Uncertainty and Unemployment Revisited: The Consequences of Financial and Labor Contracting Frictions*

Yajie Wang†

University of Missouri

December 16, 2023

Abstract

This paper revisits how uncertainty affects unemployment. Using Census employer-employee data, it finds that elevated uncertainty increases layoffs in financially constrained firms, an observation not predicted by standard search models where uncertainty freezes layoffs via irreversible search costs. A newly constructed search model can replicate the empirical evidence by incorporating financial and labor contracting frictions, so wage bills act as debt-like commitments, which firms are averse to taking on when uncertainty raises firm default risks. The model captures the increases in unemployment observed during U.S. past recessions, attributing over 70% of uncertainty's impact on unemployment to the two contracting frictions.

Keywords: Search and matching, financial frictions, incomplete labor contracts, uncertainty, volatility, firm heterogeneity, business cycles, labor market policies.

JEL Codes: E24, E32, E44, D53, D83, J08.

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*I am greatly indebted to Yan Bai and Narayana Kocherlakota for their invaluable advice and encouragement. I also thank George Alessandria, David Argente, Jonas Arias, David Autor, Martin Beraja, Mark Bils, Andres Blanco, Gaston Chaumont, Alex Clymo (discussant), Pablo D'Erasmo, Lukasz Drozd, Burcu Eyigungor, David Figlio, Hamid Firooz, Rafael Guntin, Sasha Indarte, Philipp Kircher, Zheng Liu, Igor Livshits, Ryan Michaels, Alan Moreira, Makoto Nakajima, Christina Patterson, Ronni Pavan, Marla Ripoll, Edouard Schaal, Christopher Sleet, Bryan Stuart, Daniel Yi Xu, and participants in seminars and conferences at the University of Rochester, the Federal Reserve Banks of Philadelphia and St. Louis, Midwest Macro, the North American Summer Meeting (Miami) and Asian Meeting of the Econometric Society (Tokyo), the Young Economist Symposium (Yale), and Junior SaM Workshop for their helpful comments and discussions. I thank Nichole Szembrot and Kenneth Zahringer at the RDCs for administrative support. I thank the National Science Foundation Doctoral Dissertation Research Improvement Grants (Award No. SES-2116551) for funding. Any views expressed are those of the authors and not those of the U.S. Census Bureau. The Census Bureau has reviewed this data product to ensure appropriate access, use, and disclosure avoidance protection of the confidential source data used to produce this product. This research was performed at a Federal Statistical Research Data Center under FSRDC Project Number 2652. (CBDRB-FY22-P2652-R9856) This research uses data from the Census Bureau's Longitudinal Employer Household Dynamics Program, which was partially supported by the following National Science Foundation Grants SES-9978093, SES-0339191 and ITR-0427889; National Institute on Aging Grant AG018854; and grants from the Alfred P. Sloan Foundation.

†Email: yajie.wang@missouri.edu; Address: E215 Locust Street Building, Columbia, MO 65201.

1 Introduction

Unemployment increases a lot during recessions, as does the uncertainty faced by firms. To what extent does the elevated uncertainty of firm-level idiosyncratic productivity account for the observed increase in unemployment? Existing research shows that the power of uncertainty shocks to explain unemployment is limited within the canonical search framework (Schaal, 2017). In this paper, I revisit the impact of uncertainty on unemployment and find that, when financial and labor contracting are frictional, uncertainty shocks are crucial in accounting for the observed increase in unemployment during recessions.

My argument is developed in two steps. First, using U.S. Census employer-employee matched data, I discover that financially constrained firms are more likely to lay off workers when uncertainty increases. This evidence diverges from the typical real option channel embedded in standard search models, which predict a suspension of layoffs due to increased option value of waiting during periods of high uncertainty. This discrepancy motivates me to construct a new search model by incorporating financial and labor contracting frictions. They together generate a risk premium channel: each worker means a wage commitment, which firms are less willing to maintain when heightened uncertainty raises their bankruptcy risks. This mechanism replicates layoff behaviors consistent with the data and accounts for over 70% of the impact of uncertainty on unemployment, greatly improving the model's ability to capture unemployment dynamics during recessions.

My empirical analysis estimates the effect of uncertainty shocks on layoffs, conditional on firms' financial conditions. Leveraging U.S. Census employer-employee matched data (LEHD), I distinguish layoffs from hiring at a micro level. This data is merged with Compustat-CRSP firm-level data, where I measure firm-level uncertainty as the annualized standard deviation of daily stock returns. To estimate the causal effect of uncertainty shocks, I adopt Alfaro, Bloom, and Lin's (2021) methodology, using Bartik-type instruments based on firms' exposure to exchange rate volatility and policy uncertainty, along with first-moment controls to isolate the second-moment effects of uncertainty. Firm financial constraints are defined by the mode of three indicators: absence of an S&P rating, a high Whited and Wu (2006) index, and a high Size & Age index (Hadlock, 2010).

I find that for financially constrained firms, a one standard deviation increase in uncertainty shock raises the likelihood of worker layoffs by 0.5 percentage points, a response not observed for unconstrained firms. This result is not driven by first-moment shocks, as they are controlled for, nor by contemporaneous reverse effects of layoffs, since both uncertainty shocks and financial constraint indicators are lagged. And it is not attributed to aggregations of reallocation across firms or restructuring within firms, as the analysis is conducted at the job level, with worker, firm, and time fixed effects included. This evidence challenges the reliance solely on search frictions for a complete understanding of uncertainty's impacts on labor market dynamics. The baseline search framework's lack of firm financial heterogeneity prevents it from generating the observed heterogeneous responses to uncertainty shocks. Additionally, its inherent irreversible hiring costs will predict a freeze in layoffs, counteracting the observed pattern.

Motivated by the empirical findings, I construct a new search model, building upon Schaal (2017) who extends the directed search framework in Menzio and Shi (2010) to include multi-worker firms and decreasing returns to scale production technology. This enhancement enables endogenous hirings and separations within firms. As in Schaal (2017), my model features two aggregate shocks: aggregate productivity shocks and uncertainty shocks. Then, I extend his model by introducing a labor contracting friction, along with a more standard firm financing friction. The latter assumes firms can only borrow through state-uncontingent debt with limited enforcement, so there is endogenous default. Default leads to costly liquidation. The labor contracting friction, a new feature of my model, implies wages are insensitive to transitory firm-level idiosyncratic shocks within the intertemporal firm-worker labor contracts.[1] I empirically validate this friction using Census data and theoretically micro-found it on the premise that firms have private information about their shocks.

The incomplete financial and labor contracts in my model indicate that wage bills are isomorphic to state-uncontingent debt, so firms are averse to taking on these debt-like wage commitments when idiosyncratic risk rises. This leads to less hiring and more layoffs in times of high uncertainty, so unemployment increases. The mechanism requires both financial and labor contracting frictions; neither is effective in isolation. If labor contracts are complete, firms can borrow through workers rather than through state-uncontingent debt. If the financial market is complete, how wages are paid within labor contracts is inconsequential because it is the present value of wages that determines the incentives of

[1] This does not require sticky wages: they can adjust fully in response to workers' outside opportunities.

hiring and firing. Essentially, financial and labor contracts are substitutes when they are both intertemporal and dynamic.

The model is highly non-linear, centering around a discrete default choice, occasionally binding financial constraints, search costs in the labor market, and uncertainty shocks. As these non-linearities are key to the analysis, I capture them by solving the quantitative model using a global method with parallel programming. The model is calibrated to match the business cycle moments of GDP and the interquartile range (IQR) of firm sales growth rates, alongside standard labor market flows and financial market moments. For external validation, I run regressions by simulating an employer-employee matched panel from the model. The model-simulated results show that workers in financially constrained firms are more likely to be laid off when uncertainty is high, a pattern consistent with the empirical evidence but absent in canonical search.

I then use the model for two quantitative analyses. First, I quantify the role of uncertainty shocks in escalating unemployment during past U.S. recessions. I apply a particle filter to estimate the historical series of aggregate productivity and uncertainty shocks, using GDP data and the interquartile range of firm sales growth from Compustat.[2] Then, I input the estimated structural shocks into the model to forecast unemployment. I find that the average peak-to-trough increase in unemployment during recessions implied by my model is about the same as that in the data. Counterfactual exercises further show that the model's performance along this dimension diminishes markedly if I eliminate any of three elements: uncertainty shocks, the financial friction, or the labor contracting friction. Notably, uncertainty shocks account for an average of 26% of unemployment increases in the past five recessions, from the 70s to the Great Recession. The number falls to only 7% in a counterfactual model without labor and financial contracting frictions. That is, the two contracting frictions drive over 70% of uncertainty's impact on unemployment.

In my second quantitative exercise, I evaluate two labor market stabilization policies during periods of high uncertainty: increasing unemployment benefits for workers versus providing wage subsidies to firms. First, the policy of raising unemployment benefits was implemented by the U.S. during the Covid recession. The model reveals that while this policy aims to support unemployed workers, it drives up wages, making hiring riskier

[2] A particle filter is a Monte Carlo Bayesian estimator for the posterior distribution of structural shocks. It is similar to a Kalman filter but can be applied to non-linear models.

for firms and ultimately exacerbating unemployment. Second, I investigate the policy of subsidizing firms to pay wages, similar to strategies implemented by Germany during the Great Recession and the Covid recession. According to my model, wage subsidies insure firms against idiosyncratic shocks, mitigating the negative impact of high uncertainty, so this approach outperforms the policy of raising unemployment benefits. However, wage subsidies encourage labor hoarding and hinder efficient worker reallocation. The losses from misallocation outweigh the gains from providing insurance, ultimately decreasing overall efficiency.

Related Literature. My paper contributes to four strands of literature. Primarily, it extends studies on how uncertainty shocks affect business cycles. This area is mainly influenced by two theories. First, the real option channel, investigated by Schaal (2017) and others including Bernanke (1983), Bloom et al. (2018*b*), Dixit, Dixit and Pindyck (1994), Leduc and Liu (2016), and McDonald and Siegel (1986), emphasizes the irreversible costs of employment and investment, causing firms to suspend decision-making amid heightened uncertainty. Second, the risk premium channel, as studied by Arellano, Bai and Kehoe (2019); Gilchrist, Sim and Zakrajšek (2014), centers on financial frictions, suggesting that increasing uncertainty escalates default risks and compels firms to reduce employment to ease wage bill burdens. While both theories indicate reduced investment and hiring in uncertain times, they differ in layoffs: the real-option channel implies fewer firings, whereas the risk premium channel predicts more. This divergence motivated me to use employer-employee matched data and identify layoffs from hirings. I find that uncertainty shocks result in more layoffs in financially constrained firms, revealing the need to include the risk premium channel in studies of uncertainty shocks.

Second, my model contributes to a growing literature that brings firm financial frictions into search models. Monacelli, Quadrini and Trigari (2022), Mumtaz and Zanetti (2016), Petrosky-Nadeau (2014), Petrosky-Nadeau and Wasmer (2013), and Wasmer and Weil (2004) focus on financing needs for capital acquisitions, vacancy posting, or bargaining positions, but I examine firm financing for wage payments. Christiano, Trabandt and Walentin (2011), Chugh (2013), Garin (2015), Sepahsalari (2016), and Zanetti (2019), consider intra-period financial frictions like working capital requirements and collateral constraints. In contrast, I model inter-period financial contracts to generate endogenous firm default risk, so I can capture the intertemporal risk premium channel of uncertainty shocks.[3] While Blanco and Navarro (2016) include firm default in a search framework, their model treats wages as pure internal transfers. My model, however, introduces a labor contracting friction so that wage payments within contracts do affect allocations.[4] Despite the complex interaction between frictional financial and labor contracts, I prove wage bills are uniquely determined in this case, allowing for solving the model numerically.

Third, my labor contracting friction offers a fresh perspective to the literature on wage stickiness and its impact on unemployment fluctuations. Prominent studies like Gertler and Trigari (2009), Hall (2005), Hall and Milgrom (2008), Menzio and Moen (2010), and Shimer (2004) link unemployment volatility to the stickiness of wages for newly hired workers. My model, however, focuses on within-match contracting friction, without distorting the present value for newly hired workers.[5] Some recent research also considers incumbent worker wages, yet still focuses on wage stickiness in response to aggregate shocks (Bils, Chang and Kim, 2022; Blanco et al., 2022; Fukui, 2020; Schoefer, 2021). I propose an alternative mechanism of wage insensitivity to transitory idiosyncratic firm shocks, a feature both empirically validated and theoretically grounded. My model shifts away from the conventional focus on wage stickiness to aggregate shocks. In fact, aggregate wage stickiness itself is ineffective here; if wages can fully hedge against idiosyncratic risk, the risk premium channel of uncertainty vanishes.

Fourth, my labor contracting friction is informed by literature exploring asymmetric information's impact on labor market outcomes. Acemoglu (1995), Azariadis (1983), Chari (1983), Green and Kahn (1983), Hart (1983) demonstrate how asymmetric information can affect wage variability and lead to inefficient employment. I particularly draw from Hall and Lazear's (1984) two-period model, which shows the constrained optimality of pre-determined wages under asymmetric information, and adapt this idea to a dynamic directed search framework. Recent advancements by Menzio (2005) and Kennan (2010) apply asymmetric information to generate endogenous new hire wage stickiness. In contrast, my mechanism operates through incumbent wage insensitivity and its interaction

[3] I model firms' default risk following Arellano, Bai and Kehoe (2019), Khan and Thomas (2013), and Ottonello and Winberry (2020).

[4] Favilukis, Lin and Zhao (2020) and Schoefer (2021) document empirical evidence for the interaction between labor costs and firm financing.

[5] Although it is beyond the scope of this paper, new hire wage stickiness is an ongoing debate (Bils, Kudlyak and Lins, 2022; Gertler, Huckfeldt and Trigari, 2020; Grigsby, Hurst and Yildirmaz, 2021; Hazell and Taska, 2020; Kudlyak, 2014; Pissarides, 2009; Rudanko, 2009).

with the firm financial friction.

Layout. The paper proceeds as follows. Section 2 explains the data and presents the empirical findings. Section 3 sets up the model. Section 4 parameterizes and validates the model against data. Section 5 conducts quantitative analyses. Section 6 concludes.

2 Empirical Motivation

In this section, I provide empirical motivation for incorporating the risk premium channel into the search framework for examining the effects of uncertainty shocks on labor markets. Section 2.1 describes the data and defines the variables. Section 2.2 explains the identification strategy. Sections 2.3 and 2.4 present empirical results that support the existence of firm financial friction and labor contracting friction, respectively.

2.1 Data Description

My sample is an annual employer-employee matched panel that includes job-level information on layoffs and earnings, along with firm-level uncertainty and financial conditions.

Data Sources. I draw a 10% random sample of workers from the U.S. Census Bureau's Longitudinal Employer-Household Dynamics (LEHD) Snapshot 2021, which offers labor outcome variables for each employer-employee pair.[6] LEHD is sourced from the UI wage records, recording any job with positive annual earnings across all four quarters. The data starts from the 1990s for most states, with Maryland data dating back to 1985, and extends up to the first quarter of 2022. This employer-employee matched data contains three advantages. First, it allows for distinguishing between layoffs and hiring, a distinction not available with firm-level employment data. Second, it provides granular observations that avoid aggregating the compositional change of workers within firms. Third, it includes firm identifiers, facilitating integration with datasets on the firm side.

I then merge the LEHD dataset with firm-level data from the CRSP/Compustat Merged - Fundamentals Annual (Compustat) using the Longitudinal Business Database (LBD) and the Compustat-SSEL Bridge (CSB). Additionally, I merge the sample with Alfaro, Bloom and Lin's (2022) dataset on uncertainty shocks, which is also constructed from CRSP/Compustat. Their dataset includes measures of firm-level uncertainty shocks, the

[6] This paper has access to 24 states of LEHD: Arizona, California, Colorado, Connecticut, Delaware, Indiana, Kansas, Maine, Maryland, Massachusetts, Missouri, Nevada, New Jersey, New Mexico, New York, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Utah, Virginia, and Wisconsin.

Bartik-type instruments for these shocks, and indicators of firm-level financial constraints, spanning from 1993 to 2019.

Variables. In my analysis, the key dependent variables are job-level layoffs and earnings growth at the annual frequency. The LEHD dataset provides quarterly worker earnings data. I follow Abowd, Lengermann and McKinney (2003) and Sorkin (2018), focusing on the worker's dominant employer each quarter, defined as the employer providing the highest combined earnings in the current and previous quarter. A worker is classified as laid off in a quarter if two conditions are met: the employee does not remain in their dominant job in the subsequent quarter, and the employee records zero or no earnings in any U.S. state in the subsequent quarter. The latter data is sourced from the LEHD's Employment History Files, which detail the number of states where each employee has positive earnings. Although the LEHD does not directly differentiate between layoffs and voluntary quits, Hyatt et al. (2014) shows that patterns of separation to non-employment closely align with layoffs from the Job Openings and Labor Turnover Survey (JOLTS), supporting the relevance of this indicator. The layoff indicator is annualized and set to one if the employee is laid off in any quarter within the year, and zero otherwise.

To calculate annualized earnings, I first adjust for inflation using the Consumer Price Index (CPI).[7] To mitigate bias due to varying employment start dates within a quarter, I follow Abowd, Lengermann and McKinney (2003) and categorizes employment into three types for annualization: "full-quarter" where earnings are positive in the current and both adjacent quarters, "continuous" with positive earnings in the current and one adjacent quarter, and "discontinuous" for cases not meeting the previous criteria. The annual earnings are calculated by multiplying the average "full-quarter" earnings by four if any such quarters exist; if there are no "full-quarter" but "continuous" quarters, I use eight times the average "continuous" earnings; and in the absence of both, the annual earnings are twelve times the average of "discontinuous" quarters.

The primary explanatory variables in my analysis are firm-level uncertainty shocks and financial constraint indicators, both obtained from Alfaro, Bloom and Lin's (2022) dataset based on CRSP/Compustat. Uncertainty shocks are measured as the growth rates of the annualized standard deviations of firms' stock returns, yielding a firm-level annual panel. I follow Davis and Haltiwanger (1992) and Alfaro, Bloom and Lin (2022) to define the

[7] I use the CPI for All Urban Consumers, normalizing the 2011 Q4 price to 1.

Table 1: Summary Statistics

Variables	N (observations)	Mean	St. Dev.
$\Delta\sigma_{jt}$	15,160,000	-0.015	0.987
$\mathbb{1}_{jt}^{\text{fin-constraint}}$	15,160,000	0.101	0.302
$\mathbb{1}_{ijt}^{\text{layoff}}$	15,160,000	0.055	0.229
$\Delta\text{Earnings}_{ijt}$	13,340,000	0.016	0.308

Note: This table shows the summary statistics of the variables used in regressions. The variable $\Delta\sigma_{jt}$ represents the change in firm-level uncertainty, $\mathbb{1}_{jt}^{\text{fin-constraint}}$ denotes firm financial constraint indicators , $\mathbb{1}_{ijt}^{\text{layoff}}$ means the job-level layoff indicator, and $\Delta\text{Earnings}ijt$ refers to the growth in job-level earnings (where i is workers, j firms, and t time). Uncertainty, σ_{jt}, is the annualized standard deviations of firm j's daily stock returns within year t. The firm-level financial constraint indicator is the mode of three indicators: absence of an S&P rating, a Whited and Wu (2006) index higher than the cross-sectional median, and a Size & Age index proposed by Hadlock (2010) exceeding the cross-sectional median. This research was performed at a Federal Statistical Research Data Center under FSRDC Project Number 2652. (CBDRB-FY22-P2652-R9856) The numbers are rounded according to the Census Bureau's disclosure avoidance requirements.

growth rate of variable y at quarter $t+h$ as $\frac{y_{t+h}-y_{t+h-1}}{(y_{t+h}+y_{t+h-1})/2}$, which is bounded between -2 and 2 by definition. This definition of growth rates holds throughout the paper. The firm-level financial constraint indicator is the mode of three measures: the absence of an S&P rating, a Whited and Wu (2006) index above the cross-sectional median, and a Size & Age index by Hadlock (2010) exceeding the cross-sectional median.

Sample Selection. On the worker-side, I focus on individuals aged 22 to 55 to avoid early working age and retirement-related issues, following Graham et al. (2019). Observations with annual earnings below \$3,250 in 2011Q4 dollars are excluded, as in Card, Heining and Kline (2013) and Sorkin (2018). Additionally, jobs are included in the sample only if they have a maximum duration of at least 3 years, thereby excluding part-time and temporary employment. On the firm-side, a firm needs to be matched with a minimum of 10 employees to be considered. I also adopt the same criteria as Alfaro, Bloom and Lin (2022), requiring firms to have at least 200 daily stock returns in a given year, and focusing on ordinary common shares listed on major exchanges like NYSE, AMEX, or Nasdaq. Firm-level variables are constrained within the 0.5 and 99.5 percentile range.

Table 1 presents the summary statistics. The regression samples consist of around 15 million observations, involving 3,800 unique firms and 2 million unique workers.

2.2 Identification Strategy

When using firm-level stock price volatility to estimate the effects of uncertainty shocks on job outcomes, three endogeneity concerns emerge. First, a positive second-moment shock may coincide with a first-moment shock, leading to omitted variable bias if not controlled for these first-moment effects. Second, unobserved variables such as agency frictions within firms might contribute to an additional omitted variable bias by influencing both stock price volatility and job outcomes simultaneously. Third, there is a possibility of reverse causality, where layoffs or changes in earnings could themselves impact the firm's stock price volatility.

To address these endogeneity biases, I use a two-stage least squares (2SLS) regression approach, using instruments for firm-level uncertainty shocks from Alfaro, Bloom and Lin (2022). They constructed a set of Bartik-type instruments by exploiting firms' differential exposures to the fluctuations of nine aggregate commodity prices. For my analysis, I select seven of these instruments, excluding two relatively weaker ones to ensure strong relevance with firm-level uncertainty shocks. The selected instruments are then based on seven commodities: economic policy uncertainty as developed by Baker, Bloom and Davis (2016), and the exchange rates of six currencies – Canadian Dollar, Japanese Yen, British Pound, Swiss Franc, Australian Dollar, and Swedish Krona. This approach implies an over-identification, with seven instrumental variables being used for the one endogenous variable of firm-level uncertainty shocks.

