantially lower equity premium and market volatility than the benchmark economy. Unlike the benchmark economy, in which the two financial moments are strongly countercyclical, they are largely invariant to aggregate productivity in the low-b economy. In addition, the irreversibility constraint is never binding (untabulated).

Table 5 reports the quantitative results from the low-b economy. As noted, a lower b means that wage is more elastic to productivity. As such, the marginal profits of hiring are less sensitive to shocks, and the sensitivities of employment and output to shocks are lowered as well. The low-b model produces a lower output growth volatility, 2.07% per annum, and a lower consumption growth volatility, 1.90%. The propagation mechanism is also weakened as the persistence of the output growth drops from 0.24 to 0.13. Because both the volatility and the persistence of consumption growth are lower, the equity premium decreases from 3.67% per annum in the benchmark calibration to 0.05%. The market volatility drops from 7.83% per annum to 3.52%. And labor market tightness shows no predictive power for market excess returns.

Consistent with Shimer (2005), Panel B shows that the standard deviation of labor market tightness in the model is substantially smaller than that in the data, 0.03 versus 0.26. As such, a high value of unemployment benefits is critical for producing reasonable values for both the un-

Figure 8 : Empirical Stationary Distribution, the Model with a Low Value of Unemployment Benefits, $b = 0.40$

We simulate 1,006,000 monthly periods from the model with the value of unemployment benefits $b = 0.40$, discard the first 6,000 periods, and treat the remaining as from the stationary distribution. We plot the empirical cumulative distribution functions, $ECDF(\cdot)$, for unemployment (U_t), output (Y_t), consumption (C_t), and the equity premium ($E_t[R_{t+1} - R^f_{t+1}]$).

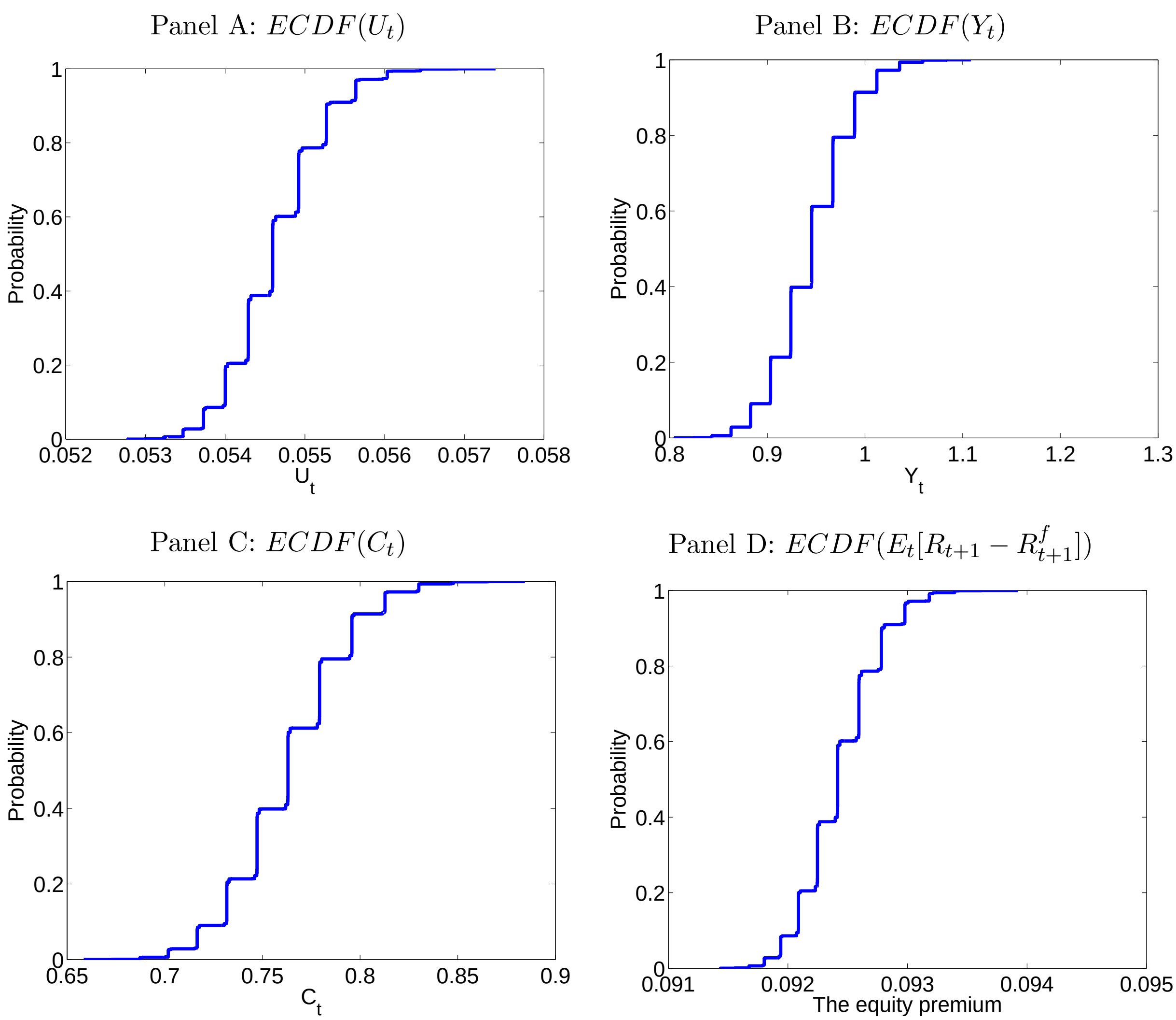
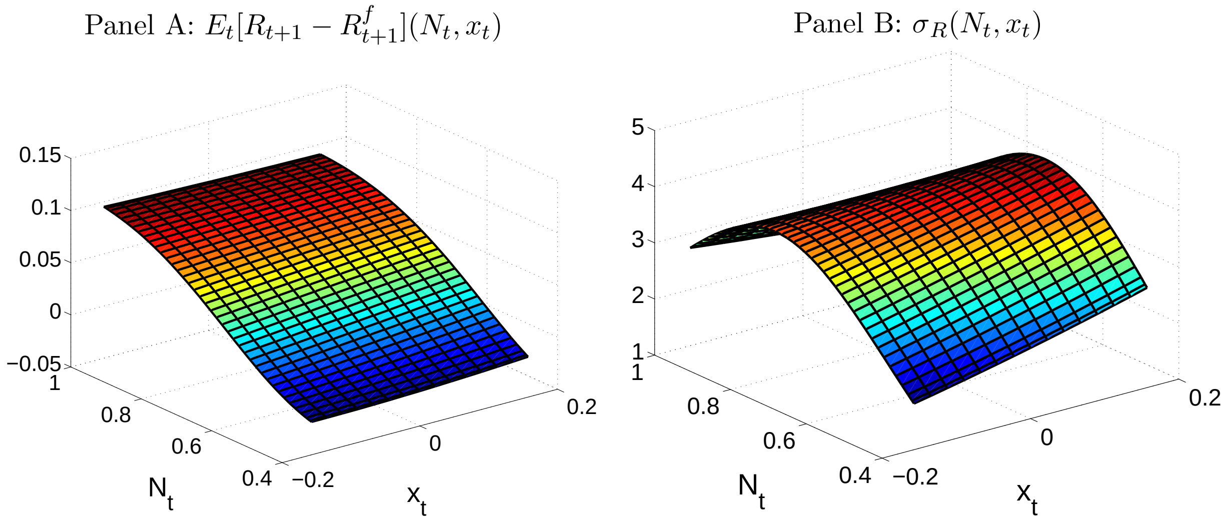


Figure 9 : The Equity Risk Premium and the Conditional Market Volatility, the Model with a Low Value of Unemployment Benefits, $b = 0.40$

For the model with a low value of unemployment benefits, $b = 0.40$, we plot the conditional equity risk premium, $E_t[R_{t+1} - R^f_{t+1}](N_t, x_t)$, and the conditional market volatility, $\sigma_R(N_t, x_t)$, on the N_t-x_t grid. Both moments are in annualized percent.



employment volatility and the equity premium. In effect, the operating leverage mechanism helps alleviate both puzzles simultaneously. Intuitively, by dampening the procyclical covariation of the wage with output, a high value of b magnifies the procyclical covariation of the residual payments to shareholders, thereby raising the equity risk premium and stock market volatility.

