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Keywords: Firm insurance, dynamic contracts, search and matching, financial frictions, distributional impact
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1 Introduction

Firms and workers typically have long-term relationships. The idea that firms try to diversify earnings risk for workers has a long tradition in economics, at least dating back to Knight (2012).[1] However, firms themselves may be subject to financial frictions and shocks. In turn, firms can only provide limited insurance and workers still face earnings risk.[2] This is particularly relevant for the Great Recession and the Financial Crisis period. A large literature points out the importance of earnings risk on workers' consumption smoothing, welfare and policy implications (see e.g., Krueger and Perri (2003, 2006), Heathcote et al. (2009, 2010)); however, the understanding of firm insurance with possible financial constraints is still limited in the literature. Therefore, in this paper, we study in detail the limited risk sharing between firms and workers empirically and quantitatively.

Specifically, to study the impact of financial constraints on risk sharing, we first build a quantitative structural model. We follow the framework as in Mortensen and Pissarides (1994), Pissarides (2009), Thomas and Worrall (1988) and Rudanko (2009). In the model, there will be a continuum of firms, ex-ante identical but ex-post with idiosyncratic productivity shocks. Risk-neutral firms post long-term contracts to risk-averse workers but firms face frictions in external financing - which is not studied extensively in the literature.[3] Both firms and workers have limited commitment to participate in the contract, and workers' outside options are endogenously determined through equilibrium search and matching. We also allow both exogenous and endogenous separations - when there are large negative shocks in external finance conditions, low productivity firms may choose to separate. Firms are heterogenous in the cross-section and insurance will be quite different across different firms. Overall, the model features relatively rich fundamental elements while quantitatively it is still manageable, and we can use it to study how risk sharing is affected by different elements in the steady state and with aggregate shocks as well.

We first characterize the properties of risk sharing with financial frictions theoretically. In the model, firms are heterogenous and they differ in productivity and the life-time utility promised to workers. We find that firms will try to smooth workers' wages - similar to a standard insurance contract - but with some additional weight, which is the firm's

[1] Earlier developments include, Baily (1974), Azariadis (1975), Thomas and Worrall (1988); recent papers include, among others, Rudanko (2009), Sigouin (2004), Guiso et al. (2005), Lagakos and Ordonez (2011), Kudlyak (2014), Lamadon (2016).

[2] There could be other frictions or shocks that affect firm insurance and wage dynamics, e.g., incomplete information in Harris and Holmstrom (1982).

[3] Workers are assumed to be hand-to-mouth; thus, we abstract from workers' optimal consumption and saving problem as in the standard incomplete-market literature. We view our paper as complementary to this large literature.

shadow value of more external finance. This is intuitive, since firms may face external financial constraints (in current period and possibly in the future). Holding productivity constant, when the promised utility increases, the firm is more likely to be constrained by external financing. Over time, a firm may experience bad shocks or good shocks in productivity. If a firm experiences negative shocks and is financially constrained in the current period, on average today's wage is decreased.[4] Also, if the firm is constrained today, on average it promises higher wages tomorrow when not separating, i.e., wages are backloaded. Ex post, if we observe such a path, we could view it as implicit lending from the worker to the firm. This implication is consistent with other existing findings (e.g., Guiso et al. (2013)).

After calibrating the model, we simulate the model in the steady state and we can quantify the amount of risk sharing between firms and workers. We find that the risk sharing is substantial but limited: On average, about 10% of the changes in productivity is transmitted into changes in wages (by using simple regression); the standard deviation of wage growth is about 1.52%, while the standard deviation of productivity innovations is about 5%.The partial insurance is also consistent with other empirical findings (e.g., Guiso et al. (2005)).[5] To see the importance of financial frictions in driving limited insurance, first note that the wages for those firms continuously being unconstrained are almost completely smoothed. However, on average, about 11% firms are financially constrained. Conditional on being constrained, the likelihood of being separated in the next period is twice as large as the average separation probability. Constrained firms will reduce current wages by about 4%, and will have wages increasing by about 1.4% on average going into the next period. Thus, firms provide substantial but not full insurance to workers; being financially constrained is the most important reason why wages are not smoothed and insurance is limited.

To further highlight the role of financial frictions on risk sharing, we experiment with alternative assumptions for the model and investigate the quantitative properties. We first change the magnitude of financial frictions relative to the benchmark model. When firms can obtain twice as much external financing as in the benchmark, the standard deviation of wage growth shrinks to less than one third of that for the benchmark, and only about 2% firms are financially constrained; on the other hand, in a extreme case when firms cannot have external financing at all, the fraction of firms being constrained is more than three times higher than in the benchmark, and wage volatility is also almost doubled.

We also compare the costs of financial frictions from an ex-ante perspective. We find that as financial friction changes, the distributional impact in the cross-section seems

[4]See Section 2.2 for more rigorous statements and proofs.

[5]In Guiso et al. (2005), they further decompose firm output into persistent and transitory components; in our model, idiosyncratic productivity simply follows an AR(1) process.

much more important in magnitude than the changes of the cost ex-ante either for firms or workers. For example, relative to the benchmark case, with twice external financing the firm value only increases by about 0.19%, and with no external finance at all the firm value only decreases by about 3.07% (when holding the promised utility to worker constant). Alternatively, if we keep firm value constant in these different cases, the life-time utility provided to a worker ex-ante will be changed only by about +0.001% and -0.02%, respectively.

We confirm our results by assuming alternative forms of financial frictions in the model. For example, the external financing limit is increasing or decreasing in firm level productivity. Comparing to the benchmark case, we find similar conclusions as before, though the quantitative magnitudes are slightly different: with more generous limits, the average separation probability and the fraction of firms being constrained decreases slightly. The standard deviation of wage growth increases as financial frictions increase, and wages still drop substantially when firms transit from being unconstrained to being constrained.

We also show that other elements in the model do not impact risk sharing in a quantitatively important way, although they are necessary for building and completing the model. For example, in our benchmark model, we assume limited commitment both for firms and workers. In experiments, we consider firms and/or workers can commit to the contract, and we find the quantitative properties of the model change little. For example, with two-sided commitment, the standard deviation of wage growth is only reduced slightly, and the fraction of firms being financially constrained is very similar to that of the benchmark case. In other exercises, we experiment with different magnitudes of search and matching frictions, and we also change the level of unemployment benefits. Overall, we find that the quantitative properties of the model remain. Thus, it appears that external financing friction is the most important driving force for limited risk sharing, and we think this is an important new finding to the literature.

Lastly, we use the model to conduct an exercise for the Great Recession in the US. We find that, with disciplined aggregate productivity shocks and financial shocks as model input, not surprisingly, the model features aggregate effects on job finding rates and unemployment rates. However, the distributional effect on the economy is also significant, and heterogenous for different types of workers; this is typically ignored in standard search and matching business cycle studies. In particular, we find that the job finding rate is lowered by about 12% on impact, and the unemployment rate could increase more than 0.9 percentage points at the peak. More importantly, the risk sharing between firms and workers is impacted significantly. During transitions, the standard deviation of wage growth (for those not separated) increases more than half of the steady state value (from

1.52% to 2.36%), and the fraction of firms (workers) being financially constrained is more than doubled. Thus, this reduction of risk sharing during the transitions is large and economically important. We further study the group of constrained firms: on average these firms have wage cuts at about 1.56%, and for those firms suddenly being constrained in current period the wage drop is about 3.71%; both of these numbers are similar to the corresponding values in a steady state. Therefore, it appears that during transitions firm insurance is reduced, and mostly this is because more firms (and workers) are becoming financially constrained.

To provide empirical support for limited risk sharing over the business cycle or in the Great Recession, ideally, we would like to investigate that, when facing exogenous financing shocks, financially constrained firms may cut current wages and backload wages conditional on not separating, compared to otherwise identical firms. If we could observe both firm and worker characteristics (e.g., using matched employer-employee data), this would be relatively straightforward. However, this is not the case for typical publicly available data. Nevertheless, we provide empirical evidence that is consistent with the model's implications. Using Compustat data for all US public firms, we find that the change of average wage relative to the change of productivity at the firm level, increased in the period with more financial market disruptions. That is, firm insurance is reduced with more financial frictions, and this is consistent with our model. In addition, using micro-level data from the Survey of Income and Program Participation (SIPP) for households, when a worker works in an industry that is more likely to be financially constrained, her earnings are reduced more conditional on not being separated and she is more likely to be laid off. All these results are consistent with our model. Admittedly, our empirical study is limited; in the future, using better data sets to study the impact of financial shocks on risk sharing is certainly warranted.

In short, this paper studies the case that firms provide insurance to workers, but firms are subject to financial frictions. Consistent with empirical facts, we show that firms provide substantial but limited insurance to workers. In a time with aggregate shocks in external financial conditions like the Great Recession, the risk sharing is even more limited, and we find it is important to take into account the distributional impact of aggregate shocks on different types of firms (workers).

The paper is organized as follows. In Section 2.1, we first specify the model details, provide theoretical characterization for the insurance problem in section 2.2, and then calibrate the model in section 2.3. In section 2.4 and 2.5 we study numerically the properties of risk sharing in the steady state. In section 2.6, we conduct an exercise for the US in the Great Recession. Section 3 provides supporting empirical evidence. Section 4 concludes and provides some suggestions for future research. All other materials are in the appendix.

Related Literature:

The model in this paper is related to the implicit contract literature (e.g., Baily (1974), Azariadis (1975), Thomas and Worrall (1988), Kudlyak (2014), Lamadon (2016)). Perhaps the closest paper is Rudanko (2009). In this very interesting paper, Rudanko proposes a micro-founded model of wage rigidity - an equilibrium search and matching model with business cycles, where risk-neutral firms use optimal long-term contracts to attract risk-averse workers. The contracts feature wage smoothing with limited commitment from both of firms and workers. She shows that using this framework can help generate aggregate wage patterns consistent with the data along typical business cycles with aggregate productivity shocks. However, our paper is closely related to but different from Thomas and Worrall (1988) and Rudanko (2009) in several aspects: (1) We are mainly motivated by the Great Recession and the financial crisis, and we focus on firms trying to provide insurance to workers but who themselves are subject to financial shocks - which Rudanko did not study. (2) We provide quantitative analysis for heterogenous firms providing limited insurance to workers, and we focus on and highlight the distribution impact in the steady state and for the transitions - this is typically ignored in search and matching business cycle studies. Indeed, we show that the distributional impact is significant and important. (3) In our model, we also allow for endogenous separations between firms and workers in the context of risk sharing - which is also another important feature of "limited" insurance; we believe it is evidently related to the spikes of unemployment rates in the Great Recession but it is typically not studied in the literature when studying risk sharing. (4) Empirically, we provide new evidence from the US in the Great Recession period. We find supportive empirical evidence that firm insurance is reduced in the Great Recession, and that when firms are more likely to be financially constrained in periods with aggregate shocks, the job-stayers' earnings are reduced more. (5) Methodologically, we also provide a new numerical algorithm for the dynamic contract problem (e.g., see Alvarez and Jermann (2001)) and we believe this is also useful for other related research.[6]

For general empirical evidence on limited insurance between firms and workers, the influential paper by Guiso et al. (2005) provides the most comprehensive econometric analysis. They use matched employer-employee data from Italy in 1990s, and find that firms provide full insurance against temporary idiosyncratic shocks, while for persistent shocks to firms' output, workers are only partially - though substantially - insured. This implies that the firm is a very effective insurance provider. A recent paper by Lagakos

[6] Computation for dynamic contracts with firm heterogeneity, limited commitment, endogenous separations, search and matching equilibrium is typically complicated; see related discussions in Alvarez and Jermann (2001), Rudanko (2009)

and Ordonez (2011) uses US industry-level data and finds that low-skilled workers have relatively less insurance from their firms. In Guiso et al. (2013), they exploit the variations in the degree of local credit market developments and matched employer-employee data from Italy (1990-1997), and find that firms operating in less financially developed markets offer lower entry wages but faster wage growth than firms in more financially developed areas. In comparison, our paper focuses more on the quantitative analysis for limited risk sharing with heterogenous firms subject to external financial frictions. We also find that firms provide substantial but not full insurance to workers, and that quantitatively financial friction is a crucial element - all these conclusions are consistent with existing empirical findings; in addition, we also provide new empirical evidence in the Great Recession that supports the model's implications. See section 3 for more discussions.

2 Model

2.1 Model Description

The model follows the standard search and matching framework in the literature (e.g., Mortensen and Pissarides (1994), Pissarides (2009)). Two new elements are added for our purpose: firms are risk-neutral but subject to financial frictions; workers are risk averse, and for simplicity, they are hand-to-mouth (such as in Thomas and Worrall (1988)). Firms post long-term labor contracts to attract risk-averse workers. Workers have the following preference over consumption, $E_t \sum_{s \geq 0} \beta^s \left[u(c_{t+s}) \right]$, where u is strictly increasing, concave, and β is the discount factor, common to workers and firms.

Timing:

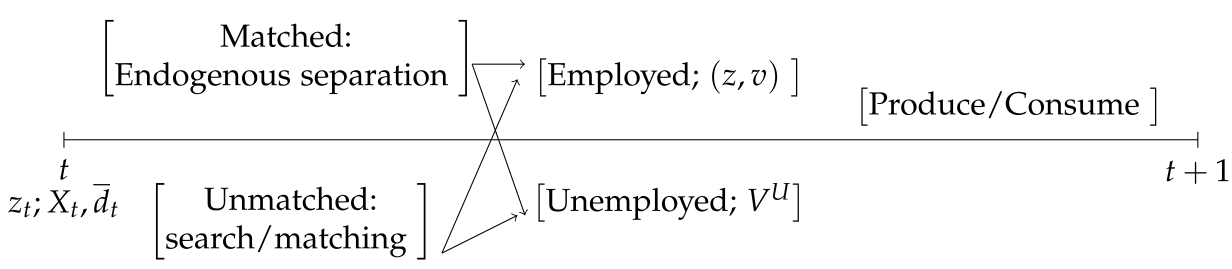

Figure 1: Timing for the model

For each period t, shocks are realized first. As it will be clear later, we allow for idiosyncratic productivity shocks z_t, aggregate productivity shocks X_t and aggregate financial shocks (in the parameter for external finance, $\bar{d}_t$, see more details below). For existing matches, it is possible to have endogenous separations and we assume those newly separated workers do not search in the current period.[7] For those previously unemployed workers, they can search at this stage and some of them may be matched with new vacancies. Unemployed workers and firm vacancies are matched according to a standard matching function: $m(u, \mu_F)$, where u is the measure of unemployed worker (before the search and matching stage) and μ_F is the measure of vacancies. Market tightness is then denoted as $\theta = \frac{\mu_F}{u}$. At the end of the search/matching stage, unemployed worker can enjoy unemployment benefit b this period and could search for jobs in next period, with her value V^U given by:

$$V^U(S_t) = u(b) + \beta E_t \left[(1 - f(\theta_{t+1})) V^U(S_{t+1}) + f(\theta_{t+1}) v_{t+1} \right]$$

where S_t denotes the aggregate state of the economy at time t (including X_t and $\bar{d}_t$), $f(\theta_t)$ is the job finding probability, and v_{t+1} is the value of the contract offered by the firm as detailed below.

Firm's Dynamic Optimization Problem

Firm output is e^{X+z} and aggregate productivity X and individual productivity z are both normalized with mean 0.[8] Denote firm value as $J(z, v; S)$, where v is the promised utility to the worker in the long-term contract. Conditional on not separated in the current period, a firm chooses current wages w, dividend d, and a plan of contingent promised utilities, $\{w, d, v'(z', S')\}$, endogenous separation choices for the next period $\rho(z', S') \in \{0, 1\}$, to maximize expected present value of dividends,

$$d + \beta(1 - \delta) E (1 - \rho(z', S')) J(z', v'(z', S'); S'), \qquad \text{(Firm value)}$$

where δ is the exogenous separation rate, S' denotes next period's aggregate states. The firm is subject to a set of constraints: the promise-keeping condition for the contract, firm budget constraint and possible external finance constraint, and firm and worker

[7] Quantitatively, assuming the newly separated workers in the current period also search in the current period has little difference.

[8] Specifically, we could have this firm output by assuming each firm hires one worker and the production function is $\left[A_0 e^{X+z}\right]^{\alpha} k^{1-\alpha}$, where A_0 is used to adjust the scale of the economy. With competitive capital markets, firms' profits after capital expense is $\left[A_0 e^{X+z}\right]^{\alpha} k^{1-\alpha} - (R_k)k = e^{X+z} \times A_0 \alpha \left[\frac{1-\alpha}{R_k}\right]^{\frac{1-\alpha}{\alpha}}$, where R_k includes the risk-free interest rate and the capital depreciation rate, and A_0 is chosen so that the profit is normalized to e^{X+z}.

participation constraint as follows:

$$u(w) + \beta E\{ \ [(1-\delta)\rho(z', S') + \delta] \, V^U(S') + (1-\delta)(1-\rho(z', S'))v'(z', S') \ \} - v \geq 0, \tag{Promise keeping}$$

$$e^{X+z} - w - d = 0, \tag{Firm budget}$$

$$d \geq \bar{d}(S), \tag{Financing-Constraint}$$

$$J(z', v'(z', S'); S') \geq 0, \ \text{ if } \rho(z', S') = 0 \tag{Firm participation}$$

$$v'(z', S') - V^U(S') \geq 0, \ \text{ if } \rho(z', S') = 0. \tag{Worker participation}$$

In the equation for (Promise keeping), the worker enjoys current wages w, having continuation value of $V^U(S')$ in the case of separation next period (endogenously or exogenously with probability of δ), and $v(z', S')$ otherwise. In (Financing-Constraint), the firm's dividend is constrained by some exogenous limit, $\bar{d}(S)$. Different $\bar{d}(S)$ reflects how difficult it is in the financial market for the firm to raise external finance. This modelling closely follows Gilchrist et al. (2017) and Caldara et al. (2016), while it is relatively simple since in our model elements with contracts are already complicated. In the transitional dynamics analysis below, we will introduce aggregate shocks to $\bar{d}$ so that $\bar{d}$ is stochastic over time. Lastly, firms and workers should both have incentives to participate in the contract.