In their approach to constructing instrumental variables, Alfaro, Bloom and Lin (2022) first estimate firms' exposures to aggregate commodity price fluctuations at the 2-digit SIC industry level, using the following regression:

$$r_{j,t}^{\text{risk-adj}} = \alpha_s + \sum_c \beta_s^c \cdot r_t^c + \epsilon_{j,t}, \tag{1}$$

where j indicates the firm, t the day, s the 2-digit SIC industry sector, and c the commodity. The dependent variable $r_{j,t}^{\text{risk-adj}}$ is the risk-adjusted stock return of firm j on day t, defined as the residuals from regressing the firm's excess stock returns on four factors from an asset pricing model, which removes systematic fluctuations due to common risk factors (Carhart, 1997). On the right-hand side, α_s is the industry fixed effect, and r_t^c represents the growth rate of commodity c's price. The coefficients β_s^c then capture industry-level sensitivities to commodity prices. These sensitivities are then multiplied by the volatilities of the commodities to formulate the instrumental variables:

$$|\beta_s^c| \cdot \Delta\sigma_t^c, \forall c. \tag{2}$$

Furthermore, they construct a set of corresponding first-moment controls as the products of the exposures and the commodities' growth rates:

$$\beta_s^c \cdot r_t^c, \forall c. \tag{3}$$

I use their methodology to address endogeneity and establish the causality effect of uncertainty shocks. First, first-moment controls are included in all my regressions to isolate the effects of the second moment. Second, the Bartik-type instruments, based on aggregate uncertainty shocks and industry-level exposure, are unlikely to be influenced by firm-level unobservables like internal agency frictions. Third, this approach reduces the risk of reverse causality bias, with job-level dependent variables within firms unlikely to impact the industry-level instruments. Additionally, in my over-identification 2SLS regressions, I use statistical tools to conduct conditional likelihood ratio tests for weak-instrument robust inference and implement Hansen-Sargan over-identification J tests for the validity of the exclusion condition.

2.3 Empirical Evidence for the Firm Financial Friction

To identify the risk premium channel from the real option channel of uncertainty shocks, I use the following regression to estimate the effect of uncertainty shocks on job-level layoffs, conditional on firms' financial conditions:

$$\mathbb{1}_{ijt}^{\text{layoff}} = \beta_1 \Delta\sigma_{jt-1} + \beta_2 \Delta\sigma_{jt-1} \cdot \mathbb{1}_{jt-5}^{\text{fin-constraint}} + \Gamma' Z_{jt} + \gamma_i + \delta_j + \phi_t + \varepsilon_{ijt}, \tag{4}$$

where $\mathbb{1}_{ijt}^{\text{layoff}}$, the dependent variable, equals one if worker i from firm j is laid off in year t. The firm's uncertainty shock, $\Delta\sigma_{jt-1}$, is standardized and interacts with a five-year lagged financial constraint indicator, $\mathbb{1}_{jt-5}^{\text{fin-constraint}}$, that captures the ex-ante financial conditions of the firm. The interaction's coefficient, β_{2h}, estimates the additional increase in layoffs due to a one standard deviation increase in uncertainty shocks in financially constrained firms. Both the uncertainty shock and its interaction are instrumented in the 2SLS regression.

The regression also includes a vector of firm-side control variables, Z_{jt}, following Alfaro, Bloom and Lin (2022). This set of controls includes six lagged firm-level financial variables: Tobin's Q, annualized stock returns, tangibility, book leverage, returns on assets, and firm

Table 2: Responses of Worker Layoffs to Uncertainty Shocks

	OLS		2SLS	OLS		2SLS
$\mathbb{1}_{ijt}^{\text{layoff}}$	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\sigma_{jt-1}$	-0.00114	-0.00112	0.00013	-0.00142	-0.00144	-0.00038
	(0.00081)	(0.00079)	(0.00157)	(0.00089)	(0.00089)	(0.00162)
$\Delta\sigma_{jt-1} \cdot \mathbb{1}_{jt-5}^{\text{fin-constraint}}$				0.00252**	0.00290**	0.00514**
				(0.00112)	(0.00120)	(0.00249)
1st-stage F			58.61			34.37
CLR test p-val			0.003			0.039
Sargan-Hansen J test p-val			0.598			0.351
Number of firms	3,800	3,800	3,800	3,800	3,800	3,800
Number of workers	2,324,000	2,324,000	2,324,000	2,324,000	2,324,000	2,324,000
Number of observations	15,160,000	15,160,000	15,160,000	15,160,000	15,160,000	15,160,000
IVs' 1st-moment controls	×	✓	✓	×	✓	✓
Firm controls	✓	✓	✓	✓	✓	✓
Firm, worker, time FEs	✓	✓	✓	✓	✓	✓

Note: This table presents OLS and 2SLS regressions results, projecting job-level layoff indicators, $\mathbb{1}_{ijt}^{\text{layoff}}$, on lagged firm-level uncertainty, $\Delta\sigma_{jt-1}$, and their interaction with firms' 5-year lagged financial constraint indicators, $\mathbb{1}_{jt-5}^{\text{fin-constraint}}$ (where i is workers, j firms, and t time). Uncertainty, σ_{jt}, is the annualized standard deviations of firm j's daily stock returns within year t. The firm-level financial constraint indicator is the mode of three indicators: absence of an S&P rating, a Whited and Wu (2006) index above the cross-sectional median, and a Size & Age index by Hadlock (2010) exceeding the cross-sectional median. Seven instrumental variables for uncertainty shocks are based on firms' exposure to seven commodity price fluctuations and sourced from Alfaro, Bloom and Lin (2022). The 1st-stage F statistic are the robust Kleibergen-Paap F statistic. CLR (Conditional Likelihood Ratio) tests yield p-values for weak instrument robust inferences. Hansen J test p-values assess over-identification. IVs' 1st-moment controls correspond to the 2nd-moment instruments for uncertainty shocks. Firm-level controls include six lagged firm financial variables: Tobin's Q, stock returns, tangibility, book leverage, returns on assets, and sales-based firm sizes. Firm-level controls also include the lagged firm's financial constraint indicator and its interactions with both IVs' 1st-moment controls and the six firm financial controls. Regressions standardize uncertainty changes and include worker, firm, and time-fixed effects. Standard errors (in parentheses) are clustered at the 2-digit SIC industry level. This research was performed at a Federal Statistical Research Data Center under FSRDC Project Number 2652. (CBDRB-FY22-P2652-R9856) The numbers are rounded according to the Census Bureau's disclosure avoidance requirements. Statistical significance stars: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

sizes measured by sales, with Tobin's Q and stock returns serving as first-moment controls. Further controls consist of the lagged firm's financial constraint indicator, alongside its interactions with the seven first-moment controls for instruments and the six firm-level financial variables. The regression also includes worker fixed effect (γ_j), firm fixed effect (δ_j), and year fixed effects (ϕ_t) to account for unobserved heterogeneity. The error term is denoted by ϵ_{ijt}. The standard errors are clustered at the 2-digit SIC industry level, in line with the variability level of the instruments.

Table 2 presents the OLS and 2SLS regression estimates for β_1 and β_2. The first three columns project layoffs on uncertainty shocks, with the estimated β_1 showing no significant average effect of uncertainty shocks. However, the next three columns examine layoffs against the interaction between uncertainty shocks and firms' financial conditions. Here, the response of layoffs to uncertainty shocks varies depending on the firms' financial conditions. The estimated coefficient of the interaction, β_2, is significantly positive in both OLS regressions (Columns 4 and 5) and the 2SLS regression (Column 6). The baseline 2SLS result in Column (6) reports a coefficient of 0.005, indicating that a one standard deviation increase in uncertainty shock raises the layoff probability in financially constrained firms by 0.5 percentage points more than in unconstrained firms. This result is validated as weak-instrument robust, with a conditional likelihood ratio (CLR) test p-value of 0.039. Additionally, the Sargan-Hansen J test of over-identification validates the exclusion restriction with a p-value of 0.351.

This evidence reveals the important role of firm financial conditions in shaping the impact of uncertainty shocks. It supports the risk premium channel as proposed in the literature, which indeed predicts increased job layoffs in financially constrained firms under high uncertainty. In contrast, the real option channel, suggesting a freeze in layoffs and hiring under high uncertainty, does not account for financial heterogeneity and lacks the mechanism to generate this observed pattern. Therefore, the empirical evidence of increased layoffs emphasizes the necessity of incorporating firm financial frictions into the modeling of uncertainty shocks.

2.4 Empirical Evidence for the Labor Contracting Friction

In my search model, the labor contracting friction is another key ingredient alongside the firm financial friction. In fact, the financial friction alone is inconsequential in the context of long-term, intertemporal employment relationships. When labor contracts are complete, they become perfect financial instruments, allowing firms to borrow through firm-worker relationships rather than relying on incomplete financial assets. This setup eliminates idiosyncratic firm risk, rendering uncertainty shocks unable to increase layoffs. To replicate the layoff patterns observed in the data, I introduce a labor contracting friction where wages are insensitive to transitory firm-specific idiosyncratic shocks. This friction restricts the use of labor contracts as a tool for hedging against idiosyncratic risk, thereby bringing financial risk to the forefront.

Existing research provides empirical evidence in support of this labor contracting friction. Guiso, Pistaferri and Schivardi (2005) use matched employer-employee data from Italy to estimate an AR(1) process for firms' value-added, finding an insignificant pass-through of transitory firm-level idiosyncratic shocks to worker earnings. Consistently, Rute Cardoso and Portela (2009) observe a similar result for firms' sales shocks, using a comparable dataset from Portugal. Together, the two studies suggest a minimal response of employee wages to short-term firm-specific fluctuations.[8]

In addition to existing empirical evidence, I use my sample to directly document that uncertainty shocks have little impact on workers' earnings, even for firms in poorer financial conditions. Similar to the empirical analysis for layoffs, I run a regression as per specification (4), substituting the dependent variable with worker earnings growth, $\Delta\text{Earnings}_{ijt}$.

Table 3 presents the regression results. The first three columns – comprising OLS (Columns 1 and 2) and 2SLS (Column 3) regressions – uniformly show an insignificant average effect of uncertainty shocks on worker earnings, evidenced by the small and insignificant coefficients of β_1. The next three columns explore worker earnings' responses to uncertainty shocks under different firms' financial conditions, incorporating an interaction between uncertainty shocks and firms' financial constraint indicators. Here, the estimated β_1 remains insignificant, suggesting little response of earnings in unconstrained firms due to uncertainty shocks. For financially constrained firms, the OLS regressions in Columns 4 and 5 show an insignificant coefficient β_2 for the interaction variable. The exception is the 2SLS regression in Column (6), which reveals a significantly negative coefficient of -0.009 for β_2. This implies that in financially constrained firms, a one standard deviation increase in uncertainty shock decreases worker earnings growth by 0.9 percentage points. The magnitude is small, but the large sample size leads to a precise and significant estimation, with a small standard error of 0.00354. The result is marginally

[8] Note that these findings do not conflict with the literature on firm size wage premium, where larger firms are associated with higher wages (Bloom et al., 2018*a*; Brown and Medoff, 1989; Lallemand, Plasman and Rycx, 2007; Oi and Idson, 1999). They have distinct focuses: one on firm shocks, the other on firm sizes. Much of the firm size heterogeneity observed in data is permanent. Both the referenced papers target transitory shocks as my research, specifically by removing the permanent component.

Table 3: Responses of Worker Earnings to Uncertainty Shocks

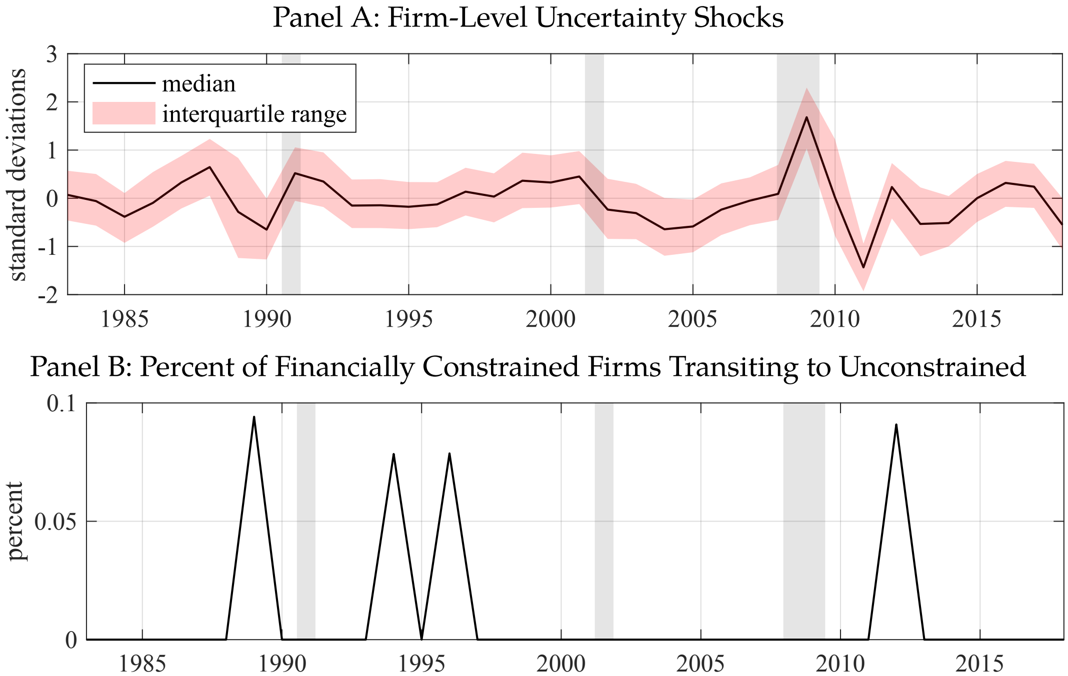
	OLS		2SLS	OLS		2SLS
$\Delta\text{Earnings}_{ijt}$	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\sigma_{jt-1}$	-0.00058	-0.00066	0.00016	-0.00029	-0.00042	0.00102
	(0.00118)	(0.00119)	(0.00403)	(0.00130)	(0.00131)	(0.00407)
$\Delta\sigma_{jt-1} \cdot \mathbb{1}_{jt-5}^{\text{fin-constraint}}$				-0.00261	-0.00226	-0.00949***
				(0.00183)	(0.00167)	(0.00354)
1st-stage F			60.01			34.79
CLR test p-val			0.182			0.064
Sargan-Hansen J test p-val			0.367			0.373
Number of firms	3,700	3,700	3,700	3,700	3,700	3,700
Number of workers	2,328,000	2,328,000	2,328,000	2,328,000	2,328,000	2,328,000
Number of observations	13,340,000	13,340,000	13,340,000	13,340,000	13,340,000	13,340,000
IVs' 1st-moment controls	×	✓	✓	×	✓	✓
Firm controls	✓	✓	✓	✓	✓	✓
Firm, worker, time FEs	✓	✓	✓	✓	✓	✓

Note: This table presents OLS and 2SLS regressions results, projecting worker earnings growth, $\Delta\text{Earnings}_{ijt}$, on lagged firm-level uncertainty, $\Delta\sigma_{jt-1}$, and their interaction with firms' 5-year lagged financial constraint indicators, $\mathbb{1}_{jt-5}^{\text{fin-constraint}}$ (where i is workers, j firms, and t time). Uncertainty, σ_{jt}, is the annualized standard deviations of firm j's daily stock returns within year t. The firm-level financial constraint indicator is the mode of three indicators: absence of an S&P rating, a Whited and Wu (2006) index above the cross-sectional median, and a Size & Age index by Hadlock (2010) exceeding the cross-sectional median. Seven instrumental variables for uncertainty shocks are based on firms' exposure to seven commodity price fluctuations and sourced from Alfaro, Bloom and Lin (2022). The 1st-stage F statistic are the robust Kleibergen-Paap F statistic. CLR (Conditional Likelihood Ratio) tests yield p-values for weak instrument robust inferences. Hansen J test p-values assess over-identification. IVs' 1st-moment controls correspond to the 2nd-moment instruments for uncertainty shocks. Firm-level controls include six lagged firm financial variables: Tobin's Q, stock returns, tangibility, book leverage, returns on assets, and sales-based firm sizes. Firm-level controls also include the lagged firm's financial constraint indicator and its interactions with both IVs' 1st-moment controls and the six firm financial controls. Regressions standardize uncertainty changes and include worker, firm, and time-fixed effects. Standard errors (in parentheses) are clustered at the 2-digit SIC industry level. This research was performed at a Federal Statistical Research Data Center under FSRDC Project Number 2652. (CBDRB-FY22-P2652-R9856) The numbers are rounded according to the Census Bureau's disclosure avoidance requirements. Statistical significance stars: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

weak instrument robust, indicated by a CLR test p-value of 0.064. The Sargan-Hansen J test's p-value of 0.373 further suggests that the instruments are not correlated with the error term, reinforcing the exclusion condition validity.

To gauge the magnitude of the 2SLS estimate β_2 of -0.009, I calculate the share of financially constrained firms transiting to unconstrained status, assuming their wage bills decrease by the estimated -0.009. First, I obtain the average wage per employee from

Figure 1: Understand the Magnitude of Wage Changes



Notes: Panel A shows the median and interquartile range of firm-level uncertainty shocks, as derived from firm-level stock returns. Panel B shows the percent of financially constrained firms that transition to a state of being unconstrained when they reduce their wage bills in reaction to these uncertainty shocks, in accordance with the empirical estimations found in Column (6) of Table 3.

BLS, then multiply it by firm-level employment from Compustat to compute firms' wage bills.[9] The percent change in firms' wage bills is computed by multiplying the -0.009 wage growth semi-elasticity with the firm-level uncertainty shocks data, which is plotted in Panel A of Figure 1. Next, I update the firms' financial constraint indicators that rely on credit ratings, the Whited-Wu index, and the Size & Age index. The Whited-Wu index, calculated as $-0.091 \cdot \text{OIBDP}_{jt}/\text{assets}_{jt-1}$ plus a function of other factors, is directly affected by wage changes through the OIBDP (operating income before depreciation). Decreased wage bills increases firms' operating income, leading to new Whited-Wu index values and updated financial constraint indicators. Panel B plots the fraction of firms shifting from financially constrained to unconstrained. The transition rate is zero for most years, peaking at under 0.1 percent, with no transition during the three recessions in the sample - the 90s, 2000s, and the Great Recession. Thus, even with the only significant point estimate

[9] Due to the widespread missing wage data in Compustat, I use the average economy-wide wage from the U.S. Bureau of Labor Statistics (BLS) as an approximation.

of wage decrease, the magnitude is too small to generate an economically significant relief of firms' financial distress, supporting the insensitivity of wages.

3 Model

I now build a search model consistent with the empirical findings to study the impact of uncertainty shocks on unemployment. To integrate the risk premium channel, this model adopts the financial friction following Arellano, Bai and Kehoe (2019), and introduces a labor contracting friction. For computational tractability, it also features directed search and block recursive equilibrium, drawing on approaches from Menzio and Shi (2010, 2011), Kaas and Kircher (2015), and Schaal (2017).

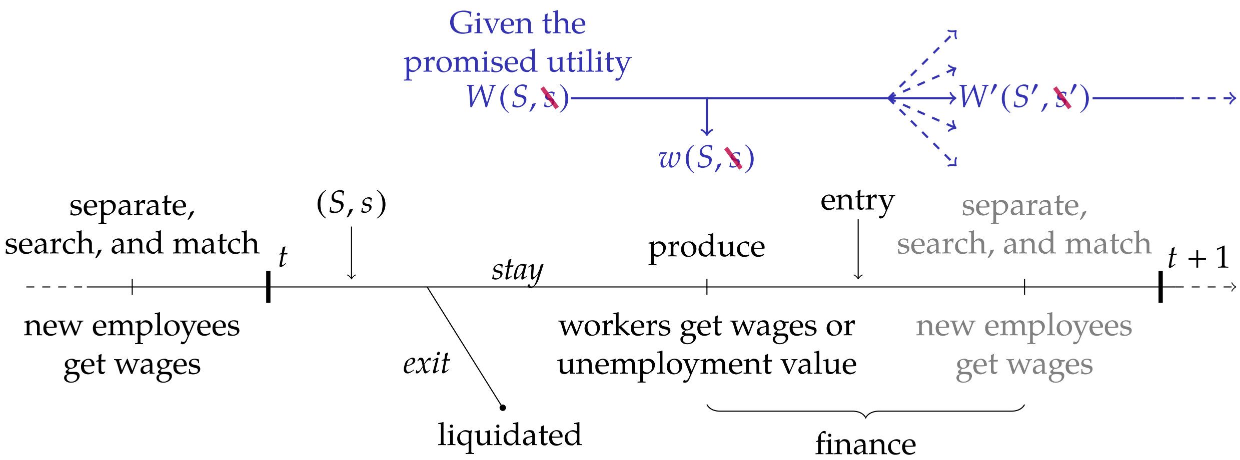
3.1 Environment and Timing

There are four types of risk-neutral agents in the economy: workers, firms, managers, and international financial intermediaries. Workers are infinitely lived with the same productivity, with their total population normalized to one unit. Firms hire workers and managers to produce homogeneous goods, financing their operations by borrowing from international financial intermediaries.

Shocks. Firms are subject to idiosyncratic productivity shocks governed by the Markov process $\pi_z(z'|z,\sigma)$, with σ representing the time-varying uncertainty in firm-level productivity. A higher σ leads to a wider spread of future shocks, increasing the probability of firms drawing lower idiosyncratic productivity. The other aggregate shock in the economy is the aggregate productivity shock A. These two aggregate shocks are represented as $S = (A, \sigma)$. Firms also face an i.i.d. operating cost shock ϵ, which follows a normal distribution $\Phi_\epsilon \equiv \mathcal{N}(\mu_\epsilon, \sigma_\epsilon^2)$. The two firm-specific idiosyncratic shocks are denoted as $s = (z, \epsilon)$.

Labor market. I assume that job search is directed. Each labor submarket is indexed by a promised utility x, representing the lifetime utility that firms offer to workers recruited from that submarket. The tightness of each submarket, θ, is the ratio of vacancies to job-seeking workers. Formally, $\theta = \frac{v}{\mu_u + \lambda\mu_e}$, where v is the number of vacancies, μ_u denotes unemployed workers, μ_e stands for employed workers, and λ represents the efficiency of on-the-job search. I use $p(\theta)$ to indicate the job-finding rate for workers and $q(\theta)$ for the vacancy-filling rate for firms. The equilibrium relationship between x and θ will be

Figure 2: Timing



Notes: This figure depicts the timing of the economy (black axis) and the evolution of promised utilities (blue axis).

governed by the free entry condition. Additionally, the recursive-form labor contract is represented as $C = \{w, \tau, W'(S', s'), d(S', s')\}$, where w is the current wage, τ the layoff probability, $W'(S', s')$ the next-period employment value as promised by the firm, and $d(S', s')$ indicates the firm's decision to exit.