4.2 The Vacancy Cost

Table 6 reports the comparative statics with the vacancy cost parameter, κ, changed from 0.975 in the benchmark calibration to 0.20, which is close to the value in Shimer (2005). All the other parameters are fixed. Because lower vacancy costs make hiring cheaper, the average unemployment rate falls from 12.14% in the benchmark model to 5.37%. The job finding rate is on average 0.88, which is twice as high as that in the benchmark economy, 0.42. Because vacancy is more abundant, the labor market is more congested with a vacancy filling rate of only 0.22. In contrast, the vacancy filling rate is 0.73 in the benchmark economy. The average V/U ratio is 4.24 in the low-κ economy,

Table 5 : Quantitative Results from the Model with a Low Value of Unemployment Benefits, $b = 0.40$

Quantitative results are from the model with the parameter b changed from 0.85 in the benchmark calibration to 0.40. All the other parameters remain unchanged. See Table 2's caption for the explanation of Panel A, Table 3's caption for Panel B, and Table 4's caption for Panel C.

Panel A: Unconditional financial moments

	Mean	5%	95%	p-value
σ_C	1.901	1.602	2.199	0.000
$\rho_C(1)$	0.134	−0.035	0.294	0.006
$\rho_C(2)$	−0.119	−0.282	0.055	0.036
$\rho_C(3)$	−0.093	−0.281	0.086	0.834
$\rho_C(5)$	−0.067	−0.248	0.130	0.137
σ_Y	2.066	1.741	2.388	0.000
$\rho_Y(1)$	0.133	−0.036	0.294	0.000
$\rho_Y(2)$	−0.119	−0.281	0.054	0.006
$\rho_Y(3)$	−0.093	−0.282	0.088	0.782
$\rho_Y(5)$	−0.067	−0.248	0.131	0.915
$E[R - R^f]$	0.047	−0.485	0.590	0.000
$E[R^f]$	4.033	3.917	4.149	1.000
σ_R	3.519	3.223	3.827	0.000
σ_{R^f}	0.127	0.115	0.139	0.000

Panel B: Labor market moments

	U	V	V/U	X	
Standard deviation	0.004	0.022	0.026	0.016	
	(0.001)	(0.002)	(0.003)	(0.002)	
Quarterly autocorrelation	0.781	0.759	0.775	0.772	
	(0.038)	(0.042)	(0.039)	(0.039)	
	1	−0.941	−0.958	−0.953	U
		(0.011)	(0.008)	(0.008)	
Correlation matrix		1	0.999	0.999	V
			(0.000)	(0.000)	
			1	1.000	V/U
				(0.000)	
				1	X

Panel C: Long-horizon regressions of market excess returns on labor market tightness

	Forecast horizon (H) in months					
	1	3	6	12	24	36
Slope	−0.230	−0.680	−1.324	−2.510	−4.528	−6.323
	(0.219)	(0.632)	(1.212)	(2.282)	(4.082)	(5.606)
t_{NW}	−1.047	−1.111	−1.178	−1.331	−1.687	−2.018
	(0.926)	(0.968)	(1.023)	(1.178)	(1.532)	(1.838)
Adjusted R^2	0.268	0.780	1.497	2.833	5.140	7.265
	(0.314)	(0.884)	(1.672)	(3.087)	(5.423)	(7.448)

which is substantially higher than 0.61 in the benchmark economy.

Lower vacancy costs mean that the representative household is more capable of smoothing the impact of exogenous productivity shocks by varying vacancy postings. As such, the volatility of output growth falls from 4.94% to 2.18%, and the volatility of consumption growth falls from 4.64% to 1.72% per annum. The autocorrelations of both fall from 0.24 to 0.14. As a result of consumption smoothing, the equity premium is even slightly negative, −0.69% per annum. The equity premium is also largely time-invariant, and is not forecastable by labor market tightness. Also, because vacancy is more responsive to shocks, so is the shadow value of an additional unit of labor, μ_t, from period to period. From equation (14), the sensitivity of μ_t translates to a high market volatility, 15.80% per annum, which is almost twice as large as the market volatility in the benchmark economy.

At the quarterly frequency, the standard deviation of labor market tightness is 0.11 in the low-κ model, which is lower than that in the benchmark model, 0.16. The standard deviation of vacancy is 0.09 in the low-κ economy, which is close to 0.10 in the benchmark economy. However, relative to output growth, vacancy has become more volatile in the low-κ economy. Because of the high job finding rate, the low unemployment rate fluctuates less with a low standard deviation of only 0.02.

4.3 The Workers' Bargaining Weight

Table 7 reports the comparative statics with the parameter of the workers' bargaining weight, η, increased from 0.10 in the benchmark economy to 0.25. A higher η makes the wage more cyclical and economic profits less cyclical. The elasticity of wage to labor productivity rises from 0.71 to 0.81. This effect weakens the operating leverage mechanism, and depresses the equity premium. Also, the wage eats up a higher portion of profits, and reduces firms' incentives to hire. The unemployment rate goes up to 23.33% from 12.14% in the benchmark economy.

The high-η economy shows more volatile and more persistent consumption growth and output growth than the benchmark economy. Intuitively, because a higher η makes wages more cyclical and profits less cyclical, firms are less responsive to shocks by varying vacancies. As such, unem-

Table 6 : Quantitative Results from the Model with a Low Vacancy Cost Parameter, $\kappa = 0.20$

Quantitative results are from the model with the κ parameter changed from 0.975 in the benchmark calibration to 0.20. All the other parameters remain unchanged. See Table 2's caption for the explanation of Panel A, Table 3's caption for Panel B, and Table 4's caption for Panel C.

Panel A: Unconditional financial moments

	Mean	5%	95%	p-value
σ_C	1.715	1.440	2.004	0.001
$\rho_C(1)$	0.142	−0.030	0.312	0.008
$\rho_C(2)$	−0.125	−0.299	0.055	0.025
$\rho_C(3)$	−0.093	−0.286	0.095	0.845
$\rho_C(5)$	−0.067	−0.252	0.121	0.116
σ_Y	2.176	1.834	2.543	0.000
$\rho_Y(1)$	0.142	−0.030	0.310	0.000
$\rho_Y(2)$	−0.125	−0.299	0.055	0.002
$\rho_Y(3)$	−0.093	−0.289	0.095	0.782
$\rho_Y(5)$	−0.067	−0.251	0.121	0.914
$E[R - R^f]$	−0.688	−3.468	1.691	0.000
$E[R^f]$	4.026	3.925	4.123	1.000
σ_R	15.802	13.697	18.348	0.990
σ_{R^f}	0.213	0.147	0.323	0.001

Panel B: Labor market moments

	U	V	V/U	X	
Standard deviation	0.022	0.091	0.105	0.016	
	(0.017)	(0.013)	(0.016)	(0.002)	
Quarterly autocorrelation	0.765	0.762	0.775	0.775	
	(0.056)	(0.041)	(0.038)	(0.039)	
	1	−0.780	−0.817	−0.812	U
		(0.098)	(0.093)	(0.096)	
Correlation matrix		1	0.999	0.999	V
			(0.002)	(0.002)	
			1	1.000	V/U
				(0.000)	
				1	X

Panel C: Long-horizon regressions of market excess returns on labor market tightness

	Forecast horizon (H) in months					
	1	3	6	12	24	36
Slope	−0.174	−0.512	−0.991	−1.905	−3.515	−4.877
	(0.211)	(0.620)	(1.190)	(2.216)	(3.955)	(5.348)
t_{NW}	−0.840	−0.884	−0.938	−1.086	−1.418	−1.703
	(1.016)	(1.075)	(1.143)	(1.293)	(1.659)	(1.938)
Adjusted R^2	0.252	0.742	1.404	2.662	4.863	6.705
	(0.333)	(0.960)	(1.726)	(3.117)	(5.484)	(7.311)

Table 7 : Quantitative Results from the Model with a High Bargaining Weight for the Worker, $\eta = 0.25$

Quantitative results are from the model with the η parameter changed from 0.10 in the benchmark calibration to 0.25. All the other parameters remain unchanged. See Table 2's caption for the explanation of Panel A, Table 3's caption for Panel B, and Table 4's caption for Panel C.

