NBER WORKING PAPER SERIES

RISK, UNEMPLOYMENT, AND THE STOCK MARKET:
A RARE-EVENT-BASED EXPLANATION OF LABOR MARKETVOLATILITY

Mete Kilic
Jessica A. Wachter

Working Paper 21575
http://www.nber.org/papers/w21575

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
September 2015

We are grateful to Andy Abel, Gabriel Chodorow-Reich, Zvi Eckstein, Joao Gomes, Urban Jermann, Christian Opp, Sang Byung Seo, Mathieu Taschereau-Dumouchel, Nancy Ran Xu, Amir Yaron, and seminar participants at the Wharton School, at the Trans-Atlantic Doctoral Conference, and at the Western Finance Association Meetings for helpful comments. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Risk, Unemployment, and the Stock Market: A Rare-Event-Based Explanation of Labor MarketVolatility
Mete Kilic and Jessica A. Wachter
NBER Working Paper No. 21575
September 2015
JEL No. E24,E32,G12

ABSTRACT

What is the driving force behind the cyclical behavior of unemployment and vacancies? What is the relation between job creation incentives of firms and stock market valuations? This paper proposes an explanation of labor market volatility based on time-varying risk, modeled as a small and variable probability of an economic disaster. A high probability of a disaster implies greater risk and lower future growth, which lowers the incentives of firms to invest in hiring. During periods of high disaster risk, stock market valuations are low and unemployment rises. The risk of a disaster generates a realistic equity premium, while time- variation in the disaster probability generates the correct magnitude for volatility in vacancies and unemployment. The model can thus explain the comovement of unemployment and stock market valuations present in the data.

Mete Kilic
The Wharton School
3620 Locust Walk, 2300 SH-DH
Philadelphia, PA 19104
mkilic@wharton.upenn.edu

Jessica A. Wachter
Department of Finance
2300 SH-DH
The Wharton School
University of Pennsylvania
3620 Locust Walk
Philadelphia, PA 19104
and NBER
jwachter@wharton.upenn.edu

1 Introduction

The Diamond-Mortensen-Pissarides (DMP) model of search and matching offers an intriguing theory of labor market fluctuations based on the job creation incentives of employers (Diamond (1982), Pissarides (1985), Mortensen and Pissarides (1994), Pissarides (2000)). When the contribution of a new hire to firm value decreases, employers reduce investment in hiring, decreasing the number of vacancies and, in turn, increasing unemployment. Due to the glut of jobseekers in the labor market, vacancies become easier for employers to fill. Therefore, unemployment stabilizes at a higher level and the number of vacancies at a lower level. That is, labor market tightness (defined as the ratio of vacancies to unemployment) decreases until the payoff to hiring changes again.

While the mechanism of the DMP model is intuitively promising, there is a fundamental question concerning the model: what is the driving force behind the cyclical behavior of job creation incentives? In the canonical DMP model and numerous successor models, the driving force is labor productivity. However, explaining labor market volatility based on productivity fluctuations is difficult, because unemployment and vacancies are much more volatile than labor productivity (Shimer (2005)). Furthermore, unemployment does not track the movements of labor productivity, as is particularly apparent in the last three recessions. Rather, these recent data suggest a link between unemployment and stock market valuations (Hall (2014)).

In this paper, we make use of the DMP mechanism to explain unemployment, as in the prior literature. However, rather than linking labor market tightness to productivity itself, we propose an equilibrium model in which fluctuations in labor market tightness arise from a small and time-varying probability of an economic disaster. We characterize recessions as periods when disaster risk is high, implying both greater risk in productivity and lower expected growth rates. Thus even if labor productivity remains constant, disaster fears lower the job-creation incentives of firms. The labor market equilibrium shifts to a lower point on the vacancy-unemployment locus (the Beveridge curve), with higher unemployment and lower vacancy openings. At the same time, stock market valuations decline.

Our model generates a high volatility in unemployment and vacancies, along with a strong negative correlation between the two. This is consistent with U.S. data. We calibrate wage dynamics to match the behavior of the labor share in the data and find that matching the observed low response of wages to labor market conditions is crucial for both labor market volatility and realistic behavior of financial markets. Furthermore, the search and matching friction in the labor market and time-varying disaster risk result in a realistic equity premium and stock return volatility. Because the labor market and the stock market are driven by the same force, the price of the aggregate stock market and labor market tightness are highly correlated, while the correlation between labor productivity and tightness is realistically low.

Our paper is related to three strands of literature. First, since Shimer (2005) showed that the DMP model with standard parameter values implies small movements in unemployment and vacancies, a strand of literature has further developed the model to generate large responses of unemployment to aggregate shocks. In these papers, the aggregate shock driving the labor market is labor productivity. Hagedorn and Manovskii (2008) argue that a calibration of the model with low bargaining power of workers and a flow value of unemployment close to labor productivity can reconcile unemployment volatility in the DMP model with the data. Other papers suggest alternatives to the Nash bargaining assumption in the canonical DMP model to render wages less responsive to productivity shocks so that they do not rapidly adjust downward following a negative shock, leading to little destruction of job creation incentives (Hall (2005), Hall and Milgrom (2008), Gertler and Trigari (2009)). Our paper departs from these in that we do not rely on time-varying labor market productivity as a driver of labor market tightness, which leads to a counterfactually high correlation between these variables. Furthermore, we also derive implications for the stock market, and explain the equity premium and volatility puzzles.

Second, the present work relates to ones that embed the DMP model into the real business cycle framework, with a representative risk averse household that makes investment and consumption decisions. In the standard real business cycle (RBC) model (Kydland and Prescott (1982)), employment is driven by the marginal rate of substitution between consumption and leisure, and, because the labor market is frictionless, no vacancies go unfilled. Merz (1995) and Andolfatto

(1996) observe that this model has counterfactual predictions for the correlation of productivity and employment, and build models that incorporate RBC features and search frictions in the labor market. These models capture the lead-lag relation between employment and productivity while having more realistic implications for wages and unemployment compared to the baseline RBC model. In this paper, we also document the lead-lag relation between productivity and employment in the period that this literature analyzes (1959 - 1988). However, our empirical analysis shows that this lead-lag relation is absent in more recent data. These papers do not study asset pricing implications.

Third, our paper is related to the literature on asset prices in dynamic production economies. In these models, as in the RBC framework described above, consumption and dividend dynamics are endogenously determined by the optimal equilibrium policy of a representative firm. This contrasts with the more standard asset-pricing approach of assuming an endowment economy, in which consumption and dividends are taken as given. The main difficulty in production economies is endogenous consumption smoothing. While higher risk aversion raises the equity premium in an endowment economy, this leads to even smoother consumption in production economies resulting in very little fluctuation in marginal utility. One way of overcoming this problem is to assume alternative preferences, for example, habit formation as in Jermann (1998), though these can lead to highly volatile riskfree rates. Another approach is to allow for rare disasters. Gourio (2012) studies the implications of time-varying disaster risk modeled as large drops in productivity and destruction of physical capital in a business cycle model with recursive preferences and capital adjustment costs. Gourio's model can explain the observed co-movement between investment and risk premia. However, unlevered equity returns have little volatility, and thus the premium on unlevered equity is low. This model can be reconciled with the observed equity premium by adding financial leverage, but the leverage ratio must be high in comparison with the data. Also, as in RBC models with frictionless labor markets, Gourio's model does not explain unemployment. Petrosky-Nadeau, Zhang, and Kuehn (2013) build a model where rare disasters arise endogenously through a series of negative productivity realizations. Like our paper, they make use of the DMP model, but with a very different aim and implementation. Their paper incorporates a calibration of Nash-bargained wages similar to Hagedorn and Manovskii (2008), leading to wages that are high and rigid. Moreover, their specification of marginal vacancy opening costs includes a fixed component, implying that it costs more to post a vacancy when labor conditions are slack and thus when output is low. Finally, they assume that workers separate from their jobs at a rate that is high compared with the data. The combination of a high separation rate, fixed marginal costs of vacancy openings and high and inelastic wages amplifies negative shocks to productivity and produces a negatively skewed output and consumption distribution. Like other DMP-based models described above, their model implies that labor market tightness is driven by productivity. Furthermore, while their model can match the equity premium, the fact that their simulations contain consumption disasters make it unclear whether the model can match the high stock market volatility and low consumption volatility that characterize the U.S. postwar data.

The paper is organized as follows. Section 2 provides empirical evidence about the relation between the labor market, labor productivity and the stock market. Section 3 presents the model and illustrates the mechanism in a simplified version. Section 4 discusses the quantitative results from the benchmark calibration and alternative calibrations. Section 5 concludes.

2 Labor Market, Labor Productivity and Stock Market Valuations

In the literature succeeding the canonical DMP model, labor productivity serves as the driving force behind volatility in unemployment and vacancies. Recent empirical work, however, has challenged this approach on the grounds that labor productivity is too stable compared with unemployment and vacancies, and that the variables are at best weakly correlated. In this section we summarize evidence on the interplay between unemployment, productivity and the stock market.

In Figure 1, we plot the time series of labor productivity Z and of the vacancy-unemployment ratio V/U, the variable that summarizes the behavior of the labor market in the DMP model.[1]

[1] All variables are measured in real terms. See Appendix F for a description of the data.

Both variables are shown as log deviations from an HP trend.[2] Figure 1 shows the disconnect between the volatility of V/U and of productivity: labor productivity Z never deviates by more than 5 percent from trend, while, in contrast, V/U is highly volatile and deviates up to a full log point from trend. The lack of volatility in productivity as compared with labor market tightness is one challenge faced by models seeking to base unemployment on fluctuations in productivity.

Another challenge arises from the co-movement in these variables. Figure 1 shows that tightness and productivity did track each other in the recessions of the early 1960s and 1980s. However, this contemporaneous correlation disappears in the later part of the sample. A striking example is the aftermath of the Great Recession, which simultaneously features a small productivity boom along with a labor-market collapse. Overall, the contemporaneous correlation between the variables is 0.10 as measured over the full sample, 0.47 until 1985 and -0.36 afterwards. There is some evidence that Z leads V/U; the maximum correlation between V/U and lagged Z occurs with a lag length of one year. However, this relation also does not persist in the second subsample; while the correlation over the full sample is 0.31, it is 0.62 in the subsample before 1985 and -0.09 after 1985.

How does the labor market relate to the stock market? We will focus on the ratio of stock market valuation P to labor productivity (output per person in the non-farm business sector) Z because P/Z has a clean counterpart in our model. P/Z closely tracks Robert Shiller's cyclically adjusted price-earnings ratio (P/E), as shown in Figure 2. The correlation between the quarterly observations of these series is 0.97 for the period from 1951 to 2013.

Figure 3 shows a consistently positive correlation between labor market tightness V/U and valuation P/Z. There is no obvious lead-lag relation between V/U and P/Z. The highest correlation is between V/U and lagged P/Z by 2 quarters with 0.57, and the contemporaneous correlation is 0.47. In the period from 1986 to 2013, the contemporaneous correlation of 0.71 is the maximum among correlations with leads and lags. Moreover, like V/U, P/Z is volatile, with deviations up to 0.5 log points below trend. Figure 4 shows that vacancies V follow a similar pattern to V/U.

[2] Following Shimer (2005) we use a low-frequency HP filter with smoothing parameter 10^5 throughout to capture business cycle fluctuations. All results are robust to using an HP filter with smoothing parameter 1,600.

This evidence motivates a united mechanism of job creation incentives and stock market valuations. In recessions, even if productivity does not change, future productivity expectations are low and uncertainty is high. This leads to lower stock market valuations and a lower present value of a new hire, increasing unemployment. This is the key mechanism of the model we present in Section 3.

3 Model

In Section 3.1 we review the DMP model of the labor market with search frictions. In Section 3.2, we use the DMP model but minimal additional assumptions to demonstrate a link between equity market valuations and labor market quantities. We confirm that this link holds in the data. In Section 3.3 we present a general equilibrium model that explains labor market and stock market volatility in terms of time-varying disaster risk (we will examine the quantitative implications of this model in Section 4). When the disaster risk is constant, the solution has a closed-form solution that gives intuition for how disaster risk affects labor market quantities and prices in financial markets, as we show in Section 3.4.

3.1 Search frictions

The labor market is characterized by the DMP model of search and matching. The representative firm posts a number of job vacancies $V_t \geq 0$. The hiring flow is determined according to the matching function $m(N_t, V_t)$, where N_t is employment in the economy and lies between 0 and 1. We assume that the matching function takes the following Cobb-Douglas form:

$$m(N_t, V_t) = \xi(1 - N_t)^\eta V_t^{1-\eta}, \tag{1}$$

where ξ is matching efficiency and η is the unemployment elasticity of the hiring flow. As a result, the aggregate law of motion for employment is given by

$$N_{t+1} = (1 - s)N_t + m(N_t, V_t), \tag{2}$$

where s is the separation rate.[3] Define labor market tightness as follows:

$$\theta_t = \frac{V_t}{U_t}.$$

The unemployment rate in the economy is given by $U_t = 1 - N_t$. Thus the probability of finding a job for an unemployed worker is $m(N_t, V_t)/U_t = \xi \theta_t^{1-\eta}$. Accordingly, we define the job-finding rate $f(\theta_t)$ to be

$$f(\theta_t) = \xi \theta_t^{1-\eta}. \tag{3}$$

Analogously, the probability of filling a vacancy posted by the representative firm is $m(N_t, V_t)/V_t = \xi \theta_t^{-\eta}$ which corresponds to the vacancy-filling rate $q(\theta_t)$ in the economy:

$$q(\theta_t) = \xi \theta_t^{-\eta}. \tag{4}$$

The functional form of f and q provide useful insights about the mechanism of the DMP model. The job-finding rate is increasing, and the vacancy-filling rate is decreasing in the vacancy-unemployment ratio. In times of high labor market tightness, namely, when the vacancy rate is high and/or the unemployment rate is low, the probability of finding a job per unit time increases, whereas filling a vacancy takes more time.

Finally, the representative firm incurs costs κ_t per vacancy opening. As a result, aggregate investment in hiring is $\kappa_t V_t$.

3.2 Equity Valuation and the Labor Market

In this section we consider a partial-equilibrium model of stock market valuation, using the framework discussed in Section 3.1 but with minimal additional assumptions. We show that a link between the stock market and the labor market prevails under these very general conditions. Let M_{t+1} denote the representative household's stochastic discount factor.[4] Consider a representative

[3] The assumption of $V_t > 0$ implies that the maximum drop in employment level is s.

[4] We use the representative agent framework throughout the model. Appendix A shows the properties of a market, populated by households with identical preferences and firms facing the same aggregate labor market, that aggregate to our representative agent model.

firm which produces output given by

$$Y_t = Z_t N_t, \tag{5}$$

where Z_t is the non-negative level of aggregate labor productivity. Assume that labor productivity follows the process

$$\log Z_{t+1} = \log Z_t + \mu + x_{t+1}, \tag{6}$$

where, for now, we leave x_{t+1} unspecified; it can be any stationary process. Let $W_t = W(Z_t, N_t, V_t)$ denote the aggregate wage rate. The firm pays out dividends D_t, which is what remains from output after paying wages and investing in hiring:

$$D_t = Z_t N_t - W_t N_t - \kappa_t V_t. \tag{7}$$

The firm then maximizes the present value of current and future dividends

$$\max_{\{V_{t+\tau}, N_{t+\tau+1}\}_{\tau=0}^{\infty}} \mathbb{E}_t \sum_{\tau=0}^{\infty} M_{t+\tau} D_{t+\tau} \tag{8}$$

subject to

$$N_{t+1} = (1-s)N_t + q(\theta_t)V_t, \tag{9}$$

where $q(\theta_t)$ is given by (4). The firm takes θ_t and W_t as given in solving (8). The economy is therefore subject to a congestion externality. By posting more vacancies, firms raise the aggregate V_t, therefore increasing θ_t and lowering the probability that any one firm will be able to hire.

The following result establishes a general relation between the stock market and the labor market.

Theorem 1. *Assume the production function (5) and that the firm solves (8). Then the ex-dividend value of the firm is given by*

$$P_t = \frac{\kappa_t}{q(\theta_t)} N_{t+1}, \tag{10}$$

and the equity return equals

$$R_{t+1} = \frac{(1-s)\frac{\kappa_{t+1}}{q(\theta_{t+1})} + Z_{t+1} - W_{t+1}}{\frac{\kappa_t}{q(\theta_t)}}. \tag{11}$$

Furthermore, if $\kappa_t = \kappa Z_t$ for fixed κ, then

$$\frac{P_t}{Z_t} = \frac{\kappa}{q(\theta_t)} N_{t+1}. \tag{12}$$

See Appendix C for a proof. Note that the assumption $\kappa_t = \kappa Z_t$ guarantees the existence of a balanced growth path, given our assumption of a nonstationary component to productivity in (6). To understand (10), it is helpful to introduce notation that we use in the proof in Appendix C. Let l_t denote the Lagrange multiplier on the firm's hiring constraint (9). We can therefore think of l_t as the value of a worker inside the firm at time $t+1$. In deciding how many vacancies to post at time t, the firm equates the marginal benefit of an additional worker with marginal cost. Because the probability of filling a vacancy with a worker is $q(\theta_t)$ (see Section 3.1), the marginal benefit is $l_t q(\theta_t)$ while the marginal cost is simply the cost of opening a vacancy, κ_t. Thus a condition for optimality is:

$$\kappa_t = l_t q(\theta_t). \tag{13}$$

It follows that $l_t = \kappa_t / q(\theta_t)$, and furthermore, that the value of the firm equals the number of workers employed multiplied by the value of each worker.

Equation 11 has a related interpretation. The $t+1$ return on the investment of hiring a worker is the value of the worker employed in the firm at time $t+2$ (multiplied by the probability that the worker remains with the firm), plus productivity minus the wage, all divided by the value of the worker at time $t+1$. Note that the previous discussion implies that the value of the worker employed at $t+1$ is $\frac{\kappa_t}{q(\theta_t)}$.

Equation 12 describes a relation that we can evaluate empirically. We take the historical time series of the price-productivity ratio and of N_{t+1}, which is one minus the unemployment rate. Given standard parameters for the matching function which we discuss further below, this implies, by way of (12), a time series for the vacancy-unemployment ratio θ_t. Figure 5 shows that the resulting ratio of vacancies to unemployment lines up closely with its counterpart in the data.