Timing. My model assumes one-sided limited commitment, where firms adhere to labor contracts due to reputational concerns, while workers can leave if they find a better outside option. Figure 2 outlines the timing. At the end of the preceding period, firms and workers engage in the labor market to draw up contracts, separate, search, and match, with newly hired workers receiving their wages. At the start of the current period, all shocks (S, s) realize. Then firms decide to exit or not. Exiting firms default on all debts, including labor contracts, leading to the liquidation of their operations. The firms that continue to operate produce goods based on their employee count from the end of the previous period, while employed workers receive wages under ongoing contracts. Unemployed workers also receive unemployment benefits at this stage. Next, potential new firms can pay an entry cost to enter, after which both new entrants and incumbent firms participate in the labor market. Throughout this process, firms finance their expenditures by borrowing from international financial intermediaries.

3.2 Worker's Problem

There are two types of workers in the economy: unemployed and employed workers. For the sake of simplicity, the model abstracts from the participation margin.

Unemployed Worker's Problem. An unemployed worker, upon receiving unemployment benefits $\bar{u}$, selects a submarket x_u to search for jobs, aiming to maximize their lifetime utility. The matching probability $p(\theta(S, x_u))$ depends on the aggregate shocks and the promised utility of the chosen submarket. The unemployment value is thus defined as:

$$\boldsymbol{U}(S) = \max_{x_u} \bar{u} + p(\theta(S, x_u))x_u + (1 - p(\theta(S, x_u)))\beta\,\mathbb{E}\,\boldsymbol{U}(S'). \tag{5}$$

Employed Worker's Problem. The value of employment depends on the labor contract $\boldsymbol{C} = \{w,\ \tau,\ W'(S', s'),\ d(S', s')\}$. An employed worker earns a wage w and engages in on-the-job searching by choosing a submarket x. If a new job is secured, the worker earns x as lifetime utility. The job finding rate for on-the-job search is discounted by the relative efficiency factor λ of on-the-job searching. In cases of layoff or firm exit, the worker becomes unemployed, receiving the unemployment value $\boldsymbol{U}(S')$ in the subsequent period. Otherwise, the worker can continue to work for the firm and earns the promised utility $W'(S', s')$. Given that firms are committed to labor contracts while workers are not, a worker can voluntarily leave if the promised utility falls below the unemployment value. The value of employment is thus formalized as follows:

$$\begin{aligned}\boldsymbol{W}(S, s, \boldsymbol{C}) = \max_{x}\ & w + \lambda p(\theta(S, x))x \\ & + (1 - \lambda p(\theta(S, x)))\beta\,\mathbb{E}\Big\{[\tau + (1 - \tau)(\pi_d + (1 - \pi_d)d(S', s'))]\boldsymbol{U}(S') \\ & + (1 - \tau)(1 - \pi_d)(1 - d(S', s'))\max\{W'(S', s'), \boldsymbol{U}(S')\}\Big\},\end{aligned} \tag{6}$$

where π_d denotes the exogenous exit rate of firms.

3.3 Firm's Problem

Firms aim to maximize their present value, defined as the discounted sum of equity payouts. A firm's states include realized aggregate shocks $S \in \boldsymbol{S}$, realized firm-specific shocks $s \in \boldsymbol{s}$, the number of employees n, and the set of promised utilities to its employees $\{W(S, s; i)\}_{i \in [0,n]}$, with i indexing incumbent employees.

Firms optimize over current equity payout Δ, next-period debt b', next-period employment n', hiring numbers n_h, search submarket x_h, and next-period exit decisions $d(S', s')$. A firm only posts vacancies in one submarket per period. It also decides current-period wages $w(i)$ for incumbent workers, layoff probabilities $\tau(i)$, wages $w_h(i')$ for new hires, and the set of next-period lifetime utilities $\{W(S', s'; i')\}_{S' \in \boldsymbol{S}', s' \in \boldsymbol{s}'; i' \in [0,n']}$, subject to participation and promise-keeping constraints. Each firm employs exactly one manager, compensated with a fixed wage labeled as $\bar{w}_m$.

Equations (7) to (15) summarize the firm's problem starting from the production stage, with explanations provided afterwards:

$$\boldsymbol{J}(S, s, b, n, \{W(S, s; i)\}_{i \in [0,n]}) = \max_{\substack{\Delta, b', n', n_h, x_h, d(S', s'), \\ \{w(i), \tau(i)\}_{i \in [0,n]}, \\ \{w_h(i')\}_{i' \in (n'-n_h, n']}, \\ \{W'(S', s'; i'), \bar{W}(i')\}_{S' \in \boldsymbol{S}', s' \in \boldsymbol{s}'; i' \in [0,n']}}} \Delta \tag{7}$$
$$+ \beta(1-\pi_d)\, \mathbb{E}_{S', s' | S, s} \left\{ (1 - d(S', s')) \boldsymbol{J}(S', s', b', n', \{W(S', s'; i')\}_{S' \in \boldsymbol{S}', s' \in \boldsymbol{s}'; i' \in [0,n']}) \right\}$$

$$\text{s.t. } \Delta = Azn^{\alpha} - \int_0^n w(i) di - \bar{w}_m - \epsilon - b - c \frac{n_h}{q(\theta(S, x_h))} - \int_{n'-n_h}^{n'} w_h(i') di' + Q(S, z, b', n') b' \geq 0, \tag{8}$$

$$n' = \int_0^n (1 - \tau(i))(1 - \lambda p(\theta(S, x^*(S; i)))) di + n_h, \tag{9}$$

$$i'(i) = \int_0^i (1 - \tau(j))(1 - \lambda p(\theta(S, x^*(S)))) dj, \forall i \in [0, n], \tag{10}$$

$$x^*(S; i) = \arg\max_x p(\theta(S, x)) \Big\{ x - \beta\, \mathbb{E} \big\{ [\tau + (1-\tau)(\pi_d + (1-\pi_d) d(S', s'))] \boldsymbol{U}(S') + (1-\tau)(1-\pi_d)(1 - d(S', s')) \max\{W'(S', s'; i'), \boldsymbol{U}(S')\} \big\} \Big\}, \tag{11}$$

$$W'(S', s'; i') = \boldsymbol{U}(S') + \bar{W}(i'), \tag{12}$$

$$\bar{W}(i') \geq 0, \tag{13}$$

$$\boldsymbol{W}(S, s, C) \geq \begin{cases} W(S, s; i) & \text{for } i \in [0, n], \\ x_h & \text{for newly hired employees,} \end{cases} \tag{14}$$

$$Q(S, z, b', n') b' - n_h \frac{c}{q(\theta(S, x_h))} - \int_{n'-n_h}^{n'} w_h(i') di' \geq M(S, z, n) - F_m(S, z), \tag{15}$$

where $F_m(S,z) = \left[\frac{\bar{w}_m+(1-\gamma)\frac{\beta}{1-\beta}\bar{w}_m}{(1-\Phi(A\xi\,\mathbb{E}[A'z'n'^{\alpha}-\int_0^{n'}w(i')di'-\bar{w}_m-\epsilon']))\zeta\,\mathbb{E}\,z'}\right]^{\frac{1}{\alpha}}\bar{u}$, and $M(S,z,n)$ denotes the maximum possible borrowing net of hiring costs:

$$M(S,z,n) = \max_{\substack{b',n',n_h,x_h,d(S',s'),\\ \{\tau(i)\}_{i\in[0,n]},\{w_h(i')\}_{i'\in(n'-n_h,n']},\\ \{W'(S',s';i'),\bar{W}(i')\}_{S'\in\boldsymbol{S}',s'\in\boldsymbol{s}';i'\in[0,n']}}} Q(S,z,b',n')b' - n_h\frac{c}{q(\theta(S,x_h))} - \int_{n'-n_h}^{n'} w_h(i')di' \tag{16}$$

$$\text{s.t. (9), (12), (13), and (14).} \tag{17}$$

Financial friction. The model features the financial friction via a non-negative equity payout constraint (eq. (8)), preventing firms from having deep pockets through unlimited equity issuance.[10] Equity payouts Δ equal output Azn^{α} minus incumbent employees' wages $\int_0^n w(i)di$, minus the manager's wage $\bar{w}_m$, minus the stochastic operating cost ϵ, minus debt b, minus vacancy posting costs $c\frac{n_h}{q(\theta(S,x_h))}$, minus wages for newly hired workers $\int_{n'-n_h}^{n'} w_h(i')di'$, and plus borrowings $Q(S,z,b',n')b'$. The production function assumes decreasing returns to scale in labor ($\alpha < 1$), facilitating the modeling of within-firm layoffs and hirings. Hiring n_h new workers results in a total vacancy posting cost of $c\frac{n_h}{q(\theta(S,x_h))}$, where q is the vacancy-filling rate, and c is the posting cost per vacancy. The bond price Q is determined such that the international financial intermediaries break even, which will be defined later.

Employment dynamics. Eq. (9) describes the law of motion for employment, with eq. (10) specifying the transition of an employee's index from i to i'. The firm's next-period employment level is the sum of staying employees and new hires. Separations can be due to on-the-job search or layoffs. Eq. (11) illustrates that the optimal on-the-job search market, $x^*(S;i)$, is selected by each employee i to maximize their expected lifetime utility. The probability for a worker transitioning to another firm is then $\lambda p(\theta(S,x^*(S;i)))$. If the worker fails to find a new job, they are subjected to a layoff probability $\tau(i)$.

Labor contracting friction. The labor contracting friction is detailed in eq. (12), which assumes a specific form of next-period promised utilities in labor contracts. These utilities consist of two components: the outside option of unemployment $\boldsymbol{U}(S')$ and a utility markup $\bar{W}(i')$ set by the firm. The outside option component allows labor contracts

[10] The model could include costly equity issuance, but recalibration for sizable issuance costs is needed to match credit spread data. Due to its computational costs, this extension is deferred to future research.

to adjust to changes in workers' outside options, while the utility markup $\bar{W}(i')$ is not contingent on future shocks (S', s'), a crucial feature for the financial friction's effectiveness. If firms could make future promises to workers contingent on upcoming shocks, labor contracts would become much better financial instruments and substitute out the state-uncontingent bonds.

In Appendix A, I micro-found this labor contracting friction with a theory of information frictions, following Hall and Lazear (1984) and Lemieux, MacLeod and Parent (2012). I assume that firms observe the shocks, but workers do not, and there are no penalties for firms misrepresenting their situation. Under these conditions, contracts based on firm-specific shocks become impractical. For aggregate shocks, workers can infer them via changes in their outside options, thereby accepting wage adjustments accordingly. However, for firm-specific idiosyncratic shocks, the absence of credible information leads workers to doubt claims of a firm's situation, given firms' inherent motive to understate their situation to minimize labor costs. Therefore, labor contracts that are incentive-compatible do not depend on firm-level idiosyncratic shocks.

Limited commitment. One-sided limited commitment is reflected in eqs. (13) and (14). My model assumes that firms are committed to labor contracts, but workers are not. The participation constraint (13) indicates that firms must promise a non-negative utility markup to keep their workers, otherwise the worker would prefer unemployment. The promise-keeping constraint (14) requires firms to fulfill their commitment that the employment value is at least the promised lifetime utility. For an incumbent worker $i \in [0, n]$, the promised utility is $W(S, s; i)$, one of the firm's state variables. For a newly hired worker, the promised utility is x_h, based on the firm's choice of hiring submarket.

Agency friction. Firms in my model, like in other models with financial frictions, have a strong incentive to save. To counteract this, Constraint (15) incorporates an agency friction, following Arellano, Bai and Kehoe (2019). This inequality requires firms to maintain sufficient leverage by including the firm's borrowings, Qb', on its left-hand side. It hinges on two parameters: agency friction ζ and auditing quality ξ. The micro-foundation is detailed in Appendix B. The intuition is to prevent the manager from diverting funds for personal use. Such a constraint is essential for matching firm leverage in the data, avoiding scenarios where firms save a large cash buffer and outgrow the financial friction. The agency friction draws inspiration from Jensen (1986). For other ways to generate borrowing under financial frictions, Quadrini (2011) provides one summary.

3.4 Debt Pricing

I assume that the economy's financial market is small compared to the global market, leading to an exogenous risk-free interest rate $r = 1/\beta - 1$. Risk-neutral international financial intermediaries lend to firms through one-period bonds competitively. This setup ensures the block recursivity of the model.

The debt price schedule $Q(S, z, b', n')$ reflects firm-specific default risks. If a firm defaults, creditors recover a portion of the firm's enterprise value $\hat{\boldsymbol{V}}(S', z', X' + b', n_0)$ by collecting current-period profits and selling the firm later. This enterprise value, detailed in eq. (27) below, represents the firm's worth without the non-negative equity payout constraint, as any negative equity payout is considered the creditors' loss. After the final production cycle, the firm's employment level, n_0, is reset to zero as all workers are dismissed. To simplify the computation, I approximate the firm's enterprise value for recovery using a linear function of its profits $\pi' = A'z'n'^{\alpha} - \int_0^{n'} w(i')di' - \bar{w}_m - \mu_\epsilon$. Model simulation reveals a high correlation coefficient of 0.96 between π' and $\hat{\boldsymbol{V}}(S', z', \pi', n_0)$, indicating a strong linear relationship and validating the approximation.

The break-even bond price $Q(S, z, b', n')$ is calculated as follows:

$$Q(S, s, b', n') = \beta\, \mathbb{E}_{S', s'|S, s} \left\{ (1-\pi_d)(1-d(S', s')) + [1-(1-\pi_d)(1-d(S', s'))] \min\{\eta \frac{\iota \pi'}{b'}, 1\} \right\}, \tag{18}$$

where η denotes the recovery rate, and ι represents the coefficient for the linear function approximating the enterprise value from profits. Their product $\tilde{\eta} = \eta\iota$ is what affects decisions, so my calibration focuses on parameterizing $\tilde{\eta}$ and refers to it as recovery.

3.5 Wages Within Labor Contracts

Studying the interaction between dynamic labor contracts and firms' financial conditions is challenging. A key difficulty, known as the 'dimensionality curse,' occurs when a firm's financial status depends on a continuum of historically-dependent labor contracts. To address this, Proposition 1 provides an approach to uniquely pin down wages.

Proposition 1 *The participation constraint* (13) *and the promise-keeping constraint* (14) *bind.*

Proof The proof can be found in Appendix C. □

The binding participation constraint (13) implies that promised utilities exactly compensate workers' outside value $\boldsymbol{U}$. From the worker's problem (5) and (6) and the binding promise-keeping constraint (14), an incumbent worker's wage becomes the net utility of unemployment less potential gains from on-the-job search:

$$\begin{aligned} w(S) &= \boldsymbol{U}(S) - \lambda \max_x p(\theta(S,x))[x - \beta \mathbb{E}\boldsymbol{U}(S')] - \beta \mathbb{E}\boldsymbol{U}(S') \\ &= \bar{u} + (1-\lambda) \max_x p(\theta(S,x))[x - \beta \mathbb{E}\boldsymbol{U}(S')]. \end{aligned} \tag{19}$$

Similarly, a newly hired worker's wage is:

$$w_h(S) = x_h - \beta \mathbb{E}\boldsymbol{U}(S'). \tag{20}$$

Given the expressions of wages, the infinite-dimensional distribution of promised utilities is not informative as a state variable, and the firm's problem can be simplified by removing the implicit contract constraints, (12), (13), and (14). The resolves the dimensionality problem and enables numerical solutions.

The uniqueness of wages results from three assumptions: asymmetric information, secured creditors, and limited commitment. First, asymmetric information prohibits labor contracts from indexing wages on future idiosyncratic firm shocks, limiting the allocation of wage payments *across states*. Second, the model assumes secured creditors have priority in firm bankruptcy recoveries, aligning with US bankruptcy law. This seniority discourages firms from deferring wages, as such backloading is like borrowing from workers at higher interest rates than collateralized bonds. Lastly, worker non-commitment to labor contracts means firms cannot frontload wages arbitrarily, as employees can leave if their job's value falls below the outside options. These latter two assumptions restrict the allocation of wages *across time*. Therefore, wages are uniquely pinned down in my model.

Notice that my model does not require wages to be sticky to aggregate shocks; it allows wages to respond flexibly to any aggregate shock that affects workers' outside opportunities. Instead, my model features wages are not contingent on idiosyncratic firm shocks. This distinction of wage responsiveness is in line with existing empirical findings. Carlsson, Messina and Skans (2016) use matched employer-employee data from Sweden and document that the response of worker earnings to sector-level productivity shocks is three times as much as the response to firm-level productivity shocks. Souchier (2022) analyzes French matched employer-employee data and reports consistent findings.

3.6 Cash on Hand

In this section, I further simplify the firm's problem. First, given that workers are homogeneous, the distribution of layoff probabilities is irrelevant. From now on, I focus on a symmetric decision rule, where all employees face the same layoff probability τ.

Second, a firm's exit results in its outside value becoming zero. Hence, a firm defaults and exits only if it cannot satisfy the non-negative equity payout constraint (8). Default occurs if the operating cost exceeds the threshold $\bar{\epsilon}(S, z, b, n)$, defined as:

$$\bar{\epsilon}(S, z, b, n) \equiv Azn^{\alpha} - \int_0^n w(i)di - b + M(S, z, n) - \bar{w}_m, \tag{21}$$

where $M(S, z, n)$ is the maximum net borrowing defined in eq. (16).

Plugging in the default cutoff (21) and wages (19) and (20), I rewrite the firm's problem (7) using cash on hand X as a state variable:

$$\boldsymbol{V}(S, z, X, n) = \max_{\substack{\Delta, b', n', \\ \tau, n_h, x_h}} \Delta + \beta(1 - \pi_d)\,\mathbb{E}_{S', z'|S, z} \int_{-\infty}^{\bar{\epsilon}(S', z', b', n')} \boldsymbol{V}(S', z', X', n')d\Phi_{\epsilon}(\epsilon') \tag{22}$$

$$\text{s.t.} \;\; (9), (11), (15) \tag{23}$$

$$\Delta = X + Q(S, z, b', n')b' - n_h \frac{c}{q(\theta(S, x_h))} - n_h[x_h - \beta\,\mathbb{E}\,\boldsymbol{U}(S')] \geq 0, \tag{24}$$

$$X' = A'z'n'^{\alpha} - n'[\bar{u} + (1 - \lambda)\mu(S')] - \bar{w}_m - \epsilon' - b', \tag{25}$$

$$\bar{\epsilon}(S', z', b', n') = A'z'n'^{\alpha} - n'[\bar{u} + (1 - \lambda)\mu(S')] - b' + M(S', z', n') - \bar{w}_m, \tag{26}$$

When a firm's cash on hand is sufficiently high, it avoids the financial friction and operates under a set of policies independent of the cash on hand, denoted as $\hat{b}(S, z, n)$, $\hat{n}(S, z, n)$, $\hat{\tau}(S, z, n)$, $\hat{n}_h(S, z, n)$, and $\hat{x}_h(S, z, n)$. Lemma 3.1 characterizes firms' decisions and provides a partitioning method to solve the firm's problem, following Khan and Thomas (2013), Arellano, Bai and Kehoe (2019), and Ottonello and Winberry (2020).

Lemma 3.1 *(Decision Cutoffs): If $X < -M(S, z, n)$, the firm cannot satisfy the nonnegative external equity payout condition and has to default. If $X \geq \hat{X}(S, z, n) \equiv -\{Q(S, z, \hat{b}, \hat{n})\hat{b} - \hat{n}_h \frac{c}{q(\theta(S, \hat{x}_h))} - \hat{n}_h[\hat{x}_h - \beta\,\mathbb{E}\,\boldsymbol{U}(S')]\}$, the firm solves following relaxed problem (27), and the level of* *cash on hand does not affect the optimal decisions:*

$$\hat{\boldsymbol{V}}(S,z,X,n) = \max_{\substack{b',n',\\ \tau,n_h,x_h}} X + Q(S,z,b',n')b' - n_h \frac{c}{q(\theta(S,x_h))} - n_h[x_h - \beta\,\mathbb{E}\,\boldsymbol{U}(S')]$$
$$+ \beta(1-\pi_d)\,\mathbb{E}_{S',z'|S,z} \int_{-\infty}^{\bar{\epsilon}(S',z',b',n')} \boldsymbol{V}(S',z',X',n')d\Phi_\epsilon(\epsilon') \tag{27}$$

$$\text{s.t. (9), (11), (15), (25), and (26).} \tag{28}$$

Proof The proof can be found in Appendix C. □

3.7 Firm Entry and Equilibrium

New firms entering the market incur a fixed entry cost, k_e. Their productivity is drawn from the stationary distribution of idiosyncratic productivity $g_z(\cdot)$. New entrants do not produce in the entry period but hire workers as do incumbent firms. Entrants start with zero debt and no labor, facing the following problem:

$$\boldsymbol{J}_e(S,z) = \max_{n_h,x_h} -n_h \frac{c}{q(\theta(S,x_h))} - n_h[x_h - \beta\,\mathbb{E}\,\boldsymbol{U}(S')] \tag{29}$$

$$+ \beta(1-\pi_d)\,\mathbb{E}_{S',z'|S,z} \int_{-\infty}^{\bar{\epsilon}(S',z',b_0,n_h)} \boldsymbol{V}(S',z',X',n_h)d\Phi_\epsilon(\epsilon'), \tag{30}$$

$$\text{s.t. } b_0 = 0, \;\; \text{(25), and (26).} \tag{31}$$

I use n_e, x_e, and d_e to denote the new entrant's optimal decisions.

Firms only post vacancies in markets with the lowest hiring cost. Define the minimum hiring cost per worker as

$$\kappa(S) \equiv \min_{x_h}[x_h + \frac{c}{q(\theta(S,x_h))}]. \tag{32}$$

Only submarkets with the lowest hiring cost are active in the equilibrium. For a given $\kappa(S)$, the mapping from a market's promised utility x to market intensity θ is

$$\theta(S,x) = \begin{cases} q^{-1}\left(\frac{c}{\kappa(S)-x}\right), & \text{if } x \le \kappa(S) - c, \\ 0, & \text{if } x \ge \kappa(S) - c. \end{cases} \tag{33}$$

Markets with a promised utility x exceeding $\kappa - c$ are inactive, as the vacancy filling probability cannot exceed one to compensate for the hiring cost.