Panel A: Unconditional financial moments

	Mean	5%	95%	p-value
σ_C	7.557	4.592	13.443	1.000
$\rho_C(1)$	0.433	0.207	0.680	0.625
$\rho_C(2)$	−0.024	−0.259	0.295	0.236
$\rho_C(3)$	−0.130	−0.350	0.121	0.689
$\rho_C(5)$	−0.129	−0.353	0.100	0.086
σ_Y	7.637	4.710	13.491	0.907
$\rho_Y(1)$	0.423	0.200	0.676	0.212
$\rho_Y(2)$	−0.025	−0.257	0.293	0.119
$\rho_Y(3)$	−0.129	−0.350	0.118	0.616
$\rho_Y(5)$	−0.127	−0.348	0.103	0.765
$E[R - R^f]$	0.880	0.581	1.220	0.000
$E[R^f]$	3.537	3.059	3.973	1.000
σ_R	3.741	3.285	4.262	0.000
σ_{R^f}	1.846	1.210	2.979	0.389

Panel B: Labor market moments

	U	V	V/U	X	
Standard deviation	0.116	0.107	0.164	0.016	
	(0.023)	(0.023)	(0.031)	(0.002)	
Quarterly autocorrelation	0.926	0.680	0.835	0.773	
	(0.021)	(0.062)	(0.032)	(0.039)	
	1	−0.402	−0.697	−0.566	U
		(0.046)	(0.087)	(0.105)	
Correlation matrix		1	0.768	0.903	V
			(0.041)	(0.025)	
			1	0.955	V/U
				(0.033)	
				1	X

Panel C: Long-horizon regressions of market excess returns on labor market tightness

	Forecast horizon (H) in months					
	1	3	6	12	24	36
Slope	−0.715	−2.096	−4.053	−7.580	−13.472	−18.337
	(0.450)	(1.306)	(2.494)	(4.634)	(8.180)	(10.869)
t_{NW}	−1.732	−1.806	−1.899	−2.117	−2.687	−3.191
	(0.830)	(0.875)	(0.935)	(1.095)	(1.497)	(1.860)
Adjusted R^2	0.490	1.429	2.749	5.148	9.247	12.686
	(0.407)	(1.164)	(2.190)	(4.088)	(7.356)	(9.761)

ployment (and employment) become more responsive to shocks. It follows that output is more responsive to shocks. Also, because vacancy is less responsive, consumption must absorb more shocks and become more volatile and persistent.

In untabulated results, we verify that across one million simulated monthly periods, the standard deviation of unemployment is 6.17% in the benchmark economy but 10.94% in the high-η economy. Vacancy, in contrast, is more volatile in the benchmark economy: 1.26% versus 0.95%. The V/U ratio is also more volatile in the benchmark economy than in the high-η economy, 0.25 versus 0.11, in (unfiltered) simulated data. However, once we remove low frequency variations via the HP-filter, the standard deviation of the V/U ratio is largely similar across the two economies.

4.4 Risk Aversion

We conduct two more comparative static experiments by varying risk aversion, γ, from ten in the benchmark calibration to zero and then to 25. We again fix all the other parameters. In particular, the elasticity of intertemporal substitution, ψ, is pegged at 1.5, because a high value of ψ keeps the interest rate volatility low. We find that consistent with Tallarini (2000), risk aversion only affects asset pricing moments, while leaving business cycle moments largely unchanged.

Table 8 reports the quantitative results for the economy with a risk aversion of zero. The equity premium drops from 3.67% in the benchmark economy to -0.33% in the zero-γ economy (Panel A). And the equity premium is largely time-invariant (Panel C). Panel A also shows that the volatility and persistence of consumption growth and output growth are quantitatively close to the benchmark economy. Panel B shows further that the labor market moments barely change. In particular, the standard deviation of the V/U ratio and the V-U correlation are 0.15 and -0.52, which are close to 0.16 and -0.51 in the benchmark calibration, respectively.

Table 9 reports the quantitative results for the economy with a high risk aversion of 25. The equity premium rises drastically from 3.67% in the benchmark economy to 12.75% in the high-γ economy (Panel A). The volatility and persistence of consumption growth and output growth are

Table 8 : Quantitative Results from the Model with Low Risk Aversion, $\gamma = 0$

Quantitative results are from the model with risk aversion, γ, changed from ten in the benchmark calibration to zero. All the other parameters remain unchanged. See Table 2's caption for the explanation of Panel A, Table 3's caption for Panel B, and Table 4's caption for Panel C.

Panel A: Unconditional financial moments

	Mean	5%	95%	p-value
σ_C	4.445	2.584	9.411	0.768
$\rho_C(1)$	0.233	0.003	0.554	0.139
$\rho_C(2)$	−0.134	−0.337	0.119	0.076
$\rho_C(3)$	−0.128	−0.337	0.092	0.736
$\rho_C(5)$	−0.084	−0.307	0.134	0.137
σ_Y	4.752	2.916	9.631	0.279
$\rho_Y(1)$	0.227	0.000	0.546	0.052
$\rho_Y(2)$	−0.129	−0.330	0.119	0.031
$\rho_Y(3)$	−0.125	−0.334	0.091	0.658
$\rho_Y(5)$	−0.082	−0.302	0.129	0.856
$E[R - R^f]$	−0.326	−1.389	0.720	0.000
$E[R^f]$	3.975	3.712	4.200	1.000
σ_R	7.792	7.096	8.454	0.000
σ_{R^f}	1.325	0.839	2.355	0.107

Panel B: Labor market moments

	U	V	V/U	X	
Standard deviation	0.139	0.091	0.150	0.016	
	(0.056)	(0.019)	(0.028)	(0.002)	
Quarterly autocorrelation	0.876	0.619	0.804	0.774	
	(0.042)	(0.064)	(0.034)	(0.038)	
	1	−0.518	−0.704	−0.648	U
		(0.087)	(0.129)	(0.148)	
Correlation matrix		1	0.862	0.913	V
			(0.056)	(0.027)	
			1	0.989	V/U
				(0.019)	
				1	X

Panel C: Long-horizon regressions of market excess returns on labor market tightness

	Forecast horizon (H) in months					
	1	3	6	12	24	36
Slope	−0.478	−1.410	−2.752	−5.226	−9.559	−13.238
	(0.445)	(1.302)	(2.524)	(4.657)	(8.339)	(11.386)
t_{NW}	−1.137	−1.193	−1.260	−1.415	−1.779	−2.095
	(0.889)	(0.947)	(1.014)	(1.156)	(1.536)	(1.868)
Adjusted R^2	0.275	0.800	1.552	2.936	5.479	7.682
	(0.343)	(0.965)	(1.846)	(3.288)	(5.821)	(7.839)

only slightly higher than those in the benchmark economy. Panel B shows further that the labor market moments are again largely similar to those in the benchmark economy with $\gamma = 10$.