Remarks on the Firm's Problem

There are a few remarks on the firm's problem: (1) We abstract from firms' endogenous precautionary saving, mainly because technically the dynamic contract problem is already complicated in our context with two-sided limited commitment and endogenous separations. Firm self-financing may allow for better insurance, thus for given firm productivity and promised wage bills, our model possibly captures the lower bound of wage insurance. Nevertheless, in Section 2.4 we confirm our main results with different forms of financial frictions and we could allow for external financing depending on firm productivity. (2) We also abstract from other labor market features for workers: (a) multi-workers within the same firm. It's possible that workers may have heterogenous idiosyncratic productivity shocks and they could mutually insure each other within the firm; in our model, the productivity shock z is a firm-level shock, and thus difficult for workers to smooth out within a firm; (b) on-the-job search for workers. Currently we have both exogenous and endogenous separations between firms and workers. Allowing for on-the-job search and employer-to-employer transitions will change workers' outside option values and possibly change the wages bargained in the current firm, but the main insight of the current model should still remain. (4) Lastly, firms from different industries may have different levels of "job security", say, exogenous separations rates, due to some industry fundamental characteristics. Different job security may affect the ex-ante present value of job offers. Admittedly, adding all these considerations into the model will enrich the setup, but then perhaps the model will become much more complicated to solve for. We therefore leave these for future research.

Free Entry of New Firms

There is unlimited supply of new firms for free entry. New firms enter with vacancy posting cost, c_F, and are assumed to have productivity of z_0 and posting contracts with initial value of v_0. In the equilibrium firms have zero profit:

$$0 = -c_F + q(\theta_t) J(z_0, v_0; S_t).$$

Lastly, we assume that upon meeting, the firm and the worker use Nash bargaining to decide the initial value of v_0. Simply, they choose v_0 to maximize the Nash product

$$\left[v_0 - V^U(S)\right]^\eta J(z_0, v_0; S)^{1-\eta}.$$

Note that for the initial value v_0 in the contract offered to newly matched workers, this is slightly different from the competitive search framework used in Rudanko (2009).[9]

2.2 Characterization for the firm's problem

Assuming productivity (z and X) are finite, we can show that: (1) there exists a unique $J(z, v; S)$, which is strictly decreasing in v, strictly concave in v; (2) $J(z, v; S)$ is differentiable in v. For proofs on these, please see Appendix A for detailed analysis. In the firm's optimization problem, we denote the Langranian multiplier for the promise-keeping condition as λ, the multiplier for firm budget as μ, the multiplier for the firm's financing constraint as γ, and $\beta(1-\delta)\mu^f \pi(z, z'; S, S')$ as the multiplier for the firm's participation constraint in (z', S') when $\rho(z', S') = 0$, and $\beta(1-\delta)\mu^W \pi(z, z'; S, S')$ as the multiplier for the worker's participation constraint in (z', S') when $\rho(z', S') = 0$. We can have first-order

[9] In principle, the bargaining power for workers η could be any value between 0 and 1. Here for simplicity, we assume it is the same as the one in the matching function. This is also used frequently in the literature, e.g., Shimer (2005).

conditions:

$$\begin{aligned} d &: \mu = 1+\gamma; \quad \gamma = 0 \ \text{ if } \ d^* > \bar{d} \ \text{ and } \quad \gamma \geq 0 \ \text{ if } \ d^* = \bar{d} \\ w &: \mu = \lambda u'(w^*), \lambda = -\frac{\partial J(z,v;S)}{\partial v} \\ v'(z',S') &: \frac{\mu}{u'(w^*)} + \mu^w(z',S') = (1+\mu^f(z',S'))\frac{\mu(z',S')}{u'(w^*(z',S'))}, \quad \text{if } \rho(z',S') = 0. \end{aligned}$$

The first order condition tells us that when the firm is not financially constrained, $\mu = 1$, and both firms and workers are not binding by the participation constraint, wages are perfectly smoothed: $\frac{1}{u'(w^*)} = \frac{1}{u'(w^*(z',S'))}$. When the firm is currently financially constrained, $\mu > 1$, and from $\frac{\mu}{u'(w^*)} = \frac{\mu(z',S')}{u'(w^*(z',S'))}$ we can see that current wage w^* tends to be lower than what it would be. Typically, this happens when z is very low and w^* is bounded at $e^{X+z} - \bar{d}$.

Similar to the standard literature (e.g., Thomas and Worrall (1988)), the firm tries to smooth wages across time and states; Differently, in our model, the firm itself is subject to the external finance constraint. Therefore, effectively, the firm tries to smooth the weighted inverse of marginal utility, $\frac{\mu}{u'(w^*)}$, across time and states. Note that μ is the shadow value of one extra dollar for the firm, so the wage smoothing is weighted by the firm's shadow value of budget.[10] We can have a very similar proposition as in the seminar work by Thomas and Worrall (1988):

Proposition 1

For any given history of productivity z_{t-1}, z_t, z_{t+1}, denote the associated optimal wages as w_t^* and w_{t+1}^*, and the associated firm's multipliers (shadow value of one more dollar) as μ_t and μ_{t+1}. Then we have:
(1): if $\frac{\mu_{t+1}}{u'(w_{t+1}^*)} > \frac{\mu_t}{u'(w_t^*)}$, then the worker's outside option is binding: $v_{t+1} = V_{t+1}^U$;
(2) if $\frac{\mu_{t+1}}{u'(w_{t+1}^*)} < \frac{\mu_t}{u'(w_t^*)}$, then the firm's outside option is binding: $J(z_{t+1}, v_{t+1}) = 0$;
(3) if $\frac{\mu_{t+1}}{u'(w_{t+1}^*)} = \frac{\mu_t}{u'(w_t^*)}$, neither party's outside option is binding: $v_{t+1} \geq V_{t+1}^U$ and $J(z_{t+1}, v_{t+1}) \geq 0$.

The proposition says that, if weighted wages ($\frac{\mu_t}{u'(w_t^*)}$) rise from the current period to the next period, firms do so in a way just to the extent where the worker is indifferent between staying in the contract or not. Similarly, we can also observe that if wages fall they do so until the firm is indifferent. Finally, the firm tries to smooth the weighted wages, and if they stay the same then we know it must be the case that both parties at least weakly prefer the contract to their respective outside options. These points are

[10] In the case of CRRA utility with risk aversion parameter equals 2, this is just weighted square of wages.

similar to Rudanko (2009) and recently Lagakos and Ordonez (2011).

Lastly, since $J(z, v; S)$ is strictly decreasing in v for each given z, we can find $\bar{v}(z, S)$ such that $J(z, \bar{v}; S) = 0$. Intuitively, $\bar{v}(z, S)$ is the highest level of promised utility that the firm can deliver to the worker. $\bar{v}(z, S)$ could be higher or lower than $V^U(S)$. if $\bar{v}(z, S) < V^U(S)$, then it's optimal in the contract for the firm and the worker to separate.

Proposition 2

The constraint $d - \bar{d} \geq 0$ will become more tightened as v increases. Formally, for any given z, and let $v_2 = v_1 + \epsilon, v_1 < v_2, v_1, v_2 \in intV$, then it is impossible to have the following optimal solution: $d^*(v_1) = \bar{d}$ and $d^*(v_2) > \bar{d}$.

See the appendix for the proof. Intuitively, this proposition says that as the promised utility increases, the firm is more likely to be constrained when trying to obtain external finance. From this proposition, we can see that the implied firm's multiplier μ, the shadow value for more external financing, will be non-decreasing over the space of v for a given value of z.

Proposition 3

Fix any path of realizations of productivity (z_t, z_{t+1}). Denote the associated optimal wages as w_t^* and w_{t+1}^*, and the associated firm's multipliers as μ_t and μ_{t+1}. If the firm is financially constrained in period t but unconstrained in $t + 1$, then we must have optimal wages increasing $w_t^* \leq w_{t+1}^*$.

See the appendix for the proof. This proposition says that over time, the firm may experience bad shocks or good shocks; when z_t is relatively bad and z_{t+1} relatively good, wages should be backloaded. When the firm is constrained in z_t, ex ante, it does not know the productivity realizations going into the next period. The firm offers a contingent plan so that, if z_{t+1} is a good state, then it will increases wages (and v' in that state). Therefore, ex ante, there is insurance between the firm and the worker; ex post, if (z_t, z_{t+1}) is as described, we could view it as backloading wages, or implicit lending from the worker to the firm (e.g., Michelacci and Quadrini (2009) and Guiso et al. (2013)).

Proposition 4

Fix any path of realizations of productivity (z_t, z_{t+1}). Denote the associated optimal wages as w_t^* and w_{t+1}^*, and the associated firm's multipliers as μ_t and μ_{t+1}. If the firm is financially unconstrained in period t but constrained in $t + 1$, then we must have optimal wages decreasing, $w_t^* > w_{t+1}^*$.

The proof is very similar to the previous proposition thus not reported. In such a case, if we further have that both parties strictly prefer to stay in the contract, the first-order condition simply is: $\frac{\mu_t}{u'(w_t^*)} = \frac{\mu_{t+1}}{u'(w_{t+1}^*)}$, and $\mu_t = 1$, $\mu_{t+1} > 1$.[11] Since the firm is financially

[11] In general, we do not need to impose that both parties strictly prefer to stay in the contract for the

constrained in $t+1$, we know $\gamma_{t+1} > 0$ and $w^*_{t+1} = e^{X_{t+1}+z_{t+1}} - \overline{d}_{t+1}$, that is, the optimal wage in $t+1$ is set at the lowest possible bound of that particular state. Similar to the previous proposition, ex ante, there is insurance between the firm and the worker; ex post, if z_{t+1} is as described in this case (this is happening most likely because z_{t+1} is low; also see numerical illustrations below), then wages decrease to the bound.

2.3 Calibration

To study more quantitative properties of risky sharing, we first calibrate our model at the steady state.[12] The model period is one quarter. The discount factor β is thus set to 0.99, so that the implied quarterly risk-free interest rate is about 1%. Assume the average capital share, $1-\alpha$, to be 0.36. Following Cooley and Prescott (1995), we assume that the depreciation rate for physical capital is 2.5%. We normalize aggregate productivity X and individual productivity z with mean 0. We assume z follows a simple AR(1) process and discretize it with finite points, as in Tauchen (1986). The individual productivity process has parameters $(\rho_z, \sigma_z) = (0.867, 0.05)$, which are consistent with various sources: Khan and Thomas (2013), Lee and Mukoyama (2008), Clementi and Palazzo (2016), and Gilchrist et al. (2017). For the worker's preference, we follow the much of the standard literature by assuming risk aversion being 2.

For the matching function $m(u,v) = c_M u^\eta v^{1-\eta}$, we have to calibrate c_M and η. We first normalize the steady-state value of market tightness $\bar{\theta}$ to 1; secondly, we assume η to be 0.5, roughly consistent with empirical estimates in the literature (e.g., 0.58 in Rogerson and Shimer (2011); 0.72 in Shimer (2005)).[13] We then choose the parameter c_M as 0.6 to target the average job finding probability of 0.6 in a quarter. We also assume the exogenous separation rate δ as 0.04 so that in combination with endogenous separations, the average unemployment rate in the steady state is about 6.5%.

For the calibration of $\bar{d}$, since we assume firms are risk neutral and there is no firm debt, the external financing in our model should be interpreted as total external financing for the firms. In the data, for non-financial firms in the US, the total liabilities relative to GDP is about 2.4 between 2001 and 2006. If we assume the average interest paid on the liabilities is about 6% (close to the values used in Caldara et al. (2016)), the quarterly

proof.

[12]The steady state is defined as follows: all aggregate variables, including aggregate productivity shock X, unemployment rate u, and vacancy θ are all constant; the distribution for individual firms of (z,v) is also stationary and does not change over time.

[13]There could be other forms of matching functions, such as in Menzio and Moen (2010), Menzio and Shi (2011), and Schaal (2012). The matching function has the form such that a worker's probability of finding a job vacancy is given by $f(\theta) = \theta(1+\theta^\gamma)^{\frac{-1}{\gamma}}$, and the probability that a firm will find a worker is $q(\theta) = \frac{f(\theta)}{\theta} = (1+\theta^\gamma)^{\frac{-1}{\gamma}}$.

average external finance relative to output is about 3.6%. In our model, we calibrate $\bar{d}$ so that the corresponding value is 3.7%.[14] As another perspective, in our model, we have about 11% firms being financially constrained (i.e., $\gamma > 0$), while in the seminar paper by Gilchrist et al. (2017), they calibrate their model such that in the steady state there is about 9% firms being financial constrained. Thus, our calibration on financial frictions seems close to the literature.

Lastly, we have to determine the parameters on unemployment benefit b and the vacancy posting cost c_F. Since c_F will be determined by the free-entry condition for firms, we need to calibrate b. There is no consensus in the literature on the value of the unemployment benefit (e.g., Shimer (2005) and Hagedorn and Manovskii (2008)). Empirical estimates show that consumption falls during unemployment for about 5% to 14% (e.g., Aguiar and Hurst (2005) and Browning and Crossley (2001)). We set our benchmark value of b to .90. We find that in our model the implied average wages to average productivity is about 96% (this value is in between the values implied by Shimer (2005) and Hagedorn and Manovskii (2008) calibrations). The parameters are summarized in Table 7 in the Appendix. After calibrating the model, we solve for the model at the steady state. For detailed numerical algorithm, please see Appendix C for computations.

2.4 Value function and Policy function

We first study the properties of risk sharing between the firm and the worker in the steady state. In Figure 2, we first plot the value functions $J(z, v)$ over v for different levels of z.[15] As shown in the previous theoretical analysis, $J(z, .)$ is strictly decreasing and strictly concave. Since firms face participation constraint, if v is too large (larger than $\bar{v}(z, S)$) $J(z, v)$ will be negative, then the firm and the worker will be separated and we will not observe them in the equilibrium; Similarly, workers also face participation constraint in our model, so in the equilibrium we will not observe any contracts with v less than V^U (the vertical line in Figure 2). For example, in Figure 2, those firms with too low productivity (dashed line with $z = -1.71\sigma_z$) will be separated.

To have an intuitive sense about which firms are constrained by external finance, for each given z, we can find the smallest value of v beyond which firms will be financially constrained, and we denote this v as $v^{FC}(z)$. From Proposition 2 we know that, for each given z, the firm will be financially constrained if $v > v^{FC}(z)$. Figure 3 thus plots the intervals $[v^{FC}(z), \bar{v}(z)]$ in the shaded area for different z. We can see that: both $\bar{v}(z)$ and

[14] In the steady state, the average dividend for those firms with negative dividend is about -.034, and the average productivity is .918.

[15] In numerical exercise, we use 15 grid points for the productivity process z. For illustration, we only pick a few points in the space of z.

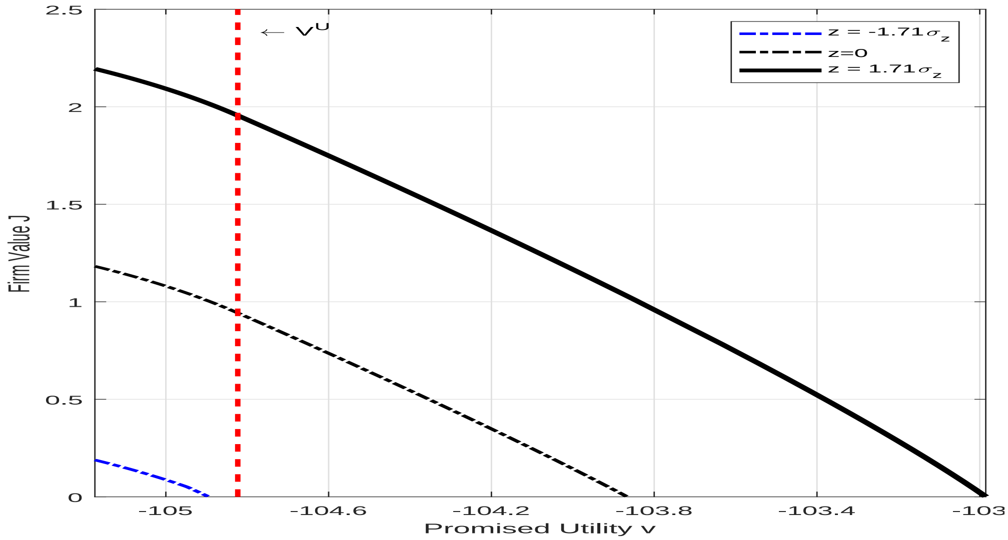

Figure 2: Firm Value Function $J(z, v)$

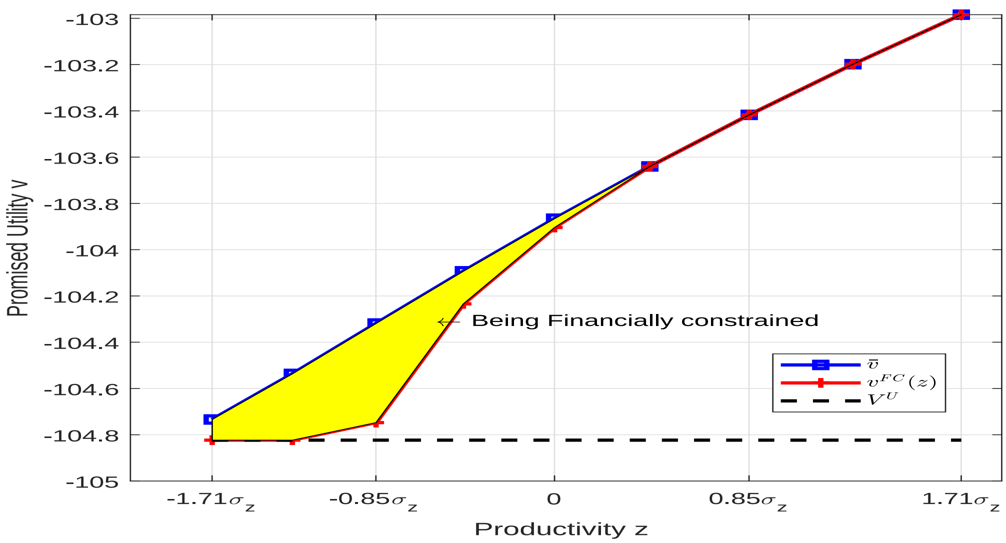

Figure 3: Financial constraint

$v^{FC}(z)$ monotonically increase in z; for low productivity firms (i.e., z is around $-2\sigma_z$), they are always financially constrained since they have $v^{FC}(z)$ even lower than V^U; for firms with very high productivity (i.e., z larger than $0.85\sigma_z$ and beyond), basically they are not financially constrained unless v is very large and almost close to $\bar{v}(z)$. For other firms (i.e., z around $-0.85\sigma_z$), if promised value v is in the interval of $[v^{FC}(z), \bar{v}(z)]$, then we know firms are financially constrained and the multipliers γ for firms' shadow value of external finance will be strictly positive.