3.3 General equilibrium

In this section, we extend our previous results to general equilibrium. Theorem 1 still holds, but the general equilibrium model allows us to model the underlying source of employment and stock price fluctuations.

3.3.1 The Representative Household

Following Merz (1995) and Gertler and Trigari (2009), we assume that the representative household is a continuum of members who provide one another with perfect consumption insurance.[5] We normalize the size of the labor force to one.[6] The household maximizes utility over consumption, characterized by the recursive utility function introduced by Kreps and Porteus (1978) and Epstein and Zin (1989):

$$J_t = \left[C_t^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t \left[J_{t+1}^{1-\gamma} \right] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right]^{\frac{1}{1-\frac{1}{\psi}}}, \tag{14}$$

where β is the time discount factor, γ is relative risk aversion and ψ is often interpreted as elasticity of intertemporal substitution (EIS). In case of $\gamma = 1/\psi$, recursive preferences collapse to power utility. The recursive utility function implies that the stochastic discount factor takes the following form:

$$M_{t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\frac{1}{\psi}} \left(\frac{J_{t+1}}{\mathbb{E}_t \left[J_{t+1}^{1-\gamma} \right]^{\frac{1}{1-\gamma}}} \right)^{\frac{1}{\psi}-\gamma}. \tag{15}$$

3.3.2 Wages

The canonical DMP model assumes that wages are determined by Nash bargaining between the employer and the jobseeker. Both parties observe the surplus of job creation and the bargaining power of the jobseeker is equal to the fraction of the surplus the jobseeker receives. Pissarides

[5] Appendix A illustrates the implications of the perfect consumption insurance assumption in an economy populated by agents with identical preferences.

[6] This assumption implies that our model focuses on the transition between employment and unemployment rather than between in and out of labor force.

(2000) shows that the Nash-bargained wage, W_t^N, is given by

$$W_t^N = (1 - B)b_t + B(Z_t + \kappa_t \theta_t), \tag{16}$$

where $0 \leq B \leq 1$ is worker's bargaining power and b_t is the flow value of unemployment.[7] The worker threatens the employer to leave the wage bargain and continue to search while receiving the flow value of unemployment. The Nash-bargained wage can be interpreted as the weighted average of two components: the opportunity cost of employment and a term that represents the contribution of the worker to the firm's profits. If the bargaining power of the worker is high, the firm has to pay a higher fraction of the output the worker produces as wage, as well as the foregone costs from not having to hire.

Furthermore, the worker receives a higher fraction of the foregone costs by the firm by employing the worker which prevents incurring vacancy costs. The compensation of the worker due to foregone vacancy costs is higher if labor market tightness is high, making it easier for the worker to find a job and more difficult for the firm to fill the vacancy in case the worker leaves the firm.

Although the Nash-bargained wage is a convenient formulation from a modeling perspective, it implies wages that are unrealistically responsive to changes in labor market tightness.[8] For this reason, we use a wage rule introduced by Hall (2005) that insulates wages from changes in market conditions:

$$W_t = \nu W_t^N + (1 - \nu)W_t^I, \tag{17}$$

where

$$W_t^I = (1 - B)b_t + B(Z_t + \kappa_t \bar{\theta}). \tag{18}$$

The parameter ν controls the degree of tightness insulation. With $\nu = 1$, we are back in the Nash bargaining case. With $\nu = 0$, wages do not respond to labor market tightness. The resulting wage remains sensitive to productivity but loses some of its sensitivity to tightness. Furthermore, this formulation allows a direct comparison between versions of the model with and without tightness insulated wages. The parameters B, κ and ν jointly determine the dynamics of wages given the

[7] Appendix B shows that the canonical DMP wage equation holds in our model.

[8] See Section 4.5 for details.

dynamics of productivity and labor market tightness. We will calibrate these parameters to match the behavior of the labor share in postwar U.S. data.

An interesting question related to wage formulation in the search and matching literature is the interpretation of the flow value of unemployment, b_t. Workers' bargaining power in the Nash-bargained wage formulation comes from an alternative benefit they will receive when being unemployed instead of working for the firm and receiving wages. Therefore, one way to interpret b_t is as the sum of foregone public benefits that the worker would receive in unemployment status. This interpretation suggests that b_t is countercyclical. However, Chodorow-Reich and Karabarbounis (2015) use detailed microeconomic data and find that the foregone value of non-working time is a large and procyclical component of the flow value of unemployment. Moreover, they find that the procyclical component accounts for most of the fluctuations in b_t resulting in a positive and high elasticity of b_t with respect to marginal product of employment. Motivated by this evidence, we assume that the flow value of unemployment is given by $b_t = bZ_t$, which also implies a convenient formulation balanced-growth path.

3.3.3 Technology and the Representative Firm

The representative firm produces output Y_t with technology Z_tN_t given in (5). In normal times, $\log Z_t$ follows a random walk with drift. In every period, there is a small and time-varying probability of a disaster. Thus,

$$\log Z_{t+1} = \log Z_t + \mu + \epsilon_{t+1} + d_{t+1}\zeta_{t+1}, \tag{19}$$

where $\epsilon_t \overset{iid}{\sim} N(0, \sigma_\epsilon^2)$. The parameter d_{t+1} is the disaster indicator:

$$d_{t+1} = \begin{cases} 1 & \text{with probability } \lambda_t \\ 0 & \text{with probability } 1 - \lambda_t, \end{cases}$$

where λ_t is the conditional disaster probability. Disaster probability dynamics are given by

$$\log\, \lambda_t = \rho_\lambda \, \log\, \lambda_{t-1} + (1 - \rho_\lambda)\, \log\, \bar{\lambda} + \epsilon_t^\lambda, \tag{20}$$

where $\epsilon_t^\lambda \overset{iid}{\sim} N(0, \sigma_\lambda^2)$.[9] Furthermore, ζ is the size of the downward jump in productivity, has a time-invariant distribution and takes only negative values. Disaster probability, disaster size and productivity shocks are independent.

3.3.4 Equilibrium

In equilibrium, the representative household holds all equity shares of the representative firm. The government bill is in zero net supply. The representative household consumes the output $Z_t N_t$ net of investment in hiring $\kappa_t V_t$, and the value of non-market activity $b_t(1 - N_t)$ achieved by the unemployed members:

$$C_t = Z_t N_t + b_t(1 - N_t) - \kappa_t V_t. \tag{21}$$

Note that consumption includes firm wages and dividends; the definition of dividends in (7) shows that the sum of wages and dividends amounts to $Z_t N_t - \kappa_t V_t$. The household also consumes the flow value of unemployment. This implies that we are treating this flow value primarily as home production as opposed to unemployment benefits (which would be a transfer that would net to zero), consistent with the results of Chodorow-Reich and Karabarbounis (2015) as discussed in Section 3.3.2. Changing to the alternative assumption that these benefits net to zero, however, does not impact our results. To ensure that our model-data comparison is valid, when quantitatively assessing the model we report the model-implied dynamics of consumption from dividends and wages, namely, $Z_t N_t - \kappa_t V_t$, as this is what is measured in consumption data.

The proportionality assumptions on vacancy costs κ_t and the flow value of unemployment b_t in productivity Z_t imply that we can write:

$$C_t = Z_t N_t + b Z_t(1 - N_t) - \kappa Z_t V_t. \tag{22}$$

Therefore, we can define consumption normalized by productivity, $c_t = \frac{C_t}{Z_t}$, as

$$c_t = N_t + b(1 - N_t) - \kappa V_t. \tag{23}$$

[9] We use a finite-state Markov process to approximate this process in our numerical calibration with all nodes smaller than one.

A disaster realization at time t results in the multiplication of aggregate consumption, output and investment in hiring by e^{ζ_t}. The decrease in output, consumption and investment is permanent. Employment level does not change on impact.

The model has three state variables: disaster probability λ_t and productivity Z_t are the exogenous state variables, and employment level N_t is the endogenous state variable. The homogeneity in consumption implies that we can normalize the household's value function by productivity:[10]

$$J(Z_t, \lambda_t, N_t) = Z_t j(\lambda_t, N_t). \tag{24}$$

The normalized value function is given by

$$j(\lambda_t, N_t) = \left[c_t^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t \left[e^{(1-\gamma)(\mu+\epsilon_{t+1}+d_{t+1}\zeta_{t+1})} j(\lambda_{t+1}, N_{t+1})^{1-\gamma} \right] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right]^{\frac{1}{1-\frac{1}{\psi}}}, \tag{25}$$

which implies

$$j(\lambda_t, N_t)^{1-\frac{1}{\psi}} = c_t^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t \left[e^{(1-\gamma)(\mu+\epsilon_{t+1}+d_{t+1}\zeta_{t+1})} j(\lambda_{t+1}, N_{t+1})^{1-\gamma} \right] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}}. \tag{26}$$

This normalization makes the optimization problem of the firm stationary. Moreover, the normalized value function is convenient to study the analytical properties of a version of the model with constant disaster probability as illustrated in the next section.

3.4 Comparative Statics in a Model with Constant Disaster Probability

Before exploring the quantitative implications of our full model in Section 4, we consider the simplified case of constant disaster probability. We show that, provided that the elasticity of intermtemporal subtitution is greater than 1, the economy is isomorphic to one without disasters but where the representative agent invests less in hiring. We show that, with an EIS greater than 1, stock prices are decreasing, and unemployment increasing as a function of disaster probability. We give intuition for these results.

[10]See Appendix A.1 for the homogeneity of the value function.

To derive closed-form solutions, we replace the random variable $d_{t+1}\zeta_{t+1}$ with a compound Poisson process with intensity $\tilde{\lambda}$. At our parameter values, the difference between the probability of a disaster λ and the intensity $\tilde{\lambda}$ is negligible, and we continue to refer to $\tilde{\lambda}$ as the disaster probability.[11] We begin by demonstrating an isomorphism between an economy with disasters and one without but with a different time-discount factor β.[12]

Theorem 2. *Assume that disaster risk is constant. The value function in a model with disasters is the same as the value function in a model without disasters but with a different time-discount factor. That is, the normalized value function (the value function divided by productivity) solves*

$$j(\tilde{\lambda}, N_t)^{1-\frac{1}{\psi}} = c_t^{1-\frac{1}{\psi}} + \hat{\beta}(\tilde{\lambda}) \left(\mathbb{E}_t \left[e^{(1-\gamma)(\mu+\epsilon_{t+1})} j(\tilde{\lambda}, N_{t+1})^{1-\gamma}\right]\right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}}, \tag{27}$$

with the time-discount factor $\hat{\beta}(\tilde{\lambda})$ defined by

$$\log \hat{\beta}(\tilde{\lambda}) = \log \beta + \frac{1-\frac{1}{\psi}}{1-\gamma} \left(\mathbb{E}\left[e^{(1-\gamma)\zeta}\right] - 1\right) \tilde{\lambda}, \tag{28}$$

Moreover, $\hat{\beta}(\tilde{\lambda})$ is decreasing in $\tilde{\lambda}$ if and only if $\psi > 1$.

Appendix D.2 provides a proof. Note that (27) recursively defines the normalized value function when there are no disasters. Theorem 2 shows that an economy with disasters is equivalent to one without, but with a less patient agent when $\psi > 1$ and a more patient agent when $\psi < 1$. As these results suggest, the change to the time-discount factor due to disasters reflects a trade-off between an income and a substitution effect. On the one hand, the presence of disasters lead the agent to want to shift consumption to the future (the income effect). But the mechanism that the agent has to shift consumption, namely, investing in hiring, becomes less attractive because there is a greater chance that the workers will not be productive (the substitution effect). When $\psi > 1$, the substitution effect dominates, and the agent, in effect, becomes less patient.

We can also see the effect of the probability of disaster in rates of return.

[11] See Appendix D.1 for properties of the compound Poisson process.

[12] An analogous isomorphism is present in the models of Gourio (2012) and Gabaix (2011).

Theorem 3. *Assume that disaster risk is constant. The log risk-free rate is given by*

$$\log R_f = -\log\beta + \frac{1}{\psi}\left(\mu + \frac{1}{2}\sigma_\epsilon^2\right) - \frac{1}{2}\left(\gamma + \frac{\gamma}{\psi}\right)\sigma_\epsilon^2 + \left(\frac{\frac{1}{\psi}-\gamma}{1-\gamma}\mathbb{E}\left[e^{(1-\gamma)\zeta}-1\right] - \mathbb{E}\left[e^{-\gamma\zeta}-1\right]\right)\tilde{\lambda}. \quad (29)$$

The riskfree rate is decreasing in $\tilde{\lambda}$.

See Appendix D.3 for a proof. The risk of a rare disaster increases agents' desire to save, which drives down the riskfree rate. In contrast to Theorem 2, this result holds regardless of the value of ψ. The adjustment to the riskfree rate due to disasters is not equivalent to the adjustment to the time-discount factor.

Theorem 4. *Assume that disaster risk is constant. The equity premium is given by*

$$\log\left(\frac{\mathbb{E}_t[R_{t+1}]}{R_f}\right) = \gamma\sigma_\epsilon^2 - \tilde{\lambda}\mathbb{E}\left[\left(e^{-\gamma\zeta}-1\right)\left(e^{\zeta}-1\right)\right]. \quad (30)$$

The equity premium is increasing in $\tilde{\lambda}$.

Appendix D.4 provides a proof. The equity premium has two terms. The first represents the normal-times risk in production and is present without disasters. Given the low volatility in productivity and consumption, this first term is very small. The second term represents the effect of rare disasters. A rare disaster causes an increase in marginal utility, represented by the term $e^{-\gamma\zeta}-1$, at the same time as it causes a decrease in the value of the representative firm, as represented by $e^{\zeta}-1$. Because the representative firm declines in value at exactly the wrong time, its equity carries a risk premium. This also implies that the equity premium is unambiguously increasing in the probability of a disaster.

These rates of return can be connected back to the effective time-discount factor $\hat{\beta}(\tilde{\lambda})$ as well as to the hiring decision of the firm. We connect these concepts through a quantity analogous to the dividend-price ratio in the literature on endowment economies. Section 3.2 highlights the importance of the valuation measure $l_t = \kappa_t/q(\theta)$, which is the value of a worker employed inside a firm (see Theorem 1). We can define the "dividend" or payout of the worker as

$$D_t^l = Z_t - W_t - sl_t.$$

Note that $Z_t - W_t$ is the output of the worker minus the cost, and sl_t is the probability that the worker will leave, multiplied by the cost of replacing the worker. It is convenient to define the notation

$$h(\tilde{\lambda}) = \log\left(1 + \frac{D_t^l}{l_t}\right). \tag{31}$$

In what follows, we will refer to $h(\tilde{\lambda})$ as the payout ratio for the worker inside the firm (or, if there is no ambiguity, simply the payout ratio).[13] The following theorem shows a tight link between $h(\tilde{\lambda})$ and the time-discount factor.

Theorem 5. *Assume that disaster risk is constant, the labor market is at its steady state, and define $\hat{\beta}(\tilde{\lambda})$ as in Theorem 2. Define $h(\tilde{\lambda})$ as in (31). Then*

$$h(\tilde{\lambda}) - h(0) = -\left(\log\hat{\beta}(\tilde{\lambda}) - \log\beta\right), \tag{32}$$

where $h(0)$ is the payout ratio when there is no disaster risk:

$$h(0) = -\log\beta - \left(1 - \frac{1}{\psi}\right)\left(\mu + \frac{1}{2}(1-\gamma)\sigma_\epsilon^2\right)$$

Thus the steady state payout ratio is increasing in $\tilde{\lambda}$ if and only if $\psi > 1$.

Appendix D.5 provides a proof. Besides linking $h(\tilde{\lambda})$ to the time-discount factor, we can also link it to the rates of return calculated earlier in this section. The effect of disaster risk on $h(\tilde{\lambda})$ can be decomposed into a discount rate effect (which in turn can be decomposed into a risk premium and riskfree rate effect) and an expected growth effect, as in the basic Gordon growth formula (see also Campbell and Shiller (1988)):[14]

$$h(\tilde{\lambda}) - h(0) = \underbrace{\left(\frac{\frac{1}{\psi}-\gamma}{1-\gamma}\left(\mathbb{E}\left[e^{(1-\gamma)\zeta}\right]-1\right) - \left(\mathbb{E}\left[e^{-\gamma\zeta}\right]-1\right)\right)\tilde{\lambda}}_{\text{risk-free rate effect}}$$
$$- \underbrace{\mathbb{E}\left[\left(e^{-\gamma\zeta}-1\right)\left(e^{\zeta}-1\right)\right]\tilde{\lambda}}_{\text{risk premium effect}} - \underbrace{\left(\mathbb{E}\left[e^{\zeta}\right]-1\right)\tilde{\lambda}}_{\text{expected cash-flow effect}}, \tag{33}$$

[13] At the steady state, the employment level is constant. It follows that the payout ratio for the worker inside the firm is equal to the payout ratio for the firm as a whole. That is $D_t^l/l_t = D_t/P_t$.

[14] In discrete-time economies, it is a general result that $\log(1 + D/P) = g - r$, where D/P is the dividend-price ratio, g the log of the expected growth rate, and r the log of the discount rate.

which directly follows from Theorems 2, 3, 4 and 5.

The decomposition (33) provides additional intuition for the effect of changes in the disaster probability on the economy. On the one hand, an increase in the risk of a disaster drives down the riskfree rate. This will raise valuations, all else equal. However, it also increases the risk premium and lowers expected cash flows. When $\psi > 1$, the risk premium and cash flow effects dominate the riskfree rate effect and an increase in the disaster probability lowers valuations.

Theorem 6. *Assume that disaster risk is constant and the labor market is at its steady state. The payout ratio for the worker inside the firm, $h(\tilde{\lambda})$, is decreasing as a function of labor market tightness. Thus labor market tightness is decreasing in the probability of a disaster if and only if $\psi > 1$.*

The proof follows from the the fact that

$$1 + \frac{D_t^l}{l_t} = \frac{(1-s)l_t + Z_t - W_t}{l_t} = 1 - s + \frac{Z_t - W_t}{l_t}. \tag{34}$$

Note that l_t is the value of the worker inside the firm, and equals $\kappa_t/q(\theta)$ (Theorem 1). The vacancy-filling rate $q(\theta)$ is decreasing as a function of θ; as tightness increases, it is harder to fill vacancies. Thus l_t is increasing as a function of θ. Furthermore $Z_t - W_t$ is decreasing in θ because wages W_t are increasing in θ (as the labor market becomes tighter, equilibrium wages increase; see Section 3.3.2). This establishes the first statement.