5 Conclusion

We study the equity premium with production by embedding the standard Diamond-Mortensen-Pissarides search and matching model of the labor market into a dynamic stochastic general equilibrium economy. The representative household has recursive Epstein-Zin preferences. With reasonable parameter values, the model reproduces an equity risk premium of 3.67% per annum and a low interest rate volatility of 1.44%. Also, the equity premium is time-varying, and is predictable by the vacancy-unemployment ratio in the model. We also confirm this predictability in the data. Intuitively, large job destruction flows, combined with search frictions, create rare but deep crashes in the model economy. As such, search frictions produce endogenously in the production economy rare disaster risk, as emphasized in the endowment economy by Rietz (1988) and Barro (2006).

References

Andolfatto, David, 1996, Business cycles and labor-market search, *American Economic Review* 86, 112–132.

Bansal, Ravi, and Amir Yaron, 2004, Risks for the long run: A potential resolution of asset pricing puzzles, *Journal of Finance* 59, 1481–1509.

Barro, Robert J., 2006, Rare disasters and asset markets in the twentieth century, *Quarterly Journal of Economics* 121, 823–866.

Boldrin, Michele, Lawrence J. Christiano, and Jonas D. M. Fisher, 2001, Habit persistence, asset returns, and the business cycle, *American Economic Review* 91, 149–166.

Campbell, John Y., and John H. Cochrane, 1999, By force of habit: A consumption-based explanation of aggregate stock market behavior, *Journal of Political Economy* 107, 205–251.

Chen, Long, and Lu Zhang, 2011, Do time-varying risk premiums explain labor market performance? *Journal of Financial Economics* 99, 385–399.

Christiano, Lawrence J., and Jonas D. M. Fisher, 2000, Algorithms for solving dynamic models with occasionally binding constraints, *Journal of Economic Dynamics and Control* 24, 1179–1232.

Table 9 : Quantitative Results from the Model with High Risk Aversion, $\gamma = 25$

Quantitative results are from the model with risk aversion, γ, changed from ten in the benchmark calibration to 25. All the other parameters remain unchanged. See Table 2's caption for the explanation of Panel A, Table 3's caption for Panel B, and Table 4's caption for Panel C.

Panel A: Unconditional financial moments

	Mean	5%	95%	p-value
σ_C	5.233	2.968	10.738	0.933
$\rho_C(1)$	0.272	0.038	0.554	0.213
$\rho_C(2)$	−0.116	−0.328	0.155	0.101
$\rho_C(3)$	−0.131	−0.348	0.101	0.700
$\rho_C(5)$	−0.090	−0.314	0.141	0.124
σ_Y	5.495	3.256	10.919	0.428
$\rho_Y(1)$	0.265	0.032	0.552	0.055
$\rho_Y(2)$	−0.112	−0.325	0.151	0.037
$\rho_Y(3)$	−0.128	−0.343	0.097	0.632
$\rho_Y(5)$	−0.089	−0.308	0.128	0.849
$E[R - R^f]$	12.749	11.049	14.097	1.000
$E[R^f]$	2.983	2.602	3.368	1.000
σ_R	7.418	6.721	8.151	0.000
σ_{R^f}	1.543	1.001	2.615	0.177

Panel B: Labor market moments

	U	V	V/U	X	
Standard deviation	0.147	0.098	0.163	0.016	
	(0.050)	(0.021)	(0.030)	(0.002)	
Quarterly autocorrelation	0.888	0.620	0.807	0.773	
	(0.038)	(0.067)	(0.035)	(0.039)	
	1.000	−0.486	−0.685	−0.636	U
		(0.075)	(0.118)	(0.132)	
Correlation matrix		1	0.837	0.909	V
			(0.058)	(0.023)	
			1	0.984	V/U
				(0.021)	
				1	X

Panel C: Long-horizon regressions of market excess returns on labor market tightness

	Forecast horizon (H) in months					
	1	3	6	12	24	36
Slope	−0.202	−0.586	−1.117	−2.075	−3.809	−5.583
	(0.560)	(1.643)	(3.195)	(6.093)	(11.051)	(15.261)
t_{NW}	−0.312	−0.331	−0.353	−0.415	−0.592	−0.815
	(1.349)	(1.406)	(1.483)	(1.669)	(2.047)	(2.354)
Adjusted R^2	0.263	0.768	1.474	2.774	4.860	6.455
	(0.348)	(1.007)	(1.881)	(3.423)	(5.832)	(7.602)

Clark, Kim B., 1990, Unemployment insurance and labor market transitions, in *Understanding Unemployment*, Lawrence Summers, ed. MIT Press, Cambridge Massachusetts.

Danthine, Jean-Pierre, and John B. Donaldson, 2002, Labour relations and asset returns, *Review of Economic Studies* 69, 41–64.

Davis, Steven J., R. Jason Faberman, John Haltiwanger, 2006, The flow approach to labor markets: New data sources and micro-macro links, *Journal of Economic Perspectives* 20, 3–26.

Epstein, Larry G., and Stanley E. Zin, 1989, Substitution, risk aversion, and the temporal behavior of consumption and asset returns: A theoretical framework, *Econometrica* 57, 937–969.

Frank, Murray Z., and Vidhan K. Goyal, 2008, Trade-off and pecking order theories of debt, in *Handbook of Corporate Finance: Empirical Corporate Finance* edited by Espen Eckbo, Volume 2, 135–202, Elsevier Science, North Holland.

Gertler, Mark, and Antonella Trigari, 2009, Unemployment fluctuations with staggered Nash wage bargaining, *Journal of Political Economy* 117, 38–86.

Guvenen, Fatih, 2009, A parsimonious macroeconomic model for asset pricing, *Econometrica* 77, 1711–1750.

Hagedorn, Marcus, and Iourii Manovskii, 2008, The cyclical behavior of equilibrium unemployment and vacancies revisited, *American Economic Review* 98, 1692–1706.

Hall, Robert E., 2005, Employment fluctuations with equilibrium wage stickiness, 2005, *American Economic Review* 95, 50–65.

Hodrick, Robert J., and Edward C. Prescott, 1997, Postwar U.S. business cycles: An empirical investigation, *Journal of Money, Credit, and Banking* 29, 1–16.

Jermann, Urban J., 1998, Asset pricing in production economies, *Journal of Monetary Economics* 41, 257–275.

Kaltenbrunner, Georg, and Lars Lochstoer, 2010, Long-run risk through consumption smoothing, *Review of Financial Studies* 23, 3190–3224.

Krause, Michael U., and Thomas 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.

Lettau, Martin, and Sydney Ludvigson, 2001, Consumption, aggregate wealth, and expected stock returns, *Journal of Finance* 56, 815–849.

Lettau, Martin, and Harald Uhlig, 2000, Can habit formation be reconciled with business cycle facts? *Review of Economic Dynamics* 3, 79–99.

Liu, Laura Xiaolei, Toni M. Whited, and Lu Zhang, 2009, Investment-based expected stock returns, *Journal of Political Economy* 117, 1105–1139.

Merz, Monika, 1995, Search in labor market and the real business cycle, *Journal of Monetary Economics* 95, 269–300.

Miranda, Mario J., and Paul L. Fackler, 2002, *Applied Computational Economics and Finance*, The MIT Press, Cambridge, Massachusetts.

Mortensen, Dale T., 1982, The matching process as a noncooperative bargaining game, in J. J. McCall, ed., *The Economics of Information and Uncertainty*, Chicago: University of Chicago Press, 233–254.

Newey, Whitney K., and Kenneth D. West, 1987, A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix, *Econometrica* 55, 703–708.

Petrongolo, Barbara, and Christopher A. Pissarides, 2001, Looking into the black box: A survey of the matching function, *Journal of Economic Literature* 39, 390–431.

Pissarides, Christopher A., 1985, Short-run dynamics of unemployment, vacancies, and real wages, *American Economic Review* 75, 676–690.

Pissarides, Christopher A., 2000, *Equilibrium Unemployment Theory* 2nd ed., Cambridge MA: MIT Press.

Rietz, Thomas A., 1988, The equity risk premium: A solution, *Journal of Monetary Economics* 22, 117–131.