The value of $\kappa(S)$ is determined by the free entry condition, which requires that the entry cost equals the expected entry value for all aggregate states S:

$$k_e = \sum_z \boldsymbol{J}_e(S,z) g_z(z), \forall S. \tag{34}$$

The model's equilibrium is then defined as follows:

Definition 3.1 *Let s^f summarize the firm's state variables (S,z,X,n). The block recursive equilibrium consists of the policy and value functions of unemployed workers $\{x_u(S), \boldsymbol{U}(S)\}$; of employed workers $\{x(S,s,C), \boldsymbol{W}(S,s,C)\}$; of incumbent firms $\{\Delta(s^f)$, $b'(s^f)$, $n'(s^f)$, $\tau(s^f)$, $n_h(s^f)$, $x_h(s^f)$, $w(S)$, $w_h(S)\}$; of new firms $\{n_e(S)$, $x_e(S)$, $\boldsymbol{J}_e(S)\}$; the hiring cost per worker $\kappa(S)$; the labor market tightness $\theta(S,x;\kappa(S))$; and bond price schedules $Q(S,z,b',n')$ such that*

1. *Given the bond price schedules, the hiring cost, and the labor market tightness, the policy and value functions of unemployed workers, employed workers, incumbent firms, and entering firms solve their respective problems (5), (6), (19), (20), (22), and (29).*

2. *The bond price schedule satisfies (18).*

3. *The hiring cost per worker and the labor market tightness function satisfy (32) and (33).*

4. *The free entry condition (34) holds.*

Let $\Upsilon(z,X,n)$ denote the mass of firms with states (z,X,n). Its law of motion is:

$$\begin{aligned}
&\Upsilon'(z',X',n') \\
&= \sum_{z,X,n,\epsilon'} (1-\pi_d)(1-d(S',s';S,z,X,n))\mathbb{1}\{X'(S',s';S,z,X,n) = X'\}\phi_\epsilon(\epsilon')\pi_z(z'|z,\sigma)\mathbb{1}\{n'(S,z,X,n) = n'\}\Upsilon(z,X,n) \\
&\quad + m_e(S,\Upsilon)\sum_{z,\epsilon'}(1-\pi_d)(1-d_e(S',s';S,z))\mathbb{1}\{X'_e(S',s';S,z) = X'\}\phi_\epsilon(\epsilon')\pi_z(z'|z,\sigma)\mathbb{1}\{n_e(S) = n'\}g_z(z),
\end{aligned} \tag{35}$$

where the mass of entrants $m_e(S,\Upsilon)$ is determined such that total jobs found by workers equals the total jobs created by incumbent firms and new entrants.[11]

4 Parameterization

Section 4.1 calibrates the model. Section 4.2 then validates it against micro-level evidence. Appendix D details the global grid search computational algorithm.

[11] In simulations, jobs created by incumbent firms may occasionally surpass those found by workers, leading to the issue of undefined negative entry. To address this, the model incorporates population growth, detailed in Appendix D.

4.1 Calibration

Functional Forms. The model features four shocks: aggregate productivity A, uncertainty σ, firm-level idiosyncratic productivity z, and operating cost ϵ. The logarithms of aggregate productivity and uncertainty follow AR(1) processes:

$$\log A_{t+1} = \rho_A \log A_t + \sigma_A \sqrt{1-\rho_A^2}\epsilon_t^A, \epsilon_t^A \sim \mathcal{N}(0,1), \tag{36}$$

$$\log \sigma_{t+1} = (1-\rho_\sigma)\log\bar{\sigma} + \rho_\sigma \log \sigma_t + \sigma_\sigma \sqrt{1-\rho_\sigma^2}\epsilon_t^\sigma, \epsilon_t^\sigma \sim \mathcal{N}(0,1). \tag{37}$$

I allow correlation between ϵ_t^A and ϵ_t^σ, denoted by the correlation coefficient $\rho_{A\sigma}$. Firm-level idiosyncratic productivity also follows an AR(1) process:

$$\log z_{jt+1} = \rho_z \log z_{jt} + \sigma_t \sqrt{1-\rho_z^2}\epsilon_{jt}^z, \epsilon_{jt}^z \sim \mathcal{N}(0,1). \tag{38}$$

where σ_t is the time-varying uncertainty affecting the standard deviation of the innovation. Finally, the i.i.d. operating cost shock ϵ follows a normal distribution $\mathcal{N}(\mu_\epsilon, \sigma_\epsilon^2)$.

The model adopts Menzio and Shi's (2010) and Schaal's (2017) job finding probability function to maintain transition rates within the range of zero to one:

$$p(\theta) = \theta(1+\theta^\gamma)^{-1/\gamma}. \tag{39}$$

The vacancy-filling rate $q(\theta) = \frac{p(\theta)}{\theta}$.

Assigned Parameters. Table 4 presents the parameter values. The parameters in Panel A are set exogenously, following standard practices in the literature. I adopt a quarterly discount factor β of 0.988, implying an annual risk-free interest rate of 5% as in Schaal (2017). The labor coefficient α is fixed at 0.66 according to the labor share. And I follow Khan and Thomas (2008) to set the persistence of idiosyncratic productivity ρ_z at 0.95.

Fitted Parameters. Panel B of Table 4 display parameters that are calibrated jointly, with matched moments in Table 5. The first set of parameters controls the AR(1) processes of aggregate shocks. For the aggregate productivity parameters (ρ_A, σ_A), the targets are are the autocorrelation and standard deviation of output, using real GDP data from BEA, detrended by an HP-filter with a parameter of 1,600, as processed by Schaal (2017). Uncertainty is calibrated by the interquartile range (IQR) of residual sales growth rates across firms, as per Bloom et al. (2018*b*). The data is from Compustat and deflated by CPI, accounting for permanent firm heterogeneity and industry-specific fluctuations

Table 4: Parameter Values

Parameters	Notations	Values	Sources/Matched Moments
Panel A: Assigned Parameters			
Discount factor	β	0.988	5% annual interest rate
Decreasing returns to scale coefficient	α	0.66	Labor share
Persistence of productivity	ρ_z	0.95	Khan and Thomas (2008)
Panel B: Parameters from Moment Matching			
Aggregate shocks			
Persistence of aggregate productivity	ρ_A	0.920	Autocorrelation of output
SD of aggregate productivity	σ_A	0.024	SD of output
Mean of uncertainty	$\bar{\sigma}$	0.248	Mean of IQR
Persistence of uncertainty	ρ_σ	0.880	Autocorrelation of IQR
SD of uncertainty	σ_σ	0.092	SD of IQR
Correlation between ϵ_t^A and ϵ_t^σ	$\rho_{A\sigma}$	−0.020	Correlation (output, IQR)
Labor market			
Unemployment benefits	$\bar{u}$	0.142	EU rate
Vacancy posting cost	c	0.001	UE rate
Relative on-the-job search efficiency	λ	0.100	EE rate
Matching function elasticity	γ	1.600	$\epsilon_{UE/\theta}$
Entry cost	k_e	15.21	Entry/Total job creation
Mean operating cost	$\bar{w}_m + \mu_\epsilon$	0.001	Average establishment size
Financial market			
SD of production costs	σ_ϵ	0.080	Mean credit spread
Agency friction	$\tilde{\zeta}$	2.400	Median leverage
Auditing quality	ξ	1.780	Correlation (output, spreads)
Recovery	$\tilde{\eta}$	2.410	Correlation (IQR, spreads)
Exogenous exit rate	π_d	0.021	Annual exit rate

Note: Panel A shows parameters exogenously assigned. Panel B shows parameters endogenously calibrated.

by projections on firm and industry-quarter fixed effects. The resulting sales growth residuals construct the IQR, which after detrending, pins down the uncertainty parameters $(\mu_\sigma, \rho_\sigma, \sigma_\sigma)$. Additionally, the correlation between output and the IQR determines the correlation $(\rho_{A\sigma})$ between aggregate productivity shocks and uncertainty shocks.

Second, for labor market dynamics, I calibrate the unemployment utility $(\bar{u})$, vacancy posting cost (c), and relative on-the-job search efficiency (λ) using transitions from employment to unemployment (EU), unemployment to employment (UE), and employment to employment (EE). The data moments are the quarterly equivalents of monthly rates in Schaal (2017), initially from Shimer (2005) for EU and UE rates and Nagypál (2007) for the EE rate. The calibrated $\bar{u}$ is about 62% of average labor productivity, similar to the 63% estimated by Schaal (2017) and 71% by Hall and Milgrom (2008). The matching function

Table 5: Matched Moments

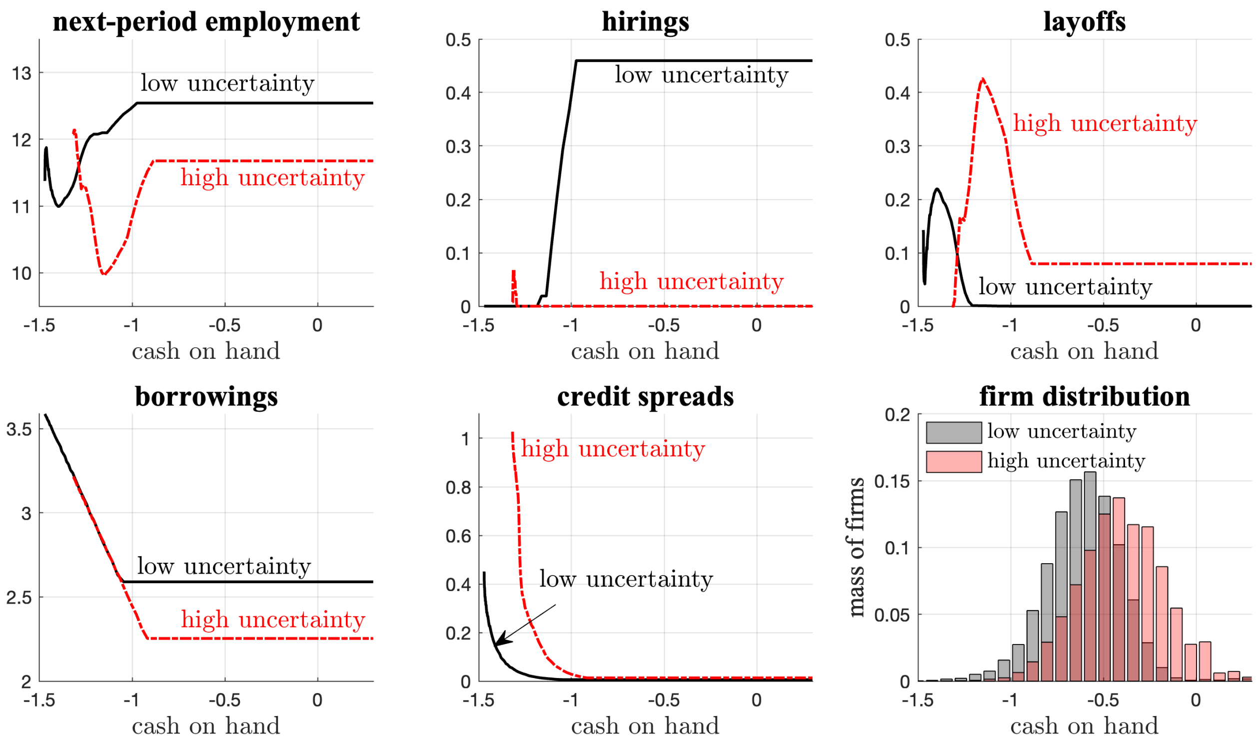
Moments	**Data**	**Benchmark Model** $A+\sigma$	**Benchmark Model** A	**No Contracting Frictions** $A+\sigma$	**No Contracting Frictions** A
Aggregate shocks					
Autocorrelation of output	0.839	0.868	0.877	0.838	0.867
SD of output	0.016	0.015	0.015	0.019	0.017
Mean of IQR	0.171	0.169	0.160	0.161	0.169
Autocorrelation of IQR	0.647	0.611	-	0.623	-
SD of IQR	0.013	0.011	-	0.010	-
Correlation (output, IQR)	-0.351	-0.305	-	-0.314	-
Labor market					
UE rate	0.834	0.814	0.817	0.840	0.832
EU rate	0.076	0.083	0.080	0.063	0.070
EE rate	0.085	0.081	0.082	0.044	0.044
$\epsilon_{UE/\theta}$	0.720	0.717	0.707	0.711	0.705
Average establishment size	15.6	15.4	15.3	15.5	15.6
Entry/Total job creation	0.21	0.18	0.18	0.27	0.25
Financial market					
Mean credit spread (%)	1.09	0.96	0.97	-	-
Median leverage (%)	26	21	21	-	-
Correlation (output, spreads)	-0.549	-0.503	-	-	-
Correlation (IQR, spreads)	0.462	0.448	-	-	-
Annual exit rate (%)	8.9	9.0	9.2	9.0	9.0

Note: This table shows the targeted data moments and moments matched by the benchmark model and the model without contracting frictions. $A+\sigma$ means the model has both aggregate productivity shocks and uncertainty shocks, and A means the model only has aggregate productivity shocks.

elasticity γ is calibrated by the elasticity of the UE rates to labor market tightness from Shimer (2005). The entry cost k_e matches the share of jobs created by entrants from Schaal (2017) using Business Employment Dynamics. The mean operating cost, $\mu_\epsilon + \bar{w}_m$, matches the average establishment size reported by Schaal (2017) using the 2002 Economic Census.

The last set of parameters deals with the financial market. The standard deviation of operating costs, σ_ϵ, is determined by the average credit spread between Baa and Aaa corporate bonds from Moody's. This credit spread is modeled as the annualized difference between borrowing costs and the risk-free interest rate: $\frac{1}{Q(S,z,b',n')} - \frac{1}{\beta}$. The agency friction parameter, $\tilde{\zeta} \equiv \zeta/(\bar{w}_m + (1-\lambda)\frac{\beta}{1-\beta}\bar{w}_m)$, encouraging firms to borrow, is calibrated using median leverage data from Moody's in Arellano, Bai and Kehoe (2019). The correlation between output and credit spreads informs the auditing technology parameter ξ, and the correlation between the interquartile range and credit spreads sets the recovery rate η.

Figure 3: Firm's Decisions Rules and Distribution



Notes: The first five panels show the median firm's decision rules for cash on hand, with the firm's productivity and employment held at median values, and aggregate productivity set high. Solid black lines represent low uncertainty states, and dash-dot red lines denote high uncertainty. The last panel contrasts the stochastic stationary distributions of firms' cash on hand under low (black) and high (red) uncertainty. "High" and "low" states are defined as one unconditional standard deviation above or below the mean.

Finally, the exogenous exit rate π_d is calibrated using the annual exit rate from Business Dynamics Statistics, capturing firm exits beyond defaults.

4.2 External Validation

In this section, I begin by explaining the mechanism via firm-level decision rules, followed by validating the model's consistency with empirical evidence.

4.2.1 Firm-Level Decisions

Figure 3 shows how the median firms' decisions depend on cash on hand and uncertainty levels, with aggregate productivity fixed high.

Cash on Hand. As cash on hand decreases, firms borrow more to meet the non-negative equity payout constraint, leading to higher credit spreads. The increased default risks make firms reduce employment by hiring less and firing more. Note that at very low cash levels, firms increase hirings due to the usually high default rate as a risk-taking strategy, aiming for higher productivity conditional on survival. However, this behavior is limited to a small segment of firms, as indicated by the firm distribution in the last panel.

Uncertainty. The level of uncertainty also affects firms' decisions. The graph reveals that higher uncertainty causes an increase in credit spreads due to the heightened probability of low productivity and subsequent default risks. So, firms are averse to borrowing. Also, the insensitivity of wages to firm-specific shocks renders wage bills similar to debt-like obligations. Consequently, retaining employees is isomorphic to borrowing more, prompting firms to reduce hiring and increase layoffs when uncertainty is high.

4.2.2 Validation Against Empirical Evidence

To validate the model, I re-estimate the empirical regression (4) using a model-simulated panel of 3,000 workers and 5,000 firms over 1,000 periods. Panel A of Table 6 presents the results of projecting job-level layoff indicators against uncertainty shocks and the interaction with firms' financial constraint indicators, controlling for first-moment shocks, fixed effects, and firm-side variables. In these model regressions, a firm's financial constraint is set to one if its cash on hand is below that period's median, as cash on hand sufficiently reflects a firm's financial condition in the model.

Column (1) in Panel A displays the baseline 2SLS regression result from Table 2, indicating a 0.51% increased layoff probability in financially constrained firms when uncertainty rises by one standard deviation. The model implies a similar coefficient of around 0.55%, with and without time fixed effects as shown in Columns (2), (3), and (4). This consistency between the model and data validates the role of financial heterogeneity in shaping the effect of uncertainty shocks on the labor market.

Panel B contrasts the results with the standard search model's predictions, examining unconditional responses to uncertainty shocks excluding firm financial conditions. The 2SLS empirical regression in Column (1) from Table 2 shows an insignificantly positive effect of uncertainty on layoffs. My model's regression results in Columns (2) and (3) also show positive estimated coefficients. In contrast, Schaal's (2017) search framework predicts a clear negative effects of uncertainty on layoffs due to the increased option value of waiting driven by irreversible search costs.[12] This comparison reemphasizes the need

[12] Appendix E details three differences in my calibration from Schaal (2017), each necessary for integrating the financial friction. But none of these differences cause the distinct layoff responses.

Table 6: Responses of layoffs to Uncertainty Shocks: Model versus Data

Panel A. Heterogenous Responses Conditional on Firm Financial Conditions

	Data	Model		
$\mathbb{1}_{ijt}^{\text{layoff}}$	(1)	(2)	(3)	(4)
$\Delta\sigma_{t-1}$	-0.00038		0.00067	0.00075
	(0.00162)		(0.00018)	(0.00018)
$\Delta\sigma_{t-1} \cdot \mathbb{1}\{\text{lagged fin-constraint}_{jt}\}$	0.00514**	0.00543	0.00557	0.00557
	(0.00249)	(0.00025)	(0.00025)	(0.00025)
Firm controls	✓	✓	✓	✓
Firm, worker FEs	✓	✓	✓	✓
Time FE	✓	✓	×	×
Aggregate controls	×	×	×	✓

Panel B. Unconditional Responses

	Data	Model		Schaal (2017)	
$\mathbb{1}_{ijt}^{\text{layoff}}$	(1)	(2)	(3)	(4)	(5)
$\Delta\sigma_{jt-1}$	0.00013	0.00317	0.00327	-0.00017	-0.00018
	(0.00157)	(0.00012)	(0.00012)	(0.00007)	(0.00007)
Firm controls	✓	✓	✓	✓	✓
Firm, worker FEs	✓	✓	✓	✓	✓
Time FE	✓	×	×	×	×
Aggregate controls	×	×	✓	×	✓

Note: This table compares the empirical evidence from Table 2 with simulations from my benchmark model and Schaal's (2017) model. Panel A shows firms' layoff responses conditional on heterogeneous financial conditions, while Panel B presents unconditional responses to uncertainty shocks. The first column in each panel is the 2SLS regression result from Table 2. Subsequent columns employ regressions using model simulations for 3,000 workers and 5,000 firms over 1,000 periods. The regressions project job-level layoff indicators, $\mathbb{1}_{ijt}^{\text{layoff}}$, against 1-year lagged changes of uncertainty, $\Delta\sigma_{t-1}$, with and without the interaction with firms' lagged financial constraint indicators, $\mathbb{1}\{\text{lagged fin-constraint}_{jt}\}$, where i denotes workers, j represents firms, and t stands for time. My model and Schaal's (2017) model differ slightly in the timing of shock realization; hence, σ_{t-1} is uniformly defined as the uncertainty shock realized right before and directly influencing layoffs at time t in both models. Each regression standardizes changes in uncertainty and incorporates both worker and firm-fixed effects. Model regressions consistently contain firm-side controls, in line with the data methodology. These include ΔA_{t-1} and Δz_{jt-1} as the first-moment controls, lagged firm sales as the gauge for firm size, their interactions with the lagged firm's financial constraint indicator, and the lagged financial constraint indicator itself. In model regressions, the financial constraint indicator is set to one if the firm's cash on hand is below that period's median. Time fixed effects are omitted in certain columns to estimate the coefficient of $\Delta\sigma_{t-1}$, compensated by including 2-period lagged uncertainty and aggregate productivity growth ($\Delta\sigma_{t-2}$ and ΔA_{t-2}) as aggregate controls, given σ and A are the sole aggregate shocks in the model. Significance stars are only reported for data regressions: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

to enrich the search model by incorporating financial heterogeneity to study uncertainty shocks' impact on the labor market.

5 Quantitative Analyses

Section 5.1 applies the parameterized model to analyze U.S. recessions, and Section 5.2 uses the model to examine labor market stabilization policies.

5.1 Event Study for U.S. Recessions

This section applies the model to five past U.S. recessions, from the 70s through the Great Recession. Using a particle filter approach akin to Bocola and Dovis (2019), I estimate the historical aggregate productivity and uncertainty shocks. I then compare the model-predicted unemployment with the data.

Model-Predicted Unemployment. A particle filter is a Monte Carlo Bayesian estimator for the posterior distribution of structural shocks in non-linear systems such as mine. The first step is to approximate the model's infinite-dimensional state of firm distribution by an auxiliary finite-state non-linear state-space system:

$$\begin{aligned} \boldsymbol{Y}_t &= g(\boldsymbol{X}_t) + \epsilon_t^Y, \\ \boldsymbol{X}_t &= f(\boldsymbol{X}_{t-1}, \epsilon_t^X), \end{aligned} \tag{40}$$

where $\boldsymbol{Y}_t$ is a vector of observables, and $\boldsymbol{X}_t$ is an auxiliary finite-dimensional state vector. The function g maps the states to observations, and f is the transition of states. ϵ_t^X refers to the vector of state variable shocks, and ϵ_t^Y is a vector of independent and serially uncorrelated Gaussian measurement errors.

The state variables $\boldsymbol{X}_t$ are combinations of aggregate productivity, uncertainty, and credit spreads.[13] The observables $\boldsymbol{Y}_t$ are aggregate output and the interquartile range (IQR) of firm sales growth. The mapping function $g(\cdot)$ is derived by projecting simulated output and IQR on the state variables, with R^2 of 0.999998 and 0.9997 validating the mapping's accuracy. The state transition function $f(\cdot)$ contains the transitions of aggregate productivity and uncertainty in eq. (36) and eq. (37).