The second statement follows from the first, combined with Theorem 5: because the payout ratio is increasing in $\tilde{\lambda}$ if $\psi > 1$, labor market tightness must be decreasing in $\tilde{\lambda}$ (and similarly, if $\psi < 1$, the payout ratio is decreasing in $\tilde{\lambda}$ and labor market tightness is increasing in $\tilde{\lambda}$). Putting the pieces together, we see that when a firm is faced with a higher risk of an economy-wide disaster, it has an incentive to reduce hiring due to higher risk and lower growth. In equilibrium, this decreases tightness θ; eventually, as θ falls enough, the economy equilibrates at a lower point on the Beveridge curve, with higher unemployment, lower vacancies, and lower firm valuations.

The previous discussion separates the effects of the risk premium and the riskfree rate. What about the discount rate overall? Hall (2014) considers a reduced-form model where discount rates drive fluctuations in labor market tightness. When discount rates rise, stock market valuations fall and unemployment rises. At the same time the riskfree rate falls, but this effect is more than countered by the change to the risk premium. As the previous paragraph shows, a similar mechanism is at work in our general equilibrium model. A subtle distinction is that the above intuition does not rely on the discount rate itself driving fluctuations in prices and unemployment; only that the combined effect of the equity premium and expected cash flows outweigh the riskfree rate (which happens as long as $\psi > 1$). The condition that the total discount rate and equity premium move together is given below:

Theorem 7. *Assume that disaster risk is constant. The expected return is increasing in $\tilde{\lambda}$ if and only if*

$$1 - \mathbb{E}\left[e^{\zeta}\right] < \frac{1 - \frac{1}{\psi}}{1 - \gamma}\left(1 - \mathbb{E}\left[e^{(1-\gamma)\zeta}\right]\right). \tag{35}$$

For this theorem to hold, it is necessary, but not sufficient, that $\psi > 1$ (under the parameter values we consider in the next section, it does indeed hold).[15]

The analysis in this section sheds light on the tight link between the valuation mechanism and the labor market. As we will show in the next section, this mechanism is helpful in quantitatively explaining historical fluctuations in the labor market.

4 Quantitative Results

4.1 Model Parameters

Table 1 describes model parameters for our benchmark calibration. We calibrate and simulate the model at a monthly frequency and calculate quarterly and annual values by aggregating monthly values.

We calibrate the labor productivity process to match the quarterly seasonally adjusted real average output per person in the non-farm business sector using data compiled by the Bureau

[15]The observed expected return in periods without disasters does move in the same direction as the equity premium whenever $\psi > 1$. If we consider this observed return, the left hand side is equal to zero.

of Labor Statistics (BLS) from Current Employment Statistics (CES). Accordingly, the monthly growth rate μ and standard deviation σ_ϵ of log productivity are set to 0.18% and 0.47%.

Labor market parameters determining wages and the aggregate law of motion for employment are calibrated following the literature. The separation rate s is set to 3.5% following Shimer (2005) and Hall (2014). Higher values for η, the elasticity of the Cobb-Douglas matching function, imply that high volatility in the labor market translates to high volatility in returns, holding everything else equal. Petrongolo and Pissarides (2001) find that the range of appropriate estimates of η is between 0.3 and 0.5, which is consistent with Yashiv (2000)'s finding that the elasticity of the matching function in the U.S. with respect to unemployment is lower than that with respect to vacancies. Hall and Milgrom (2008) and Hall (2014) take the value to be 0.5. We set η to 0.35. Following Hall and Milgrom (2008) and Hall (2014), we set the bargaining power of workers B in case of Nash bargaining to 0.5 and the flow value of unemployment b to 0.76. The vacancy cost parameter κ, which corresponds to unit costs of vacancy opening normalized by labor productivity in our model, is set to 0.5, the average of values taken by Hall and Milgrom (2008) and Hagedorn and Manovskii (2008).[16] The tightness-insulation parameter ν is set to 0.05. Parameters B, b, κ and ν jointly determine dynamics of wages given dynamics of labor market tightness and labor productivity. The tightness-insulation parameter ν is calibrated to match wage dynamics discussed in Section 4.5. Finally, we set the matching efficiency ξ to 0.365, targeting a model population value for unemployment equal to 10%.

We assume the EIS ψ is equal to 2 and risk aversion γ is equal to 5.7. Risk aversion is lower compared to many asset pricing models (e.g. Bansal and Yaron (2004) and Petrosky-Nadeau, Zhang, and Kuehn (2013) who assume a risk aversion of 10). It is higher than some models with disaster risk (e.g. Gourio (2012) and Wachter (2013)), because our average disaster probability is substantially lower than other models assume.

Section 3.4 shows that, as is standard in production models with recursive utility, the EIS must be greater than 1 for the model to deliver qualitatively realistic predictions. An important question

[16] Hagedorn and Manovskii (2008) find a constant and a pro-cyclical component in vacancy costs. We specify vacancy costs proportional to productivity for simplicity.

is whether this level of the EIS is consistent with empirical evidence on consumption and interest rates. Using instrumental variable estimation of consumption growth on interest rates, Hall (1988) and Campbell (2003) estimate this parameter to be close to zero. Bansal and Yaron (2004) note that this regression is mis-specified when returns and consumption growth are heteroskedastic, as is the case in the present model. To see whether this mis-specification is sufficient to match the empirical findings, we follow Campbell (2003) and regress consumption consumption growth on government bill rate in simulated data using twice lagged consumption growth, government bill rate and log price-productivity ratio as instruments. Among 10,000 paths, the mean estimate is 0.15 with a standard error of 0.19. Thus our model is consistent with an observed EIS of less than one.

4.2 Size Distribution and Probability of Disasters

The distribution of productivity declines in disasters is taken directly from the data on GDP declines. Barro and Ursua (2008) construct historical data on consumption per capita and GDP per capita from 42 countries (24 for consumption, 36 for GDP) from 1870 to 2006. Following Barro and Ursua, we characterize a disaster by a 10% or higher decline in GDP. Some of these disasters are characterized by default on government bonds. We follow Barro (2006) in assuming that 40% of disasters result in default. Figure 6 shows the distribution of GDP declines in a disaster, which corresponds to $1 - e^{\zeta}$ in the model.

We approximate the dynamics of monthly disaster probability λ in (20) using a 12-state Markov process. The nodes, along with their stationary probabilities, are presented in Table 2. The stationary distribution of probabilities approximates a lognormal distribution with mean 0.20% and standard deviation 1.97%. Mean disaster probability implies a lower frequency of disasters compared to the historical annual value of 3.69% calculated by Barro and Ursua (2008) and used by Gourio (2012) and Wachter (2013). The stationary distribution of disaster probability is highly skewed. We choose the persistence and the volatility of the disaster probability process to match the autocorrelation and volatility of unemployment in postwar U.S. data in model population.

Table 3 describes properties of the disaster probability. The fraction of simulations, including no disaster realization among 10,000 simulations with length 60 years, is 53%. The mean of average disaster probability across no-disaster samples is 0.05%, which roughly corresponds to an annual value of 0.60%. This value is 0.20% across all simulations and in population. Medians are below mean due to the skewness of the distribution. The distribution of disaster probability in samples with no disasters has a much lower mean and standard deviation compared to population values. This implies that our specification of the disaster probability process is conservative because we evaluate the model's performance in explaining postwar U.S. data using paths with no disaster realizations. Model values in the discussion of quantitative results refer to results from no-disaster simulations unless stated otherwise. While we calibrate the disaster probability process to unemployment, the model's performance in explaining the dynamics of vacancies as well as business cycle and financial moments confirms the accuracy of the mechanism.

4.3 What Happens at a Disaster Realization?

Figure 7 plots the response of macroeconomic variables to a disaster realization. To highlight the main mechanism in our model, we assume a simplified view of a disaster in which the entire drop in productivity is instantaneous. Consumption, dividends, and wages are all equal to productivity multiplied by a function of the stationary variables; therefore they also drop by 15% in a disaster. Labor market variables, namely employment level N_t and the vacancy rate V_t, do not change on impact.

4.4 What Happens when Disaster Probability Increases?

Figure 8 plots the response of macroeconomic variables to an increase in monthly disaster probability from 0.05% to 0.32%. This represents a close to two-standard-deviation increase in a typical no-disaster path. Productivity does not change on impact because exogenous shocks in the model are independent. Following the increase in disaster risk, the optimal level of employment in the economy decreases. Therefore, the firm substantially lowers investment in hiring by posting fewer vacancies. Eventually, vacancies and employment converge to a level below their respective pre-shock values. Because unemployment is higher, a lower vacancy rate can maintain the optimal employment level. Within 20 months, employment falls by 6% and the price-productivity ratio and vacancy rate fall by 25%. The fluctuations in disaster probability generate high volatility in vacancy and unemployment rates, as well as in asset prices, while keeping consumption volatility at a reasonable level.

Following the disaster probability shock, consumption rises slightly on impact, and falls below the pre-shock value after six months. The initial increase in consumption is a result of the high EIS, combined with the desire to lower investment in hiring. Although consumption rises on impact, high disaster probability states are still high marginal utility states as can be seen calculating the stochastic discount factor.

As Figure 9 shows, an increase in the disaster probability sharply lowers the equity return on impact. This is because it decreases stock prices, mainly through an increase in the equity premium, as discussed in Section 3.4. Thus following impact, however, the expected return on equities is higher. Meanwhile, the government bill rate falls on impact and stays low because of an increased desire to save.

4.5 Labor Market Moments

Table 4 describes labor market moments in the model and in the U.S. data from 1951 to 2013. Panel A reports U.S. data on unemployment U, vacancies V, the vacancy-unemployment ratio V/U, labor productivity Z, and the price-productivity ratio P/Z. The labor market results replicate those reported by Shimer (2005) using more recent data. The vacancy-unemployment ratio has a quarterly volatility of 39%, twenty times higher than the volatility of labor productivity of 2%. The correlation between Z and V/U is 10%, whereas the correlation between P/Z and V/U is 47%, consistent with the findings in Section 2.[17] The correlation is lower in the pre-1985 sample, and higher in the post-1985 sample. These findings, together with the more detailed analysis in

[17] As noted in Section 2, we follow Shimer (2005) in using a low-frequency HP filter with smoothing parameter 10^5. We report volatilities of log deviations from trend.

Section 2, motivate the mechanism in this paper.

Panel B of Table 4 reports the results from no-disaster simulations. Our model generates a volatility of 33% in V/U. The correlation between V and U is -0.68 compared to the data value of -0.86. The ability to produce this negative correlation is a test of the plausibility of our mechanism. Other possible mechanisms, such as shocks to the separation rate, generate a counterfactual positive correlation between V and U (Shimer (2005)). Labor market tightness and price-productivity ratio have a correlation of 0.99. Labor market models that operate through productivity shocks imply a perfect correlation between V/U and Z, which is much lower in the data compared to the correlation between V/U and P/Z. Note that this level of correlation between the labor market and the stock market arises because both are driven by a single state variable. However, the data analysis shows that this united mechanism of the stock market and the labor market is a better description of the data compared to models based on realized productivity, especially for the U.S. data from mid-1980s to today.

Figure 10 shows the Beveridge curve in the data and in the model. While the model values are concentrated along a downward sloping line, a wide range of values can be generated by the model, including data values at the lower right corner of the Beveridge curve observed during the Great Recession.

Table 5 describes the dynamics of wages in the data and in the model. These results show how the data discipline our choice of wage parameters, specificially, the tightness insulation parameter ν. Following Hagedorn and Manovskii (2008), we calculate wages by multiplying the labor share by productivity. As Table 5 shows, the volatility and autocorrelation of log deviations of wages from trend in quarterly data are 1.77% and 0.91, respectively. The elasticity of wages to labor market tightness is low throughout the sample, while elasticity of wages to labor productivity ranges from 0.67 in the full sample, to over unity in the sample after 1985.[18] Our model produces similar results because wages scale with productivity. Table 5 also shows that the estimate of the elasticity of labor market tightness to productivity is highly unstable across subsamples, replicating the results

[18]In Table 5, we report Newey-West t-statistics. These may be overstated, as the Newey-West method may not take into account the true persistence in these processes.

of Section 2. The model is consistent with these results, in that it implies a theoretical value of zero, along with estimated values that can vary widely in small samples.

Panel C of Table 5 describes dynamics of the Nash-bargained wage without tightness insulation, namely $\nu = 1$. The volatility of wages is 2.26%, higher than in the data. Furthermore, the elasticity of wages to labor market tightness is 0.13 and significantly different from zero, which contradicts the value in the data. This high elasticity sabotages the impact of aggregate shocks on labor market volatility. When disaster probability increases, labor market tightness decreases only moderately because wages strongly adjust downward which leads to a weak impact on job creation incentives.

4.6 Business Cycle and Financial Moments

Table 6 describes consumption, GDP, equity return and government bill rate moments in the data and in the model. There are two independent dimensions to cyclicality in the model, namely, comovement with labor productivity and with disaster risk. In the model, the effect of productivity shocks on consumption and output growth is identical. This is not the case for disaster risk, however. Consumption equals output by the firm, plus home production, minus investment in hiring. Because both output and investment are pro-cyclical, the consumption response to disaster probability shocks is weaker than the output response, as shown in Figure 8. This creates a higher volatility in output growth compared to consumption growth, in line with the data. The model-implied volatility of consumption growth and output growth in a typical no-disaster path is 2.28% and 2.47%, respectively.[19] The median value for the average return on government bills is 3.64% while the median value for the volatility is 3.83%. While higher than in the data, these are low compared with the values for equity returns (see below), and lower than in many models of production. The data fall well within the confidence bands implied by the model

Table 6 reports a historical equity premium of 5.32% and a return volatility of 12.26%. These returns are calculated by adjusting net market returns for financial leverage, whereas the un-

[19]Note that our definition of measured consumption does not include the flow value of unemployment as described in Section 3.3.4, and is therefore directly comparable to consumption expenditures in the data. Model-implied consumption volatility including the flow value of unemployment, $b_t(1 - N_t)$, is 1.41%.

adjusted values are 7.90% and 17.55%, respectively.[20] Although our model does not incorporate financial leverage, the equity premium in no-disaster paths is 6.66% and return volatility is 19.78%. A general issue for asset pricing in economies with production is the low riskiness of cash flows, which makes it difficult to generate the high volatility of equity returns and the high equity premium in the data. To produce reasonable return volatility, models that focus on investment use counterfactually high leverage (Gourio (2012)), or model equities as something other than the dividend claim (Croce (2014)). Our model is also one of investment; posting a vacancy implies an investment in hiring. However, we are able to match volatility in returns without the use of leverage. One reason is the operating leverage present in our model: wage rigidity keeps wages high even when the disaster probability rises. This creates cash flow volatility similar to what one would see in an endowment economy with consumption equal to dividends. A second reason we obtain high return volatility is of course the volatility in the probability of a disaster. This results in risk premia that vary strongly over time.

4.7 Sources of Volatility and Risk Premia

We compare three alternative specifications to our benchmark model to highlight the sources of volatility and risk premia: a model with constant disaster probability, where disaster probability is set to 0.20%, the stationary mean in the benchmark model; a model with no disaster risk; and a model with Nash-bargained wages, namely, $\nu = 1$. In all cases, the productivity process up to disasters remains unchanged.

Table 7 describes labor market volatility in alternative specifications. If risk is not time-varying, labor market variables and P/Z are constant. This confirms that the only source of fluctuation in the labor market and stock market valuation is disaster probability. Without tightness insulation, the sensitivity of labor market variables to aggregate shocks decreases. Specifically, Nash-bargained wages result in an 11% volatility in V/U whereas the benchmark model can generate a volatility of 33%. This finding is in line with Hagedorn and Manovskii (2008) and Hall

[20]Lemmon, Roberts, and Zender (2008) report an average market leverage ratio of 28% among U.S. firms from 1965 to 2003. Accordingly, the unlevered equity premium is calculated multiplying stock returns by 0.72.

(2014). Table 5 describes wage dynamics in the Nash bargaining case, as discussed in Section 4.5. Nash-bargained wages imply a high elasticity of wages to vacancy-unemployment ratio inconsistent with the data.

Table 8 describes business cycle and financial moments. In the absence of time-varying risk, consumption growth and output growth have the same standard deviation. The only source of variation in these variables is the productivity shock because labor market variables are constant in these economies. The absence of tightness insulation renders consumption growth and output growth statistics close because labor market volatility, which is the source of differences between consumption and output dynamics, as discussed in Section 4.6, is dampened, as shown in Table 7. A higher proportion of fluctuation is driven by the common productivity component.

The equity premium is extremely low without the tightness insulation of wages. In this case, investment in the firm becomes very safe because the firm has a cost structure that is highly sensitive to cyclical conditions in the economy. In times of low disaster probability, employment increases and wages increase substantially due to the high sensitivity of wages to labor market tightness. In contrast, when employment falls, wages adjust rapidly downward. Therefore, disaster probability shocks have little effect on job creation incentives of the firm. This leads to low volatility and extremely low risk premia because returns become more countercyclical than the government bill rate.

Panel C of Table 8 describes a version of the model with tightness-insulated wages, but without disaster risk. The equity premium is close to zero, and the risk-free rate is 5.12%. The only source of return volatility is labor productivity. This version of the model with realistic wage dynamics but without disaster risk is similar to a baseline real business cycle model with a labor share lower than one.