Rouwenhorst, K. Geert, 1995, Asset pricing implications of equilibrium business cycle models, in T. Cooley ed., *Frontiers of Business Cycle Research*, Princeton: Princeton University Press, 294–330.

Shimer, Robert, 2005, The cyclical behavior of equilibrium unemployment and vacancies, *American Economic Review* 95, 25–49.

Tallarini, Thomas D., 2000, Risk-sensitive real business cycles, *Journal of Monetary Economics* 45, 507–532.

Uhlig, Harald, 2007, Explaining asset prices with external habits and wage rigidities in a DSGE model, *American Economic Review* 97, 239–243.

A The Stock Return Equation

We prove equation (14) following an analogous proof in Liu, Whited, and Zhang (2009) in the context of the q-theory of investment. Rewrite the equity value maximization problem as:

$$S_t = \max_{\{V_{t+\triangle t}, N_{t+\triangle t+1}\}} E_t \left[\sum_{\triangle t=0}^{\infty} M_{t+\triangle t} \left[\begin{array}{c} X_{t+\triangle t} N_{t+\triangle t} - W_{t+\triangle t} N_{t+\triangle t} - \kappa V_{t+\triangle t} \\ -\mu_{t+\triangle t}[N_{t+\triangle t+1} - (1-s)N_{t+\triangle t} \\ -V_{t+\triangle t} q(\theta_{t+\triangle t})] + \lambda_{t+\triangle t} q(\theta_{t+\triangle t}) V_{t+\triangle t} \end{array} \right] \right], \tag{A.1}$$

in which μ_t is the Lagrange multiplier on the employment accumulation equation, and λ_t is the Lagrange multiplier on the irreversibility constraint on job creation. The first order conditions are equations (9) and (10), and the Kuhn-Tucker condition is equation (13).

Define dividends as $D_t = X_t N_t - W_t N_t - \kappa V_t$ and the ex-dividend equity value as $P_t = S_t - D_t$. Expanding S_t yields:

$$\begin{aligned} P_t + X_t N_t - W_t N_t - \kappa V_t = S_t = X_t N_t - W_t N_t - \kappa V_t - \mu_t \left[N_{t+1} - (1-s)N_t - V_t q(\theta_t) \right] + \lambda_t q(\theta_t) V_t \\ + E_t M_{t+1} \left[X_{t+1} N_{t+1} - W_{t+1} N_{t+1} - \kappa V_{t+1} - \mu_{t+1} \left[N_{t+2} - (1-s) N_{t+1} - V_{t+1} q(\theta_{t+1}) \right] \right. \\ \left. + \lambda_{t+1} q(\theta_{t+1}) V_{t+1} \right] + \ldots \end{aligned} \tag{A.2}$$

Recursively substituting equations (9) and (10) yields: $P_t + X_t N_t - W_t N_t - \kappa V_t = X_t N_t - W_t N_t + \mu_t (1-s) N_t$. Using equation (9) to simplify further: $P_t = \kappa V_t + \mu_t (1-s) N_t = \mu_t [(1-s)N_t + q(\theta_t)V_t] + \lambda_t q(\theta_t) V_t = \mu_t N_{t+1}$, in which the last equality follows from the Kuhn-Tucker condition (13).

To show equation (14), we expand the stock returns:

$$\begin{aligned} R_{t+1} &= \frac{S_{t+1}}{S_t - D_t} = \frac{\mu_{t+1} N_{t+2} + X_{t+1} N_{t+1} - W_{t+1} N_{t+1} - \kappa V_{t+1}}{\mu_t N_{t+1}} \\ &= \frac{X_{t+1} - W_{t+1} - \kappa \frac{V_{t+1}}{N_{t+1}} + \mu_{t+1} \left[(1-s) + q(\theta_{t+1}) \frac{V_{t+1}}{N_{t+1}} \right]}{\mu_t} \\ &= \frac{X_{t+1} - W_{t+1} + (1-s)\mu_{t+1}}{\mu_t} + \frac{1}{\mu_t N_{t+1}} \left[\mu_{t+1} q(\theta_{t+1}) V_{t+1} - \kappa V_{t+1} \right] \\ &= \frac{X_{t+1} - W_{t+1} + (1-s)\mu_{t+1}}{\mu_t}, \end{aligned} \tag{A.3}$$

in which the last equality follows because $\mu_{t+1} q(\theta_{t+1}) V_{t+1} - \kappa V_{t+1} = -\lambda_{t+1} q(\theta_{t+1}) V_{t+1} = 0$ from the Kuhn-Tucker condition. ■

B Wage Determination under Nash Bargaining

Let $0 < \eta < 1$ denote the relative bargaining weight of the worker, J_{Nt} the marginal value of an employed worker to the representative family, J_{Ut} the marginal value of an unemployed worker to the representative family, ϕ_t the marginal utility of the representative family, S_{Nt} the marginal value of an employed worker to the representative firm, and S_{Vt} the marginal value of an unemployed worker to the representative firm. Let $\Lambda_t \equiv (J_{Nt} - J_{Ut})/\phi_t + S_{Nt} - S_{Vt}$ be the total surplus from the Nash bargain. The wage equation (19) is determined via the Nash worker-firm bargain:

$$\max_{\{W_t\}} \quad \left(\frac{J_{Nt} - J_{Ut}}{\phi_t}\right)^{\eta} (S_{Nt} - S_{Vt})^{1-\eta}, \tag{B.1}$$

The outcome of maximizing equation (B.1) is the surplus-sharing rule:

$$\frac{J_{Nt} - J_{Ut}}{\phi_t} = \eta\Lambda_t = \eta\left(\frac{J_{Nt} - J_{Ut}}{\phi_t} + S_{Nt} - S_{Vt}\right). \tag{B.2}$$

As such, the worker receives a fraction of η of the total surplus from the wage bargain. In what follows, we derive the wage equation (19) from the sharing rule in equation (B.2).

B.1 Workers

Let ϕ_t denote the Lagrange multiplier for the household's budget constraint (16). The household's maximization problem is given by:

$$J_t = \left[(1-\beta)C_t^{1-\frac{1}{\psi}} + \beta\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1-1/\psi}{1-\gamma}}\right]^{\frac{1}{1-1/\psi}} - \phi_t\left(\frac{\Pi_{t+1}}{R_{t+1}^{\Pi}} - \Pi_t + C_t - W_t N_t - U_t b + T_t\right), \tag{B.3}$$

The first-order condition for consumption yields:

$$\phi_t = (1-\beta)C_t^{-\frac{1}{\psi}}\left[(1-\beta)C_t^{1-\frac{1}{\psi}} + \beta\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1-1/\psi}{1-\gamma}}\right]^{\frac{1}{1-1/\psi}-1}, \tag{B.4}$$

which gives the marginal utility of consumption.