Next we turn to wages. In Figure 4, we plot the optimal wage as functions of v for three different productivity levels. A few points are worth noting: (1) When z is relatively low but the firm still can deliver v higher than the worker's outside options ($\bar{v}(z)$ larger

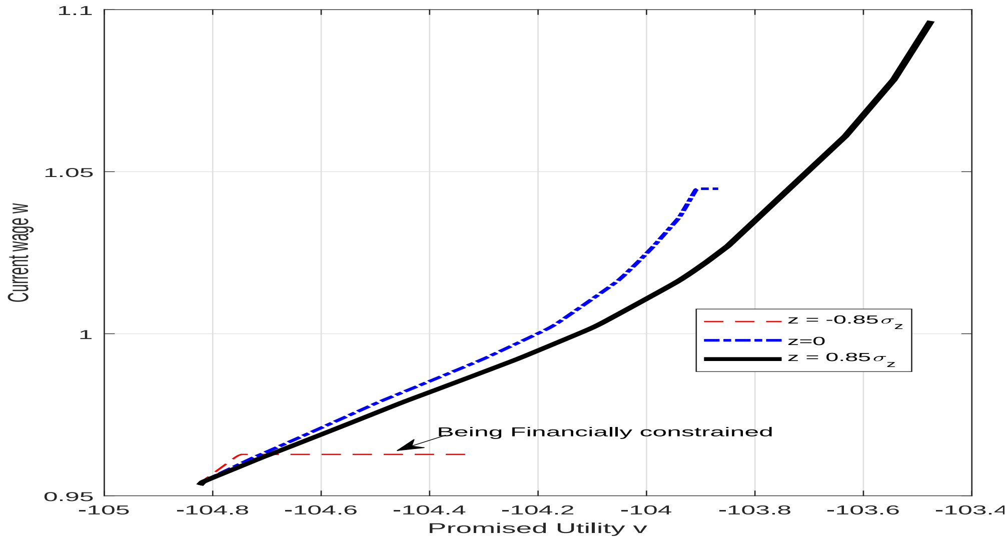

Figure 4: Optimal wages

than V^U), the wage function is like the dashed line ($z = -0.85\sigma_z$ in the figure). A typical feature for the wage function is that, when v is close enough to V^U, we can see firms with different z offer almost exactly the same wages. This is typically the case of full insurance. When the promised utility to worker v increases, close enough to $\bar{v}(z)$, low-z firms will be financially constrained but high-z firms will not. When firms are constrained, w is a flat function of v for a given z. In the figure, we can see there are flat areas for both cases when $z = -0.85\sigma_z$ and $z = 0$. (2) When z is high enough (e.g., as the solid black line for $z = 0.85\sigma_z$), wage is an increasing and smooth function of v. (3) We can also see that, when firms have different productivity and are not financially constrained currently, they will offer different current wages and it is likely that the firms with low z will have slightly higher wages for the same level of v. This is mainly because, even if the low-z firm currently is not constrained, but going to the next period, it is more likely to be constrained than high-z firms; therefore, to smooth wages as much as possible, the low-z firm will try to "squeeze" slightly more out of current firm profits.

In Figure 5, we compare the wage functions when financial frictions are different. In our benchmark case, $\bar{d}$ is calibrated to about 5% of average output; we study the cases with $\bar{d}$ equal 0% (labelled as "More constraint") and equal a very large negative number (labelled as "no constraint").[16] We can observe: (1) when financial friction increases, $\bar{v}(z)$ decreases. Intuitively, this is because firm value $J(z, v)$ decreases with external financial condition. (2) when financial friction increases, firms are more likely to be constrained for the same z and v when v is relatively large. For example, in the "More constraint"

[16] In the numerical exercise for the steady state, we double check that indeed it is large enough so that almost no firms are constrained with $\bar{d} = -0.2$.

case in panel (a), firms are constrained and wages are flat for all the admissible domain of v; while for the case of "no constraint", wage is monotone in v and the firm is not constrained. (3) We also note that, when there is more financial constraint, wages are higher even if the firm is not currently financially constrained. For example, in panel (b), we see wages are the highest (when v is around -104) for the case of $\bar{d} = 0$. The reason behind this is very similar to the precautionary saving mechanism in standard incomplete market models. In our model, since firms try to smooth wages as much as possible and workers' utility is concave, so to provide a given level of v, the cost to the firm will be convex in v, and the risk-neutral firm's objective function will be concave in v, effectively "risk averse".[17] When being financially constrained, wages are at the bounds and may not be desired. When the external financing limit is tighter, the firm (holding constant z and v) is more likely to be constrained. Thus, if the firm chooses to pay relatively higher wages, going to the next period its promised continuation utility will be relatively lower and it is as if "safer" for the firms.

(a) Low z firms　　　　(b) High z firms

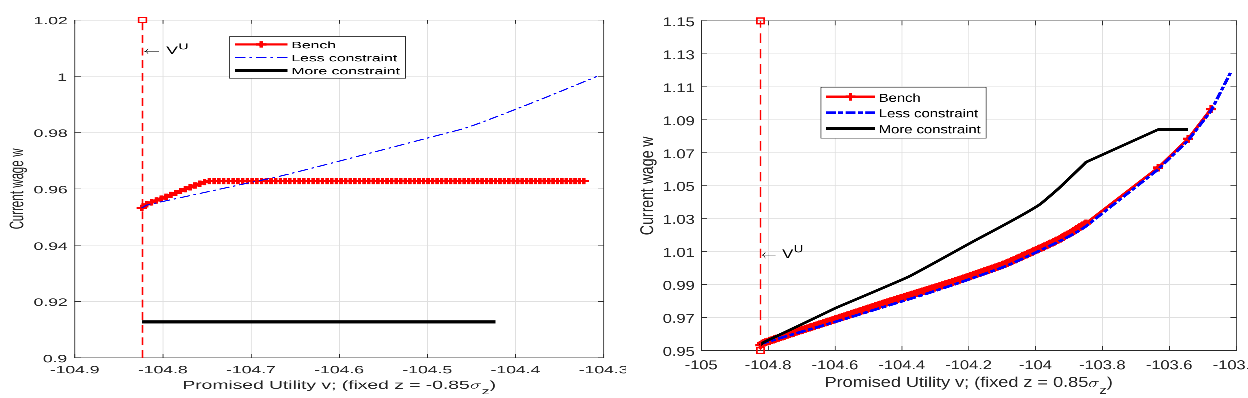

Figure 5: Comparing wages with different financial frictions

2.5 Simulating the model at the steady state

We now simulate the model at the steady state to see the quantitative properties of risk sharing when there are firm heterogeneity in the cross-section.[18] To have an intuitive sense, in Figure 6, we first pick up two typical firms to examine the dynamics of productivity and wages. In panel (a), the worker is well insured with good productivity shocks over time until period 12. However, when z is very low in period 12, wage will drop but is still

[17] For related examples, e.g., see Smith and Stulz (1985) for a discussion that, in an environment with corporate tax functions, a risk-neutral firm's objective function could also be concave, and firms are effectively "risk averse" with hedging motives.

[18] We simulate 10,000 firms for a long time period so that the economy reaches its steady state. If a firm is separated, we replace it with a new firm.

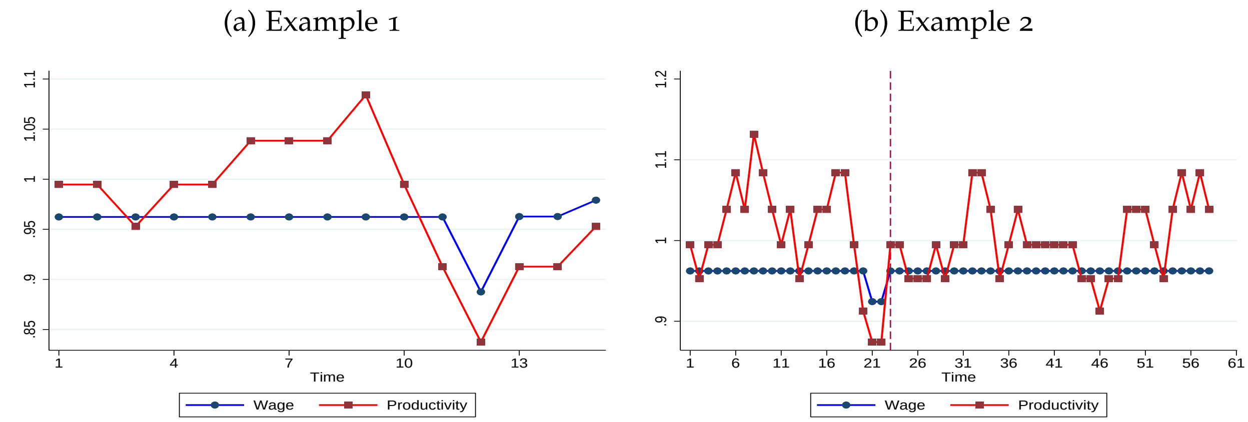

Figure 6: Productivity and wage dynamics

higher than the productivity, since the firm could use external financing to help smooth wages. After period 13, the wages will recover, even becoming slightly higher than the level before period 11; this reflects the facts that wages are backloading in the periods with bad productivity shocks, as described in Proposition 3. Ex ante, the firm promises higher wages for good states tomorrow and low wages for bad states tomorrow; ex post, from a bad state of z_t to a good state of z_{t+1}, the wage slope is positive. Therefore, in this case, there is implicit lending from the worker to the firm (e.g., Michelacci and Quadrini (2009) and Guiso et al. (2013)). In panel (b) for another simulation, the situation is very similar before period 21; but around period 22, productivity is so low and the situation persists, the firm and the worker are endogenously separated (after the vertical line, we start simulation with another new firm).

The impact of financial frictions

In Table 1, we consider different levels of external financing limits ($\overline{d}$ are different, in columns (2) and (3)) compared to the benchmark economy ($\overline{d} = -0.05$), as well as different forms of financial frictions (columns (4) and (5)). For these different economies, we keep all other parameters the same as in the benchmark model. To help understand more about the impact of financial frictions, we report summary statistics from various different perspectives for the simulated data in the steady state.

First, we compare columns (2) ("less friction") and (3) ("more friction") to the benchmark economy. A few points are worth noting: (1) Quantitatively, we can see when it is more difficult to obtain external finance, the average separation probability in the whole economy increases (from 4.81% to 4.83% and to 5.85%), and the fraction of firms being financially constrained also increases (from 2.49% to 11.14% and to 37.06%). Intuitively, as $\overline{d}$ increases, it becomes more difficult for low-productivity firms to have external finance, firms are more likely to be constrained and set wages at the lower bound. However, this is not desired and wages will be more volatile; Firms have to compensate workers and the firms' value will decrease. Thus, the separation rate for very low productivity firms is higher. (2) For the wage dynamics, we can further look into different sub-samples. For all matched firms and workers, the standard deviation of wage growth increases as $\overline{d}$ increases. For example, for the case with very little financial friction, $\sigma(\Delta w_t)$ is only about 0.42%, much smaller than the benchmark case, while for column (3), $\sigma(\Delta w_t)$ increases to as high as 2.69%. We know the main source for wages not completely smoothed is that firms sometimes are financially constrained. Therefore, we can also look at the average wage growth rate for constrained firms. For those firms being constrained in time t (and not separated), the average wage growth Δw_t is about -1.42% for all firms, -3.97% for those being constrained in time t but not in time $t-1$. Thus, we see that wage drops the most when firms are from being unconstrained to being constrained. The magnitude is large, more than two times of $\sigma(\Delta w_t)$. When the extent of financial frictions are different, this pattern is also very similar.

The costs of financial friction As we can see from above, as financial friction changes, the fraction of firms being constrained and the amount of insurance provided to workers can change a lot. However, if we compare firm values with different frictions, we find the changes are not so large. For example, relative to the benchmark case (keeping z_0 and v_0 the same), with $\overline{d} = -0.10$ the firm value only increases by about 0.19%, and with no external financing at all the firm value only decreases by about 3.07%. Alternatively, if keeping firm values constant in these three cases, the life-time utility provided to a worker ex-ante will be increased by about 0.001% (for the case of $\overline{d} = -0.10$) and will be lowered by about 0.02% (for the case of $\overline{d} = -0.00$). Therefore, as financial friction changes, the distributional impact in the cross-section seems much more important in magnitude as compared to the change of costs ex-ante.

We also inspect with different forms of financial frictions in columns (4) and (5). We assume the external financing limit is increasing (column (4)) or decreasing (column (5)) in firm productivity. Comparing to the benchmark case, we see similar conclusions as before, though the quantitative magnitudes are different: with more generous limits as in column (4) the average separation probability and the fraction of firms being constrained decrease slightly, while the pattern is the opposite for column (5). The standard deviation of wage growth increases as financial frictions increase, and wages still drop substantially when firms transit from being unconstrained to being constrained.

The role of Limited Commitment

In our benchmark model, we assume that neither firms nor workers can commit to the

Table 1: The impact of financial frictions on risk sharing

	(1) Benchmark	(2) $\bar{d} = -0.10$	(3) $\bar{d} = -0.00$	(4) $\bar{d} = -0.05 - 0.05e^z$	(5) $\bar{d} = -0.05 + 0.05e^z$
Avg. Separation (%)	4.83%	4.81%	5.85%	4.80%	4.82%
Being Constrained (%)	11.14%	2.49%	37.06%	11.11%	19.94%
$\sigma(\Delta w_t)$ (%)	1.52%	0.42%	2.69%	1.32%	1.75%
Δw_t for Constrained in t	-1.42%	-1.69%	-1.12%	-1.18%	-1.12%
Δw_t for Constrained in t but not in $t-1$	-3.97%	-2.39%	-3.23%	-3.19%	-2.45%
Δw_t for Constrained in $t-1$ and t	0.18%	0.01%	-0.24%	0.24%	-0.34%

contract. To keep them stay in the current contract, the participation constraints have to be satisfied. What if firms or workers can commit? We change the specifications in Table 2: only firm can commit to the contract (in column 2), that is, we do not have constraint $J(z', v'(z')) \geq 0$ any more; only worker can commit to the contract (in column 3) and the constraint $v'(z') \geq V^U$ is now dropped from the previous optimization problem; and lastly, both parties can commit to the contract (in column 4). To facilitate comparison, we keep other parameters the same as in the benchmark case and the initial promised utility v_0 constant as well.

Intuitively, when workers can commit, a firm with a low productivity shock could potentially choose low values in v', even lower than V^U; otherwise these firms have to provide continuation utility larger than V^U. When firms can commit, a firm with relatively large current promised utility of v could potentially choose high values in v', even if $J(z', v'(z'))$ becomes negative in some states of z'. Thus, for these firms either with low z or with high v, they are less likely to separate; on the other hand, when firms could choose from a wider range of v', it is also possible that these firms are more likely to run into financial constraints and wages will be bounded. In optimal solutions, these different forces are balanced. Inspecting the results in Table 2, we can see: (1) quantitatively, the average separation rates across different economies are very similar; with full commitment from both parties, we find it is slightly lower but magnitude of changes is fairly small (from 4.83% to 4.81%), especially comparing to the changes when we have different levels of financial frictions in previous exercises. This is also the case for the standard deviation of wage growth rates. (2) With full commitment from both parties, the fraction of firms being financially constrained increase slightly, comparing to the benchmark case. Lastly, when firms transit from being unconstrained to suddenly being constrained, the wage drop is still sizable but the magnitude on average is smaller. This reflects the fact that on average firms can provide much better insurance to workers with full commitment. In short, with different specifications on limited commitment, the results are quantitatively similar. Thus, external financial constraint appears to be the most important driving force for wage fluctuations and imperfect insurance between firms and workers.