The investigation of the constant disaster risk model described in Panel B of Table 8 highlights the role of time-varying risk in risk premia and volatility. The equity premium in population is 13.34% in the benchmark model and 9.94% in the model with constant disaster risk. While these values might seem to imply that 3/4 of the equity premium comes from the presence of disaster risk, the median equity premium in the absence of time-variation in disaster risk paths is 10.27%, which is higher than 6.66% in the benchmark model with time-varying disaster risk. The reason is the strong discrepancy in disaster probability characteristics between paths with and without disasters, as illustrated in Table 3. The constant disaster risk model is calibrated using the stationary mean (0.20%) of the benchmark disaster probability process. However, the benchmark model implies a much lower mean for disaster probability (0.05%) in no-disaster simulations. Finally, the only source of government bill rate volatility in the constant disaster risk model is disaster realizations, which leads to a positive volatility in population but to a constant rate in no-disaster paths.

5 Conclusion

This paper shows that a business cycle model with search and matching frictions in the labor market and a small and time-varying risk of an economic disaster can simultaneously explain labor market volatility, stock market volatility and the relation between unemployment and stock market valuations. While tractable, the model can generate high volatility in labor market tightness along with realistic aggregate wage dynamics. The findings suggest that time variation in aggregate uncertainty offers an important channel, through which the DMP model of labor market search and matching can operate. The model provides a mechanism through which job creation incentives of firms and stock market valuations are tightly linked, as the comovement of labor market tightness and stock market valuations in the data suggest. While the presence of disaster risk and realistic wage dynamics generate a high unlevered equity premium, the source of labor market volatility and stock market volatility is time variation in risk. Finally, the model is consistent with basic business cycle moments such as consumption growth and output growth.

Appendix

A Aggregation

A.1 Homogeneity and the Stochastic Discount Factor

In this section, we show that the recursive utility function is homogenous in consumption following Van Binsbergen, Fernández-Villaverde, Koijen, and Rubio-Ramírez (2012). We illustrate that homogeneity of the utility function implies that all households that receive a constant fraction of aggregate consumption have the same SDF as the representative household.

We generalize the notation to $C_t = C(Z_t, N_t)$ and write the representative household's utility function $J(\lambda_t, C(Z_t, N_t))$ as

$$J(\lambda_t, C(Z_t, N_t)) = \left[C(\lambda_t, N_t)^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t \left[J(\lambda_{t+1}, C(Z_{t+1}, N_{t+1}))^{1-\gamma} \right] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right]^{\frac{1}{1-\frac{1}{\psi}}}. \tag{A.1}$$

We want to show that

$$J(\lambda_t, \omega_i C(Z_t, N_t)) = \omega_i J(\lambda_t, C(Z_t, N_t)), \tag{A.2}$$

where $\omega_i > 0$. If we find a function $\widetilde{J}$ that is homogenous in consumption and that satisfies (A.1), then J needs to be homogenous by uniqueness of the solution to the Bellman equation. Suppose $\widetilde{J}(\lambda_t, \omega_i C(Z_t, N_t)) = \omega_i \widetilde{J}(\lambda_t, C(Z_t, N_t))$, then we have

$$\begin{aligned} \widetilde{J}(\lambda_t, C(Z_t, N_t)) &= \left[C(\lambda_t, N_t)^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t \left[J(\lambda_{t+1}, C(Z_{t+1}, N_{t+1}))^{1-\gamma} \right] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right]^{\frac{1}{1-\frac{1}{\psi}}} \\ &= \frac{1}{\omega_i} \left[(\omega_i C(\lambda_t, N_t))^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t \left[J(\lambda_{t+1}, \omega_i C(Z_{t+1}, N_{t+1}))^{1-\gamma} \right] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right]^{\frac{1}{1-\frac{1}{\psi}}}, \end{aligned} \tag{A.3}$$

where the term after $\frac{1}{\omega_i}$ corresponds to $\widetilde{J}(\lambda_t, \omega_i C(Z_t, N_t))$. In other words, we can multiply consumption by ω_i and still satisfy the Bellman equation which implies (A.2). In the paper, we used this to normalize the value function by productivity:

$$J(\lambda_t, \omega_i C(Z_t, N_t)) = Z_t J(\lambda_t, \omega_i C(1, N_t)) = Z_t j(\lambda_t, N_t), \tag{A.4}$$

using the linearity of consumption in productivity.

Overall, a household that consumes a share ω_i of aggregate consumption has the same utility function as the representative household up to the scaling factor ω_i.

Next, we consider the problem in our paper and the SDF M^i_{t+1} of a household that receives share ω_i of aggregate consumption in each period. We showed that, if $C^i_t = \omega_i C_t$, then $J^i_t = J(\lambda_t, \omega_i C(Z_t, N_t)) = \omega_i J(\lambda_t, C(Z_t, N_t)) = \omega_i J_t$. The form of the SDF in (15) reveals that ω_i cancels out in both the consumption growth term and the value function term, which implies

$$M^i_{t+1} = M_{t+1}. \tag{A.5}$$

The SDF of a households that receives a constant share of aggregate consumption in each period is identical to the SDF of the representative household.

A.2 Households

We consider three cases of household structures that add up to the representative household. In all cases, the productivity of each household is identical and equal to Z_t.

The first case is similar to Merz (1995). Let there be N_h households with measure ω_i, where $\sum_{i=1}^{N_h} \omega_i = 1$. Further, assume that the fraction N_t of the members in each household are at work and each households owns the fraction ω_i of the representative firm shares. In this case, the condition $C^i_t = \omega_i C_t$ is satisfied. As shown in Section A.1, the SDF of each household is the same as the representative household and can be used to solve the firm's optimization problem.

Second, we consider the case of employed and unemployed households where all households hold shares of the firm. Let ω^E_i (ω^U_i) denote the measure of the employed (unemployed) household i at time t. The measure of households is the same as their ownership share at the representative firm. Note that the measure of each family does not change over time, but the employment status of a family may change in the future. However, we are interested in a period-by-period aggregation. Let N_t^E (N_t^U) denote the number of employed (unemployed) households. Then we have

$$\sum_{i=1}^{N_t^E} \omega_i^E = N_t, \quad \sum_{i=1}^{N_t^U} \omega_i^U = 1 - N_t. \tag{A.6}$$

We assume that there is a perfect consumption insurance for households. This translates into an insurance payment from employed to unemployed households that compensates for the wage loss of unemployed households. Specifically, we have

$$\begin{aligned} C_t^{E,i} &= \omega_i^E D_t + \frac{\omega_i^E}{N_t} W_t N_t - \frac{\omega_i^E}{N_t} I_t \\ C_t^{U,i} &= \omega_i^U D_t + \frac{\omega_i^U}{1 - N_t} b_t (1 - N_t) + \frac{\omega_i^U}{1 - N_t} I_t, \end{aligned} \tag{A.7}$$

where $C_t^{E,i}$ and $C_t^{U,i}$ denote the consumption of the employed and unemployed households with weights ω_i^E and ω_i^U, respectively. I_t is the aggregate insurance payment. Both types of households receive a share of the aggregate dividend. Employed households also receive their wage share while unemployed households are equipped with the value of non-market activity. The insurance payment that facilitates perfect consumption insurance satisfies

$$C_t^{E,i} = C_t^{U,i} = \omega_i C_t \quad \text{if} \quad \omega_i^E = \omega_i^U = \omega_i. \tag{A.8}$$

The aggregate insurance payment that satisfies this condition is

$$I_t = (1 - N_t) W_t N_t - (1 - N_t) b_t N_t, \tag{A.9}$$

which corresponds to a compensation for lost wages due to unemployment net of the amount that employed households need to receive from unemployment benefits to equate consumption in employment and unemployment. If all households internalize the structure of insurance payments, household consumption is determined by aggregate quantities and all shareholders have the same SDF as the representative agent.

Finally, we consider the case where only employed hold shares of the firm. Assume that unemployed households have no access to the stock market and only employed households own shares of the firm. In this case, perfect consumption insurance is achieved with an aggregate insurance payment that also includes compensation for dividend income. In this case, we have

$$\begin{aligned} C_t^{E,i} &= \frac{\omega_i^E}{N_t} D_t + \frac{\omega_i^E}{N_t} W_t N_t - \frac{\omega_i^E}{N_t} I_t \\ C_t^{U,i} &= \frac{\omega_i^U}{1-N_t} b_t (1-N_t) + \frac{\omega_i^U}{1-N_t} I_t. \end{aligned} \tag{A.10}$$

The insurance payment that satisfies (A.8) is

$$I_t = (1-N_t) D_t + (1-N_t) W_t N_t - (1-N_t) b_t N_t. \tag{A.11}$$

A.3 Firms

Suppose the stock market is populated by N^F firms. Each firm employs the fraction f_j of the employed labor force, namely, $N_t^j = f_j N_t$, where $\sum_{j=1}^{N^F} f_j = 1$. If we can show that an individual firm's dividend, stock price and vacancies are also proportional to the corresponding aggregate quantities, namely,

$$D_t^j = f_j D_t, \quad P_t^j = f_j P_t, \quad V_t^j = f_j V_t, \tag{A.12}$$

we can argue that the ownership structure of firms does not matter for aggregate quantities, and firm value is only a function of aggregate quantities up to the scaling factor f_j. In other words, different households described in Section A.1 can own different shares at different firms. As long as the shares of a household i add up to the household's weight ω_i, each firm uses the unique SDF M_{t+1} to solve for optimal hiring and firms add up to the representative firm in the paper.

We assume that each firm solves the optimization problem taking the aggregate vacancy filling rate $q(N_t, V_t)$ and wages W_t as given. In other words, all firms face identical labor market conditions. The problem of the firm is

$$P_t^{j,c} = \max_{\{V_{t+\tau}^j, N_{t+\tau+1}^j\}_{t=0}^{\infty}} \mathbb{E}_t \sum_{\tau=0}^{\infty} M_{t+\tau} \left[Z_{t+\tau} N_{t+\tau}^j - W_t N_{t+\tau}^j - \kappa_t V_t^j \right] \tag{A.13}$$

subject to

$$N_{t+1}^j = (1-s) N_t^j + q(N_t, V_t) V_t^j. \tag{A.14}$$

The first-order conditions w.r.t. vacancies and employment are

$$\begin{aligned} 0 &= -1 + l_t^j \frac{q(N_t, V_t)}{\kappa_t} \\ l_t^j &= \mathbb{E}_t \left[M_{t+1}(Z_{t+1} - W_{t+1} + l_{t+1}^j (1-s)) \right], \end{aligned} \tag{A.15}$$

where l_t^j denotes the Lagrange multiplier on (A.14). Note that l_t^j is a function of aggregate quantities κ_t and $q(N_t, V_t)$ only, and therefore identical for all firms. Using the recursive substitution of the first-order conditions in (A.13) as in the paper, the cum-dividend value of firm j can be written as

$$P_t^{j,c} = Z_t N_t^j - W_t N_t^j + l_t^j (1-s) N_t^j. \tag{A.16}$$

Because we started with $N_t^j = f_j N_t$, we have $P_t^{j,c} = f_j P_t^c$. Furthermore, the law of motion for labor implies $V_t^j = f_j V_t$, and $D_t^j = f_j D_t$. As shown in the paper, (A.16) implies

$$P_t^j = \frac{\kappa_t}{q(N_t, V_t)} N_{t+1}^j, \tag{A.17}$$

which establishes $P_t^j = f_j P_t$. The stock price of each firm is proportional to the fraction of the employed labor force it employs.

B The Nash Wage Bargain

The following proof is adapted from Petrosky-Nadeau, Zhang, and Kuehn (2013) and shows that the canonical Nash-bargained wage formula of the DMP model holds in our setting. Let S_t denote the joint surplus from a match in terms of marginal benefits for the household and the firm:

$$S_t = \frac{J_{N,t} - J_{U,t}}{J_{C,t}} + P_{N_t}^c - P_{V,t}^c, \tag{B.1}$$

where subscripts denote partial derivatives and time and P_t^c is the cum-dividend value of the firm. We divide $J_{N,t} - J_{U,t}$ by $J_{C,t}$ to make the household and firm benefits in units of the consumption good. The bargaining power B of the household implies

$$BS_t = \frac{J_{N,t} - J_{U,t}}{J_{C,t}}. \tag{B.2}$$

The household faces the following resource constraint:

$$C_t = D_t + W_t N_t + b_t U_t - \kappa_t V_t, \tag{B.3}$$

along with the following employment and unemployment dynamics

$$\begin{aligned} N_{t+1} &= (1-s)N_t + f(\theta_t)U_t \\ U_{t+1} &= sN_t + (1-f(\theta_t))U_t. \end{aligned} \tag{B.4}$$

Taking the partial derivative of J_t with respect to C_t and N_t we have

$$\begin{aligned} J_{C,t} &= C_t^{-\frac{1}{\psi}} J_t^{\frac{1}{\psi}} \\ J_{N,t} &= W_t J_{C,t} + \beta \left(\mathbb{E}_t \left[J_{t+1}^{1-\gamma}\right]\right)^{\frac{\gamma-\frac{1}{\psi}}{1-\gamma}} \mathbb{E}_t \left[(1-\gamma)J_{t+1}^{-\gamma}((1-s)J_{N,t+1} + sJ_{U,t+1}\right], \end{aligned} \tag{B.5}$$

which results in the following marginal benefit of an employed member for the household

$$\frac{J_{N,t}}{J_{C,t}} = W_t + \mathbb{E}_t \left[M_{t+1}\left[(1-s)\frac{J_{N,t+1}}{J_{C,t+1}} + s\frac{J_{U,t+1}}{J_{C,t+1}}\right]\right]. \tag{B.6}$$

Using the same procedure for the unemployment we get

$$\frac{J_{U,t}}{J_{C,t}} = b_t + \mathbb{E}_t \left[M_{t+1}\left[f(\theta_t)\frac{J_{N,t+1}}{J_{C,t+1}} + (1-f(\theta_t))\frac{J_{U,t+1}}{J_{C,t+1}}\right]\right]. \tag{B.7}$$

Next we consider the firm's value function with optimal policy V_t:

$$P_t^c = \max_{\{V_{t+\tau}, N_{t+\tau+1}\}_{t=0}^{\infty}} \mathbb{E}_t \left[\sum_{\tau=0}^{\infty} M_{t+\tau}\left[(Z_{t+\tau} - W_{t+\tau})N_{t+\tau} - \kappa_{t+\tau}V_{t+\tau}\right]\right] \tag{B.8}$$

subject to

$$N_{t+1} = (1-s)N_t + q(\theta_t)V_t. \tag{B.9}$$

Taking the partial derivative with respect to V_t we get

$$\begin{aligned} P_{V,t}^c &= -\kappa_t + \mathbb{E}_t\left[M_{t+1}(Z_{t+1} - w_{t+1})q(\theta_t)\right] \\ &= -\kappa_t + q(\theta_t)\mathbb{E}_t\left[M_{t+1}F_{N,t+1}\right]. \end{aligned} \tag{B.10}$$

Due to free entry of firms into the labor market, firms open vacancies until the marginal benefit from vacancy openings is zero which implies $P_{V,t}^c = 0$. This term disappears in the surplus equation.

Furthermore it implies

$$\frac{\kappa_t}{q(\theta_t)} = \mathbb{E}_t\left[M_{t+1}P^c_{N,t+1}\right]. \tag{B.11}$$

The marginal benefit of employment to the firm is

$$\begin{aligned} P^c_{N,t} &= Z_t - W_t + \mathbb{E}_t\left[M_{t+1}(Z_{t+1} - W_{t+1})(1-s)\right] \\ &= Z_t - W_t + (1-s)\mathbb{E}_t\left[M_{t+1}P^c_{N,t+1}\right]. \end{aligned} \tag{B.12}$$

Using the marginal benefit equations above, we can write the total match surplus as

$$\begin{aligned} S_t &= \frac{J_{N,t} - J_{U,t}}{J_{C,t}} + P^c_{N_t} - P^c_{V,t} \\ &= W_t + \mathbb{E}_t\left[M_{t+1}\left[(1-s)\frac{J_{N,t+1}}{J_{C,t+1}} + s\frac{J_{U,t+1}}{J_{C,t+1}}\right]\right] \\ &- b_t - \mathbb{E}_t\left[M_{t+1}\left[f(\theta_t)\frac{J_{N,t+1}}{J_{C,t+1}} + (1-f(\theta_t))\frac{J_{U,t+1}}{J_{C,t+1}}\right]\right] \\ &+ Z_t - W_t + (1-s)\mathbb{E}_t\left[M_{t+1}P^c_{N,t+1}\right]. \end{aligned} \tag{B.13}$$

Merging terms we have

$$\begin{aligned} S_t &= Z_t - b_t + (1-s)\mathbb{E}_t\left[M_{t+1}\left(\frac{J_{N,t+1} - J_{U,t+1}}{J_{C,t+1}} + P^c_{N_t+1}\right)\right] \\ &- f(\theta_t)\mathbb{E}_t\left[M_{t+1}\frac{J_{N,t+1} - J_{U,t+1}}{J_{C,t+1}}\right]. \end{aligned} \tag{B.14}$$

The surplus splitting rule implies

$$S_t = Z_t - b_t + (1-s)\mathbb{E}_t\left[M_{t+1}S_{t+1}\right] - f(\theta_t)B\mathbb{E}_t\left[M_{t+1}S_{t+1}\right]. \tag{B.15}$$

Recall the marginal value of employment to the firm is

$$P^c_{N,t} = (1-B)S_t. \tag{B.16}$$

Plugging (B.15) into (B.16) and using (B.12) we get the canonical wage equation from Nash bargaining

$$W_t = (1-B)b_t + B(Z_t + \kappa_t\theta_t), \tag{B.17}$$

which corresponds to the Nash-bargained wage in Pissarides (2000).