Recalling $N_{t+1} = (1-s)N_t + f(\theta_t)U_t$ and $U_{t+1} = sN_t + (1 - f(\theta_t))U_t$, we differentiate J_t in equation (B.3) with respect to N_t:

$$\begin{aligned} J_{Nt} &= \phi_t W_t + \frac{1}{1-\frac{1}{\psi}}\left[(1-\beta)C_t^{1-\frac{1}{\psi}} + \beta\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1-1/\psi}{1-\gamma}}\right]^{\frac{1}{1-1/\psi}-1} \\ &\quad \times\frac{1-\frac{1}{\psi}}{1-\gamma}\beta\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1-1/\psi}{1-\gamma}-1} E_t\left[(1-\gamma)J_{t+1}^{-\gamma}[(1-s)J_{Nt+1} + sJ_{Ut+1}]\right]. \end{aligned} \tag{B.5}$$

Dividing both sides by ϕ_t:

$$\frac{J_{Nt}}{\phi_t} = W_t + \frac{\beta}{(1-\beta)C_t^{-\frac{1}{\psi}}} \left[\frac{1}{\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1}{1-\gamma}}} \right]^{\frac{1}{\psi}-\gamma} E_t\left[J_{t+1}^{-\gamma}[(1-s)J_{Nt+1} + sJ_{Ut+1}]\right]. \tag{B.6}$$

Dividing and multiplying by ϕ_{t+1}:

$$\begin{aligned} \frac{J_{Nt}}{\phi_t} &= W_t + E_t\left[\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\frac{1}{\psi}} \left[\frac{J_{t+1}}{\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1}{1-\gamma}}}\right]^{\frac{1}{\psi}-\gamma} \left[(1-s)\frac{J_{Nt+1}}{\phi_{t+1}} + s\frac{J_{Ut+1}}{\phi_{t+1}}\right]\right] \\ &= W_t + E_t\left[M_{t+1}\left[(1-s)\frac{J_{Nt+1}}{\phi_{t+1}} + s\frac{J_{Ut+1}}{\phi_{t+1}}\right]\right]. \end{aligned} \tag{B.7}$$

Similarly, differentiating J_t in equation (B.3) with respect to U_t yields:

$$\begin{aligned} J_{Ut} &= \phi_t b + \frac{1}{1-\frac{1}{\psi}}\left[(1-\beta)C_t^{1-\frac{1}{\psi}} + \beta\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1-1/\psi}{1-\gamma}}\right]^{\frac{1}{1-1/\psi}-1} \\ &\times\frac{1-\frac{1}{\psi}}{1-\gamma}\beta\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1-1/\psi}{1-\gamma}-1} E_t\left[(1-\gamma)J_{t+1}^{-\gamma}[f(\theta_t)J_{Nt+1} + (1-f(\theta_t))J_{Ut+1}]\right]. \end{aligned} \tag{B.8}$$

Dividing both sides by ϕ_t:

$$\frac{J_{Ut}}{\phi_t} = b + \frac{\beta}{(1-\beta)C_t^{-\frac{1}{\psi}}}\left[\frac{1}{\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1}{1-\gamma}}}\right]^{\frac{1}{\psi}-\gamma} E_t\left[J_{t+1}^{-\gamma}[f(\theta_t)J_{Nt+1} + (1-f(\theta_t))J_{Ut+1}]\right]. \tag{B.9}$$

Dividing and multiplying by ϕ_{t+1}:

$$\begin{aligned} \frac{J_{Ut}}{\phi_t} &= b + E_t\left[\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\frac{1}{\psi}}\left[\frac{J_{t+1}}{\left[E_t\left(J_{t+1}^{1-\gamma}\right)\right]^{\frac{1}{1-\gamma}}}\right]^{\frac{1}{\psi}-\gamma}\left[f(\theta_t)\frac{J_{Nt+1}}{\phi_{t+1}} + (1-f(\theta_t))\frac{J_{Ut+1}}{\phi_{t+1}}\right]\right] \\ &= b + E_t\left[M_{t+1}\left[f(\theta_t)\frac{J_{Nt+1}}{\phi_{t+1}} + (1-f(\theta_t))\frac{J_{Ut+1}}{\phi_{t+1}}\right]\right]. \end{aligned} \tag{B.10}$$

B.2 The Firm

We start by rewriting the infinite-horizon value-maximization problem of the firm recursively as:

$$S_t = X_tN_t - W_tN_t - \kappa V_t + \lambda_t q(\theta_t)V_t + E_t[M_{t+1}S_{t+1}], \tag{B.11}$$

subject to $N_{t+1} = (1-s)N_t + q(\theta_t)V_t$. The first-order condition with respect to V_t says:

$$S_{Vt} = -\kappa + \lambda_t q(\theta_t) + E_t[M_{t+1} S_{Nt+1} q(\theta_t)] = 0 \tag{B.12}$$

Equivalently,

$$\frac{\kappa}{q(\theta_t)} - \lambda_t = E_t[M_{t+1} S_{Nt+1}] \tag{B.13}$$

In addition, differentiating S_t with respect to N_t yields:

$$S_{Nt} = X_t - W_t + E_t[M_{t+1}(1-s)S_{Nt+1}]. \tag{B.14}$$

Combining the last two equations yields the intertemporal job creation condition in equation (11).

B.3 The Wage Equation

From equations (B.7), (B.10), and (B.14), the total surplus of the worker-firm relationship is:

$$\begin{aligned}
\Lambda_t &= W_t + E_t\left[M_{t+1}\left[(1-s)\frac{J_{Nt+1}}{\phi_{t+1}} + s\frac{J_{Ut+1}}{\phi_{t+1}}\right]\right] \\
&\quad -b - E_t\left[M_{t+1}\left[f(\theta_t)\frac{J_{Nt+1}}{\phi_{t+1}} + (1-f(\theta_t))\frac{J_{Ut+1}}{\phi_{t+1}}\right]\right] \\
&\quad +X_t - W_t + E_t[M_{t+1}(1-s)S_{Nt+1}] \\
&= X_t - b + (1-s)E_t\left[M_{t+1}\left(\frac{J_{Nt+1} - J_{Ut+1}}{\phi_{t+1}} + S_{Nt+1}\right)\right] - f(\theta_t)E_t\left[M_{t+1}\frac{J_{Nt+1} - J_{Ut+1}}{\phi_{t+1}}\right] \\
&= X_t - b + (1-s)E_t\left[M_{t+1}\Lambda_{t+1}\right] - \eta f(\theta_t)E_t\left[M_{t+1}\Lambda_{t+1}\right],
\end{aligned} \tag{B.15}$$

in which the last equality follows from the definition of Λ_t and the surplus sharing rule (B.2).

The surplus sharing rule implies $S_{Nt} = (1-\eta)\Lambda_t$, which, combined with equation (B.14), yields:

$$(1-\eta)\Lambda_t = X_t - W_t + (1-\eta)(1-s)E_t\left[M_{t+1}\Lambda_{t+1}\right]. \tag{B.16}$$

Combining equations (B.15) and (B.16) yields:

$$\begin{aligned}
X_t - W_t + (1-\eta)(1-s)E_t\left[M_{t+1}\Lambda_{t+1}\right] &= (1-\eta)(X_t - b) + (1-\eta)(1-s)E_t\left[M_{t+1}\Lambda_{t+1}\right] \\
&\quad -(1-\eta)\eta f(\theta_t)E_t\left[M_{t+1}\Lambda_{t+1}\right] \\
X_t - W_t &= (1-\eta)(X_t - b) - (1-\eta)\eta f(\theta_t)E_t\left[M_{t+1}\Lambda_{t+1}\right] \\
W_t &= \eta X_t + (1-\eta)b + (1-\eta)\eta f(\theta_t)E_t\left[M_{t+1}\Lambda_{t+1}\right]
\end{aligned}$$

Using equations (B.2) and (B.13) to simplify further:

$$W_t = \eta X_t + (1-\eta)b + \eta f(\theta_t) E_t\left[M_{t+1} S_{Nt+1}\right] \quad \text{(B.17)}$$

$$W_t = \eta X_t + (1-\eta)b + \eta f(\theta_t)\left(\frac{\kappa}{q(\theta_t)} - \lambda_t\right) \quad \text{(B.18)}$$

Using the Kuhn-Tucker condition, when $V_t > 0$, then $\lambda_t = 0$, and equation (B.18) reduces to the wage equation (19) because $f(\theta_t) = \theta_t q(\theta_t)$. On the other hand, when the irreversibility constraint is binding, $\lambda_t > 0$, but $V_t = 0$ means $\theta_t = 0$ and $f(\theta_t) = 0$. Equation (B.18) reduces to $W_t = \eta X_t + (1-\eta)b$. Because $\theta_t = 0$, the wage equation (19) continues to hold.

C The Projection Algorithm with Parameterized Expectations

We solve the model using the projection method, combined with parameterized expectations.