Table 2: Firm and worker limited commitment

	(1) Benchmark	(2) Only Firm	(3) Only Worker	(4) Both commit
Avg. Separation (%)	4.83%	4.80%	4.83%	4.81%
Being Constrained (%)	11.14%	11.33%	15.15%	14.96%
$\sigma(\Delta w_t)$ (%)	1.52%	1.54%	1.50%	1.49%
Δw_t for Constrained in t	-1.42%	-0.38%	-0.63%	-0.63%
Δw_t for Constrained in t but not in $t-1$	-3.97%	-0.79%	-1.15%	-1.17%
Δw_t for Constrained in $t-1$ and t	0.18%	-0.16%	-0.33%	-0.32%

The role of idiosyncratic productivity

We next inspect the role of idiosyncratic firm productivity on equilibrium risk sharing. This is motivated from previous discussions that firms tend to separate endogenously with extremely low productivity, are more likely to be financially constrained with low z, and will be unconstrained if z is high enough. Therefore, the degree of persistence and the size of idiosyncratic productivity shocks are important for risk sharing. Table 3 reports the results.

When we change the persistence parameter ρ_z to different values (column (2) and (3)), we can see that: when ρ_z increases, both the average separation probability and the fraction of firms being currently financially constrained increase. Intuitively, when the productivity is more persistent, a firm with low z is more likely to have low z in the next period. Therefore, if the firm with low z is constrained this period, it is also likely to be constrained next period and there is not so much improvement. This will affect the average separation probability and the overall probability of being constrained. Specifically, when ρ_z increases from 0.60 to 0.86 and to 0.98, the average separation probability increases from about 3.99% to 4.83% and to 6.13%, respectively. On the other hand, we find $\sigma(\Delta w_t)$ is not necessarily monotone in ρ_z, but wage growth for those firms transiting from being unconstrained to being constrained is still negative and substantial.

For the impact of changes in σ_z^2 on wage dynamics, the results are in columns (4) and (5). In the benchmark we have $\sigma_z^2 = 0.0025$, and now we experiment with a half and two times of that. When σ_z^2 increases, we see that the average separation probability, the fraction of firms being constrained and the standard deviation of wage growth all increase. In short, when idiosyncratic volatility is small, firms can provide much better insurance to workers. But of course, there are still about 10% firms being constrained, and when they are, the wage drops are still large (larger when the size of volatility larger).

Changing outside option V^U and labor market search frictions

Table 3: Risk sharing with different persistence and volatility

	(1) Benchmark	(2) $\rho_z = 0.60$	(3) $\rho_z = 0.98$	(4) $\sigma_z^2 = 0.0025/2$	(5) $\sigma_z^2 = 0.0025 \times 2$
Avg. Separation (%)	4.83%	3.99%	6.13%	4.35%	5.84%
Being Constrained (%)	11.14%	6.50%	17.65%	10.99%	20.17%
$\sigma(\Delta w_t)$ (%)	1.52%	1.12%	0.47%	0.79%	2.36%
Δw_t for Constrained in t	-1.42%	-2.01%	-0.48%	-0.53%	-1.43%
Δw_t for Constrained in t but not in $t-1$	-3.97%	-2.98%	-1.56%	-1.03%	-4.03%
Δw_t for Constrained in $t-1$ and t	0.18%	-0.06%	0.00%	-0.19%	0.15%

In our model, matched workers have outside option in V^U, and firms have to provide higher continuation utility v' to keep workers staying in the contract. What is the impact of changes in V^U on risk sharing between firms and workers? We conduct some experiments here to illustrate the impacts. Since V^U is an equilibrium object in the model, we can not treat it as exogenous parameters. To make the exercise more clear, we change the value of V^U by about 1% (lower V^U in column (2) and higher V^U in column (3)) (say, due to exogenous changes in unemployment benefit b) and simulate a panel of matched firms and workers; Other parameters are the same and the initial promised utility v_0 are also the same. Similarly, we also change the magnitude of search and matching friction parameter, c_M, by 10% smaller in column (4) and 10% larger in column (5); all these changes will affect the outside options for the matched pair. A few points are worth noting: (1) On the one hand, when V^U is lower, to deliver the same promised utility the firm has to provide higher expected continuation utility comparing to the benchmark case; this will cause current matches are more likely to be constrained. On the other hand, when V^U is lower, a firm with a low productivity shock could potentially use a lower value of v' in that particular state. Thus, these low-z firms could face less constraint. Quantitatively, across different economies, the average separation probability does not change so much in a meaningful pattern, but the fraction of firms being constrained could vary a lot. In particular, when V^U is lower or the job finding probability is lower, more firms are constrained. (2) Also, we find that the standard deviation of wage growth increases when the fraction of firms being constrained increases, and the wage drop for firms being suddenly constrained is still substantial. Overall, it appears that the impact of changing workers' outside options may work through different channels and may not have monotonic effects. However, with different experiments, we still see that external financial friction is important in driving wage fluctuations and imperfect insurance, and it will interacts with other frictions endogenously.

Table 4: Risk sharing: different V^U and different search frictions

	(1) Benchmark	(2) Lower V^U	(3) Higher V^U	(4) Lower $f(\theta)$	(5) Higher $f(\theta)$
Avg. Separation (%)	4.83%	4.81%	4.82%	4.88%	4.83%
Being Constrained (%)	11.14%	19.83%	14.37%	20.12%	11.29%
$\sigma(\Delta w_t)$ (%)	1.52%	1.71%	3.36%	1.55%	1.54%
Δw_t for Constrained in t	-1.42%	-1.19%	-0.83%	-0.22%	-1.50%
Δw_t for Constrained in t but not in $t-1$	-3.97%	-2.67%	-2.94%	-0.42%	-3.81%
Δw_t for Constrained in $t-1$ and t	0.18%	-0.33%	0.24%	-0.17%	0.08%

2.6 Transitional dynamics

Lastly, we can also use the model to study the impact of the Great Recession and Financial Crisis on the risk sharing between firms and workers. It is widely recognized that the US has experienced a large negative shock in the financial market around 2008-2009 (e.g., see Gilchrist et al. (2013), Caldara et al. (2016)), and this may impact the firms' ability to provide insurance to workers. To do so, we assume the model economy starts from its steady state; we then shock the economy starting from time 2 with both aggregate productivity shocks in X_t and external financial shocks in $\bar{d}_t$. This is an one-time, "MIT" type shock. Admittedly, this is a simple way of utilizing the model to mimic the exogenous shocks starting from 2007Q4. Since in the data, we can directly observe aggregate labor productivity[19], we chose a time series close to the data as the model input (as shown in Figure 11 panel (a) in the appendix). For Financial shock, we do not observe it in the data but we can observe credit spreads in the data[20]; we then chose a time series of $\bar{d}_t$ in the model, so that the model implied average external financial premium is fairly close to the data (see Figure 11 panel (b) in the appendix).

For the transitional analysis, we solve it using backward induction. For the details of numerical computation, see the appendix. Along the transitional path, there are three important aggregate variables: the market tightness θ_t, unemployment rate u_t, and the value of being unemployed $V^U(S_t)$. Note that θ_t is determined by the free-entry condition, while the dynamics of u_t and $V^U(S_t)$ are given by:

$$\begin{aligned} u_{t+1} &= (1-u_t) \times \int \left[(1-\delta)\rho(z,v)+\delta\right]\mu_t(z,v) + u_t(1-f(\theta_t)) \\ V^U(S_t) &= u(b) + \beta E_t\left[(1-f(\theta_{t+1}))V^U(S_{t+1}) + f(\theta_{t+1})v_{0,t+1}\right]. \end{aligned}$$

[19]Data source: Federal Reserve Bank of St. Louis; See the link: "https://fred.stlouisfed.org/series/LABSHPUSA156NRUG#0".

[20]Moody's Seasoned Baa Corporate Bond Yield Relative to Yield on 10-Year Treasury Constant Maturity; Data source: Federal Reserve Bank of St. Louis.

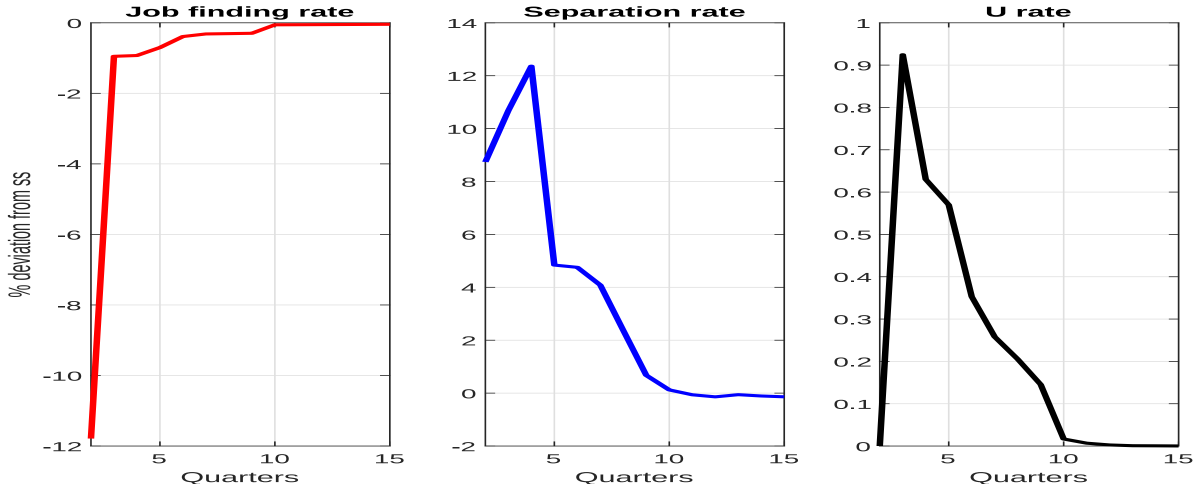

Figure 7: Dynamics of Job finding rate, Separation rate, and Unemployment rate

In Figure 7, we first plot the responses of the aggregate variables.[21] On impact, the job finding rate drops about 12%, and the endogenous separation rate increases by about 0.35 percentage points relative to its steady state, and implied unemployment rates jump on impact from 6.5% to about 7.2%.[22]

Distributional impact

We then look at wage dynamics and firm insurance in the cross-section along the transitional path. In the transition, we focus on the dynamics in the first 10 quarters since after that the model economy almost returns to its steady state. In Figure 8 we first show the distributions for wage growth and productivity growth among constrained firms and unconstrained firms separately in the transition. Evidently, we see that wages are much more smoothed in financially unconstrained firms, even though the distributions for productivity growth are more or less similar across these two groups.[23] Also, financially constrained firms are more likely to have cuts in current wages when productivity drops.

In Table 5 we report some summary statistics. During transitions, the separation probability increases, from steady state value of 4.83% to about 5.08% on average in the first 10 quarters. We also find that the fraction of firms being constrained by external financing is more than twice of the corresponding value in the steady state. Also, firms'

[21]We plot the percentage deviations from the corresponding steady state values; for unemployment rates u_t, following much of the convention we just plot the changes.

[22]We also conduct several sensitivity analyses; all the results are available upon request and contained in the previous version of the working paper (sections 2.5 and 2.6). In particular, we show that - although not the focus of this paper - with higher unemployment benefit parameters b, there could be more amplification for the aggregate shocks and the unemployment rates could increase to almost 9% in the peak. This is consistent with the insight from Hagedorn and Manovskii (2008).

[23]Note that in the computation, productivity process is discrete, and productivity growth is also discrete.

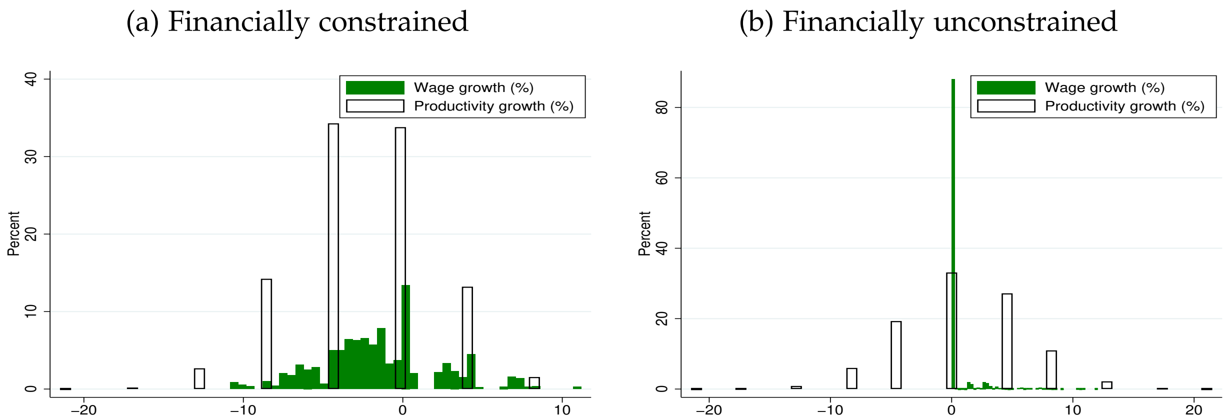

Figure 8: Distribution for Firms and workers in the transition dynamics

ability to provide insurance to workers is limited: (1) in Figure 9, we can intuitively see that, financially constrained firms are more likely to have larger cuts in wages and also in the continuation values of v in the dynamic contracts. That is, when firms experience those unfavorable states along the transition path, the optimal contracts suggest reduction in wages and promised utility. (2) the standard deviation of wage growth (conditional on not being separated) increases from the steady state value of 1.52% to about 2.36%. Recall that the standard deviation of innovations in idiosyncratic productivity is about 5%; or, the increased volatility in wage growth is about 16% of volatility in productivity. Thus, this reduction of risk sharing during the transition, is large and economically important.

Focusing on the group of firms that are currently financially constrained, we can see their average productivity (the component of z) is about 0.91, almost 4% higher than the corresponding steady state value. That is, during the transitions with more severe financial shocks, more firms are constrained, even though some of them are with relatively high productivity and are not constrained in the steady state. Conditional on being constrained in the current period, there are also more firms continuously being constrained. Lastly, for wage growth, constrained firms have wage cuts at about 1.56%, similar to those changes in a steady state. For those firms transiting from being unconstrained in period $t-1$ to being constrained in period t, the wage drop is still sizable, on average at about 3.71%. Comparing to the steady state, the magnitude of drops is slightly smaller for these particular group of firms; this may reflect the fact that external financing limits are tighter during transitions and wages are bounded for these constrained firms.

Overall, we find that during transitions firm insurance is reduced, and mostly this is because more firms (and workers) in the cross-section are becoming financially constrained at the extensive margin; within the group of financially constrained firms,

Table 5: Transition analysis: Wage dynamics and firm insurance

	(1) Transitions	(2) Steady state
Avg. Separation (%)	5.08%	4.83%
Being Constrained (%)	25.9%	11.8%
$\sigma(\Delta w_t)$ (%)	2.36%	1.52%
For those Constrained in t		
Avg. productivity of z	0.91	0.88
Fraction of Constrained in t but not in $t-1$	58.3%	61.4%
Fraction of Constrained in $t-1$ and t	41.7%	38.6%
Δw_t for Constrained in t	-1.56%	-1.42%
Δw_t for Constrained in t but not in $t-1$	-3.71%	-3.97%
Δw_t for Constrained in $t-1$ and t	-0.03%	0.18%

(a) Growth in wages

(b) Growth in continuation values of v

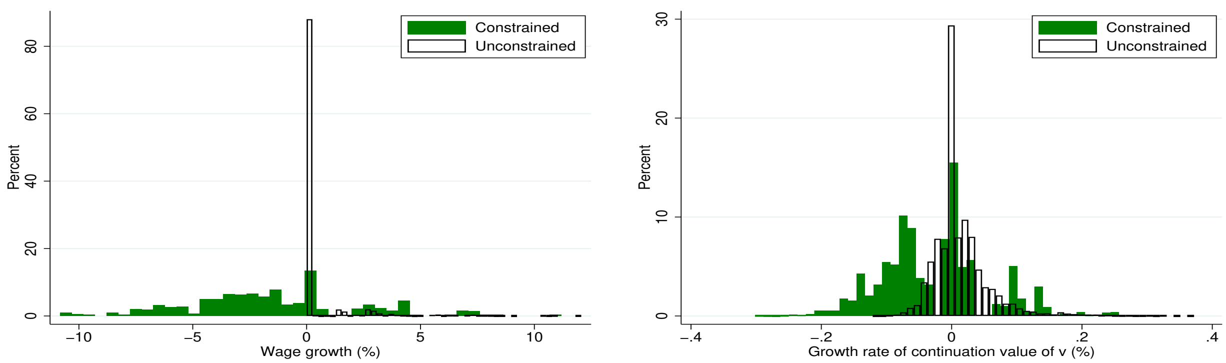

Figure 9: Distribution for Firms and workers in the transition dynamics

the wage changes are similar to those patterns in a steady state. Thus, the distributional impact during transitions is significant and important, and this is typically not studied extensively in the literature.

3 Supportive Empirical Evidence

Based on previous analysis, we see that when the degree of financial market friction increases, the insurance provided by firms will decrease and the standard deviation of wage growth will increase. When firms are suddenly being constrained, wages typically fall. Here we provide several pieces of empirical evidence that are consistent with the model's implications.