C Equity Return and Firm Value (Proof of Theorem 1)

The representative firm pays out as dividend what is left from output after subtracting wage costs and investment:

$$D_t = Z_t N_t - W_t N_t - \kappa_t V_t. \tag{C.1}$$

The firm takes wages W_t and labor market tightness θ_t as given and maximizes the cum-dividend value

$$P_t^c = \max_{\{V_{t+\tau}, N_{t+\tau+1}\}_{t=0}^{\infty}} \mathbb{E}_t \sum_{\tau=0}^{\infty} M_{t+\tau} \left[Z_{t+\tau} N_{t+\tau} - W_{t+\tau} N_{t+\tau} - \kappa_{t+\tau} V_{t+\tau} \right], \tag{C.2}$$

subject to the firm's law of motion for employment

$$N_{t+1} = (1-s) N_t + q(\theta_t) V_t. \tag{C.3}$$

The first order conditions with respect to $V_{t+\tau}$ and $N_{t+\tau+1}$ are given by

$$0 = -1 + l_t \frac{q(\theta_t)}{\kappa_t} \tag{C.4}$$

$$l_t = \mathbb{E}_t \left[M_{t+1} (Z_{t+1} - W_{t+1} + l_{t+1}(1-s)) \right], \tag{C.5}$$

where l_t is the Lagrange multiplier on the aggregate law of motion for employment level. Combining the first order conditions we have $\mathbb{E}_t \left[M_{t+1} R_{t+1} \right] = 1$ where

$$R_{t+1} = \frac{Z_{t+1} - W_{t+1} + (1-s) \frac{\kappa_{t+1}}{q(\theta_{t+1})}}{\frac{\kappa_t}{q(\theta_t)}}. \tag{C.6}$$

We can rewrite the return on hiring using $\kappa_t = \kappa Z_t$ and $b_t = b Z_t$:

$$R_{t+1} = e^{\mu + \epsilon_{t+1} + d_{t+1} \zeta_{t+1}} \left[\frac{1 - w_{t+1} + (1-s) \frac{\kappa}{q(\theta_{t+1})}}{\frac{\kappa}{q(\theta_t)}} \right]. \tag{C.7}$$

Consider the ex-dividend value of equity $P_t = P_t^c - D_t$. We can rewrite the value of the firm:

$$P_t^c = P_t + Z_t N_t - W_t N_t - \kappa_t V_t \tag{C.8}$$

Expanding (C.2) and recursively substituting the expressions obtained from the first-order conditions (C.4) and (C.5), we can use

$$
\begin{aligned}
P_t^c &= Z_t N_t - W_t N_t - \kappa_t V_t - l_t(N_{t+1} - (1-s)N_t - \frac{q(\theta_t)}{\kappa_t}\kappa_t V_t) \\
&+ \mathbb{E}_t\left[M_{t+1}\left[Z_{t+1}N_{t+1} - W_{t+1}N_{t+1} - \kappa_{t+1}V_{t+1} - l_{t+1}\left(N_{t+2} - (1-s)N_{t+1} - \frac{q(\theta_{t+1})}{\kappa_{t+1}}\kappa_{t+1}V_{t+1}\right)\right]\right] \\
&+ ...
\end{aligned}
\tag{C.9}
$$

and verify that

$$
P_t^c = Z_t N_t - W_t N_t + l_t(1-s)N_t. \tag{C.10}
$$

Specifically the investment terms in the first line of (C.9) cancel out as a result of (C.4). Furthermore the term $l_t N_{t+1}$ in the first line cancels out with next period's zero-coupon equity value value up to the investment terms and $l_{t+1}N_{t+2}$ and so on. Therefore, the ex-dividend value of the firm is given by

$$
\begin{aligned}
P_t &= Z_t N_t - W_t N_t + l_t(1-s)N_t - Z_t N_t + W_t N_t + \kappa_t V_t \\
&= \kappa_t V_t + l_t(1-s)N_t \\
&= \frac{\kappa_t}{q(\theta_t)}(N_{t+1} - (1-s)N_t) + \frac{\kappa_t}{q(\theta_t)}(1-s)N_t \\
&= l_t N_{t+1}.
\end{aligned}
\tag{C.11}
$$

Combining (C.11) with (C.4) results in (10).

Now we return to the basic definition of equity return and show that it is equivalent to the return on hiring in (C.6):

$$\begin{aligned}
\frac{P^c_{t+1}}{P^c_t - D_t} &= \frac{P_{t+1} + D_{t+1}}{P_t} \\
&= \frac{l_{t+1}N_{t+2} + Z_{t+1}N_{t+1} - W_{t+1}N_{t+1} - \kappa_{t+1}V_{t+1}}{l_t N_{t+1}} \\
&= \frac{l_{t+1}\frac{N_{t+2}}{N_{t+1}} + Z_{t+1} - W_{t+1} - \frac{\kappa_{t+1}V_{t+1}}{N_{t+1}}}{l_t} \\
&= \frac{l_{t+1}\left[1 - s + \frac{q(\theta_{t+1})}{\kappa t+1}\frac{\kappa_{t+1}V_{t+1}}{N_{t+1}}\right] + Z_{t+1} - W_{t+1} - \frac{\kappa_{t+1}V_{t+1}}{N_{t+1}}}{l_t} \qquad \text{(C.12)} \\
&= \frac{Z_{t+1} - W_{t+1} + l_{t+1}(1-s)}{l_t} \\
&= \frac{Z_{t+1} - W_{t+1} + (1-s)\frac{\kappa_{t+1}}{q(\theta_{t+1})}}{\frac{\kappa_t}{q(\theta_t)}} \\
&= R_{t+1}.
\end{aligned}$$

This shows the equivalence between the return on hiring and the equity return leading to (11).

D Constant Disaster Risk Model

D.1 Compound Poisson Process

The algebraic rules for compound Poisson processes illustrated in this section are adapted from Cont and Tankov (2004). Drechsler and Yaron (2011) model jumps in expected growth and volatility using compound Poisson processes. Let $Q_{t,t+1}$ be a compound Poisson process with intensity $\tilde{\lambda}$. Specifically, $\tilde{\lambda}$ represents the expected number of jumps in the time period $(t, t+1]$. Agents in the model view the jumps in $(t, t+1]$ as occurring at $t+1$. Then, $Q_{t,t+1}$ is given by

$$Q_{t,t+1} = \begin{cases} \sum_{i=1}^{\mathcal{N}_{t+1}-\mathcal{N}_t} \zeta_i & \text{if } \mathcal{N}_{t+1} - \mathcal{N}_t > 0 \\ 0 & \text{if } \mathcal{N}_{t+1} - \mathcal{N}_t = 0, \end{cases}$$

where $\mathcal{N}_t$ is a Poisson counting process and $\mathcal{N}_{t+1} - \mathcal{N}_t$ is the number of jumps in the time interval $(t, t+1]$. Jump size ζ is *iid*. We can take conditional expectations with $Q_{t,t+1}$ using

$$\mathbb{E}_t\left[e^{uQ_{t+1}}\right] = e^{\tilde{\lambda}\left(\mathbb{E}\left[e^{u\zeta}\right]-1\right)}, \qquad \text{(D.1)}$$

where log of the right-hand side is the cumulant-generating function of $Q_{t,t+1}$. More precisely, the probability of observing k jumps over the course one period $(t, t+1]$ is equal to $e^{\tilde{\lambda}} \frac{\tilde{\lambda}^k}{k!}$. We take the t to be in units of months in our quantitative assessment of the model.

D.2 Role of the EIS (Proof of Theorem 2)

Consider the normalized value function in (25) and replace the disaster term with the compound Poisson process $Q_{t,t+1}$ with constant intensity $\tilde{\lambda}$:

$$j(\tilde{\lambda}, N_t) = \left[c_t^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t \left[e^{(1-\gamma)(\mu+\epsilon_{t+1}+Q_{t,t+1})} j(\tilde{\lambda}, N_{t+1})^{1-\gamma} \right] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right]^{\frac{1}{1-\frac{1}{\psi}}}. \tag{D.2}$$

Conditional on time-t information, the realizations of ϵ_{t+1}, $Q_{t,t+1}$ and N_{t+1} are independent. Therefore, we can write (27) with

$$\hat{\beta}(\tilde{\lambda}) = \beta \mathbb{E}_t \left[e^{(1-\gamma)Q_{t,t+1}} \right]^{\frac{1-\frac{1}{\psi}}{1-\gamma}}. \tag{D.3}$$

Taking the expectation using the algebra introduced in Appendix D.1, we can compute the log time discount factor:

$$\log\left(\hat{\beta}(\tilde{\lambda})\right) = \log(\beta) + \frac{1-\frac{1}{\psi}}{1-\gamma} \left(\mathbb{E}\left[e^{(1-\gamma)\zeta} \right] - 1 \right) \tilde{\lambda}. \tag{D.4}$$

Note that ζ takes only negative values and $\mathbb{E}\left[e^{(1-\gamma)\zeta}\right]$ is always positive. There are two cases we need to investigate: $\gamma < 1$ and $\gamma > 1$.[21] In both cases, we have

$$\frac{\mathbb{E}\left[e^{(1-\gamma)\zeta}\right] - 1}{1-\gamma} < 0. \tag{D.5}$$

Therefore, the $\log\left(\hat{\beta}(\tilde{\lambda})\right)$ is decreasing in $\tilde{\lambda}$ is negative if and only if $1 - \frac{1}{\psi} > 0$ which is equivalent to $\psi > 1$.

[21] We do not consider the case of $\gamma = 1$ which would lead to a different functional form for the value function.

D.3 Risk-free Rate (Proof of Theorem 3)

Due to the homogeneity of the value function in consumption, the stochastic discount factor becomes:

$$M_{t+1} = \frac{\beta e^{-\frac{\mu}{\psi}-\gamma(\epsilon_{t+1}+Q_{t+1})}}{\mathbb{E}_t\left[e^{(1-\gamma)(\epsilon_{t+1}+Q_{t+1})}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\gamma}}}. \tag{D.6}$$

Taking the expectation in the denominator, the log stochastic discount factor becomes

$$\begin{aligned}\log(M_{t+1}) = \log(\beta) - \frac{\mu}{\psi} - \gamma(\epsilon_{t+1}+Q_{t+1})\\ -\frac{1}{2}\left(\frac{1}{\psi}-\gamma\right)(1-\gamma)\,\sigma_\epsilon^2 - \frac{\frac{1}{\psi}-\gamma}{1-\gamma}\left(\mathbb{E}\left[e^{(1-\gamma)\zeta}\right]\right)\tilde{\lambda}.\end{aligned} \tag{D.7}$$

It follows that the log risk-free rate $\log(R_f) = -\log \mathbb{E}[M_{t+1}]$ is given by:

$$\begin{aligned}\log(R_f) = -\log(\beta) + \frac{\mu}{\psi} + \frac{1}{2}\left(\frac{1}{\psi}-\frac{\gamma}{\psi}-\gamma\right)\sigma_\epsilon^2\\ +\left[\frac{\frac{1}{\psi}-\gamma}{1-\gamma}\left(\mathbb{E}\left[e^{(1-\gamma)\zeta}\right]-1\right)-\left(\mathbb{E}\left[e^{-\gamma\zeta}\right]-1\right)\right]\tilde{\lambda}.\end{aligned} \tag{D.8}$$

Note that the term $\frac{\frac{1}{\psi}-\gamma}{1-\gamma}$ is bounded above by $\gamma/(\gamma-1)$. The properties of the exponential implies $\frac{1}{\gamma}\mathbb{E}\left(\left[e^{-\gamma\zeta}\right]-1\right) > \frac{1}{\gamma-1}\mathbb{E}\left(\left[e^{-\gamma\zeta}\right]-1\right)$, which, together with the fact that ζ takes only negative values, implies that the risk-free rate is decreasing in disaster intensity (Tsai and Wachter (2015)).

D.4 Expected Returns and Equity Premium (Proof of Theorem 4)

Lemma 1. *The Euler equation* $\mathbb{E}_t\left[M_{t+1}R_{t+1}\right] = 1$ *becomes*

$$\hat{\beta}(\tilde{\lambda})e^{\mu\left(1-\frac{1}{\psi}\right)+\frac{1}{2}(1-\gamma)\left(1-\frac{1}{\psi}\right)\sigma_\epsilon^2}\left[\frac{1-w(\theta_{t+1})+(1-s)\frac{\kappa}{\theta_{t+1}}}{\frac{\kappa}{q(\theta_t)}}\right] = 1, \tag{D.9}$$

where

$$w(\theta_t) = (1-B)b + B(1+\kappa(\nu\theta_t+(1-\nu)\bar{\theta})). \tag{D.10}$$

Proof. The result follows from the form of the stochastic discount factor in (D.6) and the hiring return in (C.6). Note that the only state variable in the economy with constant disaster risk is employment level N_t. In this case, labor market variables are deterministic. At time t, N_{t+1} is known and the policy function for vacancies V_t only depends on N_t. Therefore, V_{t+1} is known at time t as well which leads to the fact that θ_{t+1} is known at time t.

Lemma 2. *The Euler equation implies the following form for the equity return:*

$$R_{t+1} = \frac{e^{\mu+\epsilon_{t+1}+Q_{t+1}}}{\hat{\beta}(\tilde{\lambda})e^{\mu\left(1-\frac{1}{\psi}\right)+\frac{1}{2}(1-\gamma)\left(1-\frac{1}{\psi}\right)\sigma_\epsilon^2}}, \tag{D.11}$$

Moreover, the log expected equity return becomes

$$\begin{aligned}\log \mathbb{E}_t\left[R_{t+1}\right] =& -\log(\beta) + \frac{\mu}{\psi} + \frac{1}{2}\left(\frac{1}{\psi} - \frac{\gamma}{\psi} + \gamma\right) \\ & + \underbrace{\left(\mathbb{E}\left[e^{\zeta}\right] - 1\right)}_{\textit{Productivity growth}} \tilde{\lambda} \\ & - \underbrace{\left(\frac{1-\frac{1}{\psi}}{1-\gamma}\left(\mathbb{E}\left[e^{(1-\gamma)\zeta}\right] - 1\right)\right)}_{\textit{Labor market}} \tilde{\lambda}.\end{aligned} \tag{D.12}$$

Proof. The term $\left[\frac{1-w(\theta_{t+1})+(1-s)\frac{\kappa}{\theta_{t+1}}}{\frac{\kappa}{q(\theta_t)}}\right]$ in (C.7) can be rewritten as $\left(\hat{\beta}(\tilde{\lambda})e^{\mu\left(1-\frac{1}{\psi}\right)+\frac{1}{2}(1-\gamma)\left(1-\frac{1}{\psi}\right)\sigma_\epsilon^2}\right)^{-1}$ using (D.9) which implies (D.11). Equation (D.12) follows from taking the expectation of (D.11) using rules introduced in Section D.1.

Proof of Theorem 4: Log expected return follows directly from Lemma 2. We use the log risk-free rate from Theorem 3 to compute the equity premium.

D.5 Payout Ratio of a Worker Inside the Firm (Proof of Theorem 5)

When the labor market is in steady state, labor market tightness is constant. In this case, we can rewrite the Euler equation in Lemma 1 as

$$\begin{aligned}&-\log\left(1 - s + \frac{1-w(\theta)}{\kappa}\xi\theta^{-\eta}\right) \\ &= \frac{1-\frac{1}{\psi}}{1-\gamma}\left(\mathbb{E}\left[e^{(1-\gamma)\zeta} - 1\right]\right)\tilde{\lambda} + \log(\beta) + \mu\left(1-\frac{1}{\psi}\right) + \frac{1}{2}(1-\gamma)\left(1-\frac{1}{\psi}\right)\sigma_\epsilon^2,\end{aligned} \tag{D.13}$$

where all terms including θ are on the left-hand side. Moreover, we can write the payout from a worker inside the firm as

$$D_t^l = Z_t - W_t - sl_t. \tag{D.14}$$

which can be seen from

$$l_t = \mathbb{E}_t \left[M_{t+1}(Z_{t+1} - W_{t+1} - sl_{t+1} + l_{t+1}) \right]. \tag{D.15}$$

From (13), we know that the value of a worker is given by $l_t = \kappa_t / q(\theta_t)$. As a result, the payout ratio of a worker is

$$\begin{aligned} \frac{D_t^l}{l_t} &= \frac{Z_t - W_t - sl_t}{l_t} \\ &= \frac{1 - w(\theta) - s\frac{\kappa}{q(\theta)}}{\frac{\kappa}{q(\theta)}}, \end{aligned} \tag{D.16}$$

where the second line follows from normalizing the numerator and the denominator by Z_t. We can then define the transformed payout ratio $h(\tilde{\lambda})$:

$$h(\tilde{\lambda}) = \log\left(1 + \frac{D_t^l}{l_t}\right). \tag{D.17}$$

which will correspond to the negative of the left-hand side in (D.13). Theorem 2 implies that the right-hand side of equation (D.13) is decreasing in $\tilde{\lambda}$ if and only if $\psi > 1$ which implies Theorem 5. Moreover, the left-hand side of (D.13) is increasing in θ which implies Theorem 6.

E Equilibrium Solution

Let x' denote the value of the variable x in period $t+1$ and x the value at t. We can rewrite the normalized value function of the household as

$$g(\lambda, N) = j(\lambda, N)^{1-\frac{1}{\psi}}. \tag{E.1}$$

The value function and policy functions are functions of the exogenous state variable λ and the endogenous state variable N. The dynamics of the stochastic discount factor and returns are driven by four shocks: disaster probability λ', normal times productivity shock ϵ', disaster indicator d' and disaster size ζ'. Let $\mathbb{E}$ be the expectation operator over four shocks. In our numerical procedure, we solve for the consumption policy $c(\lambda, N)$ and the value function $g(\lambda, N)$. The market clearing condition allows us to compute the vacancy rate given the consumption policy.

The stochastic discount factor is characterized by

$$\begin{aligned} M(\lambda, N; \lambda', \epsilon', d', \zeta') =& \beta e^{-\frac{\mu}{\psi}+\frac{1}{2}(1-\gamma)\left(\gamma-\frac{1}{\psi}\right)\sigma_\epsilon^2} e^{-\gamma(\epsilon'+d'\zeta')} \\ & \cdot \mathbb{E}\left[e^{(1-\gamma)d'\zeta'} g(\lambda', N')^{\frac{1-\gamma}{1-\frac{1}{\psi}}}\right]^{\frac{\gamma-\frac{1}{\psi}}{1-\gamma}} \left(\frac{c(\lambda', N')}{c(\lambda, N)}\right)^{-\frac{1}{\psi}} g(\lambda', N')^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}. \end{aligned} \tag{E.2}$$

The equity return is given by

$$R(\lambda, N; \lambda', \epsilon', d', \zeta') = e^{\mu+\epsilon'+d'\zeta'} \left[\frac{1 - w(\lambda', N') + (1-s)\frac{\kappa}{q(\theta(\lambda', N'))}}{\frac{\kappa}{q(\theta(\lambda, N))}}\right], \tag{E.3}$$

where

$$w(\lambda, N) = (1-B)b + B(1 + \kappa((1-\nu)\bar{\theta} + \nu\theta(\lambda, N))) \tag{E.4}$$

and

$$\theta(\lambda, N) = \frac{N + b(1-N) - c(\lambda, N)}{\kappa(1-N)}, \tag{E.5}$$

which follows from (21).