C.1 The Projection Method

The state space for the model is (N_t, x_t), in which $N_t \in (N_{\min}, N_{\max})$ and $x_t \equiv \log(X_t)$. A traditional projection algorithm would be to solve for the optimal vacancy function: $V_t = V(N_t, x_t)$, the Lagrange multiplier: $\lambda_t = \lambda(N_t, x_t)$, and an indirect utility function: $J_t = J(N_t, x_t)$ from the following two functional equations:

$$J(N_t, x_t) = \left[(1-\beta)C(N_t, x_t)^{1-\frac{1}{\psi}} + \beta\left(E_t\left[J(N_{t+1}, x_{t+1})^{1-\gamma}\right]\right)^{\frac{1-1/\psi}{1-\gamma}}\right]^{\frac{1}{1-1/\psi}} \quad \text{(C.1)}$$

$$\frac{\kappa}{q(\theta_t)} - \lambda(N_t, x_t) = E_t\left[M_{t+1}\left[X_{t+1} - W_{t+1} + (1-s)\left(\frac{\kappa}{q(\theta_{t+1})} - \lambda(N_{t+1}, x_{t+1})\right)\right]\right]. \quad \text{(C.2)}$$

$V(N_t, x_t)$ and $\lambda(N_t, x_t)$ must also satisfy the Kuhn-Tucker condition: $V_t \geq 0, \lambda_t \geq 0$, and $\lambda_t V_t = 0$.

In the numerical implementation, the two functional equations should be expressed only in terms of state variables N_t and x_t. To this end, we perform the following set of substitutions:

$$N_{t+1} = (1-s)N_t + \frac{U_t V_t}{(U_t^\iota + V_t^\iota)^{1/\iota}}; \quad \text{(C.3)}$$

$$U_t = 1 - N_t; \quad \text{(C.4)}$$

$$x_{t+1} = \rho x_t + \sigma \epsilon_{t+1}; \quad \text{(C.5)}$$

$$C(N_t, x_t) = \exp(x_t) N_t - \kappa V(N_t, x_t); \quad \text{(C.6)}$$

$$q(\theta_t) = \left[1 + \left(\frac{V(N_t, x_t)}{1 - N_t}\right)^\iota\right]^{-\frac{1}{\iota}}; \quad \text{(C.7)}$$

$$M_{t+1} = \beta\left[\frac{C(N_{t+1}, x_{t+1})}{C(N_t, x_t)}\right]^{-\frac{1}{\psi}}\left[\frac{J(N_{t+1}, x_{t+1})}{E_t[J(N_{t+1}, x_{t+1})^{1-\gamma}]^{\frac{1}{1-\gamma}}}\right]^{\frac{1}{\psi}-\gamma}; \quad \text{(C.8)}$$

and

$$W_t = \eta \left[\exp(x_t) + \kappa \frac{V(N_t, x_t)}{1 - N_t} \right] + (1 - \eta) b. \tag{C.9}$$

The traditional projection method parameterizes the vacancy policy function, $V(N_t, x_t)$, and the multiplier function, $\lambda(N_t, x_t)$, such that the parameterized functions solve the two functional equations, while obeying the Kuhn-Tucker condition. As pointed out by Christiano and Fisher (2000), with occasionally binding constraints, this traditional approach is tricky and cumbersome.

C.2 Parameterized Expectations

We follow Christiano and Fisher (2000) in parameterizing a conditional expectation function in the job creation equation. This parameterized expectations approach exploits a convenient mapping from the conditional expectation function to policy and multiplier functions, thereby eliminating the need to separately parameterize the multiplier function. Specifically, we parameterize:

$$\mathcal{E}_t \equiv \mathcal{E}(N_t, x_t) = E_t \left[M_{t+1} \left[X_{t+1} - W_{t+1} + (1 - s) \left(\frac{\kappa}{q(\theta_{t+1})} - \lambda(N_{t+1}, x_{t+1}) \right) \right] \right]. \tag{C.10}$$

With the parameterized $\mathcal{E}_t$, we first calculate:

$$\bar{q}(\theta_t) = \frac{\kappa}{\mathcal{E}_t}. \tag{C.11}$$

If $\bar{q}(\theta_t) < 1$, the irreversibility constraint is not binding, we set $\lambda_t = 0$ and $q(\theta_t) = \bar{q}(\theta_t)$. We solve $\theta_t = q^{-1}(\kappa / \mathcal{E}_t)$, in which $q^{-1}(\cdot)$ is the inverse function of $q(\cdot)$ given by equation (3), and $V_t = \theta_t(1 - N_t)$. If $\bar{q}(\theta_t) \geq 1$, the irreversibility constraint is binding, we set $V_t = 0$, $\theta_t = 0$, $q(\theta_t) = 1$, and $\lambda_t = \kappa - \mathcal{E}_t$. This approach is convenient in practice because it enforces the Kuhn-Tucker condition automatically, and eliminates the need of parameterizing the multiplier function.

C.3 Additional Qualitative Properties of the Model's Solution

We approximate the first-order autoregressive process of $\log(X_t)$ based on the discrete state space method of Rouwenhorst (1995) with 15 grid points. Kopecky and Suen (2010) show that this method is more reliable and accurate than other methods in approximating highly persistent processes. We use cubic splines with 40 basis functions on the N space to approximate $\mathcal{E}(N_t, x_t)$ on each grid of x. We set $N_{\min} = 0.03$ and $N_{\max} = 0.99$. With x on the discrete state space, conditional expectations are implemented as matrix multiplication. Our projection programs use extensively the approximation took kit in the CompEcon Toolbox of Miranda and Fackler (2002). In practice, we use the numerical solution to the social planner's problem solved via value function iteration as the initial guess for the projection algorithm. The social planner takes into account the congestion effect of posting a new vacancy on labor market tightness, whereas the firm in the decentralized economy does not. In particular, the firm takes $q(\theta_t)$ as given, but the social planner does not.

Figure C.1 : Errors in the J and $\mathcal{E}$ Functional Equations

The J function error is $J(N_t, x_t)^{1-\frac{1}{\psi}} - (1-\beta)C(N_t, x_t)^{1-\frac{1}{\psi}} - \beta\left(E_t\left[J(N_{t+1}, x_{t+1})^{1-\gamma}\right]\right)^{\frac{1-1/\psi}{1-\gamma}}$, and the $\mathcal{E}$ function error is $\mathcal{E}(N_t, x_t) - E_t\left[M_{t+1}\left[X_{t+1} - W_{t+1} + (1-s)\left(\frac{\kappa}{q(\theta_{t+1})} - \lambda(N_{t+1}, x_{t+1})\right)\right]\right]$. See Section C.1 for variable definitions. We plot the errors on the two-dimensional grid of N_t and x_t.