[13] There are five groups of state variables in $\boldsymbol{X}_t$: (i) a constant; (ii) $\{\log A_{t-p}, \log \sigma_{t-p}\}_{p=0}^5$; (iii) $\{\log A_{t-p} \cdot \log \sigma_{t-p}, \{\log A_{t-p} \cdot \log \sigma_{t-q}, \log A_{t-q} \cdot \log \sigma_{t-p}\}_{q=p+1}^3\}_{p=0}^2$; (iv) $\{(\Delta \log A_{t-p})^2, (\Delta \log \sigma_{t-p})^2, (\Delta \log A_{t-p})^2 \cdot \log \sigma_{t-1}, (\Delta \log \sigma_{t-p})^2 \cdot \log A_{t-1}\}_{p=0}^3$; (v) $\{\log \text{spr}_{t-1} \cdot \log A_t, \log \text{spr}_{t-1} \cdot \log \sigma_t, \{\log \text{spr}_{t-p}, \log \text{spr}_{t-p} \cdot \log A_{t-1}, \log \text{spr}_{t-p} \cdot \log \sigma_{t-1}, \{\log \text{spr}_{t-p} \cdot (\Delta \log A_{t-q})^2, \log \text{spr}_{t-p} \cdot (\Delta \log \sigma_{t-q})^2\}_{q=0}^2\}_{p=1}^5\}$.

Given the parameterized system (40), I apply a particle filter to estimate historical shocks. This analysis uses GDP per capita from BEA and the interquartile range (IQR) of firm sales growth from Compustat, from 1972 to 2018, as observables. The series are detrended by a band-pass filter for business cycle fluctuations within 6 to 32 quarters, consistent with Schaal (2017). I use 10,000 particles to mimic the states. They evolve to predict observables, with the data refining the particles according to their likelihoods. Figure F.2 plots the estimated shocks, and Figure F.3 confirms the observables are accurately matched.

Given the estimated shocks, Panel A of Figure 4 displays model-predicted unemployment during recessions: actual data (black lines) and benchmark model predictions (dash-dotted red lines). Their alignment in unemployment spikes suggests that the benchmark model effectively captures the rise in unemployment.[14] To isolate the role of uncertainty shocks, the figure also includes predictions from the model with only aggregate productivity shocks (dashed blue lines).[15] The explanatory power decreases significantly. The deterioration is pronounced for the 2001 Recession and the Great Recession, periods with large increases in uncertainty but only modest decreases in aggregate TFP (Figure F.2).

The Role of Contracting Frictions. The key to this result is the interaction between financial and labor contracting frictions. Without either of them, the model collapses to the one without contracting frictions at all. If labor contracts are complete, firms can borrow from workers, eliminating the need for state-uncontingent bonds. Conversely, if the financial market is complete, the labor market friction has no impact because how wages are paid within labor contracts is irrelevant. Instead, only the present value of wages matters for decisions.

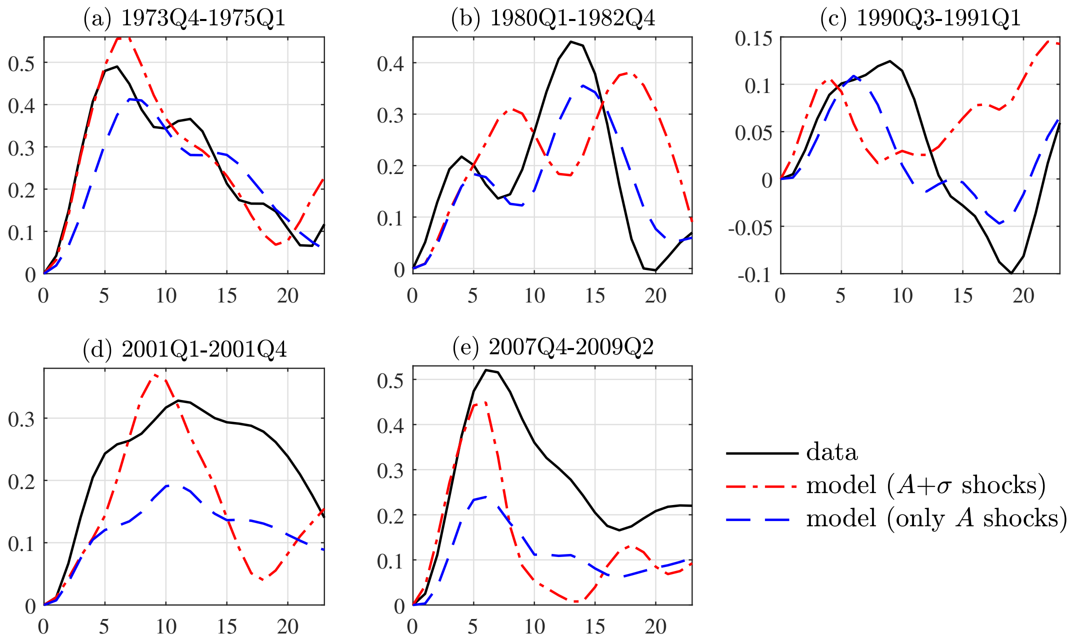
Panel B of Figure 4 shows that the model without contracting frictions underperforms in explaining the rise in unemployment. Table 7 reports that uncertainty shocks explain 26% of unemployment increases in my benchmark model, a stark contrast to only 7% in the model without contracting frictions. That is, over 70% of uncertainty's impact is due to the financial and labor contracting frictions. Business cycle statistics in Table F.2 echoes this conclusion. The finding aligns with Schaal (2017), who discovers that the canonical search framework falls short in replicating unemployment increases particularly during

[14] To avoid unemployment fluctuations being mechanically driven by varying default rates, I assume that firms continue production in the default period, contributing to GDP and employment (see Appendix D).

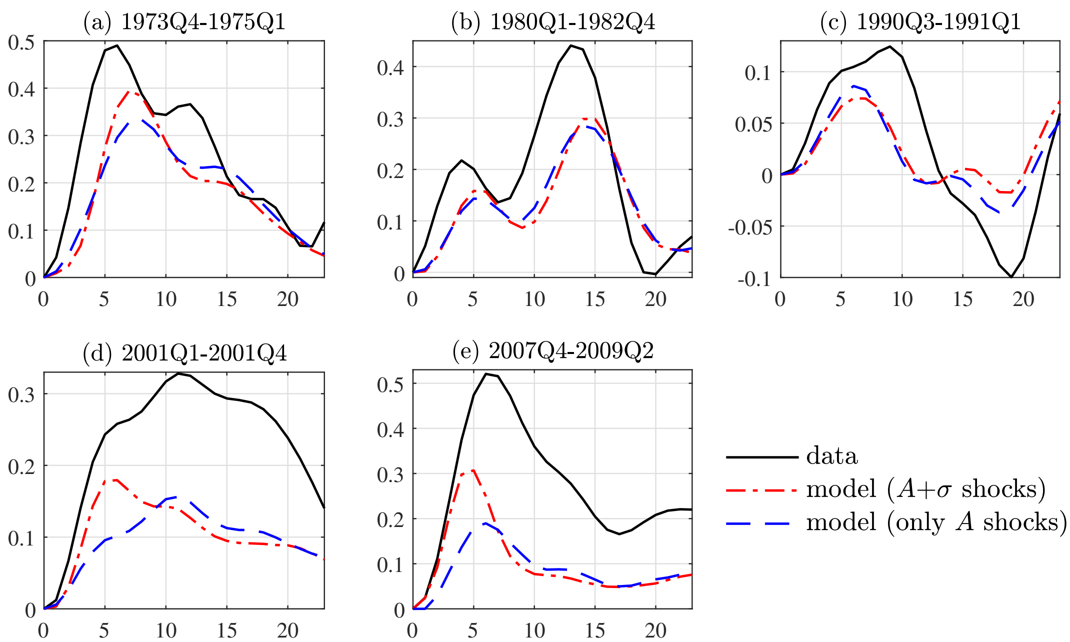
[15] All reference models have been recalibrated, featuring parameter values reported in Table F.1 and corresponding matched moments presented in Table 5.

Figure 4: Unemployment Series With and Without Modeling Contracting Frictions

Panel A: Benchmark Models



Panel B: Models Without Contracting Frictions



Notes: The panels display model predictions for unemployment during recessions: Panel A uses benchmark models; Panel B, models without contracting frictions. Models are recalibrated, with aggregate productivity and uncertainty shocks estimated using a particle filter on output data and firms' sales growth IQR, detrended for 6 to 32 quarter fluctuations per Schaal (2017). Each panel compares model-predicted unemployment (dash-dotted red lines for $A + \sigma$ shocks, dashed blue lines for only A shocks) against actual data (solid black lines). Series are depicted as log deviations from pre-recession peaks. I use Schaal's (2017) code when plotting this figure.

Table 7: Peak-To-Trough Changes of Unemployment During Recessions

	1973-1975	1980-1982	1990-1991	2001	2007-2009
Data	0.490	0.441	0.124	0.328	0.521
Benchmark models					
Both A and σ shocks	0.557	0.382	0.107	0.370	0.449
Only A shocks	0.413	0.355	0.109	0.193	0.239
⇒ Data explained by adding σ shocks	29.5%	5.9%	-1.7%	53.9%	40.2%
	25.6% on average				
Models without contracting frictions					
Both A and σ shocks	0.395	0.298	0.074	0.179	0.307
Only A shocks	0.333	0.285	0.086	0.156	0.190
⇒ Data explained by adding σ shocks	12.6%	3.0%	-9.6%	7.1%	22.6%
	7.1% on average				

Note: The table compares peak-to-trough unemployment changes during recessions across data, benchmark models, and models without contracting frictions. 'Both A and σ Shocks' refers to models with both aggregate productivity shocks and uncertainty shocks, while 'Only A Shocks' means models with only aggregate productivity shocks. Models are recalibrated.

the Great Recession. My paper extends his work by incorporating the contracting frictions and re-assessing the impact of uncertainty shocks.

Specialness of Uncertainty Shocks. Table 7 also reveals that contracting frictions amplify the effects of uncertainty shocks more than aggregate productivity shocks. The key is equilibrium wage responses. As observed by Shimer (2005), the free entry condition in search models leads to wage declines that greatly absorb the negative impact of aggregate productivity shocks. Similarly, in my model, wages decrease a lot to contract TFP shocks, despite the presence of contracting frictions.

However, for uncertainty shocks, the offsetting effect is considerably weaker, as indicated by the smaller wage declines in response to uncertainty shocks depicted in Figures F.4 and F.5. The reason is that uncertainty shocks are also dispersion shocks, spreading the distribution of firm-level productivity. This spread, in turn, leads to higher expected profits for firms due to the Oi-Hartman-Abel effect (Oi (1961), Hartman (1972), Abel (1983)), particularly for high-productivity firms. This expectation limits the need for substantial wage reductions to meet the free entry condition. As equilibrium wages do not decrease enough to cancel out the higher risk of drawing low idiosyncratic productivity, firms tend to hire less and fire more.

5.2 Policy Implications

Given the new insights my model provides on uncertainty and unemployment, it is used to evaluate two labor market stabilization policies that became topical during recent recessions: increasing unemployment benefits and subsidizing wage payments.

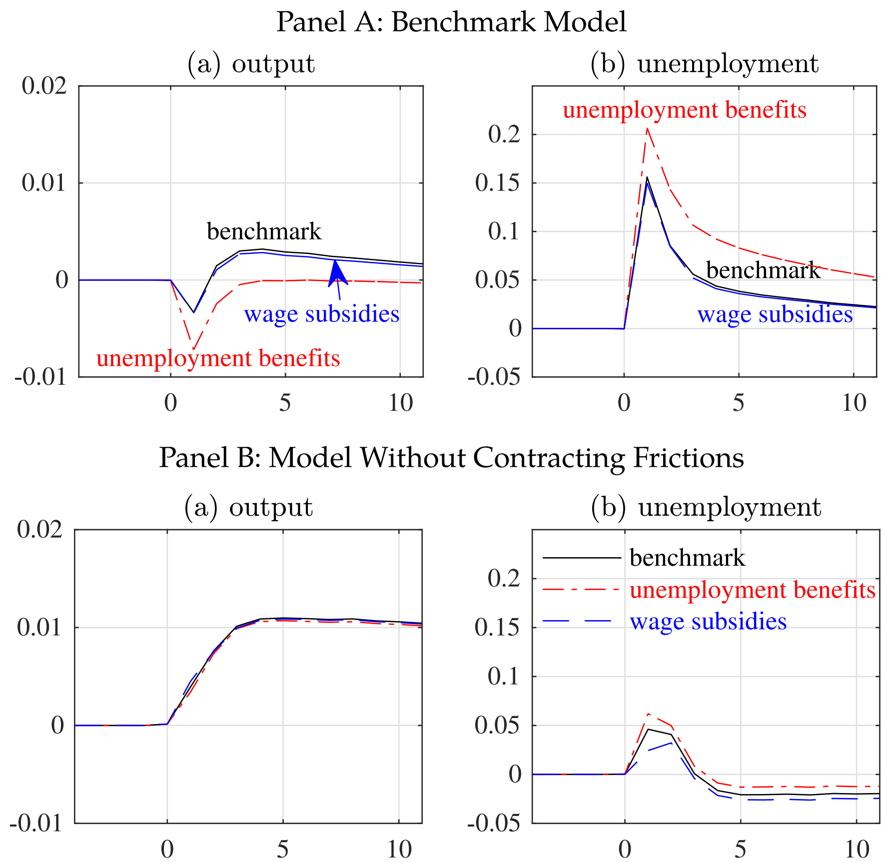
Increasing Unemployment Benefits. During the 2020 Covid-19 pandemic, uncertainty surged dramatically (Altig et al., 2020). And the U.S. government implemented the Federal Pandemic Unemployment Compensation (FPUC) program, which increased weekly unemployment benefits by $600. To examine the policy impacts, my model incorporates a government increase in unemployment benefits by 1% targeting high uncertainty. This policy, anticipated by agents in the economy, is financed through a lump-sum tax, which costs 4.81 basis points of output according to the simulation.

Figure 5, Panel A, shows the impulse responses to a 5% positive uncertainty shock. The solid black lines represent the benchmark model without any policy intervention, while the dashed red lines show the effects of increased unemployment benefits. Evidently, this policy deepens the recession by lowering output and increasing unemployment. Table F.3 summarizes the policy's effects on model-simulated moments, indicating a 4.3 basis point reduction in total surplus for workers and firms. The losses are attributed to labor market distortions caused by elevated unemployment benefits, which lead to higher wages, increased production costs, and greater financial concerns regarding wage commitments, ultimately deepening the recession and reducing welfare.

Subsidizing Wage Payments. Germany's social insurance program, Kurzarbeit, is another notable labor market policy. In this system, firms reduce workers' hours, and the government partially compensates for the employees' earnings losses, enabling firms to retain their staff during adverse economic conditions. During the Great Recession and the Covid recession, this program was expanded to provide more wage subsidies. I model this policy by allowing firms the option to idle part of their workforce when uncertainty is high, with the government subsidizing 84.4% of these idle workers' wages and firms paying the rest. This subsidy rate is set to match the government expenditure-to-output ratio of the UI policy experiment, also costing 4.86 basis points of output.

Figure 5, Panel A, displays impulse responses to wage subsidies with dash-dot blue lines, revealing a slight decrease in output and a smaller rise in unemployment. The

Figure 5: Aggregate Responses to a 5% Uncertainty Shock Under Policy Intervention



Notes: The panels depict impulse responses of aggregate output and unemployment to a 5% positive uncertainty shock at quarter 0. Panel A shows the benchmark model's results, and Panel B displays the results of the reference model without contracting frictions. Solid black lines are the results without policy intervention, labeled 'benchmark'. Dash-dot red lines correspond to the model with enhanced unemployment benefits policy, and dashed blue lines to the model with wage subsidies. Policies are activated when uncertainty exceeds its average. These impulse responses are averaged over 4,000 simulated paths and displayed as log deviations from the mean. I use Schaal's (2017) code when plotting this figure.

policy's small effect stems from its counteracting advantages and disadvantages. On the one hand, wage subsidies act as state-contingent insurance for firms, aiding wage payments and employee retention. On the other hand, wage subsidies encourage labor hoarding, leading to an inefficient allocation of labor towards low-productivity firms that should downsize. According to Table F.3, the net impact of this policy is negative, with a total surplus reduction of 2.6 basis points.

The Role of Contracting Frictions. Financial and labor contracting frictions are crucial for accurate policy evaluation. Figure 5, Panel B, displays results from the counterfactual model without these frictions. The UI policy (dashed red lines) now causes a much smaller output decline and unemployment rise. Also, wage subsidies (dash-dot blue lines) exhibit a stronger stabilization effect by reducing unemployment, as wages minimally distort firms' liquidity incentives now. Table F.3 further quantifies these differences: efficiency loss from the UI policy plummets from 4.3 to 7×10^{-5} basis points, and for wage subsidies, it drops from 2.6 to 4×10^{-3} basis points. This indicates that the model excluding contracting frictions greatly underestimates the distortions caused by policies, and it misleadingly suggests that the UI policy is better than wage subsidies.

6 Conclusion

Prior research finds that uncertainty shocks have a limited impact on unemployment rates in the canonical search framework (Schaal, 2017). I contribute to the literature by empirically identifying an additional risk premium channel of uncertainty shocks using micro-level layoff data. I then build a novel search model that aligns with this empirical evidence by incorporating financial and labor contracting frictions. Given the two frictions, the model shows that uncertainty shocks have a large impact on unemployment rates. This is largely because firms, with limited ability to hedge against idiosyncratic risks, are averse to taking on the commitment to employment when uncertainty is high. My model further provides a fresh perspective on evaluating labor market stabilization policies.

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Online Appendices

A Micro-Foundations for the Labor Contracting Friction

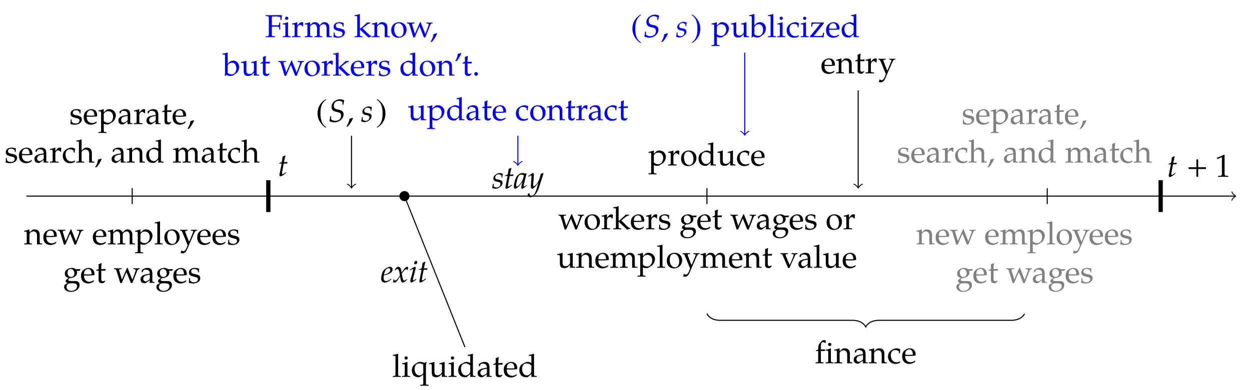
In this section, I micro-found the labor contracting friction in eq. (12), using the asymmetric information between firms and their employees. The logic follows Hall and Lazear (1984), who demonstrates the optimality of predetermined wages in a two-period model under asymmetric information. My model builds on this by allowing intertemporal labor contracts, operating under two main assumptions: firms immediately recognize realized shocks while employees become aware later during the production stage; additionally, firms are not penalized for misrepresenting information. Given the two assumptions, the only incentive-compatible promises are state-uncontingent. This section first establishes a model with asymmetric information, then demonstrates the optimality of state-uncontingent promises.

Timing. Figure A.1 adds the timing for asymmetric information on top of Figure 2. When shocks (S, s) realize at the beginning of each period, firms know the shocks, but workers do not. If a worker leaves the firm now, he is unemployed and obtains the unemployment value in the current period. Given the shocks, firms choose to exit or stay. Staying firms declare their current shocks are $\tilde{S}$ and $\tilde{s}$ and update contracts. Notice that the declaration can differ from the true state since workers do not observe the information now. I allow the declarations to differ across the firm's employees. Given that the labor contract has been updated, the worker gets nothing in the current period if he leaves the firm now. At the production stage, workers receive wage payments according to the labor contract, based on the firm's declaration of the state $(\tilde{S}, \tilde{s})$. After that, shocks (S, s) become public information. At the end of the period, firms separate, search, and match.

The labor contract C includes elements $\left\{w, \tau, \bar{W}(S', s'), d(S', s')\right\}$. Notice I assume that the contact directly specifics the markup $\bar{W}(S', s')$ between the lifetime promised utility $W'(S', s')$ and the outside value of unemployment $\boldsymbol{U}(S')$. This assumption of contracting only the utility markup, rather than the entire lifetime utility, allows for a realistic variation of the promised lifetime utility in response to changes in aggregate states.

Employed worker's problem. The unemployment worker's problem does not change,

Figure A.1: Timing With Asymmetric Information



while the employed worker's problem becomes:

$$\begin{aligned} \boldsymbol{W}(S,s,C) = \max_x \; & w + \lambda p(\theta(S,x))x + (1-\lambda p(\theta(S,x)))\tau\beta\,\mathbb{E}_{S'|S}\,\boldsymbol{U}(S') \\ & + (1-\lambda p(\theta(S,x)))(1-\tau)\beta \max\Big\{ \underbrace{\mathbb{E}_{S'|S}\,\boldsymbol{U}(S'),}_{\substack{\text{leave before the}\\ \text{contract is updated}}} \; \mathbb{E}_{S',s'|S,s}\,\{(\pi_d + (1-\pi_d)d(S',s'))\boldsymbol{U}(S') \\ & + (1-\pi_d)(1-d(S',s'))\max\{\boldsymbol{U}(S') + \bar{W}(\tilde{S}'^{*},\tilde{s}'^{*}), \underbrace{0 + \beta\,\mathbb{E}_{S''|S'}\,\boldsymbol{U}(S'')}_{\substack{\text{leave after the}\\ \text{contract is updated}}}\}\}\Big\}. \end{aligned} \tag{41}$$

As before, the worker receives the wage w at the production stage. The worker can conduct on-the-job search and leave the firm. If the worker stays but gets laid off, he will be unemployed in the next period and receive the unemployment value $\boldsymbol{U}(S')$.