The equilibrium conditions that $c(\lambda, N)$ and $g(\lambda, N)$ have to satisfy are

$$\mathbb{E}\left[M(\lambda, N; \lambda', \epsilon', d', \zeta') R(\lambda, N; \lambda', \epsilon', d', \zeta')\right] = 1 \tag{E.6}$$

and

$$g(N, \lambda) = c(N, \lambda)^{1-\frac{1}{\psi}} + \beta e^{\left(1-\frac{1}{\psi}\right)\mu + \frac{1}{2}\left(1-\frac{1}{\psi}\right)(1-\gamma)\sigma_\epsilon^2} \left(\mathbb{E}\left[e^{(1-\gamma)d'\zeta'} g(\lambda', N')^{\frac{1-\frac{1}{\psi}}{1-\gamma}}\right]\right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}}. \tag{E.7}$$

We approximate the AR(1) process for log disaster probability by a 12-state Markov process and use the corresponding probability transition matrix to calculate expectations over λ'. The expectations over ζ' and ϵ' can be taken directly since their distributions are *iid*.

We approximate the policy function and the value function by a polynomial of employment level N where the polynomial coefficients are estimated for each value of the disaster probability separately. We use $n+1$ nodes for employment to conduct the approximation by an n'th order polynomial. As a result we have $24(n+1)$ unknowns and equations resulting from the equilibrium conditions (E.6) and (E.7). We evaluate the equilibrium conditions at the nodes of the Chebyshev polynomial of order n. Our quantitative results are not significantly different for polynomial approximations of order 3 or higher.

F Data Sources

We use data from 1951 to 2013 for all variables.

- Z is the seasonally adjusted quarterly real average output per person in the nonfarm business sector, constructed by the Bureau of Labor Statistics (BLS) from National Income and Product Accounts (NIPA) and the Current Employment Statistics (CES).
- P is the real price of the S&P composite stock price index, downloaded from Robert Shiller's website (www.econ.yale.edu/ shiller/data.htm).
- P/E is the cyclically adjusted price-earnings ratio, downloaded from Robert Shiller's website (www.econ.yale.edu/ shiller/data.htm).
- P/Z is the price-productivity ratio scaled to have the same value as P/E in the first quarter of 1951.
- U is the seasonally adjusted unemployment, constructed by the BLS from the Current Population Survey (CPS). Quarterly values are calculated averaging monthly data.
- V is the help-wanted advertising index constructed by the Conference Board until June 2006. We use data on vacancy openings from Job Openings and Labor Turnover Survey (JOLTS) from 2000 to 2013. We extrapolate the help-advertising index until 2013 and observe that our extrapolation has a correlation of 0.96 in the period from 2000 to 2006 where both data sources are available. For data plots, we remove a downward sloping time trend in log V/U. Quarterly values are calculated averaging monthly data.

- W denotes wages measured as the product of labor productivity Z and labor share from the BLS. Quarterly values are calculated averaging monthly data.

- C is annual real personal consumption expenditures (GDP) per capita from the BEA.

- Y is annual real gross domestic product (GDP) per capita from the BEA.

- R is the value weighted return market index return including distributions from CRSP. Real returns are calculated using inflation rate data from CRSP. Net returns are multiplied by 0.68 to adjust for financial leverage.

- R_b is the 1-month Treasury bill rate from CRSP. Real rates are calculated using inflation rate data from CRSP.

- Δc and Δy denote log consumption and log output growth. Annual growth rates from monthly simulations that we compare to data values are calculated aggregating consumption and output levels over every year. Let $C_{t,h}$ denote the consumption level in year t and month h. Annual log consumption growth in the model is calculated as

$$\Delta c_{t+1} = \log \left(\frac{\sum_{i=1}^{12} C_{t+1,i}}{\sum_{i=1}^{12} C_{t,i}} \right). \tag{F.1}$$

  The same method is applied to output growth as well.

References

Andolfatto, David, 1996, Business Cycles and Labor-Market Search, *American Economic Review* 86, 112–32.

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

Barro, Robert J, 2006, Rare Disasters and Asset Markets in the Twentieth Century, *The Quarterly Journal of Economics* 121, 823–866.

Barro, Robert J., and Jose F. Ursua, 2008, Macroeconomic crises since 1870, *Brookings Papers on Economic Activity* 1, 255–350.

Campbell, John Y, 2003, Consumption-based asset pricing, in G. Constantinides, M. Harris, and R. Stulz, eds.: *Handbook of the Economics of Finance,* (Elsevier Science, North-Holland).

Campbell, John Y, and Robert J Shiller, 1988, The dividend-price ratio and expectations of future dividends and discount factors, *Review of Financial Studies* 1, 195–228.

Chodorow-Reich, Gabriel, and Loukas Karabarbounis, 2015, The cyclicality of the opportunity cost of employment, Working paper, National Bureau of Economic Research.

Cont, Rama, and Peter Tankov, 2004, *Financial modelling with jump processes* vol. 2. (CRC press).

Croce, Mariano Massimiliano, 2014, Long-run productivity risk: A new hope for production-based asset pricing?, *Journal of Monetary Economics* 66, 13–31.

Diamond, Peter A, 1982, Wage determination and efficiency in search equilibrium, *The Review of Economic Studies* 49, 217–227.

Drechsler, Itamar, and Amir Yaron, 2011, What's vol got to do with it, *Review of Financial Studies* 24, 1–45.

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

Gabaix, Xavier, 2011, Disasterization: A Simple Way to Fix the Asset Pricing Properties of Macroeconomic Models, *The American Economic Review* 101, 406–409.

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

Gourio, François, 2012, Disaster Risk and Business Cycles, *American Economic Review* 102, 2734–2766.

Hagedorn, Marcus, and Iourii Manovskii, 2008, The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited, *American Economic Review* 98, 1692–1706.

Hall, Robert E, 1988, Intertemporal Substitution in Consumption, *The Journal of Political Economy* 96, 339–357.

Hall, Robert E, 2005, Employment Fluctuations with Equilibrium Wage Stickiness, *American Economic Review* 95, 50–65.

Hall, Robert E, 2014, High Discounts and High Unemployment, Working paper, National Bureau of Economic Research.

Hall, Robert E, and Paul R Milgrom, 2008, The Limited Influence of Unemployment on the Wage Bargain, *The American Economic Review* 98, 1653–1674.

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

Kreps, D., and E. Porteus, 1978, Temporal resolution of uncertainty and dynamic choice theory, *Econometrica* 46, 185–200.

Kydland, Finn E, and Edward C Prescott, 1982, Time to build and aggregate fluctuations, *Econometrica* pp. 1345–1370.

Lemmon, Michael L, Michael R Roberts, and Jaime F Zender, 2008, Back to the beginning: persistence and the cross-section of corporate capital structure, *The Journal of Finance* 63, 1575–1608.

Merz, Monika, 1995, Search in the labor market and the real business cycle, *Journal of Monetary Economics* 36, 269–300.

Mortensen, Dale T, and Christopher A Pissarides, 1994, Job creation and job destruction in the theory of unemployment, *The Review of Economic Studies* 61, 397–415.

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.

Petrosky-Nadeau, Nicolas, Lu Zhang, and Lars-Alexander Kuehn, 2013, Endogenous economic disasters and asset prices, *Fisher College of Business Working Paper*.

Pissarides, Christopher, 1985, Short-run equilibrium dynamics of unemployment, vacancies, and real wages, *American Economic Review* 85, 676–690.

Pissarides, Christopher A, 2000, *Equilibrium unemployment theory.* (MIT press).

Shimer, Robert, 2005, The Cyclical Behavior of Equilibrium Unemployment and Vacancies, *American Economic Review* 95, 25–49.

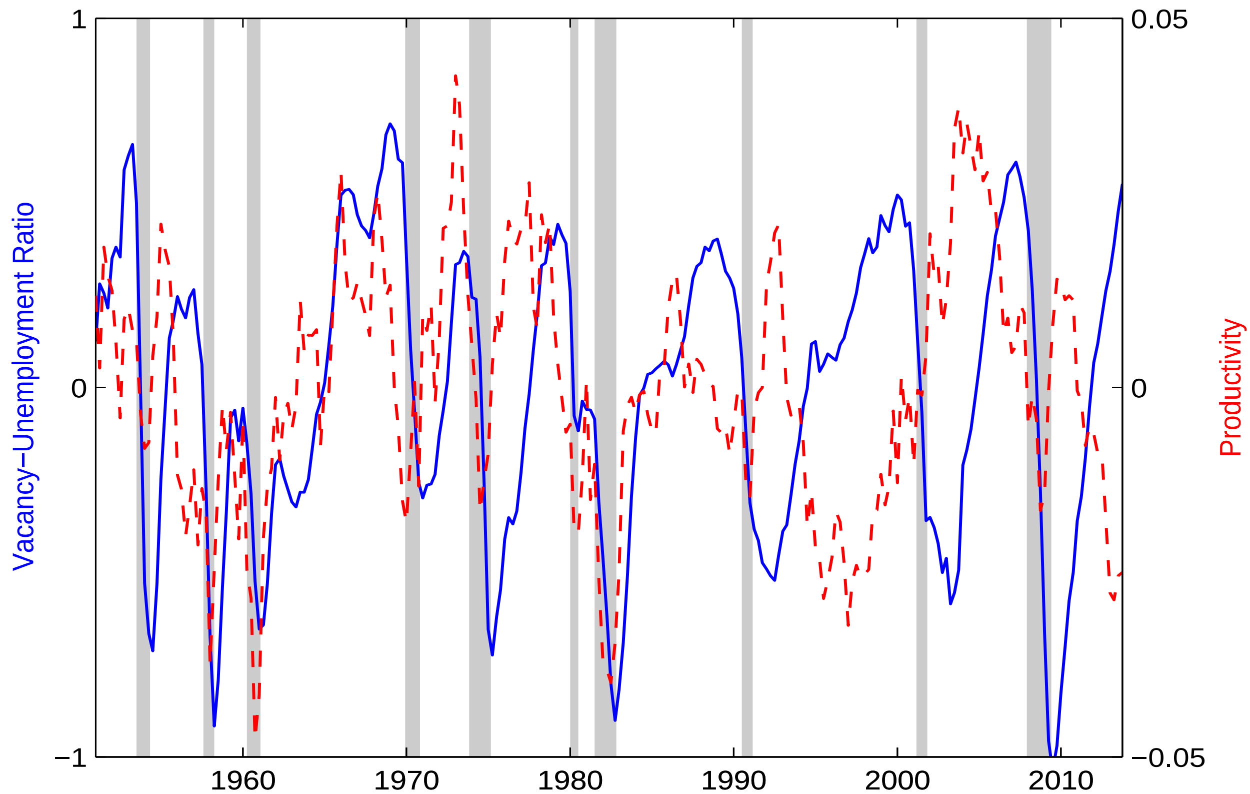
Tsai, Jerry, and Jessica A Wachter, 2015, Disaster Risk and Its Implications for Asset Pricing, *Annual Review of Financial Economics* 7.

Van Binsbergen, Jules H, Jesús Fernández-Villaverde, Ralph SJ Koijen, and Juan Rubio-Ramírez, 2012, The term structure of interest rates in a DSGE model with recursive preferences, *Journal of Monetary Economics* 59, 634–648.

Wachter, Jessica A, 2013, Can Time-Varying Risk of Rare Disasters Explain Aggregate Stock Market Volatility?, *The Journal of Finance* 68, 987–1035.

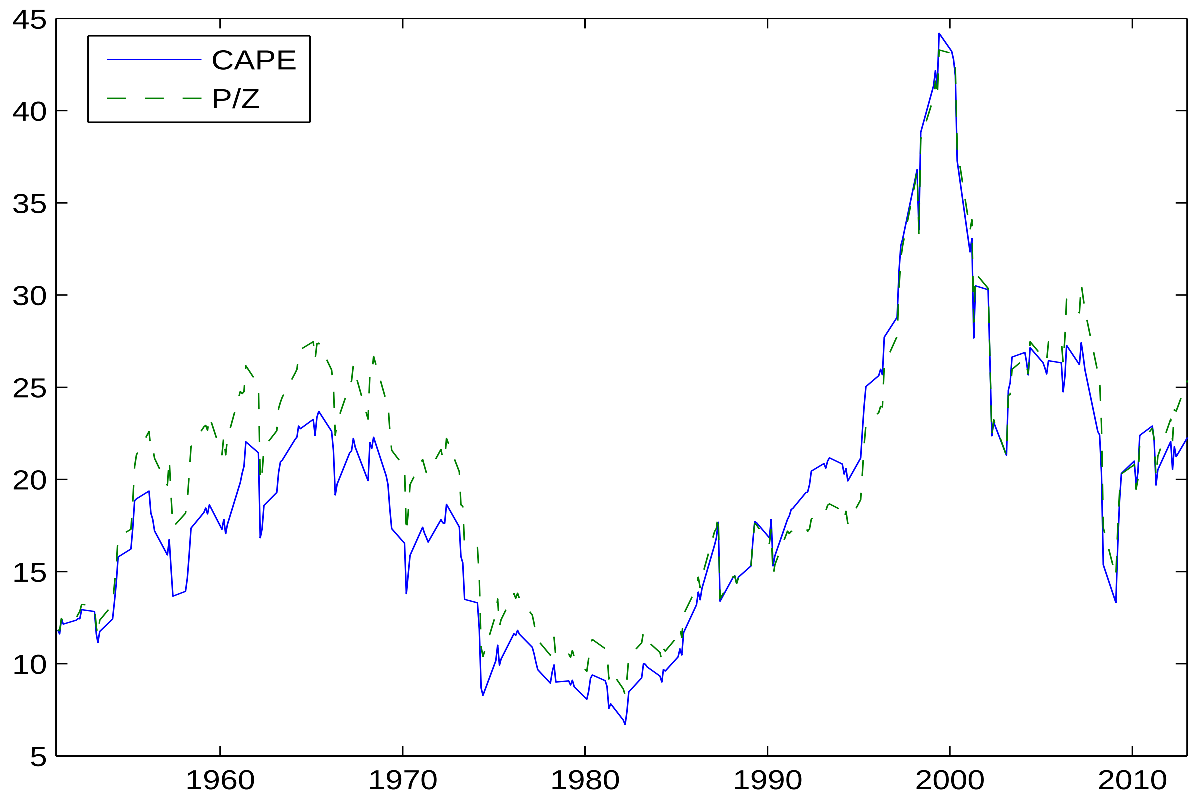
Yashiv, Eran, 2000, The Determinants of Equilibrium Unemployment, *American Economic Review* 90, 1297–1322.

Figure 1: Vacancy-Unemployment Ratio and Labor Productivity: 1951 - 2013



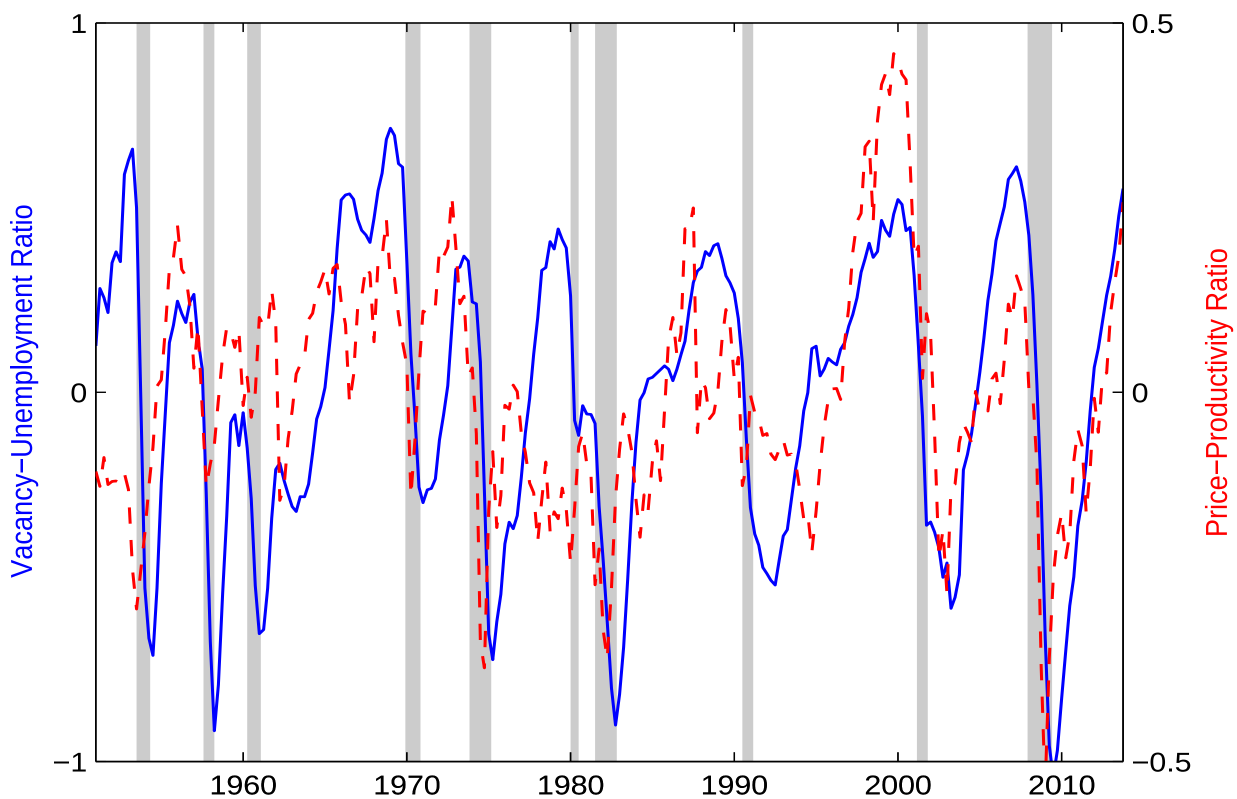
Notes: The solid line shows the vacancy-unemployment ratio, the dashed line labor productivity. Both variables are reported as log deviations from an HP trend with smoothing parameter 10^5. Shaded periods are recessions defined by the National Bureau of Economic Research (NBER).