In Guiso et al. (2013), they exploit the variations in the degree of local credit market developments and matched employer-employee data from Italy (1990-1997) to assess the role of the firm as an internal credit market. In particular, they find that firms operating in less financially developed markets offer lower entry wages but faster wage growth than firms in more financially developed markets. This helps firms finance their operations by implicitly raising funds from workers. This observation is consistent with our quantitative model's implications in the steady state: for example, see the left panel in the Figure 6 and the discussions there. Unfortunately, Guiso et al. (2013) focuses more on the long-run effects of financial market developments; for studying the effect of financial shocks on firm insurance over the business cycles, to our best knowledge it is very limited, if it exists at all.

Compustat Data in the Great Recession Based on the model simulations, we can see that the insurance for workers is more limited in the Great Recession period. Naturally, we would like to see whether this is consistent with empirical fact. A very simple check is to look at changes in wages relative to changes in productivity at firm level, by regressing Δw_t on Δz_t. Full insurance implies the coefficient should be 0 and no insurance implies 1. To check this empirically, we need data on both measures of firm productivity and worker wages. The best publicly available data, perhaps, is the Compustat data for all US public firms. To be close to the model as much as possible, in the Compustat data we define firm productivity as value added per employee, and define wage as the average wage for all employees (see the Appendix for more details). The results are in Table 6. The estimated coefficient is 0.202 for the periods 2007 to 2012, and 0.167 for periods before 2007 (both estimates are significant at 1%). Thus, the degree of insurance is reduced in the great recession period. Admittedly, Compustat data is not perfectly ideal for our purpose.[24] Nevertheless, this finding is still consistent with our model's implications (the corresponding estimates from the model simulation data are 0.169 for the transitions and 0.097 for the steady state).

[24]The Compustat data we use is limited: we can only observe the average wages and we are not able to control for individual workers characteristics; the value added is not measured precisely, since Compustat does not report the value of intermediate goods used; it is only for public firms, which are relatively large and not nationally representative. Nevertheless, we still find a consistent message for the model implications.

Model Data:			
	2007 to 2010	**Steady state**	**Difference**
Δz	0.169***	0.097***	0.072
	(0.000)	(0.000)	
Adj. R-squared	0.247	0.226	

Compustat Data			
	2007 to 2010	**before 2007**	**Difference**
Δz	0.202***	0.167***	0.035
	(0.000)	(0.000)	
Adj. R-squared	0.107	0.054	
Alternative measure of w**:**			
Δz	0.163**	0.143***	0.02
	(0.001)	(0.000)	
Adj. R-squared	0.074	0.042	

Table 6: Comparing insurance in the model and in the data; Regressing $\Delta w_{t-1,t}$ on $\Delta z_{t-1,t}$

3.1 Supportive Empirical Evidence from SIPP Data in the Great Recession

Brief introduction

The model in the previous section implies that, when firms help insure workers, in normal times they can provide almost full insurance and wages are smoothed; however, when there are large financial shocks, firms may be constrained and can only provide limited insurance to workers. One implication is that when firms are more likely to be financially constrained, workers' earnings are reduced. In this section we further find supportive evidence from the Great Recession in the US from a household survey data.

3.1.1 Empirical data and strategy

Household Survey Data

We use the micro-level workers' data from the Survey of Income and Program Participation (SIPP) in the US. SIPP data is a large, nationally representative panel data from household surveys with monthly frequencies for most of the variables that we need. In the data, we can observe each worker's demographic information, household and family variables, and labor-market variables. For instance, we know workers' monthly employment status, total earnings, working hours, employers' IDs, workers' industry/occupation/job tenure, the employer's size at the working place, union coverage, etc. Though our main econometric analysis below uses the 2008 panel of SIPP data (from May 2008 to December 2013), we also use the 2001 and 2004 panels for additional analysis and robustness checks. For sample selection, construction, and for definitions of variables in the SIPP data, please see the data appendix for more information.

External Financial Dependence Data

To measure firms' likelihood of facing financing constraint, we follow the idea in Rajan and Zingales (1998) and many others (e.g., see Beck et al. (2005), Hurst and Lusardi (2004), Bekaert et al. (2005), Brown et al. (2009), Manova (2012), Duygan-Bump et al. (2015), etc.): production technology is quite different across industries and sectors, and consequently, the needs for external finance are quite different. For instance, different industries could differ substantially on the extent of the initial project scale, the gestation period, the cash harvest period, and the financing requirement for continuing investment.

Specifically, we use the data from Duygan-Bump et al. (2015) and measure industry-level financial dependence using mature firms from Compustat data from 1980-1996. Mature firms are those firms that are going public and have been on Compustat for at least 10 years. Financial dependence is measured as the proportion of physical capital expenditures financed by external funds (external debt finance and external equity finance) at the two-digit SIC level. Typically, these mature firms face much less financing difficulty when compared to other small and medium firms or private firms. Therefore, this external financial dependence measure largely reflects the nature of different production technology and thus quasi-exogenous variation in financing needs across industries. Since SIPP 2008 panel uses the 2002 Naics coding system, we then use the mapping between SIC code and 2002 Naics coding.[25] In cases where some three-digit naics industries are not mapped well with two-digit SIC data (about six cases in total), we manually assign the value of financial dependence from its closet neighboring industries according to the details of industry descriptions.[26]

Data Summary

Table 8 summarizes workers' demographic and labor market information in the 2008 panel. On average, workers have monthly real earnings of about 2300 dollars (2008

[25]See the link: "https://www.census.gov/eos/www/naics/concordances/concordances.html".

[26]The details can be found here: "https://www.census.gov/cgi-bin/sssd/naics/naicsrch?chart=2002".

constant dollars). Note that this measure includes those workers with possibly very small earnings, and there is a large variation across the sample. For total working hours per month, the average number is 170 hours and the standard deviation is close to 50. Hourly real wages also vary a lot, with a standard deviation of 28 dollars and possible maximal of 5000 dollars. Finally, about 60% of the workers are employed by small firms, and later on we will compare the differential impact of financial shocks across small and large firms.

Tables 9 provide more details related to the measure of financial dependence. In Table 9, as an illustration, we present about 20 three-digit industries for each category of financial dependence measures: the lowest level, medium level and the highest level of financial dependence, to let readers have a sense about these industries. For instance, for three-digit industries like Oil and gas extraction, Hardware stores, Air transportation, Building material and supplies dealers, the Compustat data shows that on average, firms in these industries have about 40% of capital expenditures relying on external finance; some other industries rely even more on external finance, such as Coal mining, Construction, Household appliance stores, and Pipeline transportation. On the other hand, we can also see that industries like Footwear manufacturing, Tobacco manufacturing, Apparel accessories and other apparel manufacturing, and Banking and related activities have a large fraction of liquid assets at hand and do not rely on external finances for investment expenditures. Roughly, 13% of the sample workers have the highest level of financial dependence, and 62% of the sample workers have a medium level of financial dependence.

3.1.2 Econometric Analysis

The sample we used is at monthly frequency. For regression, it is restricted to job stayers, namely those workers who continuously work for the same employer, are salaried workers or paid hourly. Furthermore, for each worker we only use the data point from the last month of each wave (the month in which the respondent is surveyed) so effectively workers are observed every four months.

Our main econometric specification is as follows:

$$\begin{aligned} Log(E)_{i,t} \quad = \quad & \alpha_i + \beta_1 \mathbb{I}\{Highest\ Financial\ Dependence\}_{i,t} \times U.rate_t \\ & + \beta_2 \mathbb{I}\{Medium\ Financial\ Dependence\}_{i,t} \times U.rate_t \\ & + \beta_0 U.rate_t + \delta\ Individual\ Controls_{i,t} + \epsilon_{i,t}, \end{aligned} \qquad (1)$$

where E is the real earnings, i is for individual worker, t is time index, and α_i is the unobserved individual fixed effect. We include the monthly, national unemployment rate

$U.rate_t$, individual demographic and labor market variables $Individual\,Controls_{i,t}$, and Industry dummy variables. We also cluster the standard errors at the industry level.

With the above specification, we are mostly interested in the coefficient β_1 and β_2. While β_0 captures the traditional cyclicality of worker earnings across business cycles, β_1 captures the extra cyclicality if the worker works for a firm with the highest level of external financial dependence, relative to our benchmark category (workers with the lowest level of external financial dependence). Similarly, β_2 measures the extra cyclicality for workers with medium level of financial dependence.

Our empirical strategy is to exploit the exogenous variation in financial dependence across three-digit industries. As introduced before, the financial dependence measure is arguably exogenous, and likely reflects the nature of production across industries. In addition, around the 2008 financial crisis period, it is well known that the US credit markets had experienced a large, nation-wide, negative shock in credit supply (among others, see Gilchrist and Zakrajšek (2012)). One example is the credit spreads, as shown in Figure 12, where we can see that evidently there was a big spike during the recession period. Therefore, we can plausibly study the differential impact of financial shocks across industries during the financial crisis period.

3.1.3 Results

Basic results

Table 10 and Table 11 report the results for real, monthly earnings for the 2008 sample. In Table 10, we follow the fixed-effect specification as described above. Column (1) is without control variables for individual characteristics. Column (2) adds demographic controls, and Column (3) further adds tenure for the current job. The results show that real earnings on average move negatively with unemployment rates with a semi-elasticity of -0.6. For industries with the highest level of financial dependence, the real earnings have an extra semi-elasticity of about -1.1 with respect to the national unemployment rate. The results are robust and statistically significant at 1% level. For industries with the medium level of financial dependence, we actually do not find a significant extra cyclicality for real earnings. The results are plotted in Figure 10 to illustrate intuitively.

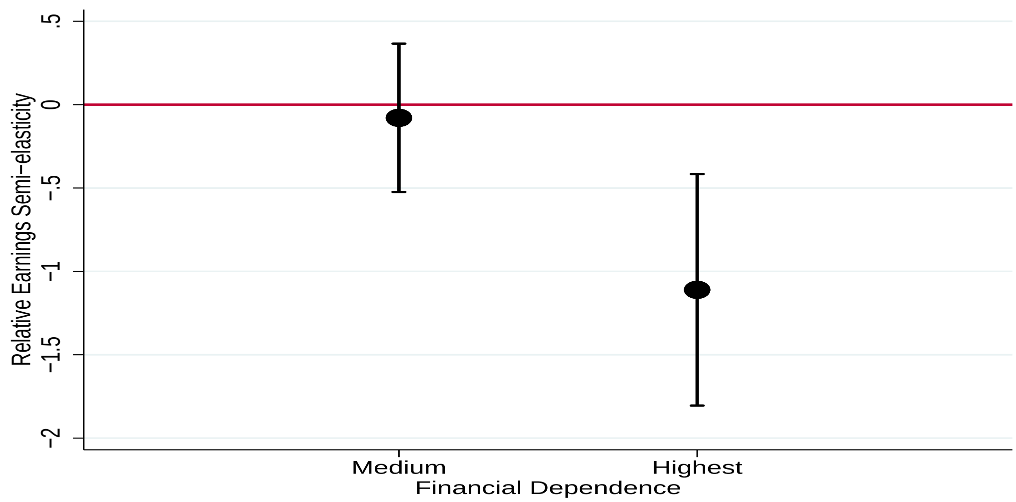

Figure 10: Earnings changes across different industries

In the literature (e.g., see Bils (1985) and Gertler et al. (2016)), sometimes the method based on first difference is used. In Table 11 we show our results are robust to either approach. For instance, in Column (1) and (2) we use the changes in log earnings, $\Delta Log(Real\ Earnings)_{i;t,t-4}$, and use an OLS regression for analysis (please see the Table notes for more information on the specification); in Column (3) and (4) we still use the changes in log earnings, but use a fixed-effect econometric specification. The results are significant and quite consistent with the previous findings by using levels of real earnings. Thus, across these results, we find that for job stayers in industries with the highest level of financial dependence, the real earnings on average decrease by about 1% more if the national unemployment rate increases by one percentage point, relative to the benchmark category workers. These results are also intuitively illustrated in Figure 13 in the appendix.

Robustness and Heterogeneity

We also divide workers by different characteristics and examine the differential impact of the Great Recession. We find our results are quite robust: in Figure 14 in the appendix, for the most vulnerable firms, workers without college degrees on average have earnings reduced more than do college workers. We also find workers with more job tenure tend to reduce earnings more in the industries with more financial dependence (Figure 15); Low-earnings workers also reduce earnings more if they work for the most vulnerable firms (Figure 16); Workers with different ages have similar responses (Figure 17); workers in small firms clearly have earnings reduced (Figure 18), while for workers in large firms, the earnings are also reduced but the responses are more dispersed.

Further analysis: Comparing different groups of workers

In Table 12, we explore the heterogeneity among workers and the dynamics for earnings. We find additional intuitive and supportive evidence. (1) In industries with higher levels of external financial dependence, ordinary workers have more real earnings reduced, but we do not find such a pattern for managers. This suggests the labor demand and supply for ordinary workers is quite different from that for managers - perhaps it is intuitive to see that, individual, ordinary workers do not have much say in the process of negotiating earnings and hours. (2) We compare workers covered by labor/industry unions to those not covered. The drop in earnings for union workers in vulnerable industries is only mild, and not as severe as it was for other workers during the 2008 recession. (3) We also compare workers in private and for-profit firms with others working for public sectors/non-profit institutions or organizations. Plausibly, the latter group will be less affected by the credit supply shocks during the Great Recession. Indeed, we do not find the latter group has significant earnings reduced, and the comparison between the two groups is quite stark.

Further analysis: Extensive margin analysis

Lastly, we analyze the extensive margin in the labor market. Previous analysis only focused on the intensive margin, namely job stayers' earnings. One would naturally ask that if our index for external financial dependence measure indeed helps us capture the differential exposure to financial shocks, then we should also observe some implications at the extensive margin. That is our objective here. In SIPP 2008 panel data, we can look at the probability of an employed worker transitioning to not being employed, or the so called "lay off" probability, and we focus on the time period from the beginning of the sample up to the trough of the recession (June 2009). In addition, we further explore another dimension of heterogeneity across firms: small firms vs. large firms. The fact that small firms are financially more vulnerable and more likely to face liquidity constraints than large firms has been stressed frequently in the literature of financial frictions since at least Gertler and Hubbard (1989), Gertler and Gilchrist (1994) and also Whited and Wu (2006). Recently, Gilchrist et al. (2012), Chodorow-Reich (2014), and Hadlock and Pierce (2010) use different detailed data sets,[27] and found that in the 2008 financial crisis smaller firms indeed faced higher borrowing costs and/or more limited credit.

In Table 13 we report the results for different specifications. In Column (1) we only use the dummy variable for external financial dependence, and in Column (2) we have a full interaction between the two dummies for firm size and for external dependence (for

[27] Gilchrist et al. (2013) use firm-level borrowing costs, Chodorow-Reich (2014) use matched bank-firm data, and Hadlock and Pierce (2010) use survey data.

the sake of space, we only report some coefficients). In Column (3) we add more control variables for workers, and in Column (4) we include those workers not being employed, both in and out of labor force participation.

The results show that: (1) on average, firms with higher external financial dependence were more likely to fire workers during the 2008 recession. This is consistent with other empirical studies, such as Chodorow-Reich (2014) and Duygan-Bump et al. (2015). In terms of magnitude, for an increase of 1 percentage point in unemployment rate, the extra probability to be laid off is about 17% higher monthly if a worker works for the most vulnerable firms. (2) When using the information from firm sizes, we can see small firms in industries with the highest level of financial dependence will likely lay off more workers, relative to the benchmark group. Overall, these messages are consistent, and provide a more complete picture for the differential impact of financial shocks across firms in the labor market.

Summary

Overall, by exploiting the exogenous variation in external financial dependence across disaggregated industries and through numerous exercises, we find that: (1) financial shocks could have quite differential impact across different industries. (2) A robust message is that, with a large negative shock in credit supply during the 2008-9 Great Recession, for an increase in the national unemployment rate by 1 percentage point, workers in industries with the highest level of external dependence had their earnings reduced by an extra about 1%. Overall, the empirical findings are consistent with our model implications.

4 Concluding remarks

We explore the idea that firms try to diversify earnings risk for workers, but firms themselves may be subject to financial constraints and face large financial shocks (and with other aggregate shocks), such as during the Great Recession period. What is the impact of financial shocks on the risk sharing between firms and workers? This paper investigates, both empirically and quantitatively, that firms provide insurance to workers, but firms are heterogeneous and are possibly financially constrained. We build a new, structural model, featuring risk-neutral firms posting long-term contracts to workers and firms facing financial shocks. We also embed firm insurance into an equilibrium search and matching framework. The risk sharing implied in the model is substantial but limited, consistent with existing empirical findings. We show that, both in the steady state and during the transitions, external financial friction is crucial for limited risk sharing. We also find that the distributional impact of financial shocks during the Great Recession is significant and important - typically not studied extensively in the search and matching business cycle literature.

For future research, there are several related directions that would be interesting to explore: (1) if more micro-level data, especially matched employer-employee data for the US, is available, one could study in detail how the wage dynamics is affected in the Great Recession period or in other periods with aggregate shocks, and what is the role of financial frictions in limiting risk sharing. Unfortunately, in this paper, our empirical analysis is admittedly limited. (2) This paper abstracts away from workers' consumption and saving; one could study, empirically and quantitatively, how (limited) firm insurance impacts workers' choices (e.g., see Fagereng et al. (2017) for uninsurable wage risk and households' financial portfolio choices). (3) We also abstract away from policy implications. In general, it is possible to study the impact of redistributional policies and public insurance policies for unemployment in the context of firms providing insurance to workers (see, e.g., Lamadon (2016)).