If the worker is not laid off, he can still leave the firm when the outside value is high enough. But the outside value depends on the timing of leaving the firm. If the worker leaves the firm before the contract is renewed, he is counted as unemployed and receives the unemployment value just like a laid-off worker. However, if he leaves the firm after the contract is renewed, he receives zero and gets the unemployment value one period later. This setup can be understood as the worker being ineligible to receive unemployment benefits after the labor relation renews, and drawing up contracts is time-consuming, so he does not have time to produce at home in the same period. Hence, the utility is zero in that period. This assumption implies that workers have no incentive to quit when they find the firm lies (Proposition 2(i)).

If the labor relation persists, the worker will receive the lifetime utility $\boldsymbol{U}(S')+\bar{W}(\tilde{S}'^{*},\tilde{s}'^{*})$. Notice that because of asymmetric information, the promised utility markup $\bar{W}$ to the worker depends on the firm's declaration of states $(\tilde{S}'^{*},\tilde{s}'^{*})$. To clarify, $\{\bar{W}(S',s')\}$ in the labor contract is the set of utility markups for the next period. However, how much the worker can get in the next period depends on the firm's declaration of states $(\tilde{S}'^{*},\tilde{s}'^{*})$.

Firm's problem. A firm's states include realized aggregate shocks $S\in\boldsymbol{S}$, realized firm-specific shocks $s\in\boldsymbol{s}$, the number of employees n, and the set of promised utility markups to its employees $\{\bar{W}(S,s;i)\}_{S\in\boldsymbol{S},s\in\boldsymbol{s};i\in[0,n]}$, where i is the index of incumbent employees within the firm. In a slight abuse of notation, S and s inside $\bar{W}(\cdot,\cdot;i)$ refer to the possible shocks instead of the realized shocks.

Besides the choice variables in the original firm's problem (7), the firm now also chooses to declare the current shocks, $\tilde{S}(i)$ and $\tilde{s}(i)$, to each employee i. The following equations (42) to (47) summarize the firm's problem:

$$\begin{aligned}\boldsymbol{J}(S,s,b,n,\{\bar{W}(S,s;i)\}_{S\in\boldsymbol{S},s\in\boldsymbol{s};i\in[0,n]}) = &\max_{\substack{\Delta,b',n',n_h,x_h,d(S',s')\\ \{\tilde{S}(i),\tilde{s}(i),w(i),\tau(i)\}_{i\in[0,n]},\\ \{w_h(i')\}_{i'\in(n'-n_h,n']},\\ \{\bar{W}(S',s';i')\}_{S'\in\boldsymbol{S}',s'\in\boldsymbol{s}';i'\in[0,n']}}} \Delta \\ &+\beta(1-\pi_d)\,\mathbb{E}_{S',s'|S,s}\left\{(1-d(S',s'))\boldsymbol{J}(S',s',b',n',\{\bar{W}(S',s';i')\}_{S'\in\boldsymbol{S}',s'\in\boldsymbol{s}';i'\in[0,n']})\right\}\end{aligned} \tag{42}$$

$$\text{s.t. } (8),(9),(10),(11),(15), \tag{43}$$

$$\begin{aligned}\boldsymbol{W}^E(i')\equiv\mathbb{E}_{S',s'|S,s}\,\{&(\pi_d+(1-\pi_d)d(S',s'))\boldsymbol{U}(S')\\ &+(1-\pi_d)(1-d(S',s'))\max\{\boldsymbol{U}(S')+\bar{W}(\tilde{S}'^{*},\tilde{s}'^{*};i'),0+\beta\,\mathbb{E}_{S''|S'}\,\boldsymbol{U}(S'')\}\},\end{aligned} \tag{44}$$

$$\boldsymbol{W}^E(i')\geq\mathbb{E}_{S'|S}\,\boldsymbol{U}(S'),\forall i'\in[0,n'], \tag{45}$$

$$\begin{aligned}\max_x\ &w(i)+\lambda p(\theta(S,x))x+(1-\lambda p(\theta(S,x)))\tau(i)\beta\,\mathbb{E}_{S'|S}\,\boldsymbol{U}(S')\\ &+(1-\lambda p(\theta(S,x)))(1-\tau(i))\beta\boldsymbol{W}^E(i')\geq\boldsymbol{U}(S)+\bar{W}(\tilde{S},\tilde{s};i),\ \text{ for } i'\in[0,n'-n_h],\end{aligned} \tag{46}$$

$$w_h(i')+\beta\boldsymbol{W}^E(i')\geq x_h,\ \text{ for } i'\in(n'-n_h,n']. \tag{47}$$

Equations (44) to (47) describe the new implicit contract constraints in the presence of asymmetric information. First, eq. (44) uses W^E to denote the worker's expected lifetime utility if he stays with the firm. W^E is also the last part of the employment value (41).

Constraint (45) is the new participation constraint, meaning that the worker's expected utility is at least the expected unemployment value so that he will stay. Eq. (46) is the new promise-keeping constraint for incumbent workers. This constraint requires the firm to commit to paying the employee at least the promised lifetime utility. The left-hand side is the incumbent worker's employment value, i.e., eq. (41). The right-hand side is the promised lifetime utility, comprised of two parts—the unemployment value $\boldsymbol{U}(S)$ and the promised utility markup $\bar{W}(\tilde{S}, \tilde{s}; i)$. Notice that $\tilde{S}(i)$ and $\tilde{s}(i)$ are the firm's declarations of shocks, two of the firm's choice variables. They can be different from the true shocks because of asymmetric information. Eq. (47) is the new promise-keeping constraint for newly hired workers. Its left-hand side is the newly hired worker's employment value. On the right-hand side, x_h is the submarket where the firm employs new workers, and x_h is also the promised lifetime utility of the vacancies posted in that submarket. Thus, firms can guarantee that newly hired workers receive at least the lifetime utility promised by the offer.

The following Proposition 2 demonstrates that the promised utility markup $\bar{W}$ is state-uncontingent.

Proposition 2 *The labor relation between the firm and its employees has the following properties:*

(i) Workers do not leave the firm even if they find the firm lied.

(ii) The promised utility markup $\bar{W}$ is state-uncontingent.

Proof As for point (i), recall that employees discover whether the firm lied about shocks in the production stage, i.e. after the contract is updated. If they leave the firm now, they get nothing today and start receiving the unemployment value in the next period. So, even if the firm gives the worker zero wages and fires them right after the production stage, the worker is willing to stay with the firm.

As for point (ii), because employees will not leave the firm regardless, according to point (i), lying about the shocks has no consequences for the firm. Thus, firms always declare the lowest employment surplus in $\{\bar{W}(S, s; i)\}_{S \in \boldsymbol{S}, s \in \boldsymbol{s}}$ to each employee i. Therefore, the incentive-compatible labor contract requires the promised utility markup $\bar{W}$ to be state-uncontingent. □

B Micro-Foundations for the Agency Friction

The micro-foundation of the agency friction in eq. (15), following Arellano, Bai and Kehoe (2019), is as follows. I assume there is a pool of potential managers, each firm employing one to operate its business. The total mass of managers is much smaller than of workers, so I abstract from managers when calculating unemployment. Managers have the option of self-employment, producing $\bar{w}_m$ units of goods. The market for managers is competitive, so a manager's wage is also $\bar{w}_m$.

Each period consists of a day and night. During the day, managers are monitored by the firm's shareholders, so managers conduct the firm's optimal policies: the manager uses borrowing $Q(S, z, b', n')b'$ and sales to pay dividends, wages of incumbent workers, his own wage, the operating cost, and debt. Search happens overnight, and the manager is supposed to use the remaining resources to pay vacancy posting costs and the wages of new workers. However, what happens during the night cannot be observed by shareholders until the next day. Therefore, the manager can propose an alternative production plan to the financial intermediary to borrow as much as possible. To convince the financial intermediary of the new plan $(\bar{b}', \bar{n}')$, the manager should prove by posting vacancies to have $\bar{n}'$ workers in the next period. That is, the manager needs to pay vacancy posting costs and wages for newly hired workers for this alternative proposal. In sum, to maximize available funds, the manager will come up with a proposal to achieve maximum possible borrowing net of hiring costs $M(S, z, n)$ defined in eq. (16).

Given the maximum net borrowing $M(S, z, n)$, the remaining credit available for the manager is the maximum net borrowing minus the previous borrowing plus the originally planned but unused money for search, i.e., the numerator of eq. (48). The manager uses the remaining credit to hire workers to produce for his own project. Because the manager only needs to hire workers for the next-period production, the outside value of unemployment benefits $\bar{u}$ is the lowest wage for the manager to retain workers to produce. The manager then uses the remaining credit to hire as many workers n_s as possible:

$$n_s = \frac{M(S, z, n) - Q(S, z, b', n')b' + n_h \frac{c}{q(\theta(S, x_h))} + \int_{n'-n_h}^{n'} w_h(i')di'}{\bar{u}}. \tag{48}$$

The manager takes advantage of the firm's productivity for his sided project, so the output is

$$\zeta z' n_s^{\alpha}, \tag{49}$$

where ζ indicates the profitability of the manager's own project.

I allow an auditing technology to detect a manager's intention to deviate at night. The effectiveness of the auditing technology, ξA, is based on a measure of auditing quality, ξ, proportional to aggregate productivity. The incentive and available resources to use the auditing technology are approximated by the firm's expected income $\mathbb{E}[A'z'n'^{\alpha} - \int_0^{n'} w(i')di' - \bar{w}_m - \epsilon']$. The more the firm expects to earn, the more it can and should pay for the auditing technology. I assume that the probability of the manager being caught is Gaussian and determined by the amount of auditing:

$$\Phi\Big(\xi A\, \mathbb{E}[A'z'n'^{\alpha} - \int_0^{n'} w(i')di' - \bar{w}_m - \epsilon]\Big). \tag{50}$$

I model the auditing technology to match the negative correlation between credit spreads and aggregate output. Without this auditing technology, a positive aggregate productivity shock would counterfactually raise credit spreads, as firms, experiencing higher income, would borrow more to avoid managerial deviations. In contrast, the auditing technology reduces the need for borrowing during periods of high aggregate productivity, thereby leading to a decrease in credit spreads, consistent with the data.

To deter managerial deviations, firms must ensure that their credit use does not leave substantial excess funds. If a manager deviates from the firm's optimal policies, shareholders will detect and fire him the next day. The deviating manager faces a probability γ of becoming self-employed (else returning to the manager market). Therefore, the firm adheres to the following incentive-compatible condition to prevent potential deviations:

$$\Big(1-\Phi\Big(\xi A\, \mathbb{E}[A'z'n'^{\alpha} - \int_0^{n'} w(i')di' - \bar{w}_m - \epsilon]\Big)\Big)\, \mathbb{E}_t\, \beta\zeta A_{t+1} z_{t+1} n_s^{\alpha} + \gamma\, \mathbb{E}_t \sum_{j=2}^{\infty} \beta^j \bar{w}_m \leq \mathbb{E}_t \sum_{j=1}^{\infty} \beta^j \bar{w}_m. \tag{51}$$

This equation delivers the agency friction constraint (15) by plugging in eq. (48).

C Additional Proofs

Proposition 1 *The participation constraint* (13) *and the promise-keeping constraint* (14) *bind.*

Proof First, the promise-keeping constraint (14) always binds. Otherwise, firms could lower wages and earn more. Then, I prove that the participation constraint (13) binds by contradiction. Imagine a scenario under the firm's optimal policy where a worker, designated as i' for the next period, has a positive $\bar{W}(i') > 0$ in the contract. I can propose an alternative policy that sets $\bar{W}(i') = 0$ and delivers a higher firm's value. This analysis is first applied to incumbent employees, followed by the case of newly hired workers.

Case 1. Suppose i' refers to an incumbent worker. Use i to denote the worker's index in the current period and ϵ^m to denote the worker's mass of the firm's entire labor force.

I construct an alternative policy by making the following four changes to the original policy. The idea is to frontload wages and borrow more simultaneously:

1. Decrease the promised utility markup $\bar{W}(i')$ to zero, which just satisfies the participation constraint (13). To simply the notation, I use δ to denote $\bar{W}(i')$ from now on.

2. Decrease the worker's next-period wage $w(i')$ by exactly δ. Since the wage decreases as much as the promised utility, the next-period promise-keeping constraint (14) still holds.

3. Promise to pay a bonus $\tilde{w}$ to the worker today conditional on not leaving the firm by on-the-job search, where $\tilde{w}$ equals $\beta \mathbb{E}[(1 - \tau(i))(1 - \pi_d)(1 - d(S',s'))]\delta$. This additional payment guarantees that the worker has the same lifetime promised utility today, so today's promise-keeping constraint (14) is unaffected. Importantly, the worker's on-the-job search decision is not affected because the payment is given to the worker conditional on not transiting to another firm. From the firm's perspective, its labor expense today increases by $\epsilon^m(1 - \lambda p(\theta(S, x^*(S; i))))\tilde{w}$.[1]

4. Increase the debt b' by $\epsilon^m(1-\tau(i))(1-\lambda p(\theta(S, x^*(S; i))))\delta$, which equals the decrease in the firm's wage bills in the next-period. So, the next-period cash on hand of the firm does not change.

Given these four changes, I next show the firm's value increases. First, because the next-period cash on hand is the same, the next-period default decisions are unchanged.

[1] Notice that this additional payment is conditional on the worker does not leave the firm by on-the-job search. To simplify the wage expression derivation, I do not consider the conditional wage payments in the main paper. This simplification does not diminish the model's general applicability; it only changes the timing of wage payment within a given period without affecting the firm's total wage bills, $\int w(i)di$. The assumption can be relaxed by adding an additional first-order condition to the firm's problem. This change would not impact the uniqueness of wages within labor contracts as the job-finding function is strictly concave, although it would add a layer of complexity. An alternative simplification could be omitting on-the-job search altogether. I leave these to future research.

Also, the next-period employment n' does not change, so neither is the expected value of the firm in the next period.

Second, the borrowing increases more than the increase in today's wage payments, so today's equity payouts increase:

$$\begin{aligned}
&\Delta^{\text{new}} - \Delta = Q(S, s, b'^{\text{new}}, n)b'^{\text{new}} - Q(S, s, b', n)b' - \epsilon^m(1 - \lambda p(\theta(S, x^*(S; i))))\tilde{w} \\
&= \beta\,\mathbb{E}\left\{(1 - \pi_d)(1 - d(S', s'))\right\}b'^{\text{new}} + \beta\,\mathbb{E}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\frac{\pi'^{\text{new}}}{b'^{\text{new}}}, 1\}\right\}b'^{\text{new}} \\
&\quad - \beta\,\mathbb{E}\left\{(1 - \pi_d)(1 - d(S', s'))\right\}b' - \beta\,\mathbb{E}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\frac{\pi'}{b'}, 1\}\right\}b' \\
&\quad - \epsilon^m(1 - \lambda p(\theta(S, x^*(S; i))))\tilde{w} \\
&= \beta\,\mathbb{E}\left\{(1 - \pi_d)(1 - d(S', s'))\right\}b'^{\text{new}} - \beta\,\mathbb{E}\left\{(1 - \pi_d)(1 - d(S', s'))\right\}b' \\
&\quad + \beta\,\mathbb{E}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi'^{\text{new}}, b'^{\text{new}}\}\right\} \\
&\quad - \beta\,\mathbb{E}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi', b'\}\right\} - \epsilon^m(1 - \lambda p(\theta(S, x^*(S; i))))\tilde{w} \\
&= \beta\,\mathbb{E}\left\{(1 - \pi_d)(1 - d(S', s'))\right\}(b'^{\text{new}} - b') - \epsilon^m(1 - \lambda p(\theta(S, x^*(S; i))))\tilde{w} \\
&\quad + \beta\,\mathbb{E}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi'^{\text{new}}, b'^{\text{new}}\}\right\} \\
&\quad - \beta\,\mathbb{E}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi', b'\}\right\} \\
&= \beta\,\mathbb{E}\left\{(1 - \pi_d)(1 - d(S', s'))\right\}\epsilon^m(1 - \tau(i))(1 - \lambda p(\theta(S, x^*(S; i))))\delta \\
&\quad - \epsilon^m(1 - \lambda p(\theta(S, x^*(S; i))))\beta\,\mathbb{E}[(1 - \tau(i))(1 - \pi_d)(1 - d(S', s'))]\delta \\
&\quad + \beta\,\mathbb{E}_{S', s'|S, s}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi'^{\text{new}}, b'^{\text{new}}\}\right\} \\
&\quad - \beta\,\mathbb{E}_{S', s'|S, s}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi', b'\}\right\} \\
&= \beta\,\mathbb{E}_{S', s'|S, s}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi'^{\text{new}}, b'^{\text{new}}\}\right\} \\
&\quad - \beta\,\mathbb{E}_{S', s'|S, s}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi', b'\}\right\}.
\end{aligned}$$

Notice that $b'^{\text{new}} \geq b'$ by construction and $\pi'^{\text{new}} \geq \pi'$ because the next-period wage bills decrease. Therefore, $\min\{\eta\pi'^{\text{new}}, b'^{\text{new}}\} \geq \min\{\eta\pi', b'\}$. So,

$$\begin{aligned}
\Delta^{\text{new}} - \Delta \geq &\beta\,\mathbb{E}_{S', s'|S, s}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi', b'\}\right\} \\
&- \beta\,\mathbb{E}_{S', s'|S, s}\left\{[1 - (1 - \pi_d)(1 - d(S', s'))]\min\{\eta\pi', b'\}\right\} \\
= &0.
\end{aligned} \tag{52}$$

Lastly, the agency friction constraint (15) holds under this constructed policy. The constraint's left-hand side increases as the borrowing increases, and its right-hand side decreases because of lower next-period wage bills.

Case 2. Suppose i' is a newly hired worker in the current period. Similarly, construct an alternative policy by making the following four changes to the original policy:

1. Decrease the promised utility markup $\bar{W}(i')$ to zero, just satisfying the participation constraint. I use δ to denote $\bar{W}(i')$.

2. Decrease the worker's next-period wage $w(i')$ by δ, so the next-period promise-keeping constraint still holds.

3. Increase the newly hired workers' wage $w_h(i')$ by $\beta\,\mathbb{E}[(1-\pi_d)(1-d(S',s'))]\delta$, guaranteeing that the worker still has the same lifetime promised utility x_h, so today's promise-keeping constraint still holds. On the firm-side, today's labor expense increases by $\epsilon^m\tilde{w}$, where ϵ^m denotes the worker's mass.

4. Increase the debt b' by $\epsilon^m\delta$, which equals the decrease in the firm's wage bills in the next-period. Thus, the next-period cash on hand does not change.

Given these four changes, the firm's value increases for the following reasons. First, the firm's value in the next period is unaffected because the cash on hand and labor force are unchanged.

Second, the borrowing increases more than the increase in wage payments, so the equity payouts increase. Formally,

$$
\begin{aligned}
\Delta^{\text{new}} - \Delta &= Q(S,s,b'^{\text{new}},n)b'^{\text{new}} - Q(S,s,b',n)b' - \epsilon^m\tilde{w} \\
&= \beta\,\mathbb{E}\left\{(1-\pi_d)(1-d(S',s'))\right\}(b'^{\text{new}} - b') - \epsilon^m\tilde{w} \\
&\quad + \beta\,\mathbb{E}\left\{[1-(1-\pi_d)(1-d(S',s'))]\min\{\eta\pi'^{\text{new}}, b'^{\text{new}}\}\right\} \\
&\quad - \beta\,\mathbb{E}\left\{[1-(1-\pi_d)(1-d(S',s'))]\min\{\eta\pi', b'\}\right\} \\
&= \beta\,\mathbb{E}\left\{(1-\pi_d)(1-d(S',s'))\right\}\epsilon^m\delta - \epsilon^m\beta\,\mathbb{E}\left\{(1-\pi_d)(1-d(S',s'))\right\}\delta \\
&\quad + \beta\,\mathbb{E}_{S',s'|S,s}\left\{[1-(1-\pi_d)(1-d(S',s'))]\min\{\eta\pi'^{\text{new}}, b'^{\text{new}}\}\right\} \\
&\quad - \beta\,\mathbb{E}_{S',s'|S,s}\left\{[1-(1-\pi_d)(1-d(S',s'))]\min\{\eta\pi', b'\}\right\} \\
&= \beta\,\mathbb{E}_{S',s'|S,s}\left\{[1-(1-\pi_d)(1-d(S',s'))]\min\{\eta\pi'^{\text{new}}, b'^{\text{new}}\}\right\} \\
&\quad - \beta\,\mathbb{E}_{S',s'|S,s}\left\{[1-(1-\pi_d)(1-d(S',s'))]\min\{\eta\pi', b'\}\right\} \\
&\geq 0,
\end{aligned}
$$

where the last inequality is due to $b'^{\text{new}} \geq b'$ and $\pi'^{\text{new}} \geq \pi'$.

Lastly, the agency friction constraint (15) holds. The constraint's left-hand side increases as the borrowing increases more than the increase in newly hired workers' wages, and its right-hand side decreases as next-period wage bills decrease.

In sum, I construct a feasible and better alternative policy, which contradicts the optimality of the original policy with a loose participation constraint. Therefore, the participation constraint always binds in the equilibrium. □

Lemma 3.1 *(Decision Cutoffs): If $X < -M(S,z,n)$, the firm cannot satisfy the nonnegative external equity payout condition and has to default. If $X \geq \hat{X}(S,z,n) \equiv -\{Q(S,z,\hat{b},\hat{n})\hat{b} - \hat{n}_h \frac{c}{q(\theta(S,\hat{x}_h))} - \hat{n}_h[\hat{x}_h - \beta\,\mathbb{E}\,\boldsymbol{U}(S')]\}$, the firm solves the relaxed problem (27), and the level of cash on hand does not affect the optimal decisions.*

Proof If the firm's cash on hand X is less than $-M(S,z,n)$, even though the firm borrows as much as possible, it cannot make nonnegative external equity payouts. So, the firm defaults and exits. If the firm's cash on hand X is more than $\hat{X}(S,z,n)$, then $(\hat{b},\hat{n},\hat{\tau},\hat{n}_h,\hat{x}_h)$ is also the solution to the firm's problem (22), as the non-negative equity payout constraint (24) holds automatically. In this case, cash on hand does not affect any constraints, and the optimal decisions do not depend on cash on hand. □

D Computational Algorithm

This section explains the computational algorithm for solving and simulating the model. I use Fortran as the programming language and parallelize to run the code with 20 cores.