Figure 2: Valuation Ratios: 1951 - 2013



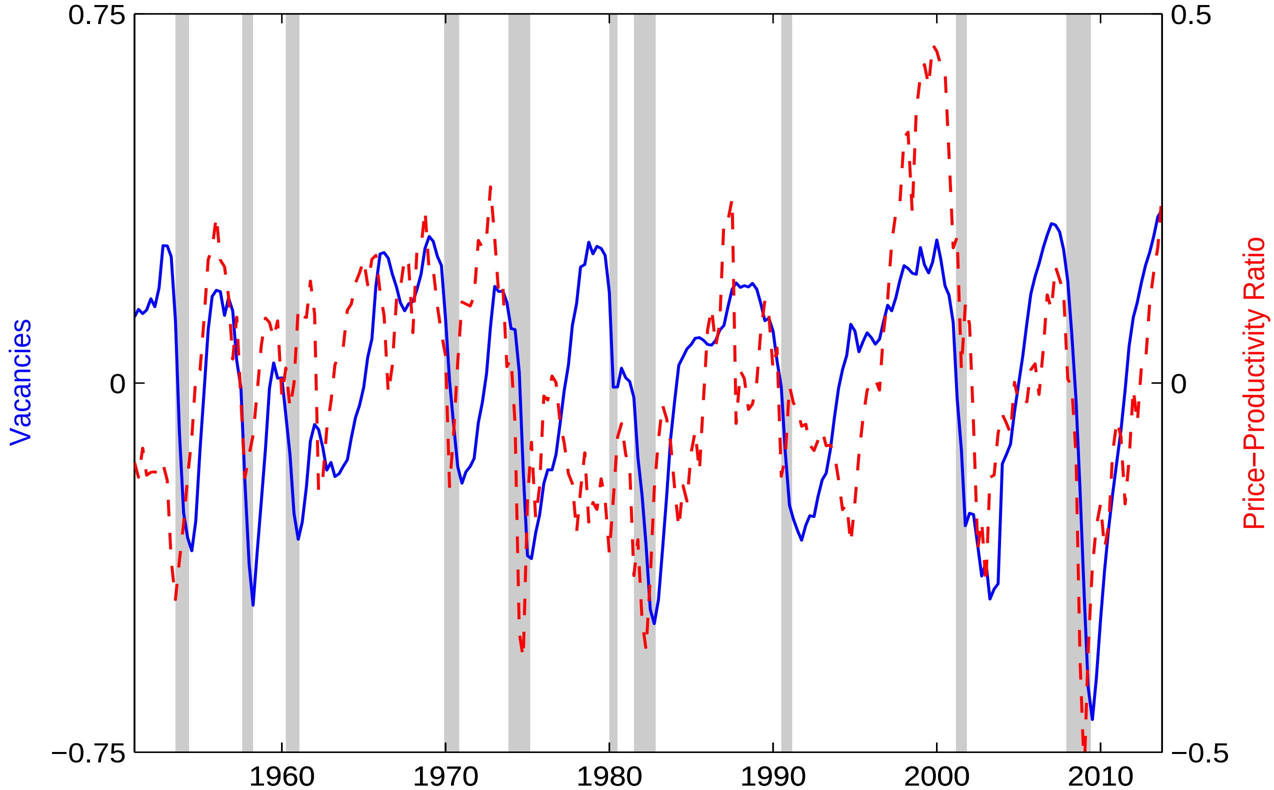
Notes: P/Z denotes the price-productivity ratio defined as the real price of the S&P composite stock price index P divided by labor productivity Z. P/E is the cyclically adjusted price-earnings ratio of the S&P composite stock price index. P/Z is scaled such that P/Z and P/E are equal in the first quarter of 1951.

Figure 3: Vacancy-Unemployment Ratio and Price-Productivity Ratio: 1951 - 2013



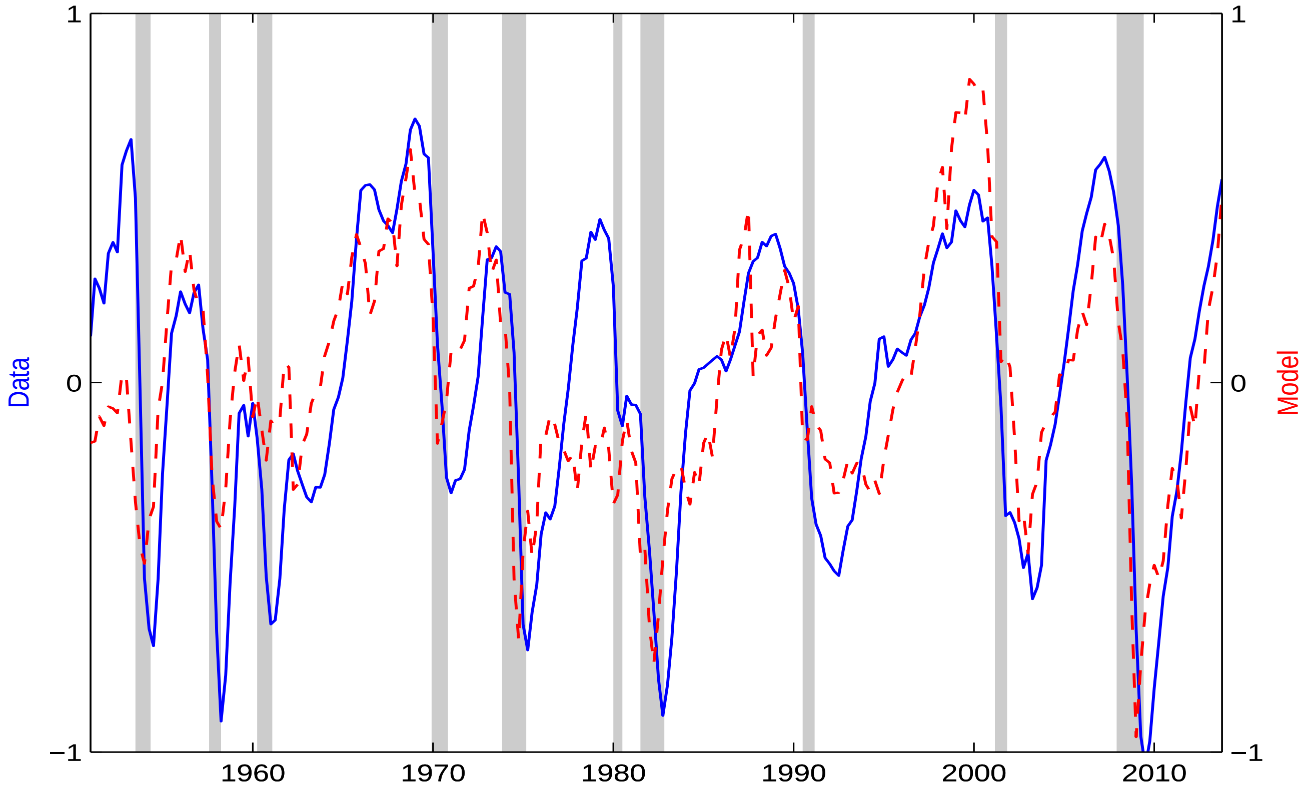
Notes: The solid line shows the vacancy-unemployment ratio, the dashed line the price-productivity ratio. Both variables are reported as log deviations from an HP trend with smoothing parameter 10^5. Shaded periods are recessions defined by the National Bureau of Economic Research (NBER).

Figure 4: Vacancy Openings and Price-Productivity Ratio: 1951 - 2013



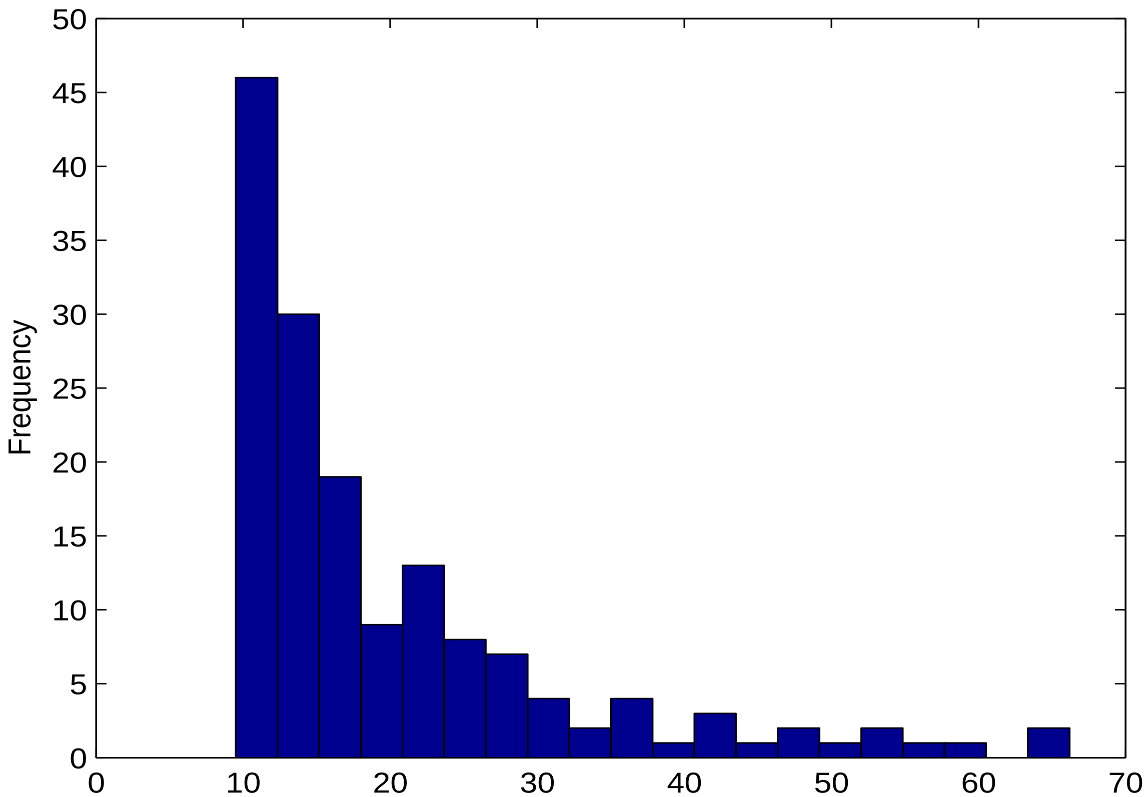
Notes: The solid line shows vacancies, the dashed line the price-productivity ratio. Both variables are reported as log deviations from an HP trend with smoothing parameter 10^5. Shaded periods are recessions defined by the National Bureau of Economic Research (NBER).

Figure 5: Vacancy-Unemployment Ratio: Data vs. Model



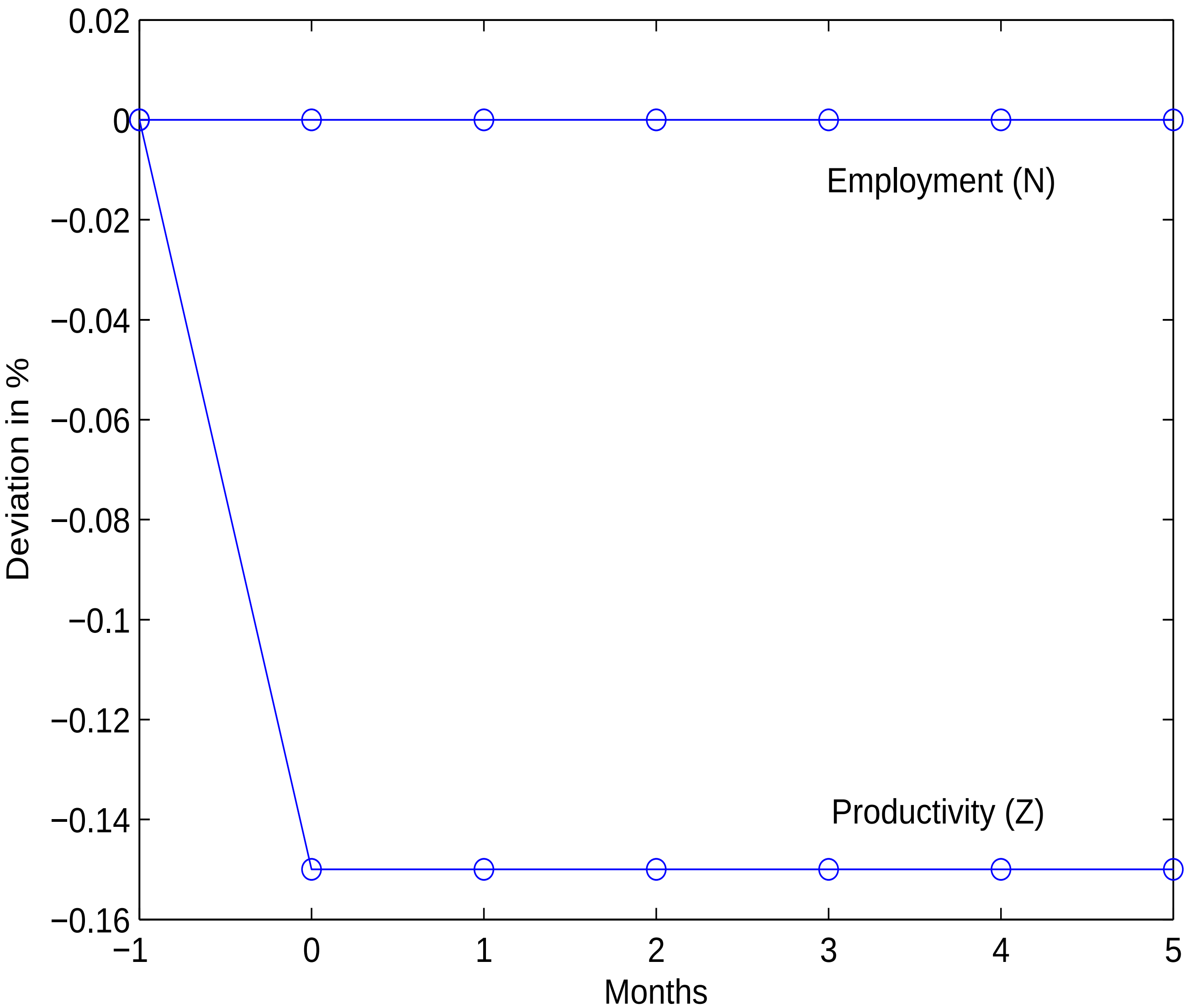
Notes: The solid line and the dashed line show the vacancy-unemployment ratio in the data and in the model, respectively. Model implied vacancies are calculated plugging observed price-productivity ratio and employment level into equation (12). All values are log deviations from an HP trend with smoothing parameter 10^5. Shaded periods are recessions defined by the National Bureau of Economic Research (NBER).

Figure 6: Size Distribution of Disaster Realizations



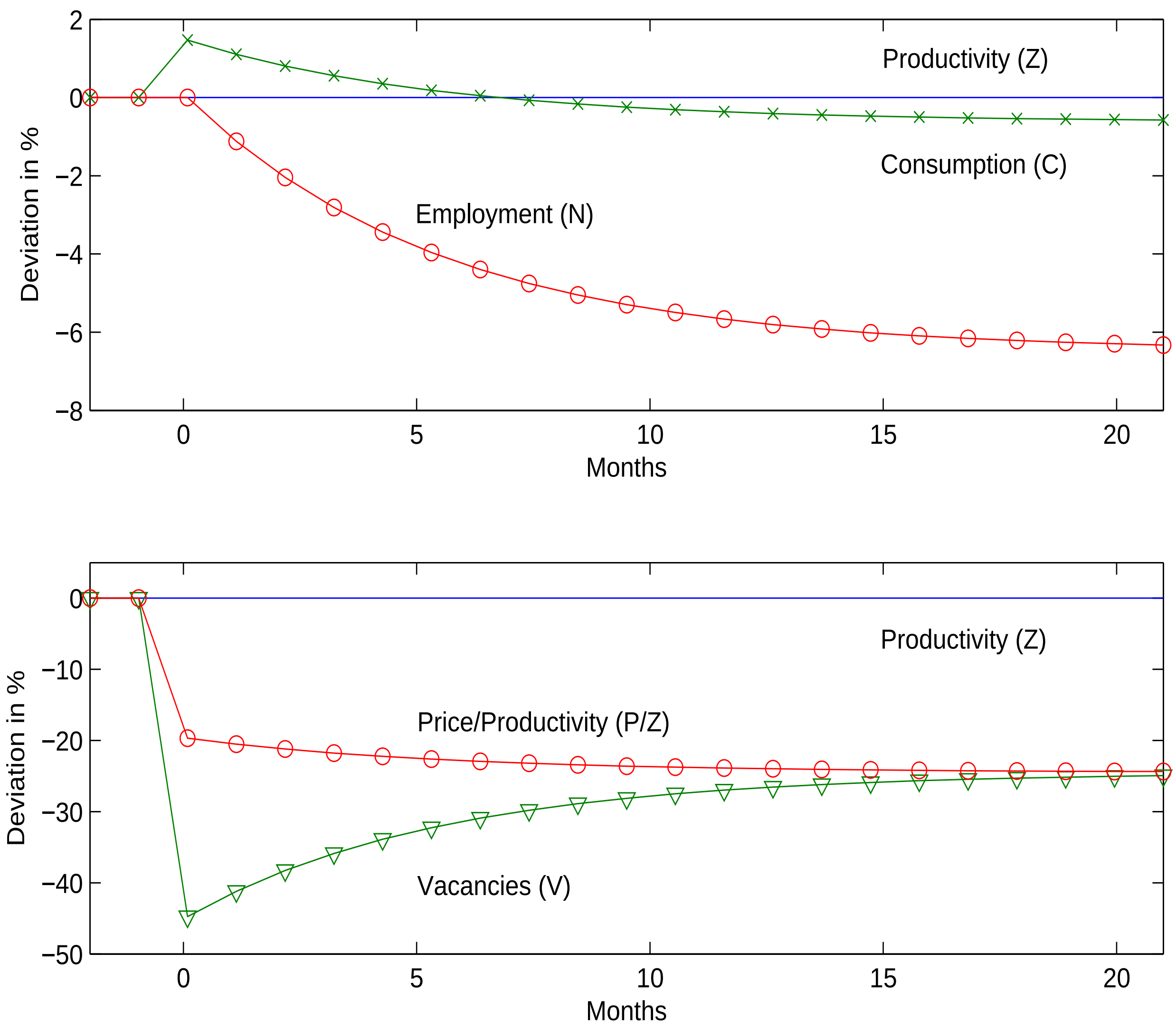
Notes: Histogram shows the distribution of large declines in GDP per capita (in percentages). Data are from Barro and Ursua (2008). Values correspond to $1 - e^{\zeta}$ in the model.