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Appendices

A Model Analysis

J is concave in v

First, with the assumption that productivity are finite, $z \in Z = \{z_1, ..., z_N\}$ and $X \in \{X_1, ..., X_N\}$, we can define a bounded domain for v: $v \in V \subset [\frac{u(b)}{1-\beta}, \frac{u(e^{zmax+Xmax})}{1-\beta}]$. We can inspect the properties of J . First, J is bounded, since $d \leq e^{z_{max}+X_{max}}$, $d \geq \bar{d}$ and $\beta(1-\delta) < 1$. Second, we want to apply the standard contraction mapping theorem (Stokey et al. (1989)) by showing the properties of monotonicity and discounting. Denote the functional mapping as $\Gamma(J)$:

$$
\begin{aligned}
\Gamma J(z, v; S) \quad &= \quad Max_{\{w,d,v'(z',S')\}} \\
&\quad\quad d + \beta(1-\delta)E(1-\rho(z', S'))J(z', v'(z', S'); S') \\
s.t. \quad &: \\
&\quad\quad -v + u(w) + \\
&\quad\quad \beta E\left\{\left[(1-\delta)\rho(z', S') + \delta\right] V^U(S') + \left[(1-\delta)(1-\rho(z', S'))\right] v'(z', S')\right\} \geq 0, \\
&\quad\quad e^{X+z} - w - d \geq 0, \\
&\quad\quad d - \bar{d} \geq 0, \\
&\quad\quad J(z', v'(z', S'); S') - J^{Out}(S') \geq 0, \text{ if } \rho(z', S') = 0 \\
&\quad\quad v'(z', S') - V^U(S') \geq 0, \text{ if } \rho(z', S') = 0
\end{aligned}
$$

Suppose we have two functions, $J_1 \leq J_2$, then we can see the optimal plan for $\Gamma(J_1)$ $(z, v; S)$ is also feasible for the optimization problem of $\Gamma(J_2)$ $(z, v; S)$. $J_1 \leq J_2$ gives us that $\Gamma(J_1)$ $(z, v; S) \leq \Gamma(J_2)$ $(z, v; S)$. Also, for $\Gamma(J + c)$ with some constant function c, we can see $\Gamma(J + c) \leq \Gamma(J) + \beta(1-\delta)c$ with $\beta(1-\delta) < 1$. Therefore, we have the existence of J. Second, to show the concavity, first, assume J is concave and we can show that the mapping $\Gamma(J)$ is concave as well. For any given z and any given $v_1 < v_2$, denote the optimal plan as $\pi^{(1)}$and $\pi^{(2)}$, respectively. For any α between 0 and 1, denote $\widehat{v} = \alpha v_1 + (1-\alpha)v_2$. We would like to show $\Gamma J(z, \widehat{v}; S) \geq \alpha \Gamma J(z, v_1; S) + (1-\alpha)\Gamma J(z, v_2; S)$. We first check that the convex combinations of $\pi^{(1)}$and $\pi^{(2)}$, with $\widehat{w} = \alpha w_1 + (1-\alpha)w_2$, $\widehat{d} = \alpha d_1 + (1-\alpha)d_2$, $\widehat{v'(z', S')} = \alpha v'(z', S')_1 + (1-\alpha)v'(z', S')_2$, is also feasible for $(z, \widehat{v})$: (1) the concavity of utility function $u(w)$, and the linearity of v' make sure the promise-keeping condition is satisfied; (2) since the firm's budget constraint, finance constraint, and worker participation are all linear in their corresponding arguments, so the convex combination is also feasible; (3) lastly, since we assume J is concave, so $\widehat{v'(z', S')}$ also satisfies the firm's participation constraint. Therefore, the convex combination is feasible but not necessarily the optimal solution. This leads to the conclusion that $\Gamma J(z, \widehat{v}; S) \geq \alpha \Gamma J(z, v_1; S) + (1-\alpha)\Gamma J(z, v_2; S)$. By standard arguments as in Stokey et al. (1989), we know the contraction mapping gives a concave function J and uniqueness of J. Numerically, we can also see the graph for J in the body text. ■

J is strictly decreasing in v

To show that J is strictly decreasing in v, fix z and pick up v_1 and v_2 such that $v_1 < v_2$ in the interior of V. Denote the optimal plan for v_2 as $\{w(v_2), d(v_2), v'(z', S')(v_2)\}$. Since this plan can deliver v_2 to the worker, we can base on this plan and find a new feasible plan for the optimization problem of z, v_1: reduce $w(v_2)$ slightly by Δ and increase $d(v_2)$ by Δ, and keep all the continuation utilities unchanged; Δ is chosen so that $v_2 - v_1 = u(w(v_2)) - u(w(v_2) - \Delta)$ with Δ is strictly positive. It's easy to check that this plan is feasible for the optimization problem of z, v_1 but not necessarily the best; therefore, $J(z, v_1) \geq J(z, v_2) + \Delta$.■

J is Differentiable in v

Moreover, we can show that J is differentiable at $intV$ under some conditions, and this property can enable us to use first order conditions. To show it is differentiable, we want to apply the results in Benveniste and Scheinkman (1979). We do it in two steps.

Step 1:

First, for the largest productivity level, $z^{\max}$,and with the domain for $V = [v^{\min}, v^{\max}]$ such that $z^{\max}$ is large enough and $v^{\max}$ is not too large, we can first show $J(z^{\max}, v)$ is differentiable at the interior of V. To do so, the basic idea is to construct a new function, defined in the interior of V, concave and differentiable, dominated by $J(z^{\max}, v)$ and coincides with J at some point. To do this, take a small interval $[v_1, v_2]$ in the interior of V and contains some point v_0. Denote the optimal solution for $(z^{\max}, v_0)$ as $\{w(v_0), d(v_0), v'(z', S')(v_0)\}$.We can find a small enough $\epsilon > 0$ such that $(v_0 - \epsilon, v_0 + \epsilon) \subset [v_1, v_2]$. Define a new function $G(v)$ over the domain $(v_0 - \epsilon, v_0 + \epsilon)$ in the following construction. For $\forall v \in (v_0 - \epsilon, v_0 + \epsilon)$, first define a new wage $w(v)$ such that

$$v = u(w(v)) + \beta E \left\{ \left[(1-\delta)\rho(z', S') + \delta \right] V^U(S') + \left[(1-\delta)(1-\rho(z', S')) \right] v'(z', S')(v_0) \right\},$$

That is, the continuation utility part is the same as the optimal plan under v_0.Define $G(v)$ as:

$$G(v) \equiv e^{X+z} - w(v) + \beta(1-\delta)E(1-\rho(z', S'))J(z', v'(z', S')(v_0); S').$$

Note that for $\forall v \in (v_0 - \epsilon, v_0]$, since $d(v_0) \geq \bar{d}, w(v) \leq w(v_0)$, so $e^{X+z} - w(v) \geq e^{X+z} - w(v_0) = d(v_0) \geq \bar{d}$. Thus the firm's budget constraint and the external financing constraint are all satisfied; For $\forall v \in (v_0, v_0 + \epsilon)$, if the dividend constraint is not binding at v_0, $d(v_0) > \bar{d}$, then for small enough $\epsilon, e^{X+z} - w(v) = e^{X+z} - w(v_0) - O(\epsilon) = d(v_0) - O(\epsilon) > \bar{d}$. In the numerical exercise, we always make sure that $z^{\max}$ is large enough and $v^{\max}$ is not too large, so that the dividend constraint is not binding for $z^{\max}$. Thus, we have the $G(v)$:

$$\begin{aligned} G(v_0) &= J(z^{\max}, v_0), \\ G(v) &\leq J(z^{\max}, v), \text{ for } \forall v \in (v_0 - \epsilon, v_0 + \epsilon), \end{aligned}$$

where $G(v) \leq J(v)$, for $\forall v \in (v_0 - \epsilon, v_0 + \epsilon)$, since the plan of $\{w(v), e^{X+z} - w(v), v'(z', S')(v_0)\}$ is feasible for the optimization problem of $J(z^{\max}, v_0)$ but not necessarily optimal. By applying Lemma 1 in Benveniste and Scheinkman (1979), we can establish that $J(z^{\max}, v)$ is differentiable at the interior of V.

Step 2:

For other levels of z, we proceed similarly but with the construction of a different $G(v)$. Fix any z. Again, take a small interval $[v_1, v_2]$ in the interior of V and contains some point v_0. Denote the optimal solution for (z, v_0) as $\{w(v_0), d(v_0), v'(z', S')(v_0)\}$.We can find a small enough $\epsilon > 0$ such that $(v_0 - \epsilon, v_0 + \epsilon) \subset [v_1, v_2]$. Define a new function $G(v)$ over the domain $(v_0 - \epsilon, v_0 + \epsilon)$ in the following construction. For $\forall v \in (v_0 - \epsilon, v_0 + \epsilon)$, first define a feasible plan for the optimization problem of $J(z, v_0)$ as follows: $\{w(v_0), d(v_0), v'(z', S')(v_0)_{z' \neq z^{\max}}\}$ are the same as the optimal plan for $J(z, v_0)$; but for $z^{\max}$, the continuation utility is $(v'(z^{\max}, S') + \Delta)$, which is different from $v'(z^{\max}, S')$ by Δ. $\Delta(v)$ is chosen so that the promise-keeping condition is always satisfied:

$$\begin{aligned} v = \; & u(w(v_0)) + \beta\pi(z, z^{\max}; S, S') \times \\ & \left\{ \left[(1-\delta)\rho(z^{\max}, S') + \delta \right] V^U(S') + \left[(1-\delta)(1-\rho(z^{\max}, S')) \right] \left(v'(z^{\max}, S') + \Delta \right) \right\} \\ & + \beta \sum_{z' \neq z^{\max}} \pi(z, z'; S, S') \times \\ & \left\{ \left[(1-\delta)\rho(z', S') + \delta \right] V^U(S') + \left[(1-\delta)(1-\rho(z', S')) \right] v'(z', S')(v_0) \right\}, \end{aligned}$$

When $v = v_0$, $\Delta = 0$ of course. For small enough ϵ, Δ is also small enough so that the firm's participation constraint is always satisfied. Therefore, this plan is feasible for the optimization problem of $J(z,v)$ but not necessarily optimal. Now we are ready to define $G(v)$ as:

$$
\begin{aligned}
G(v) \quad \equiv \quad & e^{X+z} - w(v_0) + \beta(1-\delta)\pi(z, z^{\max}; S, S') \times \\
& (1-\rho(z^{\max}, S'))J(z^{\max}, v'(z^{\max}, S') + \Delta(v)); S' \\
& \beta(1-\delta) \sum_{z' \neq z^{\max}} \pi(z, z'; S, S')(1-\rho(z', S'))J(z', v'(z', S')(v_0); S'),
\end{aligned}
$$

It's also easy to check that

$$
\begin{aligned}
G(v_0) &= J(z, v_0), \\
G(v) &\leq J(z, v), \text{ for } \forall v \in (v_0 - \epsilon, v_0 + \epsilon),
\end{aligned}
$$

and we can establish that $J(z,v)$ is differentiable at the interior of V. ■

Proposition 2

The constraint $d - \bar{d} \geq 0$ will become more tightened as v increases. Formally, fix z and let $v_2 = v_1 + \epsilon, v_1 < v_2, v_1, v_2 \in intV$, then it is impossible to have: $d^*(v_1) = \bar{d}$ and $d^*(v_2) > \bar{d}$.

Proof: A simple counter argument applies. Assume it's true that $d^*(v_1) = \bar{d}$ and $d^*(v_2) > \bar{d}$. Then since $d^*(v_2) > \bar{d}$, we know the dividend constraint not binding and the first-order condition gives $J'(v_2) = \frac{1}{u'(w(v_2))}$. First, denote the optimal solution for v_2 as $\{w(v_2), d(v_2), v'(z', S')(v_2)\}$. Now we want to find a feasible solution for v_1: consider the plan $\{w(v_1), d(v_2), v'(z', S')(v_2)\}$, with $w(v_1)$ defined by

$$
\begin{aligned}
& -v_1 + u(w(v_1)) \\
+\beta E \Big\{ & \left[(1-\delta)\rho(z', S') + \delta\right] V^U(S') + \left[(1-\delta)(1-\rho(z', S'))\right] v'(z', S')(v_2) \Big\} = 0.
\end{aligned}
$$

That is, the continuation utility part is the same as the optimal plan under v_2, but $w(v_1)$ different from $w(v_2)$ so that the promise-keeping condition is satisfied for v_1. We know $w(v_1) < w(v_2)$ since $v_1 < v_2$, and from

$$
\begin{aligned}
& -v_2 + u(w(v_2)) \\
+\beta E \Big\{ & \left[(1-\delta)\rho(z', S') + \delta\right] V^U(S') + \left[(1-\delta)(1-\rho(z', S'))\right] v'(z', S')(v_2) \Big\} = 0,
\end{aligned}
$$

we know:

$$
\begin{aligned}
-v_1 + u(w(v_1)) &= -v_2 + u(w(v_2)) \\
&\Rightarrow \quad w(v_1) = w(v_2) - \frac{1}{u'(w(v_2))}\epsilon + o(\epsilon).
\end{aligned}
$$

This plan will be feasible under v_1, since all the firm's constraints and worker's constraints are satisfied. Now we want to show that, this will imply a contradiction for the value of $J(v_1)$:

We can find that,

$$\begin{aligned} J(v_1) &\geq e^{X+z} - w(v_1) \\ &\quad +\beta(1-\delta)E(1-\rho(z',S'))J(z',v'(z',S')(v_2);S') \\ &= \frac{1}{u'(w(v_2))}\epsilon - o(\epsilon) + e^{X+z} - w(v_2) \\ &\quad +\beta(1-\delta)E(1-\rho(z',S'))J(z',v'(z',S')(v_2);S') \\ &= \frac{1}{u'(w(v_2))}\epsilon - o(\epsilon) + J(v_2), \end{aligned}$$

Where the first inequality is because the new plan is feasible but not necessarily optimal under v_1, the second equality is from the relationship between $w(v_1)$ and $w(v_2)$, and the third equality is just using the definition of $J(v_2)$. so it implies that $J(v_1) - J(v_2) \geq \frac{1}{u'(w(v_2))}\epsilon$. However, since J is strictly decreasing, and strictly concave around v_2, we must have $0 \leq J(v_1) - J(v_2) < (v_2 - v_1) * |J'(v_2)| = \epsilon |J'(v_2)|$, and the fact that $J'(v_2) = \frac{1}{u'(w(v_2))}$ since it was assumed that it is not binding at v_2, $d^*(v_2) > \bar{d}$. A contradiction is obtained and we are done.■

Proposition 3

Fix any path of realizations of productivity (z_t, z_{t+1}). Denote the associated optimal wages as w_t^* and w_{t+1}^*, and the associated firm's multipliers as μ_t and μ_{t+1}. If the firm is financially constrained in period t but unconstrained in $t+1$, then we must have $w_t^* \leq w_{t+1}^*$.