Value Function Iteration. First, I define $h(A,\sigma)$ as the vacancy posting cost plus a newly hired worker's wage:

$$h(A,\sigma) \equiv \min_{x_h}\left[\frac{c}{q(\theta(A,\sigma,x_h))} + w_h(A,\sigma,x_h)\right] \tag{53}$$

$$= \min_{x_h}\left[\frac{c}{q(\theta(A,\sigma,x_h))} + x_h - \beta\,\mathbb{E}\,\boldsymbol{U}(A',\sigma')\right] \tag{54}$$

$$= \kappa(A,\sigma) - \beta\,\mathbb{E}\,\boldsymbol{U}(A',\sigma'). \tag{55}$$

$h(A,\sigma)$ represents the costs paid in the current period to hire a new worker, which is the key price I use to solve the labor market equilibrium.

Second, I discretize the state space. Aggregate productivity, A, is discretized into two points, i.e., high and low, the same for uncertainty, σ. The number of grids for firm-level idiosyncratic productivity, z, equals 13. The grids of z depend on the last-period uncertainty, σ_{-1}. Therefore, both σ and σ_{-1} are firms' state variables in the numerical implementation. I use Tauchen's method to discretize A, σ, and z. Cash on hand, X, has 64 grids. Debt, b, has 301 grids. Employment, n, has 260 grids.

Then I use the following steps to solve the problem:

1. Initialize the iteration counter $k = 0$. Make the initial guess for the current-period hiring cost $h^{(0)}(A,\sigma)$.

2. Given $h^{(k)}(A,\sigma)$, solve the unemployment value $\boldsymbol{U}^{(k)}(A,\sigma)$ by the value function iteration, along with the first-order condition with respect to x_u:

$$\boldsymbol{U}^{(k)}(A,\sigma) = \max_{x_u} \bar{u} + p(\theta^{(k)}(A,\sigma,x_u))x_u + (1 - p(\theta^{(k)}(A,\sigma,x_u)))\beta\,\mathbb{E}\,\boldsymbol{U}^{(k)}(A',\sigma') \tag{56}$$

$$= \bar{u} + \max_{x_u} p(\theta^{(k)}(A,\sigma,x_u))[x_u - \beta\,\mathbb{E}\,\boldsymbol{U}^{(k)}(A',\sigma')] + \beta\,\mathbb{E}\,\boldsymbol{U}^{(k)}(A',\sigma') \tag{57}$$

Given the following mapping from eq. (32):

$$x(A,\sigma,\theta) = \kappa(A,\sigma) - \frac{c}{q(\theta)}, \tag{58}$$

derive the first-order condition with respect to x_u that indicates the optimal choice of the labor market to search:

$$\theta_u^*(A,\sigma) = \left\{\left[\frac{c}{\max\{\kappa(A,\sigma) - \beta\,\mathbb{E}\,\boldsymbol{U}(A',\sigma'), c\}}\right]^{-\frac{\gamma}{1+\gamma}} - 1\right\}^{\frac{1}{\gamma}} \tag{59}$$

$$= \left\{\left[\frac{c}{\max\{h(A,\sigma), c\}}\right]^{-\frac{\gamma}{1+\gamma}} - 1\right\}^{\frac{1}{\gamma}} \tag{60}$$

When $h(A,\sigma) < c$, workers choose $\theta_u^* = 0$ to stay unemployed because the value of working offered in every submarket is less than the value of unemployment. On the other hand, as long as $h(A,\sigma) \geq c$, there always exists a market with θ close to 0 such that the value of employment is higher than unemployment, so workers want to search for jobs.

Plug the search decision $\theta_u^*(A,\sigma)$ into eq. (57) and get the updated $\boldsymbol{U}(A,\sigma)$. Repeat this process until $\boldsymbol{U}(A,\sigma)$ converges.

3. Given $h^{(k)}(A,\sigma)$, solve the bond pricing schedule $Q^{(k)}(A,\sigma,\sigma_{-1},z,b',n')$ using the following iteration.

First, guess the bond pricing schedule $Q^{\text{old}}(A,\sigma,\sigma_{-1},z,b',n') = \beta$ and the maximum net borrowing $M^{\text{old}}(A,\sigma,\sigma_{-1},z,n)=\beta * b_{\max}$, where $b_{\max}$ denotes the upper-bound of the grids of debt.

Next, update Q and M. Then repeat until the relative difference between M^{old} and M^{new} is less than 10^{-7} and that between Q^{old} and Q^{new} is less than 10^{-10}.

(a) Update $Q(A,\sigma,\sigma_{-1},z,b',n')$ according to the following equation:

$$\begin{aligned}Q^{\text{new}}(A,\sigma,\sigma_{-1},z,b',n') = \beta\,\mathbb{E}\Big\{&(1-\pi_d)\Phi_\epsilon(\bar{\epsilon}(A',\sigma',\sigma,z',b',n')) \\ &+ [1-(1-\pi_d)\Phi_\epsilon(\bar{\epsilon}(A',\sigma',\sigma,z',b',n'))]\min\{\tilde{\eta}\frac{A'z'n'^{\alpha}-n'w(A',\sigma')-\bar{w}_m-\mu_\epsilon}{b'},1\}\Big\},\end{aligned} \tag{61}$$

where the default cutoff, $\bar{\epsilon}(A',\sigma',\sigma,z',b',n')$, is calculated as follows

$$\bar{\epsilon}(A',\sigma',\sigma,z',b',n') \equiv A'z'n'^{\alpha} - n'w(A',\sigma') - b' + M^{\text{old}}(A',\sigma',\sigma,z',n') - \bar{w}_m, \tag{62}$$

and the incumbent worker's wage, $w(A',\sigma')$, is computed according to eq. (19).

(b) Update $M(A,\sigma,\sigma_{-1},z,n)$:

$$M^{\text{new}}(A,\sigma,\sigma_{-1},z,n) \equiv \max_{b',n',n_h,x_h} Q^{\text{new}}(A,\sigma,\sigma_{-1},z,b',n')b' - n_h\frac{c}{q(\theta(A,\sigma,x_h))} - n_h w_h(A,\sigma,x_h) \tag{63}$$

$$= \max_{b',n',n_h} Q^{\text{new}}(A,\sigma,\sigma_{-1},z,b',n')b' - n_h h^{(k)}(A,\sigma) \tag{64}$$

$$= \max_{b',n'} Q^{\text{new}}(A,\sigma,\sigma_{-1},z,b',n')b' - H^{(k)}(A,\sigma,n,n') \tag{65}$$

where $H(A,\sigma,n,n')$ denotes the matrix of hiring costs

$$H^{(k)}(A,\sigma,n,n') \equiv \begin{cases}[n'-(1-\lambda p(\theta^*(A,\sigma)))n]h^{(k)}(A,\sigma), & \text{if } n' > (1-\lambda p(\theta^*(A,\sigma)))n, \\ 0, & \text{if } n' \leq (1-\lambda p(\theta^*(A,\sigma)))n,\end{cases} \tag{66}$$

where the optimal on-the-job search market, $\theta^*(A,\sigma)$, is the same as the choice of unemployed workers, $\theta_u^*(A,\sigma)$.

4. Given $h^{(k)}(A,\sigma)$ and $Q^{(k)}(A,\sigma,\sigma_{-1},z,b',n')$, solve the firm's problem by value function iteration as follows.

(a) Guess the firm's value function $\boldsymbol{V}^{\text{old}}(A,\sigma,\sigma_{-1},z,X,n)$.

(b) Compute the expected future value:

$$G(A,\sigma,\sigma_{-1},z,b',n') \equiv \mathbb{E}\int_{-\infty}^{\bar{\epsilon}(A',\sigma',\sigma,z',b',n')} \boldsymbol{V}^{\text{old}}(A',\sigma',\sigma,z',X',n')d\Phi_{\epsilon}(\epsilon'), \tag{67}$$

where the default cutoff, $\bar{\epsilon}(A',\sigma',\sigma,z',b',n')$, is from eq. (62) and tomorrow's cash on hand is determined by

$$X' = A'z'n'^{\alpha} - n'w(A',\sigma') - \bar{w}_m - \epsilon' - b', \tag{68}$$

Then the firm's problem can be simplified into

$$\boldsymbol{V}^{\text{new}}(A,\sigma,\sigma_{-1},z,X,n) = \max_{\Delta,b',n'} \Delta + \beta(1-\pi_d)G(A,\sigma,\sigma_{-1},z,b',n')$$

$$\text{s.t. } \Delta = X + Q(A,\sigma,\sigma_{-1},z,b',n')b' - H(A,\sigma,n,n') \geq 0,$$

$$Q(A,\sigma,\sigma_{-1},z,b',n')b' - H(A,\sigma,n,n') \geq M(A,\sigma,\sigma_{-1},z,n) - F_m(A,\sigma,\sigma_{-1},z).$$

(c) Before solving $\boldsymbol{V}^{\text{new}}$, solve the relaxed problem first:

The relaxed problem is

$$\hat{\boldsymbol{V}}(A,\sigma,\sigma_{-1},z,n) = \max_{b',n'} Q(A,\sigma,\sigma_{-1},z,b',n')b' - H(A,\sigma,n,n') + \beta(1-\pi_d)G(A,\sigma,\sigma_{-1},z,b',n')$$

$$\text{s.t. } Q(A,\sigma,\sigma_{-1},z,b',n')b' - H(A,\sigma,n,n') \geq M(A,\sigma,\sigma_{-1},z,n) - F_m(A,\sigma,\sigma_{-1},z).$$

Let $\hat{b}(A,\sigma,\sigma_{-1},z,n)$ and $\hat{n}(A,\sigma,\sigma_{-1},z,n)$ denote the optimal policies of the relaxed problem.

(d) Given $\hat{b}(A,\sigma,\sigma_{-1},z,n)$ and $\hat{n}(A,\sigma,\sigma_{-1},z,n)$, update the grids of cash on hand. The grids of cash on hand X are equidistantly distributed on $[X_{\text{min}}, X_{\text{max}}]$. The lower bound, X_{min}, equals $-M(A,\sigma,\sigma_{-1},z,n)$. The upper bound, X_{max}, equals the maximum of $\hat{X}(A,\sigma,\sigma_{-1},z,n) = -[Q(A,\sigma,\sigma_{-1},z,\hat{b},\hat{n})\hat{b} - H(A,\sigma,\sigma_{-1},n,\hat{n})]$.

(e) Update the firm's value function, $\boldsymbol{V}(A,\sigma,\sigma_{-1},z,X,n)$, by grid search. For each state $(A,\sigma,\sigma_{-1},z,X,n)$ of $\boldsymbol{V}(\cdot)$, I go though the combinations of choices (b',n') to find the maximum objective value to update $\boldsymbol{V}^{\text{new}}(A,\sigma,\sigma_{-1},z,X,n)$, where (b',n') should satisfy the non-negative equity payout constraint and the agency friction constraint. The grid search for optimal b' and n' in value function iterations is around the frictionless optimal levels of b' and n'.

(e) Given $\boldsymbol{V}^{\text{new}}(A,\sigma,\sigma_{-1},z,X,n)$, update the expected future value, $G(A,\sigma,\sigma_{-1},z,b',n')$. For each state $(A,\sigma,\sigma_{-1},b',n')$ of $G(\cdot)$, I use Gauss-Legendre method to compute the integration with respect to ϵ', with the linear interpolation of $\boldsymbol{V}^{\text{new}}(A',\sigma',\sigma,z',X',n')$ with respect to X'. Denote the updated expected future value as $G^{\text{new}}(A,\sigma,\sigma_{-1},z,b',n')$.

5. Renew the current-period hiring cost, $h^{(k+1)}(A,\sigma)$, such that the free entry condition holds for each aggregate state (A,σ):

$$k_e = \sum_z \boldsymbol{J}_e(A,\sigma,z)g_z(z), \forall (A,\sigma), \tag{69}$$

where the new entrant's value is solved by

$$\boldsymbol{J}_e(A,\sigma,z) = \max_{n_h,x_h} -n_h \frac{c}{q(\theta(A,\sigma,x_h))} - n_h w_h(A,\sigma,x_h) + \beta(1-\pi_d)G^{\text{new}}(A,\sigma,\sigma_{-1},z,b_0,n_h) \tag{70}$$

$$= \max_{n_h} -n_h h^{(k+1)}(A,\sigma) + \beta(1-\pi_d)G^{\text{new}}(A,\sigma,\sigma_{-1},z,b_0,n_h), \tag{71}$$

where the initial debt, b_0, equals zero.

6. The iteration stops when the expected future value converges, i.e., $\text{dist}(G^{\text{new}}, G^{\text{old}}) < 10^{-6}$, where I follow Judd (1998) and define the distance function as $\text{dist}(f^{(k+1)}, f^{(k)}) = \frac{(\sum_x (f^{(k+1)}(x) - f^{(k)}(x))^2)^{\frac{1}{2}}}{1 + (\sum_x f^{(k)}(x)^2)^{\frac{1}{2}}}$. If the problem does not converge, assign k with $k+1$ and start from Step 2 again.

New Entrants. In simulations, the mass of entrants $m_e(S,\Upsilon)$ is determined such that total jobs found by workers equals the total jobs created by incumbent firms and new entrants:

$$JF_{\text{workers}}(S,\Upsilon) = JC_{\text{incumbents}}(S,\Upsilon) + m_e(S,\Upsilon)JC_{\text{entrants}}(S,\Upsilon), \tag{72}$$

where

$$JF_{\text{workers}}(S,\Upsilon) = p(\theta(S,x_u^*(S)))\Big(1 - \sum_{z,X,n} n\Upsilon(z,X,n)\Big) + \sum_{z,X,n} \lambda p(\theta(S,x^*(S)))n\Upsilon(z,X,n), \tag{73}$$

$$JC_{\text{incumebents}}(S,\Upsilon) = \sum_{z,X,n} n_h(S,z,X,n)\Upsilon(z,X,n), \tag{74}$$

$$JC_{\text{entrants}}(S,\Upsilon) = \sum_z g_z(z)n_e(S,z). \tag{75}$$

In simulated business cycles, there can be instances where jobs created by incumbent firms, $JC_{\text{incumbents}}$, surpass those found by workers, JF_{workers}. When the total worker population is capped at one, this can result in undefined negative entry. To address this, I assume zero entry under such conditions and allow the worker population to expand to satisfy eq. (72). The expanded population is then normalized back to one unit. Simulation shows an average annual population growth rate below 0.5%, implying a small impact from the potential issue of negative entry. Another solution is to assign different entry costs for different aggregate states. See Kaas and Kircher (2015) for this treatment.

Firm Defaults. To avoid unemployment fluctuations being mechanically driven by varying default rates, I assume that firms continue production in the default period, contributing to GDP and employment, although their firm values drop to zero upon defaulting. In the current period, these firms' employees are not included in unemployment statistics. They are laid off post-production, become eligible for unemployment benefits, and can immediately seek new employment. The distribution of producing firms, denoted by $\Upsilon^p(z, n)$, is defined as follows:

$$\begin{aligned}\Upsilon^p(z', n') = &\sum_{z,X,n,\epsilon'} (1-\pi_d)\pi_z(z'|z,\sigma)\mathbb{1}\{n'(S,z,X,n) = n'\}\Upsilon(z,X,n) \\ &+ m_e(S,\Upsilon)\sum_{z,\epsilon'}(1-\pi_d)\pi_z(z'|z,\sigma)\mathbb{1}\{n_e(S) = n'\}g_z(z).\end{aligned} \tag{76}$$

Aggregate output is the sum of all firms' output:

$$Y = \sum_{z,n} Azn^{\alpha}\Upsilon^p(z,n), \tag{77}$$

and the unemployment rate u is the share of workers who do not produce:

$$u = 1 - \sum_{z,n} n\Upsilon^p(z,n). \tag{78}$$

E Differences from the Calibration of Schaal (2017)

In my parametrization, I largely adhere to Schaal's (2017) methodology for estimating parameters related to shocks and the labor market, with three differences to incorporate financial friction.

First, while Schaal (2017) employs a monthly frequency, my model is quarterly, aligning better with financial data, particularly leverage and spreads. Firm leverage is typically defined as a firm's debt relative to annualized sales. In a quarterly model, annualized sales are four times the quarterly sales, whereas a monthly model requires multiplying monthly sales by 12. When targeting the same leverage ratio, the monthly model would require counterfactually high firm debt compared to per-period sales, leading to unrealistically high default risks. And incorporating multi-period debt in a monthly model would add unnecessary complexity. Thus, following finance literature, I choose a quarterly frequency.

Second, Schaal (2017) uses 0.85 as the decreasing returns to scale coefficient α, and I use 0.66. Neither of our models explicitly incorporates capital; Schaal's (2017) choice of 0.85 aims to approximate total decreasing returns. He also points out that his results remain unaffected when adopting a labor share target of 0.66. My model focuses on wage payments, so I align with this labor share target of 0.66. Choosing 0.85 for the decreasing returns to scale coefficient would result in higher wage commitments, increasing risks for firms and potentially leading to counterfactually high credit spreads.

Third, in calibrating the uncertainty shock process, Schaal (2017) uses the interquartile range (IQR) of innovations to idiosyncratic productivity, as calculated by Bloom et al. (2018*b*). In contrast, I follow both Bloom et al. (2018*b*) and Arellano, Bai and Kehoe (2019) in using the IQR of firms' sales growth rates. This is because targeting the IQR of idiosyncratic productivity innovations results in sales volatility more than five times higher than what is observed in real data. Such heightened sales volatility raises firm default risks and leads to excessively high credit spreads.[2] To ensure more realistic financial behaviors, I adopt the IQR of firms' sales growth rates. The main difference between these two approaches is in the level of uncertainty $\bar{\sigma}$, but they exhibit similar business cycle behaviors in terms of uncertainty shocks ϵ_t^σ. Figure F.1 illustrates this similarity, comparing the estimated aggregate productivity and uncertainty shocks in my model (without contracting frictions) with those in Schaal (2017).

Despite the three outlined differences, they do not affect the model's core mechanism. For example, Figure 4, which displays changes in unemployment during recessions, shows that my model (without contracting frictions) yields patterns similar to those in Schaal (2017). Additionally, Table F.2 demonstrates that the business cycle statistics of my model without contracting frictions closely resemble those in Schaal (2017).

[2] Another concern about the idiosyncratic productivity measure is its basis in revenue total factor productivity (TFPR), which may reflect firm pricing power rather than productivity (Bils, Klenow and Ruane, 2021; Hsieh and Klenow, 2009).

F Additional Tables and Figures

Table F.1: Parameters of Reference Models

Parameters	Notations	Benchmark Model		No Contracting Frictions	
		$A+\sigma$	A only	$A+\sigma$	A only
Aggregate shocks					
Persistence of aggregate productivity	ρ_A	0.920	0.920	0.912	0.912
SD of aggregate productivity	σ_A	0.024	0.028	0.042	0.035
Mean of uncertainty	$\bar{\sigma}$	0.248	0.250	0.300	0.280
Persistence of uncertainty	ρ_σ	0.880	-	0.926	-
SD of uncertainty	σ_σ	0.092	-	0.186	-
Correlation between ϵ_t^A and ϵ_t^σ	$\rho_{A\sigma}$	−0.020	-	−0.920	-
Labor market					
Unemployment benefits	$\bar{u}$	0.142	0.142	0.150	0.155
Vacancy posting cost	c	0.001	0.001	0.002	0.002
Relative on-the-job search efficiency	λ	0.100	0.100	0.120	0.120
Matching function elasticity	γ	1.600	1.600	1.600	1.600
Entry cost	k_e	15.21	14.87	14.70	15.21
Mean operating cost	$\bar{w}_m+\mu_\epsilon$	0.001	0.001	0.100	0.100
Financial market					
SD of production costs	σ_ϵ	0.080	0.071	0.080	0.080
Agency friction	$\tilde{\zeta}$	2.400	2.400	-	-
Auditing quality	ξ	1.780	1.780	-	-
Recovery rate	η	2.410	2.410	-	-
Exogenous exit rate	π_d	0.021	0.022	0.022	0.022

Notes: This table reports the calibrated parameters of the benchmark model and the model without contracting frictions. '$A+\sigma$' means the model has both aggregate productivity shocks and uncertainty shocks, and 'A' means the model only has aggregate productivity shocks. The corresponding matched moments are shown in Table 5.

Table F.2: Business Cycle Statistics

	Y	Y/L	U	V	Hirings	Quits	Layoffs	Wages
Panel A: Data								
Std Dev.	0.016	0.012	0.121	0.138	0.058	0.102	0.059	0.008
cor(Y,x)	1	0.590	-0.859	0.702	0.677	0.720	-0.462	0.555
Panel B: Benchamark Model								
Both A and σ Shocks								
Std Dev.	0.015	0.013	0.106	0.097	0.048	0.029	0.111	0.011
cor(Y,x)	1	0.910	-0.500	0.774	0.140	0.884	-0.202	0.876
Only A Shocks								
Std Dev.	0.015	0.011	0.079	0.081	0.019	0.028	0.053	0.010
cor(Y,x)	1	0.988	-0.901	0.904	0.010	0.964	-0.853	0.980
Panel C: Model Without Contracting Frictions								
Both A and σ Shocks								
Std Dev.	0.019	0.016	0.090	0.085	0.060	0.079	0.068	-
cor(Y,x)	1	0.990	-0.797	0.485	-0.101	0.401	-0.602	-
Only A Shocks								
Std Dev.	0.017	0.014	0.076	0.061	0.041	0.057	0.053	-
cor(Y,x)	1	0.994	-0.882	0.658	-0.158	0.610	-0.813	-

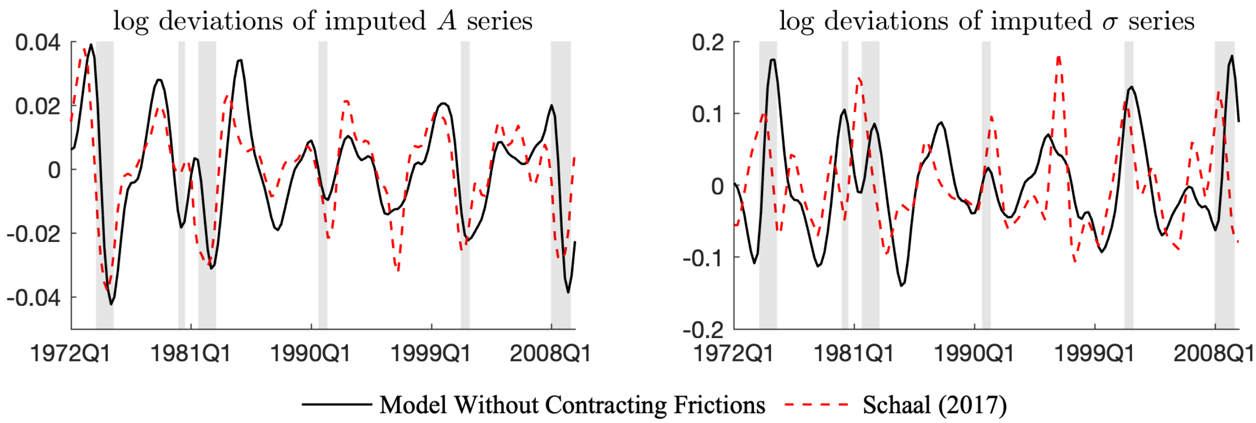
Notes: Panel A shows the business cycle moments observed in the data. Panels B and C present moments from 3,000-quarter simulations of the benchmark model and the model without contracting frictions, both including and excluding uncertainty shocks. 'Both A and σ Shocks' indicates the model incorporates both aggregate productivity shocks and uncertainty shocks, while 'Only A Shocks' refers to the model having only aggregate shocks. Both the data and the model simulations are log-detrended using the Hodrick-Prescott (HP) filter with smoothing parameter 1600. For consistency with the notations in Schaal (2017), Y denotes output, Y/L is output per worker, U represents unemployment, and V is vacancies.