Figure 7: Macroeconomic Response to a Disaster Realization



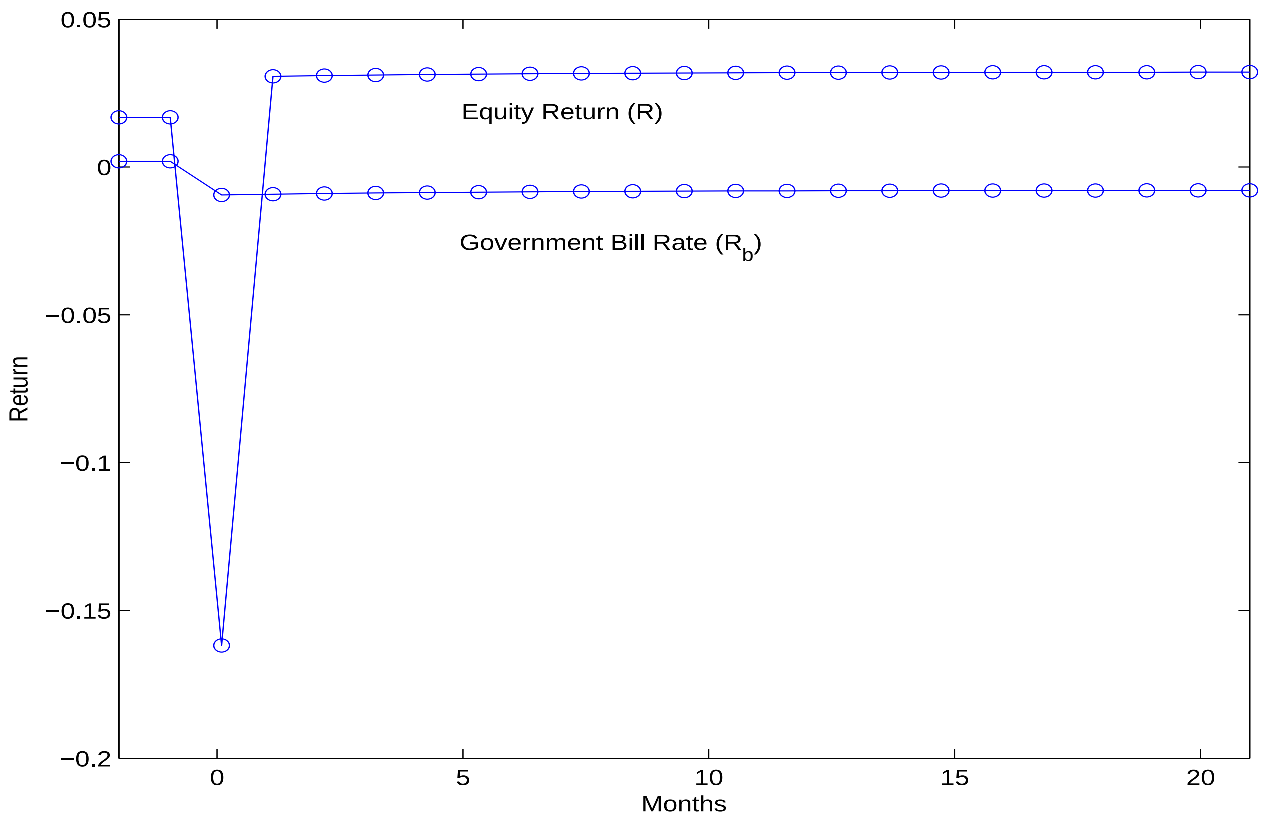
Notes: The behavior of consumption C, dividends D and wages W is identical to productivity Z. Vacancy rate V and employment N do not change on impact. In month zero, a disaster with size $1 - e^{\zeta} = 0.15$ occurs.

Figure 8: Macroeconomic Response to Increase in Disaster Probability



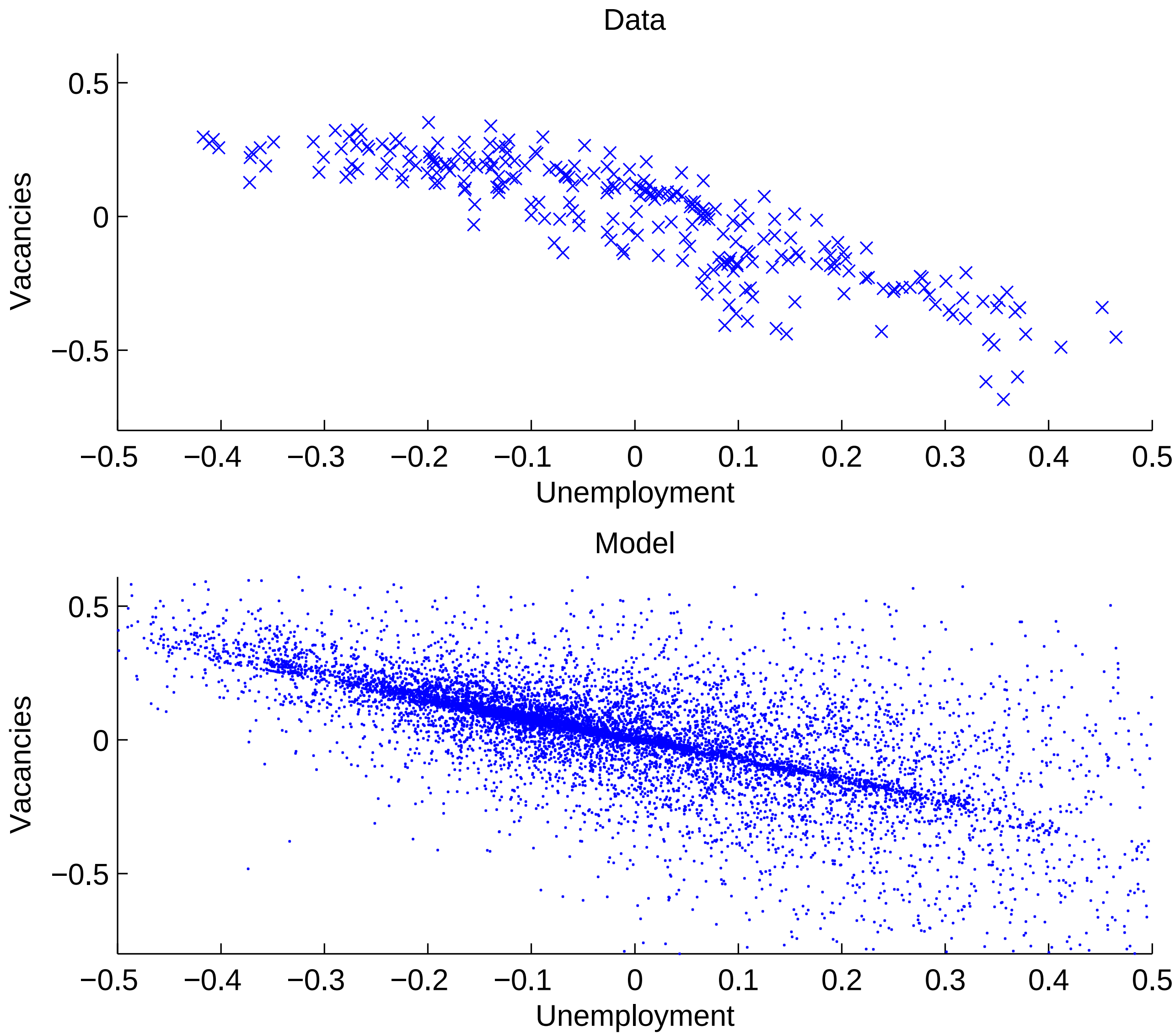
Notes: In month zero, monthly disaster probability increases from 0.05% to 0.32% and stays at 0.32% in the remaining months.

Figure 9: Return Response to Increase in Disaster Probability



Notes: In month zero, monthly disaster probability increases from 0.05% to 0.32% and stays there in the remaining months.

Figure 10: Beveridge Curve



Notes: Data are quarterly from 1951 to 2013. Model implied curve is a quarterly sample with length 10,000 years from the stationary distribution. All values are log deviations from an HP trend with smoothing parameter 10^5.

Table 1: Parameters Values for Monthly Benchmark Calibration

Parameter	Value
Time preference, β	0.997
Risk aversion, γ	5.7
Elasticity of intertemporal substitution, ψ	2
Disaster distribution (GDP), ζ	multinomial
Productivity growth, μ	0.0018
Productivity volatility, σ_ϵ	0.0047
Matching efficiency, ξ	0.365
Separation rate, s	0.035
Matching function parameter, η	0.35
Bargaining power, B	0.50
Value of non-market activity, b	0.76
Vacancy cost, κ	0.50
Tightness insulation, ν	0.05
Government default probability, q	0.40

Table 2: Monthly Disaster Probability

Value	Stationary Probability
1×10^{-7}	0.0005
7×10^{-7}	0.0054
4×10^{-6}	0.0269
3×10^{-5}	0.0806
0.0002	0.1611
0.0012	0.2256
0.0076	0.2256
0.0495	0.1611
0.3212	0.0806
2.0827	0.0269
13.5045	0.0054
87.5661	0.0005

Notes: Table lists the nodes of a 12-state Markov process which approximates an AR(1) process for log probabilities. Disaster probabilities are in percentage terms.

Table 3: Monthly Disaster Probability in Simulations

		No-Disaster				All Simulations			
	Population	Mean	5%	50%	95%	Mean	5%	50%	95%
$\mathbb{E}[\lambda]$	0.20	0.05	0.01	0.03	0.16	0.20	0.01	0.07	0.75
$\sigma(\lambda)$	1.97	0.20	0.01	0.11	0.58	0.84	0.02	0.27	2.81
$\rho(\lambda)$	0.91	0.86	0.65	0.89	0.96	0.87	0.66	0.90	0.96

Notes: σ denotes volatility, ρ monthly autocorrelation. Disaster probabilities are in percentage terms. Population is a sample of 100,000 years. We simulate 10,000 samples with length 60 years at monthly frequency and report statistics from all simulations as well as from 53% of simulations that include no disaster realization. All simulations are in monthly frequency.

Table 4: Labor Market Moments

	U	V	V/U	Z	P/Z	
Panel A: Data						
SD	0.19	0.21	0.39	0.02	0.16	
AC	0.94	0.94	0.95	0.88	0.89	
	1	-0.86	-0.96	-0.18	-0.44	U
	—	1	0.97	0.03	0.47	V
	—	—	1	0.10	0.47	V/U
	—	—	—	1	0.00	Z
	—	—	—	—	1	P/Z
Panel B: No-Disaster Simulations						
SD	0.17	0.19	0.33	0.02	0.14	
	(0.04)	(0.05)	(0.07)	(0.01)	(0.03)	
AC	0.95	0.76	0.90	0.93	0.91	
	(0.01)	(0.04)	(0.02)	(0.03)	(0.02)	
	1	-0.68	-0.90	-0.06	-0.92	U
	—	1	0.93	-0.06	0.90	V
	—	—	1	0.00	0.99	V/U
	—	—	—	1	0.01	Z
	—	—	—	—	1	P/Z
Panel C: Population						
SD	0.19	0.22	0.39	0.04	0.17	
AC	0.95	0.76	0.90	0.93	0.91	
	1	-0.69	-0.91	-0.06	-0.92	U
	—	1	0.93	-0.06	0.90	V
	—	—	1	0.00	0.99	V/U
	—	—	—	1	0.01	Z
	—	—	—	—	1	P/Z

Notes: SD denotes standard deviation, AC quarterly autocorrelation. Data are from 1951 to 2013. All data and model moments are in quarterly terms. U is unemployment, V vacancies, Z labor productivity and P/Z price-productivity ratio. We simulate 10,000 samples with length 60 years at monthly frequency and report means from 53% of simulations that include no disaster realization in Panel B. Standard errors across simulations are reported in parentheses. Population values in Panel C are from a path with length 100,000 years at monthly frequency. Standard deviations, autocorrelations and the correlation matrix are calculated using log deviations from an HP trend with smoothing parameter 10^5.

Table 5: Properties of Aggregate Wages

	SD	AC	$\epsilon_{W,\theta}$	$\epsilon_{W,Z}$	$\epsilon_{\theta,Z}$
Panel A: Data					
1951 - 2013	1.77	0.91	0.00	0.67	2.46
	—	—	[0.33]	[5.43]	[0.76]
1951 - 1985	1.21	0.91	0.01	0.35	11.22
	—	—	[2.75]	[3.04]	[3.86]
1986 - 2013	2.29	0.91	-0.01	1.07	-8.49
	—	—	[-1.15]	[6.79]	[-2.37]
Panel B: Benchmark model					
50%	1.71	0.91	0.01	0.99	0.00
5%	1.33	0.87	-0.01	0.95	-6.39
95%	2.31	0.95	0.03	1.05	6.08
Panel C: No tightness insulation					
50%	2.26	0.89	0.13	1.00	0.04
5%	1.80	0.83	0.08	0.74	-1.95
95%	2.89	0.93	0.18	1.27	1.93

Notes: SD denotes standard deviation, AC quarterly autocorrelation. Z is labor productivity, θ labor market tightness. Data are from 1951 to 2013. All data and model moments are in quarterly terms. We simulate 10,000 samples with length 60 years at monthly frequency and report quantiles from 53% of simulations that include no disaster realization. $\epsilon_{x,y}$ is the elasticity of variable x to y, namely, the regression coefficient of log x on log y. Data t-statistics in brackets are based on Newey-West standard errors. All variables are used in logs as deviations from an HP trend with smoothing parameter 10^5.

Table 6: Business Cycle and Financial Moments

	$\mathbb{E}[\Delta c]$	$\mathbb{E}[\Delta y]$	$\sigma(\Delta c)$	$\sigma(\Delta y)$	$\mathbb{E}[R - R_b]$	$\mathbb{E}[R_b]$	$\sigma(R)$	$\sigma(R_b)$
Data	1.97	1.90	1.78	2.29	5.32	1.01	12.26	2.22
Simulation 50%	2.16	2.16	2.28	2.47	6.66	3.64	19.78	3.83
Simulation 5%	1.80	1.79	1.59	1.71	-0.02	0.06	11.75	0.87
Simulation 95%	2.51	2.54	3.44	3.72	20.39	4.96	33.94	12.50
Population	1.63	1.63	6.85	6.89	13.32	1.22	38.97	12.19

Notes: Δc denotes log consumption growth, Δy log output growth, R the unlevered equity return, R_b the government bill rate. All data and model moments are in annual terms. We simulate 10,000 samples with length 60 years at monthly frequency and report quantiles from 53% of simulations that include no disaster realization. Population values are from a path with length 100,000 years. Returns and growth rates are aggregated to annual values.

Table 7: Labor Market Volatility in Comparative Statics

	U	V	V/U	Z	P/Z
Data	0.19	0.21	0.39	0.02	0.16
Benchmark	0.17	0.19	0.33	0.02	0.14
Constant λ	0.00	0.00	0.00	0.02	0.00
No disaster	0.00	0.00	0.00	0.02	0.00
No tightness insulation	0.06	0.06	0.11	0.02	0.05

Notes: Table reports only standard deviations. U is unemployment, V vacancies, Z labor productivity and P/Z price-productivity ratio. Data are from 1951 to 2013. All data and model moments are in quarterly terms. We simulate 10,000 samples with length 60 years at monthly frequency and report means from 53% (24%) of simulations that include no disaster realization for the benchmark (constant λ) model. In the constant disaster probability model, we set disaster probability to 0.20%, the stationary mean of the disaster probability process used in the benchmark model. Standard deviations are calculated using log deviations from an HP trend with smoothing parameter 10^5.

Table 8: Business Cycle and Financial Moments in Comparative Statics

	$\mathbb{E}[\Delta c]$	$\mathbb{E}[\Delta y]$	$\sigma(\Delta c)$	$\sigma(\Delta y)$	$\mathbb{E}[R - R_b]$	$\mathbb{E}[R_b]$	$\sigma(R)$	$\sigma(R_b)$
Data	1.97	1.90	1.78	2.29	5.32	1.01	12.26	2.22
Panel A: Benchmark								
50%	2.16	2.16	2.28	2.47	6.66	3.64	19.78	3.83
Population	1.63	1.63	6.85	6.89	13.32	1.22	38.97	12.19
Panel B: Constant λ								
50%	2.16	2.16	1.31	1.31	10.27	-3.48	1.73	0.00
Population	1.59	1.59	4.03	4.03	9.94	-3.66	3.49	2.16
Panel C: No Disaster Risk								
50%	2.16	2.16	1.32	1.32	0.16	5.12	1.70	0.00
Population	2.16	2.16	1.32	1.32	0.16	5.12	1.71	0.00
Panel D: No Tightness Insulation								
50%	2.16	2.16	1.47	1.52	-49.63	3.67	11.55	3.32
Population	1.68	1.68	6.46	6.44	-47.76	1.53	20.32	11.27

Notes: Δc denotes log consumption growth, Δy log output growth, R the unlevered equity return, R_b the government bill rate. All data and model moments are in annual terms. We simulate 10,000 samples with length 60 years at monthly frequency and report the 50% quantile from 53% (24%) of simulations that include no disaster realization for the benchmark (constant λ) model. In the constant disaster probability model, we set disaster probability to 0.20%, the stationary mean of the disaster probability process used in the benchmark model. Population values are from a path with length 100,000 years. Returns and growth rates are aggregated to annual values.