Proof: Suppose this is not true. Then we have the following information: first, we know that $\mu_t > \mu_{t+1} = 1$, and $d_t^* = \bar{d}$, $d_{t+1}^* > \bar{d}$; if we had $w_t^* > w_{t+1}^*$, we can show this will lead to a contradiction: we can construct a better solution that delivers the same life-time utility to the worker but the firm has a strictly positive gain. To do so, first denote the relevant weight for the transition from z_t to z_{t+1} as ψ to simplify notations, $\psi \equiv \beta\pi(z_t, z_{t+1}; S, S') \times [(1-\delta)(1-\rho(z_{t+1}, S'))]$. The alternative solution is constructed as follows: for the transition from z_t to z_{t+1}, we can reduce w_t and increase w_{t+1} to make the wage path more flatter: define a new path $w_t = w_t^* - \epsilon, w_{t+1} = w_{t+1}^* + \epsilon_2$, and choose small enough $\epsilon_1 > 0, \epsilon_2 > 0$, such that

$$u(w_t) + \psi u(w_{t+1}) = u(w_t^*) + \psi u(w_{t+1}^*).$$

For any other nodes in the event tree, we keep it the same as the original optimal solution. For the dividends on the new path, we have: $d_t = d_t^* + \epsilon_1, d_{t+1} = d_{t+1}^* - \epsilon_2$. First, for ϵ_1, ϵ_2, we should have:

$$\begin{aligned} u(w_t) + \psi u(w_{t+1}) &= u(w_t^*) - \epsilon_1 u'(w_t^*) + \psi\left[u(w_{t+1}^*) + \epsilon_2 u'(w_{t+1}^*)\right] + o(\epsilon_1) \\ &= u(w_t^*) + \psi u(w_{t+1}^*) - \epsilon_1 u'(w_t^*) + \psi\epsilon_2 u'(w_{t+1}^*) + o(\epsilon_1), \end{aligned}$$

or, to first-order approximation, we should have:

$$\epsilon_1 = \psi\epsilon_2 \frac{u'(w_{t+1}^*)}{u'(w_t^*)},$$

and the corresponding part in the firm's value for the transition from z_t to z_{t+1} now is given by:

$$\begin{aligned} & d_t + \psi d_{t+1} \\ = \; & d_t^* + \epsilon_1 + \psi \left[d_{t+1}^* - \epsilon_2 \right] \\ = \; & d_t^* + \psi d_{t+1}^* + \epsilon_1 - \psi \epsilon_2 \\ = \; & d_t^* + \psi d_{t+1}^* + \psi \epsilon_2 \left[\frac{u'(w_{t+1}^*)}{u'(w_t^*)} - 1 \right] \\ > \; & d_t^* + \psi d_{t+1}^*, \end{aligned}$$

where we have used the information that $w_t^* > w_{t+1}^*$. Thus, we could find a better solution that delivers the same life-time utility to the worker but the firm has a strictly positive gain. This leads to a contradiction that the original solution is optimal.■

B Calibration

Pre-calibrated			
Risk aversion	σ	2	
Discount factor	β	0.99	
Average capital share	$1-\alpha$	0.36	
Matching function parameter	c_M	0.60	
Exogenous separation rate	δ	0.04	
Calibrated			(Reasons/Targets)
Persistence of idiosyncratic prod.	ρ_z	0.867	Output process
Std. of idiosyncratic prod.	σ_z	0.05	Output process
Entry cost	c_F	2.74	U. rate 6.5% in s.s.
Unemployment benefit	b	0.90	See the text.
External finance limit	$\bar{d}$	-0.05	External finance to output

Table 7: Calibration

C Numerical Computation

Computation for the steady state

We solve for the value functions and policy functions $J(z,v;S)$, $\rho(z;S)$,$\mu(z,v;S)$,$w(z,v;S)$, $d(z,v;S)$, $v'(z',S')$ using a combination of value function iteration and first-order conditions iteration. The details are listed below:

- Guess initial functions of $J^{(n-1)}(z,v;S), \rho^{(n-1)}(z;S), \mu^{(n-1)}(z,v;S), w^{(n-1)}(z,v;S)$, and we should update these value functions and policy functions so that all of them converge;
- for any given $(z,v;S)$, we first use $J^{(n-1)}$ and find the interval $[V^U(S), \bar{v}(z,S)]$ where v' should locate in;
- For any given $(z,v;S)$, using $\mu^{(n-1)}(z,v;S)$ and $w^{(n-1)}(z,v;S)$, we are able to compute the derivatives: $\mu^{(n-1)}(z,v;S)/u'(w^{(n-1)}(z,v;S))$; We use this to proxy $-\frac{\partial J^{(n-1)}(z,v;S)}{\partial v}$;

- Now, for given $(z, v; S)$, we want to find the optimal solution for $w^{(n)}(z, v; S)$ and for $v'(s', S')$. To do so, we first find the derivatives for $-J^{(n-1)}(z', .; S')$ at the lower and the upper point of $[V^U(S'), \bar{v}(z', S')]$, denoted as $\frac{\partial -J}{\partial v'}|_{v'=V^U(S')}$, and $\frac{\partial -J}{\partial v'}|_{v'=\bar{v}(z',S')}$;

- We then search for optimal wages $w^{(n)}(z, v; S)$ over the admissable space; For each given w, we know the derivative is approximated by $\mu^{(n-1)}(z, v; S)/u'(w)$; We now exploit the first order conditions: If $\mu^{(n-1)}(z, v; S)/u'(w) < \frac{\partial -J}{\partial v'}|_{v'=V^U(S')}$, then we set $v'(s', S') = V^U(S')$; and if $\mu^{(n-1)}(z, v; S)/u'(w) > \frac{\partial -J}{\partial v'}|_{v'=\bar{v}(z',S')}$, then we set $v'(s', S') = \bar{v}(z', S')$; if $\mu^{(n-1)}(z, v; S)/u'(w)$ is within this interval, we search for $v'(s', S')$ so that $\mu^{(n-1)}(z, v; S)/u'(w) = -\frac{\partial J(z', v'; S')}{\partial v'}$, which is approximated by $\mu^{(n-1)}(z', v'; S)/u'(w^{(n-1)}(z', v'; S))$. We combine grid search and bisection search (using the monotonicity of $-\frac{\partial J(z', v'; S')}{\partial v'}$ in theory) to find the optimal w so that the value function is maximized. We always make sure that the budget constraint for the worker is satisfied:
  $u(w) + \beta E\{[\left[(1-\delta)\rho(z', S') + \delta\right] V^U(S') + (1-\delta)(1-\rho(z', S'))v'(s', S')]\} \geq v.$

  If v is such that we could not find feasible solution for wages, then we simply set $J^{(n)}(z, v; S) = J^{Out}(S)$

- Now update: $J^{(n)}(z, v; S), \rho^{(n)}(z; S), \mu^{(n)}(z, v; S), w^{(n)}(z, v; S)$; Given current choice of w, we can solve for d and update $\mu^{(n)}(z, v; S)$; Given $J^{(n-1)}(z, v; S), \rho^{(n-1)}(z, v; S)$ and solutions for $v'(s', S')$, we can update $J^{(n)}(z, v; S)$; Lastly, given $J^{(n)}(z, v; S)$, we can update $\rho^{(n)}(z; S)$ by comparing $J^{(n)}(z, v; S)$ and $J^{Out}(S)$. Find the interval $[V^U(S), \bar{v}(z, S)]$; if the interval is empty, we know the firm and the worker must be separated: $\rho^{(n)}(z; S) = 1$.

Computation for the transition dynamics

For the transition dynamics, we first solve for the steady state value functions and policy functions $J(z, v; S)$, $\rho(z; S)$, $\mu(z, v; S)$, $w(z, v; S)$, $d(z, v; S)$, $v'(z', S')$ as described above. Then, we assume the economy initially is in its steady state, hit by aggregate shocks in period 1 and after T periods of transition the economy reaches its steady state again. We solve it using backward induction.

- Assume the path for aggregate productivity X_t and external financing constraint $\bar{d}_t$ are exogenously known at time 1. Guess a series of $\{V_t^U\}_{t=1,(Old)}^{t=T+1}$.

- In period $T+1$, the economy is associated with steady state value functions and policy functions $g^{(T+1)} \equiv (J(z, v; S), \rho(z; S), \mu(z, v; S), w(z, v; S), d(z, v; S), v'(z', S'))$

- For any period $2 \leq t \leq T$, we use backward induction. We first solve for the problem at $t = T$: using similar algorithm as in the computation for the steady state, using first-order conditions and taking into account of the constraints. We can update the set of value functions and policy functions, denoted as $g^{(T)}$. Recursively, we can obtain the series of $g^{(t)}$.

- Using the free-entry condition for the new firms, we can find the implied series of market tightness: $\{\theta_t\}_{t=1}^{t=T+1}$ and implied initial values of v_t^*; Using the value function for unemployed workers:

  $$V^U(S_t) = u(b) + \beta\left[f(\theta_{t+1})V^U(S_{t+1}) + (1 - f(\theta_{t+1}))v_{t+1}^*\right],$$

  we can update the series of $\{V_t^U\}_{t=1,(New)}^{t=T+1}$.

- We iterate until the $\{V_t^U\}_{t=1,(New)}^{t=T+1}$ and $\{V_t^U\}_{t=1,(Old)}^{t=T+1}$ are close enough.

(a) Aggregate productivity (b) External financial premium

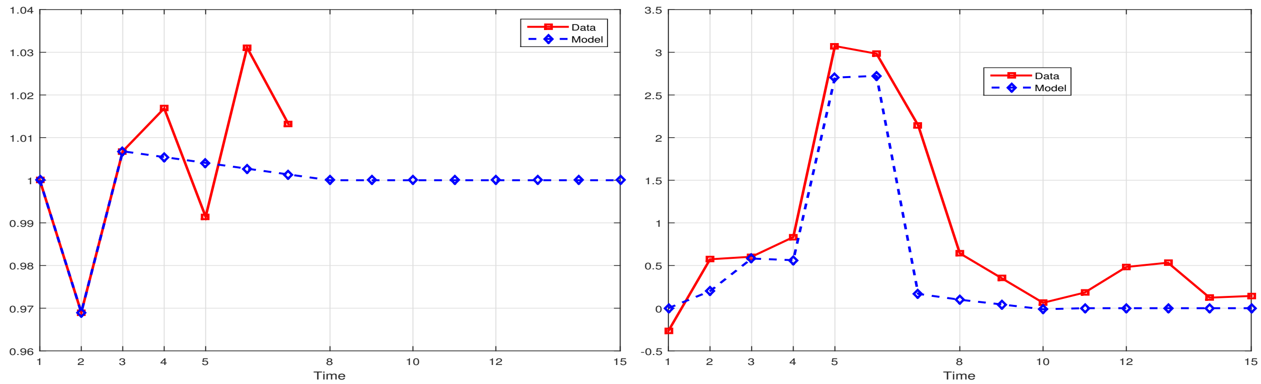

Figure 11: Transition analysis: Model and Data

D Empirical Analysis

Compustat Data

The sample includes all U.S. firms in CRSP-Compustat merge file from 1960-2016. I include firms with fiscal year ending month in December (fyr=12), firms with non-missing SIC codes, and I use additional sample selection rules as follows.

I extract the following variables from Compustat: book value of physical capital (Items 7 and 8), sales (Item 12), assets (Item 6), employment (item 29), gross debt (item 9+ item 34), cash and equivalents (item 1), physical investment (item 30 - item 107 if any), operating income (Item 13), cash flows (item 14+item 18), dividends (item 19+item 21), equity (item 60), return to equity (item 18-item 19+item 50 if any, divided by item 60), staff expense (item 42), cost of goods sold (item 41), equity issuance (item 108 -item 115), Tobin's Q (item 6+ 24*25-60-74 divided by item 6). These definitions are commonly used in empirical corporate finance. For Value added, we use gross sales minus the cost of goods sold. We use staff expense to measure the labor compensation whenever it is available; if not, we replace it by the cost of goods sold. Value added labor productivity is Value added divided by total number of employees.

For sample selection, all finance, public utility, and foreign firms are dropped first; we then drop firms before 1986 (too few samples in those years). We drop firms if book asset, physical asset, gross debt, cash, or sales are missing. Lastly, we trim the data according to the growth rates of sales and employment at the top 1% and the bottom 1%.

SIPP data

We use data from the Survey of Income and Program Participation (SIPP) from May 2008 to December 2013. SIPP data is a large, nationally representative panel data from household surveys with high frequencies. Each sample household and the members of the household are reinterviewed at four-month intervals, referred to as a "wave". We use wave 1 to wave 16, the latest available one. The original data is available from the US census or NBER.[28]

[28] See "https://www.census.gov/programs-surveys/sipp/data.2008.html" and "http://www.nber.org/data/survey-of-income-and-program-participation-sipp-data.html".

Sample selection and Variables

Since we focus on employed workers' labor market activity, we keep those samples for workers aged between 25 and 65.

We define a worker as employed during a month using the monthly employment record (RMESR): if he/she has a job the entire month, worked at least one week, and spent no time on layoff and no time looking for work (in SIPP, the coded variable RMESR=1, or 2, or 3, or 4). A worker is unemployed if he or she is either on layoff or looking for jobs for at least more than one week in that month (RMESR=5, or 6, or 7); otherwise, the worker is out of labor force.

Real earnings:

We use earnings from the main job received this month (SIPP variable tpmsum1). We only use data for the interview month and do not use data in the preceding months since they are recalled and potentially subject to greater measurement error. We deflate the nominal values by four-month averages of CPI. In the robustness analysis, we also used four-month averages of PCE index and PCE index excluding food and energy.

Total working hours:

We have used slightly different versions of definitions for total working hours. **Def.1** Our benchmark definition is defined as usual hours worked per week for the main job (SIPP variable ejbhrs1) times number of weeks in this month (SIPP variable rwksperm). We restrict the usual hours worked so they are non-missing, not negative and we exclude the case when a worker reports varying hours worked (SIPP variable ejbhrs1 == -8). We also experiment with alternative definitions of working hours: the number of working weeks; or, we replace the usual hours worked by the sample mean when a worker reports varying hours worked (SIPP variable ejbhrs1 == -8).

For all the variables we used, we make sure the data is not imputed by using the information on allocation flag in the data (e.g., SIPP variable apyrate1 for the variable tpyrate1). Among other control variables, we have used: **No. of members in HH** is the total number of members in the household; **HH total income (2008 dollar, monthly)** is the real, monthly, total household income, and **HH total property income (2008 dollar, monthly)** is the real, monthly, total household property income, including any profit or income received by virtue of owning property/capital equipment, and interests from owning financial assets. In the regression analysis, we have used logarithms of **No. of members in HH**. For income and property income, since there are negative values in the data, we used the so called Yeo-Johnson transformation: $sign(x) \times log(1 + abs(x))$. In the data, we know the employer's size from workers' perspective. "Small Firms" equal 1 if the number of employees at the location the worker works is less than 100 (SIPP variable tempsiz1==1 or 2 in waves 1-10 and SIPP variable tempsiz1==1, 2, 3, or 4 in waves 11 and onward), and equal 0 otherwise.

For the additional robustness analysis, we also used all waves from the SIPP 2001 panel data, covering February 2001 to January 2004. The sample selection is the same as the 2008 panel, and all the variables are defined in the same way.

Table 8: Summary statistics for the 2008 Panel SIPP data

	Mean	S.D.	Min	Max	Obs.
Age	44.6	11.6	25	65	2,809,204
College Degree and above	0.404	0.491	0	1	2,809,204
White	0.811	0.391	0	1	2,809,204
Male	0.490	0.500	0	1	2,809,204
Married	0.615	0.487	0	1	2,809,204
No. of members in HH	3.1	1.6	1.0	22.0	2,809,204
HH total income (2008 dollar, monthly)	6212.4	5790.5	-49454.5	129596.3	2,809,204
HH total property income (2008 dollar, monthly)	89.9	571.7	-10137.2	42219.2	2,809,204
Real earnings (2008 dollar, monthly)	2347.6	3350.4	0	60071.2	2,809,204
Total working hours (monthly)	170.8	47.8	4	495	1,654,765
Hourly real wages (2008 dollar)	21.1	28.7	0	4916.5	1,654,765
Quarterly real earnings growth rate	0.006	0.392	-10.282	9.149	340,129
Tenure for current job	8.3	8.6	0.0	52.3	1,846,292
Working for small firms (<100 employees)	0.581	0.493	0	1	1,846,292

NOTE: Summary statistics for 2008 panel SIPP data. The data is from wave 1 to the latest available wave 16 at the time of writing. For the definitions of variables, please see the data appendix for sample selection and variable constructions.

(a) Unemployment rate (b) Credit spread

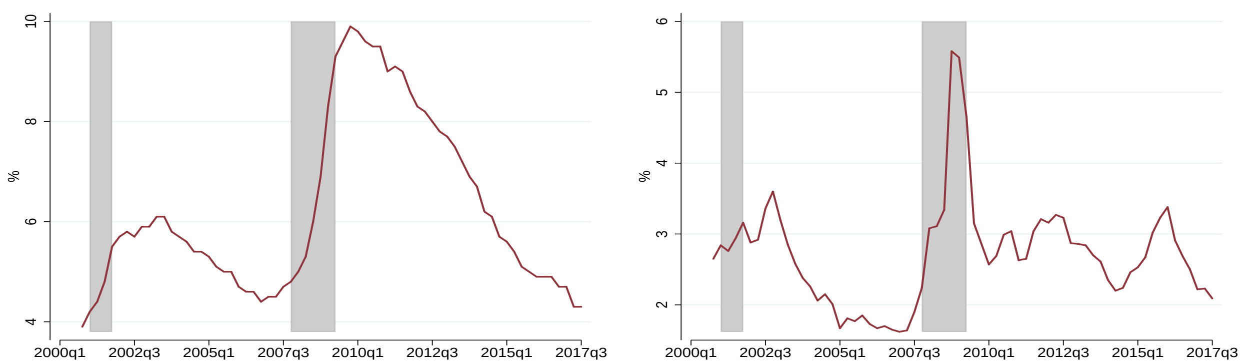

Figure 12: The Great Recession in the US

Table 9: Industry financial dependence: selected industries

Industry Name	SIPP 2008 Code	Naics 2002 Code	Financial Dependence
Logging	0270	113	-4.63
Forestry except logging	0190	113	-4.63
Insurance carriers and related activities	6990	524	-3.96
Non-depository credit and related activities	6890	522	-1.80
Savings institutions, including credit unions	6880	522	-1.80
Banking and related activities	6870	521	-1.80
Footwear manufacturing	1770	316	-0.96
Leather tanning and finishing and other allied products manufacturing	1790	316	-0.96
Beverage manufacturing	1370	312	-0.92
Tobacco manufacturing	1390	312	-0.92
Apparel accessories and other apparel manufacturing	1690	315	-0.61
Knitting fabric mills, and apparel knitting mills	1670	315	-0.61
Cut and sew apparel manufacturing	1680	315	-0.61
Business, technical, and trade schools and training	7880	611	-0.55
Elementary and secondary schools	7860	611	-0.55
Colleges and universities, including junior colleges	7870	611	-0.55
Other schools and instruction, and educational support services	7890	611	-0.55
Museums, art galleries, historical sites, and similar institutions	8570	712	-0.49
Securities, commodities, funds, trusts, and other financial investments	6970	523	-0.44
Vocational rehabilitation services	8390	624	-0.43
Not specified retail trade	5790	453	0.16
Sewing, needlework, and piece goods stores	5280	451	0.16
Gift, novelty, and souvenir shops	5570	453	0.16
Beer, wine, and liquor stores	4990	445	0.16
Music stores	5290	451	0.16
Electronic shopping	5590	454	0.16
Used merchandise stores	5490	453	0.16
Miscellaneous retail stores	5580	453	0.16
Retail florists	5470	453	0.16
Other direct selling establishments	5690	454	0.16
Grocery stores	4970	445	0.16
Office supplies and stationery stores	5480	453	0.16
Fuel dealers	5680	454	0.16
Specialty food stores	4980	445	0.16
Vending machine operators	5670	454	0.16
Mail order houses	5592	454	0.16
Health and personal care, except drug, stores	5080	446	0.16
Electronic auctions	5591	454	0.16
Sound recording industries	6590	512	0.17
Motion pictures and video industries	6570	512	0.17
Scenic and sightseeing transportation	6280	487	0.21
Real estate	7070	531	0.38
Management of companies and enterprises	7570	551	0.38
Oil and gas extraction	0370	211	0.40
Other motor vehicle dealers	4680	441	0.41
Gasoline stations	5090	447	0.41
Auto parts, accessories, and tire stores	4690	441	0.41
Automobile dealers	4670	441	0.41
Hardware stores	4880	444	0.47
Lawn and garden equipment and supplies stores	4890	444	0.47
Building material and supplies dealers	4870	444	0.47
Air transportation	6070	481	0.48
Metal ore mining	0390	212	0.55
Nonmetallic mineral mining and quarrying	0470	212	0.55
Coal mining	0380	212	0.55
Construction	0770	23	0.57
Water transportation	6090	483	0.67
Furniture and home furnishings stores	4770	442	0.69
Household appliance stores	4780	443	0.69
Sporting goods, camera, and hobby and toy stores	5270	443	0.69
Radio, TV, and computer stores	4790	443	0.69
Pipeline transportation	6270	486	1.00