Table F.3: The Aggregate Outcomes of Labor Market Policies

	No Policy	UI Policy	Wage Policy
Panel A: Policies			
Increase in unemployment benefits	-	1%	-
The replacement rate of wage subsidies	-	-	84.4%
Panel B: Aggregate Outcomes			
Benchmark Model			
Mean of output	100	99.593	99.938
SD of output	0.015	0.015	0.015
Mean of unemployment (%)	5.823	6.210	5.804
SD of unemployment	0.106	0.123	0.104
Mean of average wages	100	100.061	100.014
SD of average wages	0.011	0.011	0.011
UE rate	0.814	0.799	0.814
EU rate	0.083	0.085	0.083
EE rate	0.081	0.080	0.081
Mean credit spread (%)	0.96	0.96	0.97
Median leverage (%)	21	21	21
Annual exit rate (%)	9.0	9.0	9.0
Fiscal cost share of output (basis points)	-	4.809	4.862
Total surplus	100	99.957	99.974
Model Without Contracting Frictions			
Mean of output	100	99.963	99.992
SD of output	0.019	0.019	0.019
Mean of unemployment (%)	4.306	4.334	4.275
SD of unemployment	0.090	0.091	0.089
Mean of average wages	-	-	-
SD of average wages	-	-	-
UE rate	0.840	0.839	0.840
EU rate	0.063	0.064	0.063
EE rate	0.044	0.044	0.044
Mean credit spread (%)	-	-	-
Median leverage (%)	-	-	-
Annual exit rate (%)	9.0	9.0	9.0
Fiscal cost share of output (basis points)	-	3.274	0.000
Total surplus	100	99.99993	99.996

Notes: The table compares model-simulated moments with and without labor market policies. Panel A specifies the policies, and Panel B displays moments from 3,000-quarter simulations of the benchmark model and the model without contracting frictions. Policies are implemented when uncertainty exceeds its average level. For each policy, the model is re-solved, with the policies anticipated by economic agents. In the models without policy, the output, average wages, and total surplus are normalized to 100 for comparison. The standard deviations of output, unemployment, and average wages are calculated using log deviations, as determined by the Hodrick-Prescott (HP) filter with a smoothing parameter of 1,600.

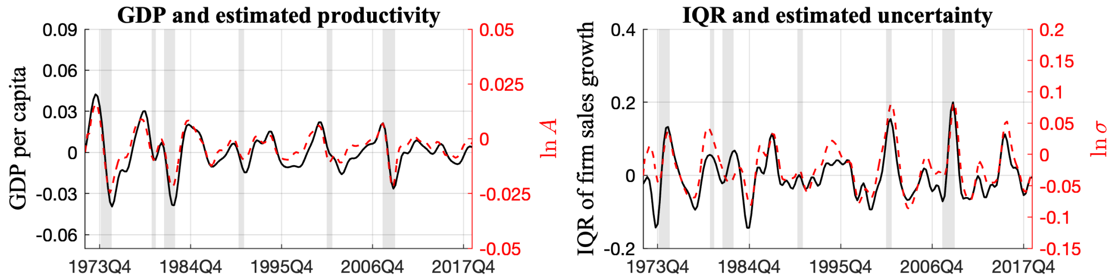
Figure F.1: Comparison of Estimated Shocks with Schaal (2017)



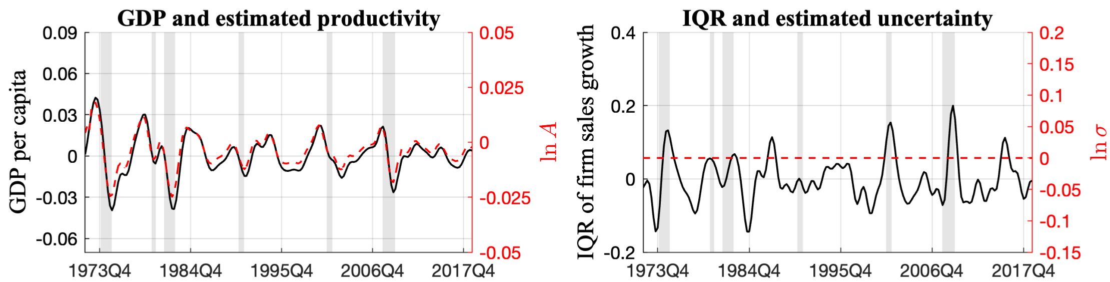
Notes: This figure compares the shocks estimated by my model (without contracting frictions) with those estimated by Schaal (2017). The black lines show the estimated log deviations of aggregate productivity, A, and uncertainty, σ, from my model. The red dashed lines depict the shocks as estimated by Schaal (2017). Both series end at 2009Q4, the last period studied in Schaal (2017).

Figure F.2: Estimated Aggregate Productivity and Uncertainty

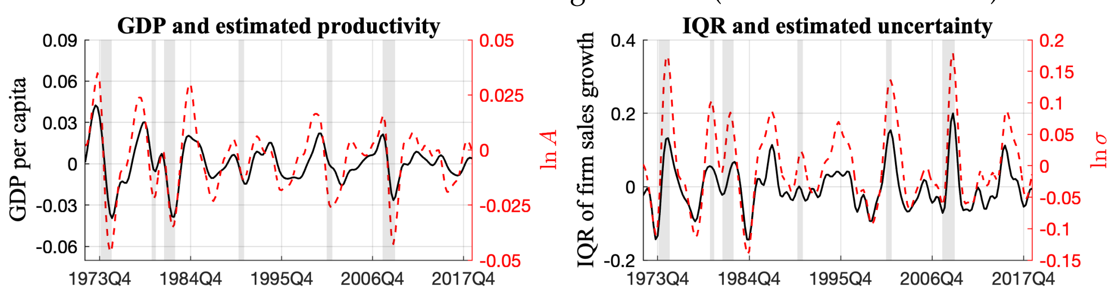
Panel A: Benchmark Model (Both A and σ Shocks)



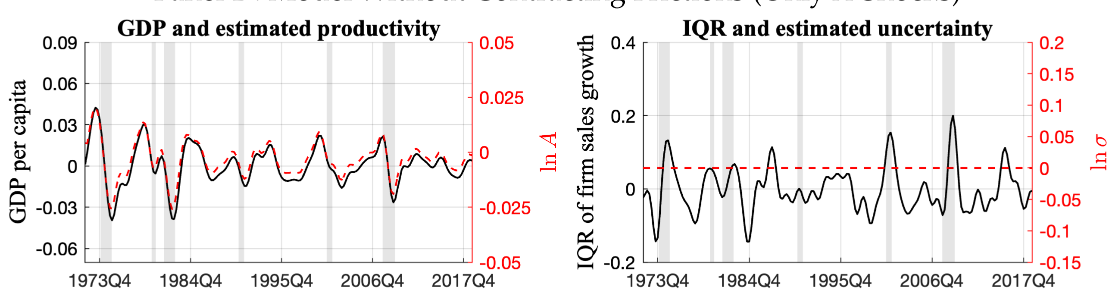
Panel B: Benchmark Model (Only A Shocks)



Panel C: Model Without Contracting Frictions (Both A and σ Shocks)



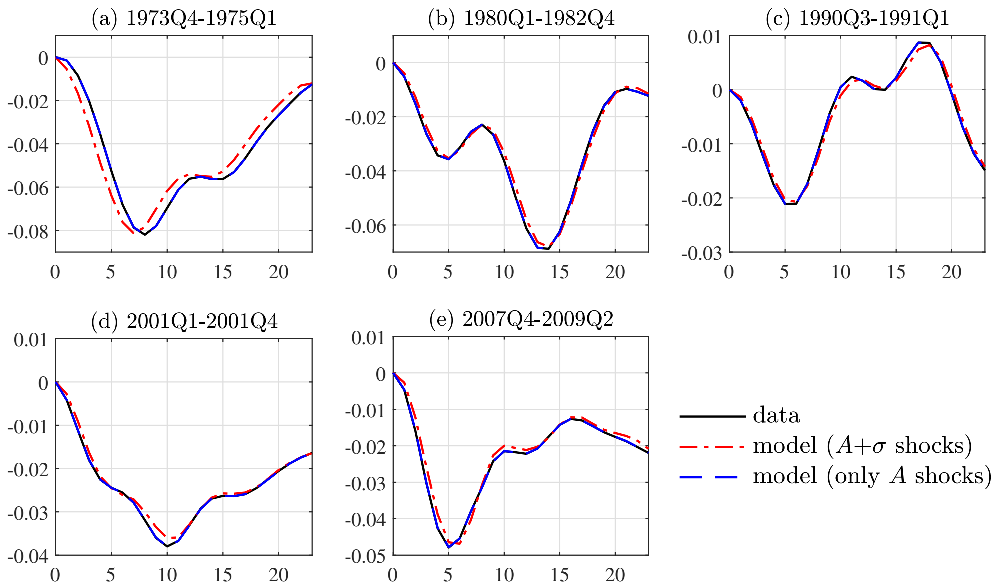
Panel D: Model Without Contracting Frictions (Only A Shocks)



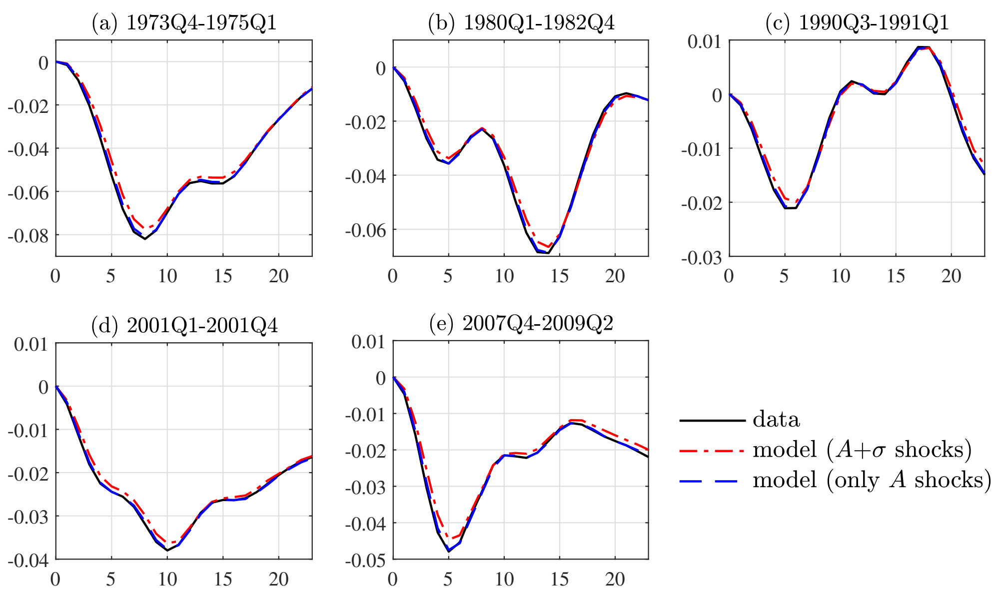
Notes: This figure shows the estimated aggregate productivity and uncertainty of four models. Using the particle filter, I estimate aggregate productivity, A, and uncertainty, σ, from GDP per capita and the interquartile range (IQR) of firm sales growth data series. These series are detrended with a band-pass filter to focus on fluctuations between 6 and 32 quarters, following Schaal (2017). The left-hand side panels show the log deviations of GDP (solid black lines) alongside the estimated demeaned logged aggregate productivity (dashed red lines). On the right-hand side, the panels present the log deviations of the IQR of firm sales growth (solid black lines) and the estimated demeaned logged uncertainty (dashed red lines). The log uncertainty is demeaned to facilitate comparison of its fluctuations across the models.

Figure F.3: Output Series With and Without Modeling Contracting Frictions

Panel A: Benchmark Models

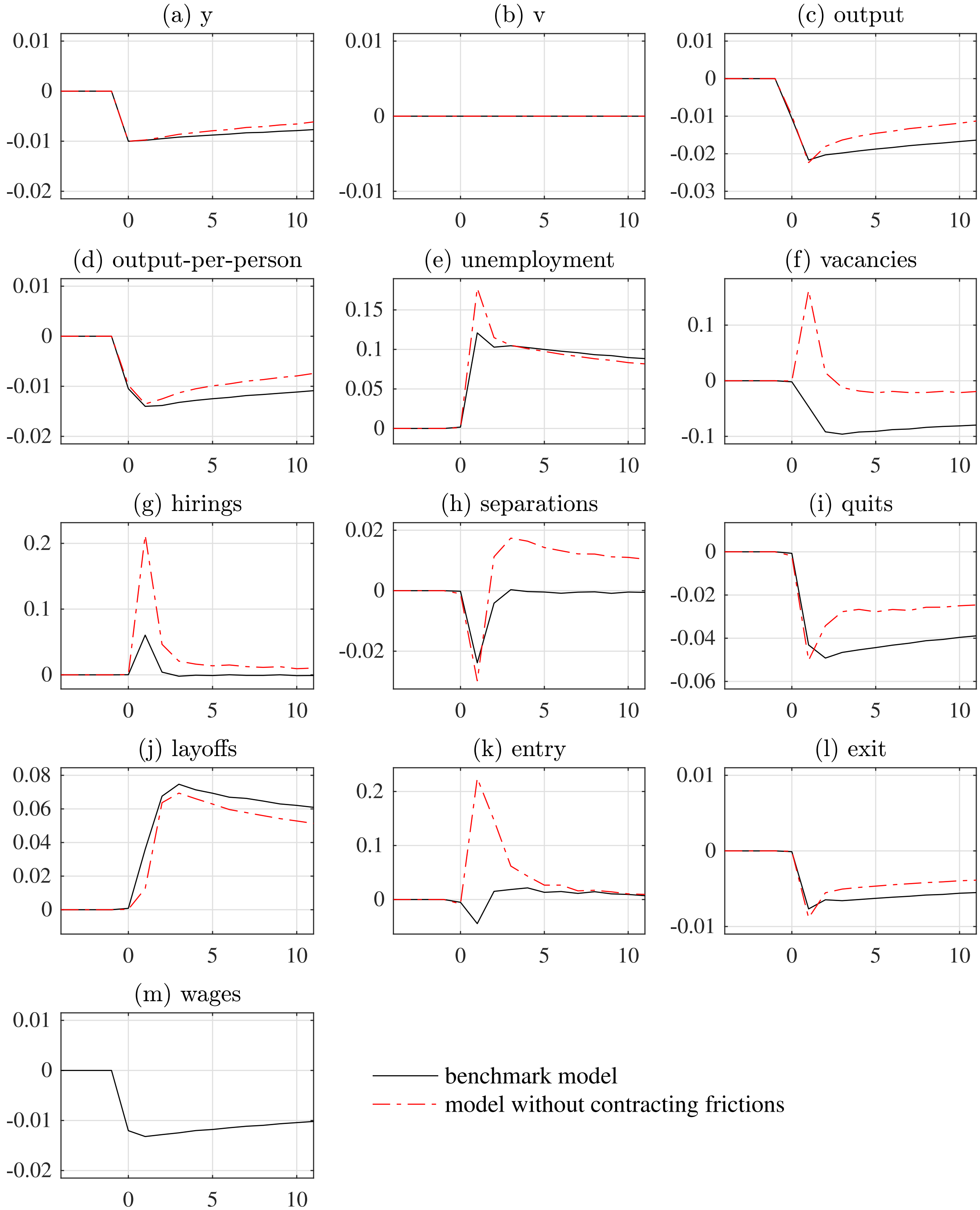


Panel B: Models Without Contracting Frictions



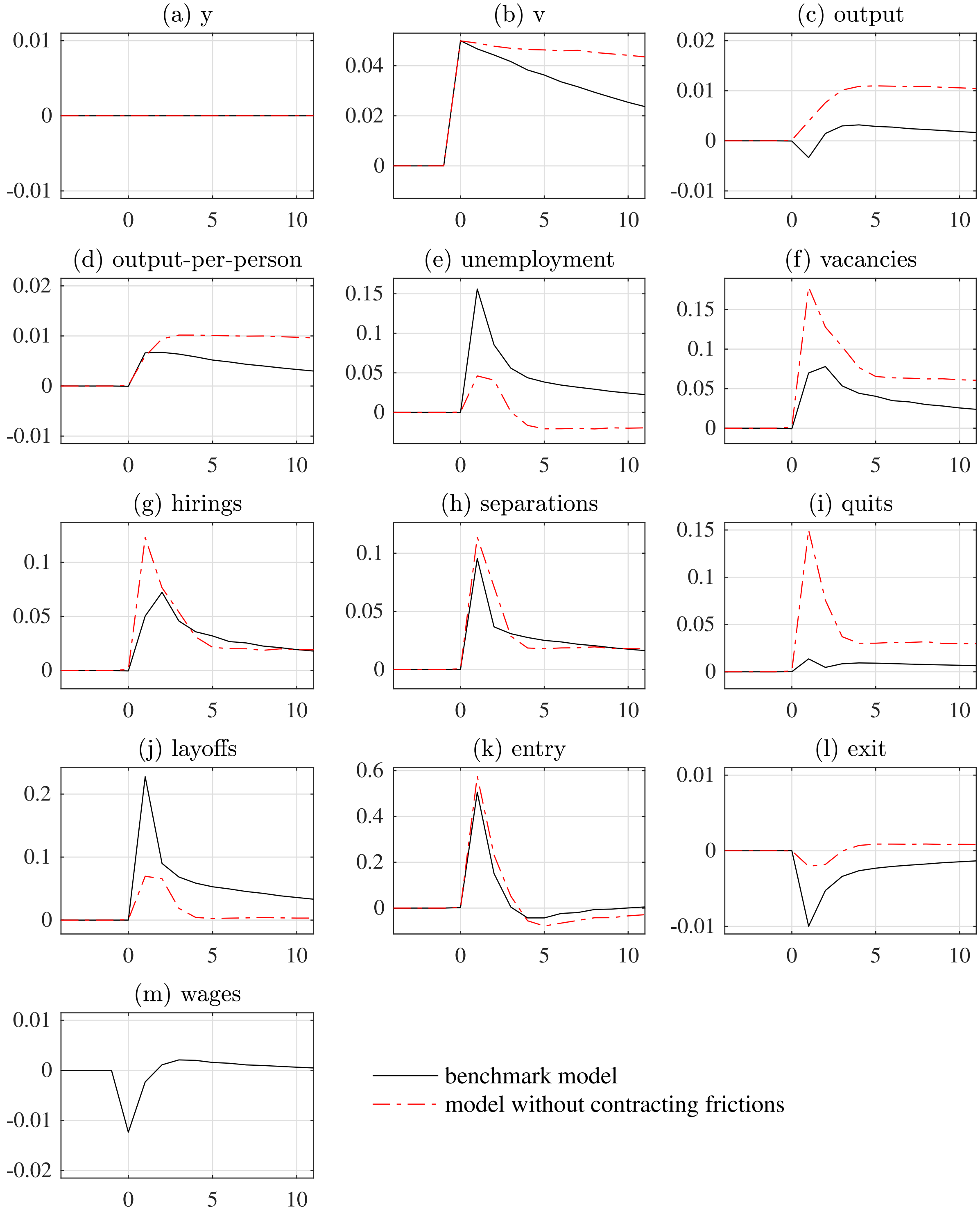
Notes: The panels display the model's predictions for output during recessions. Panel A presents the benchmark models, and Panel B shows the models with contracting frictions. Employing the particle filter, the aggregate productivity and uncertainty shocks are jointly estimated by matching output and the IQR of firm sales growth in the data. These data are detrended with a band-pass filter to highlight fluctuations between 6 and 32 quarters, following Schaal (2017). The actual output data are depicted by solid black lines. Models incorporating both aggregate productivity and uncertainty shocks are represented with dash-dotted red lines (labeled as $A + \sigma$ shocks), whereas models excluding uncertainty shocks are indicated by dashed blue lines (labeled as only A shocks). All series represent log deviations from the peak prior to each recession. I use Schaal's (2017) code when plotting this figure.

Figure F.4: Aggregate Impulse Responses to a 1% Negative Aggregate Productivity Shock



Notes: The panels are impulse responses to a 1% transitory negative aggregate productivity shock at quarter 0. The impulse responses are the average of 4,000 simulated paths, presented as log deviations from the mean. Solid black lines are the benchmark results. Dash-dot red lines are for the model without contracting frictions. I use Schaal's (2017) code when plotting this figure.

Figure F.5: Aggregate Impulse Responses to a 5% Positive Uncertainty Shock



Notes: The panels are impulse responses to a 5% positive uncertainty shock at quarter 0. The impulse responses are the average of 4,000 simulated paths, presented as log deviations from the mean. Solid black lines are the benchmark results. Dash-dot red lines are for the model without contracting frictions. I use Schaal's (2017) code when plotting this figure.