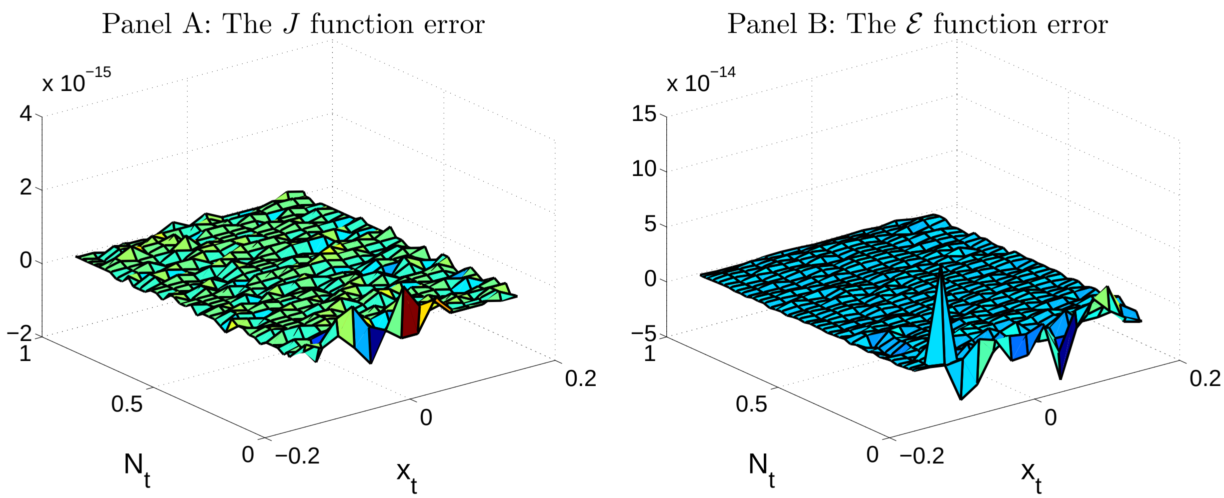


Figure C.1 reports the error in the J functional equation (C.1) and the error in the $\mathcal{E}$ functional equation (C.10), defined as $J(N_t, x_t)^{1-\frac{1}{\psi}} - (1-\beta)C(N_t, x_t)^{1-\frac{1}{\psi}} - \beta\left(E_t\left[J(N_{t+1}, x_{t+1})^{1-\gamma}\right]\right)^{\frac{1-1/\psi}{1-\gamma}}$ and $\mathcal{E}(N_t, x_t) - E_t\left[M_{t+1}\left[X_{t+1} - W_{t+1} + (1-s)\left(\frac{\kappa}{q(\theta_{t+1})} - \lambda(N_{t+1}, x_{t+1})\right)\right]\right]$, respectively. These errors, in the magnitude of 10^{-14}, are extremely small. As such, the projection algorithm with parameterized expectations does an accurate job in solving the two functional equations that characterize the competitive equilibrium in the search economy.

Figure C.2 reports additional properties of the model's solution not shown in Section 3.2. The indirect utility function, $J(N_t, x_t)$, is increasing in both N_t and x_t (Panel A). The multiplier on the employment accumulation equation (4), $\mu(N_t, x_t)$, is identical to the conditional expectation, $\mathcal{E}(N_t, x_t)$ (Panel B). Not surprisingly, optimal consumption, C_t, is weakly procyclical, and is decreasing in employment, N_t (Panel C). Sensibly, the stock price, P_t, is procyclical, and is increasing in N_t (Panel D). The job finding rate, $f(\theta_t)$, is procyclical, and is increasing in employment, N_t (Panel E). Finally, wage is also procyclical, and is increasing in employment (Panel F).

Figure C.3 reports additional results for the model's stationary distribution not reported in Section 3.3. Panel A shows that dividend largely inherits the same disaster-like behavior as output and consumption. From Panel B, the irreversibility constraint on vacancy binds only infrequently. The remaining panels show that vacancy, labor market tightness, the job-filling rate, and wage largely inherit the shape of cumulative distribution function of the exogenous aggregate productivity, $\log(X_t)$.

Figure C.2 : Additional Qualitative Properties of the Model: Indirect Utility, the Multiplier on Employment Accumulation, Consumption, Stock Price, Job Finding Rate, and Wage

We plot the following variables on the two-dimensional grid of N_t and x_t: $J(N_t, x_t)$ is the indirect utility in equation (C.1); $\mu(N_t, x_t)$ is the multiplier on the employment accumulation equation (4); $C(N_t, x_t)$ is consumption; $P(N_t, x_t) = \mu_t N_{t+1}$ is the stock price; $f(N_t, x_t)$ is the job finding rate in equation (2); and $W(N_t, x_t)$ is the wage rate in equation (C.9).

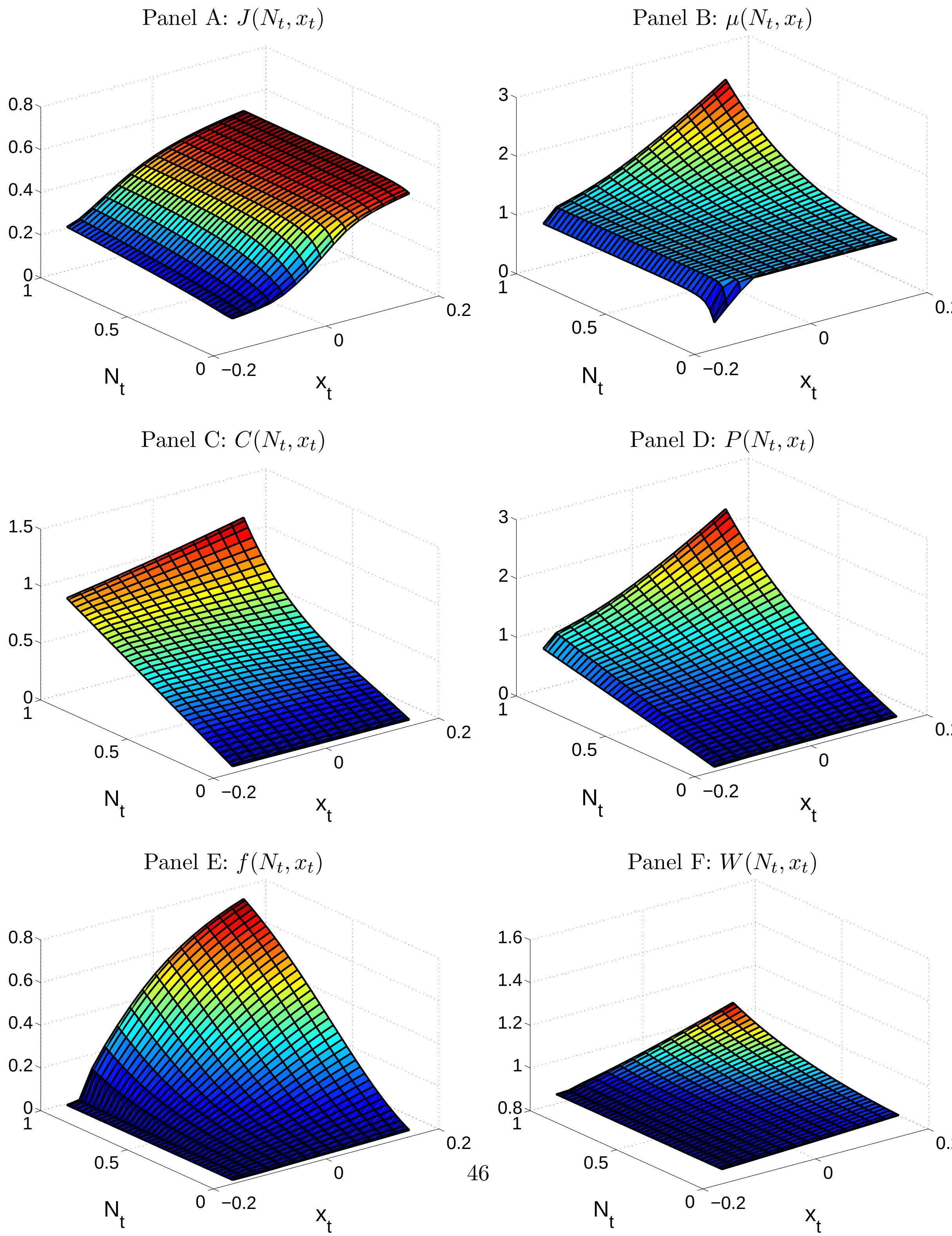


Figure C.3 : Empirical Stationary Distribution of the Model: Dividend, the Multiplier on the Irreversibility Constraint of Vacancy, Vacancy, Labor Market Tightness, the Vacancy-Filling Rate, and Wage

We simulate 1,006,000 monthly periods from the model, discard the first 6,000 periods, and treat the remaining as from the stationary distribution. We plot the empirical cumulative distribution functions, $ECDF(\cdot)$, for dividend (D_t), the multiplier on the irreversibility constraint of vacancy (λ_t), vacancy (V_t), labor market tightness (θ_t), the vacancy-filling rate (q_t), and wage (W_t).