Table 10: Real earnings and Industry Financial Dependence: Fixed effects model

Log(Real Earnings)	(1)	(2)	(3)
Highest Financial Dependence × U. rate	-1.123***	-1.103***	-1.143***
	(0.355)	(0.354)	(0.354)
Medium Financial Dependence × U. rate	-0.0800	-0.0749	-0.117
	(0.228)	(0.227)	(0.226)
Unemployment rate	-0.570***	-0.610***	-0.554***
	(0.193)	(0.191)	(0.191)
Age		0.0668***	0.0622***
		(0.00432)	(0.00431)
Age Squared		-0.000788***	-0.000783***
		(4.78e-05)	(4.75e-05)
Education		0.0652***	0.0672***
		(0.0116)	(0.0116)
Race		0.00201	0.00252
		(0.0126)	(0.0127)
Sex		0.0416	0.0489
		(0.103)	(0.0981)
Tenure for Current Job			0.0101***
			(0.000710)
Observations	382,269	382,269	382,269
Number of Worker ID	49,137	49,137	49,137
Industry dummies	YES	YES	YES
Fixed Effects	YES	YES	YES
R-squared overall	0.109	0.150	0.179
R-squared within	0.0161	0.0200	0.0247

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

NOTE: The data is from SIPP, wave 1 to the latest available wave 16 at the time of writing. The sample is restricted to those workers who continuously work for the same employer, who are salaried workers or paid hourly. Further more, for each person we only use the data point from the last month of each wave (the month in which the respondent is surveyed). For the definitions of variables, please see the data appendix for sample selection and variable constructions. The regression equation for this table is as follows: $Log(Real\ Earnings)_{i,t} = \alpha_i + \delta\ Individual\ Controls_{i,t} + \beta_0 U.rate_t + \beta_1 \mathbb{I}\{Medium\ Financial\ Dependence\} \times U.rate_t + \beta_2 \mathbb{I}\{Highest\ Financial\ Dependence\} \times U.rate_t + \epsilon_{i,t}$. Robust standard errors are reported in parentheses below the coefficients.

Table 11: Real earnings and Industry Financial Dependence: First Differences

Δ**Log(Real Earnings)**$_{i;t,t-4}$	(1) OLS	(2) OLS	(3) FE	(4) FE
Highest Financial Dependence $\times$ Δ**U. rate**$_t$	-1.131***	-1.146***	-0.920**	-0.874**
	(0.420)	(0.420)	(0.414)	(0.414)
Medium Financial Dependence $\times$ Δ**U. rate**$_t$	-0.235	-0.236	-0.181	-0.154
	(0.256)	(0.256)	(0.257)	(0.257)
Δ**U. rate**$_{t,t-4}$	-0.343	-0.345	0.00996	-1.043***
	(0.222)	(0.222)	(0.216)	(0.349)
Unemployment rate $_{t-4}$	-0.437***	-0.429***	-0.351***	-0.798***
	(0.0893)	(0.0892)	(0.0817)	(0.152)
Age $_{i,t-4}$		-0.000775		-0.00191
		(0.000629)		(0.00262)
Age Squared $_{i,t-4}$		6.29e-06		-1.39e-05
		(7.01e-06)		(2.52e-05)
Education $_{i,t-4}$		0.00232***		0.00602
		(0.000845)		(0.00810)
Race $_{i,t-4}$		-0.00121		-0.00393
		(0.00111)		(0.0105)
Sex $_{i,t-4}$		0.00234		-0.0421
		(0.00169)		(0.0464)
Tenure for Current Job $_{i,t-4}$		-0.000605***		-0.00292***
		(9.65e-05)		(0.000445)
Observations	302,185	302,185	302,185	302,185
Industry dummies	YES	YES	YES	YES
First Difference	YES	YES	YES	YES
OLS	YES	YES		
Adj. R-sq	0.000264	0.000573		
Fixed Effects			YES	YES
Number of Worker ID			41,417	41,417
R-squared overall			0.000202	0.000399
R-squared within			0.00202	0.00245

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: The data is from SIPP, wave 1 to the latest available wave 16. The sample is restricted to those workers who continuously work for the same employer. For the definitions of variables, please see the data appendix for sample selection and variable constructions. For "OLS", we use $\Delta Log(Real\ Earnings)_{i;t,t-4} = \gamma_0\ Individual\ Controls_{i,t-4} + \beta_0 U.rate_{t-4} + \beta_1 \Delta U.rate_{t,t-4} + \beta_2 \mathbb{I}\{Medium\ Financial\ Dependence\} \times \Delta U.rate_{t,t-4} + \beta_3 \mathbb{I}\{Highest\ Financial\ Dependence\} \times \Delta U.rate_{t,t-4} + \epsilon_{i,t}$. Robust standard errors are reported in parentheses below the coefficients. For "FE", we use a fixed-effect model: $\Delta Log(Real\ Earnings)_{i;t,t-4} = \alpha_i + \gamma_0\ Individual\ Controls_{i,t-4} + \beta_0 U.rate_{t-4} + \beta_1 \Delta U.rate_{t,t-4} + \beta_2 \mathbb{I}\{Medium\ Financial\ Dependence\} \times \Delta U.rate_{t,t-4} + \beta_3 \mathbb{I}\{Highest\ Financial\ Dependence\} \times \Delta U.rate_{t,t-4} + \epsilon_{i,t}$.

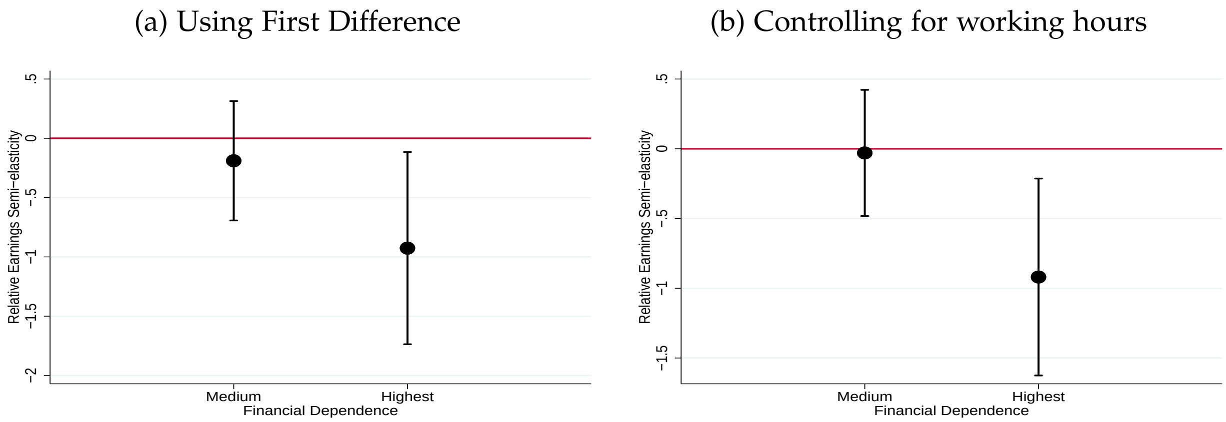

Figure 13: Robustness Check

Note: This figure reports the estimated semi-elasticity of earnings growth to national unemployment rate for workers in industries with medium and highest level of financial dependence. Both elasticities are relative to those with the lowest level of financial dependence. Panel (a) uses the first difference of earnings, and Panel (b) controls for workers' working weeks and look at wage rates. The data is from SIPP, wave 1 to the latest available wave 16. The sample is restricted to those workers who continuously work for the same employer. For the definitions of other variables, please see the data appendix for sample selection and variable constructions.

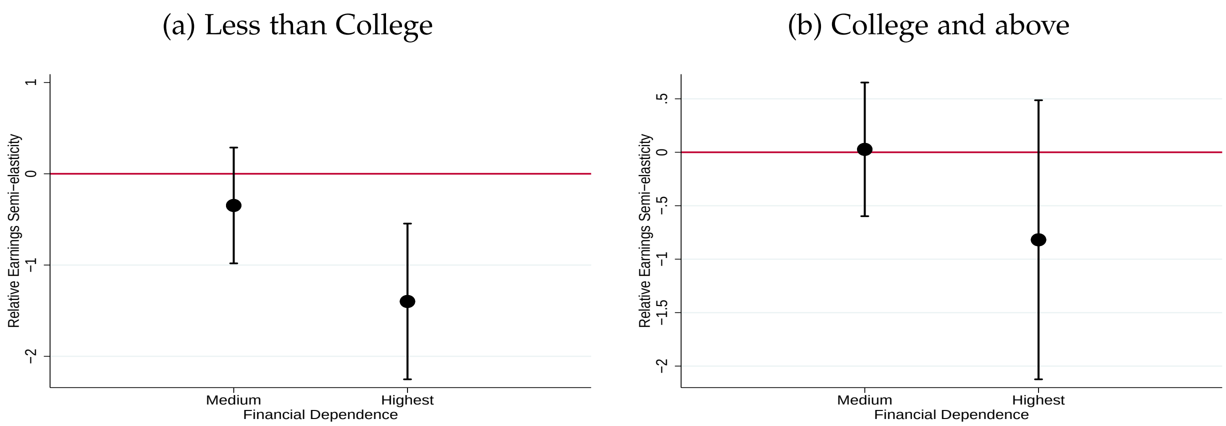

Figure 14: Earnings responses by education groups

Note: This figure reports the estimated semi-elasticity of earnings growth to national unemployment rate for workers in industries with medium and highest level of financial dependence. Both elasticities are relative to those with the lowest level of financial dependence. Both panels use fixed effect model as specified previously. Panel (a) is for workers without college degrees, and Panel (b) for workers with college degrees and above. The data is from SIPP, wave 1 to the latest available wave 16. The sample is restricted to those workers who continuously work for the same employer. For the definitions of other variables, please see the data appendix for sample selection and variable constructions.

(a) Current Job Tenure less than 5.58 years (b) Current Job Tenure longer than 5.58 years

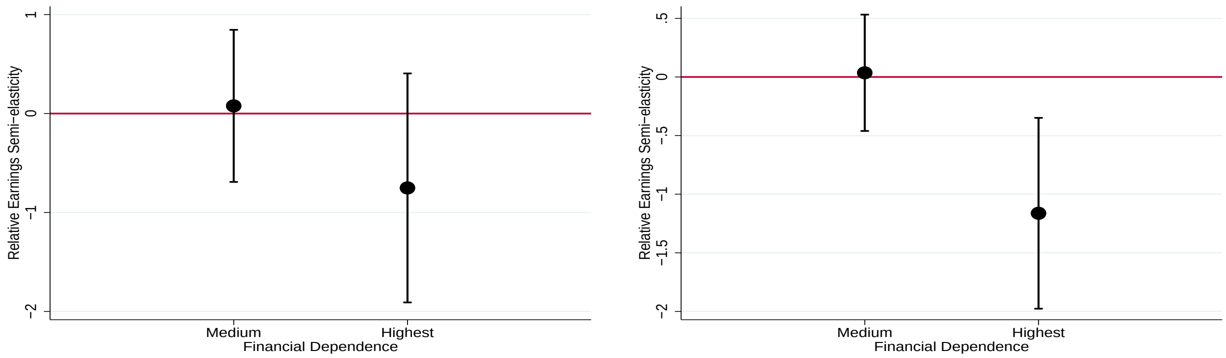

Figure 15: Earnings responses by current job tenure

Note: This figure reports the estimated semi-elasticity of earnings growth to national unemployment rate for workers in industries with medium and highest level of financial dependence. Both elasticities are relative to those with the lowest level of financial dependence. Both panels use fixed effect model as specified previously. We compute the median value for current job tenures, which is about 5.58 years. Panel (a) is for workers with tenure less than the median value and Panel (b) is for workers with job tenure longer than that. The data is from SIPP, wave 1 to the latest available wave 16. The sample is restricted to those workers who continuously work for the same employer. For the definitions of other variables, please see the data appendix for sample selection and variable constructions.

(a) Low earnings workers (b) High earnings workers

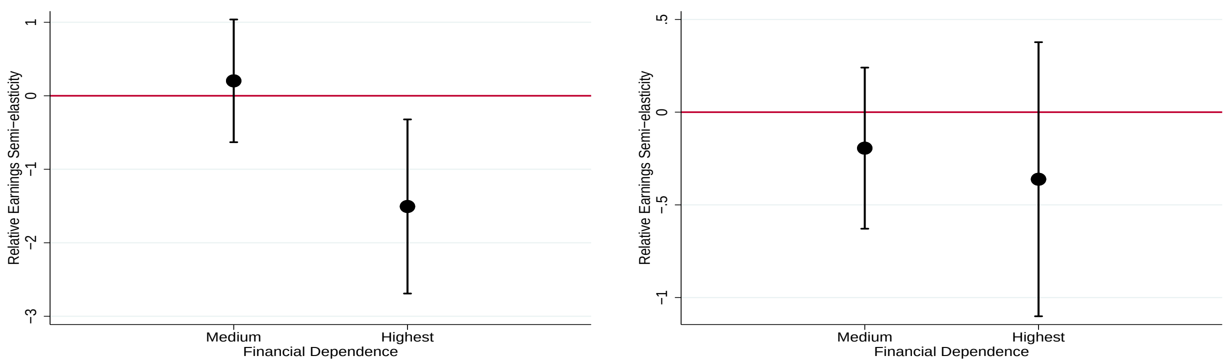

Figure 16: Earnings responses by the level of recent earnings

Note: This figure reports the estimated semi-elasticity of earnings growth to national unemployment rate for workers in industries with medium and highest level of financial dependence. Both elasticities are relative to those with the lowest level of financial dependence. Both panels use fixed effect model as specified previously. For individual real earnings, we first use year dummies to net of year fixed effects; then we compute individual means and find the median value for the whole distribution of mean levels. Panel (a) is for workers with real earnings less than the median value and Panel (b) is for workers with real earnings larger than that. The data is from SIPP, wave 1 to the latest available wave 16. The sample is restricted to those workers who continuously work for the same employer. For the definitions of other variables, please see the data appendix for sample selection and variable constructions.

(a) Young workers (b) Old workers

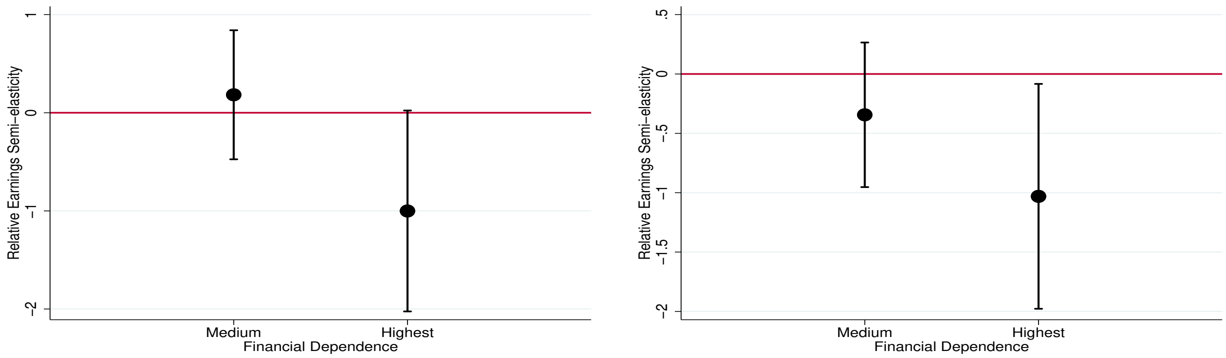

Figure 17: Earnings responses by worker ages

Note: This figure reports the estimated semi-elasticity of earnings growth to national unemployment rate for workers in industries with medium and highest level of financial dependence. Both elasticities are relative to those with the lowest level of financial dependence. Both panels use fixed effect model as specified previously. We compute the median value for worker ages, which is about 43. Panel (a) is for workers younger than the median value and Panel (b) is for workers older than that. The data is from SIPP, wave 1 to the latest available wave 16. The sample is restricted to those workers who continuously work for the same employer. For the definitions of other variables, please see the data appendix for sample selection and variable constructions.

(a) Workers at small firms (b) Workers at large firms

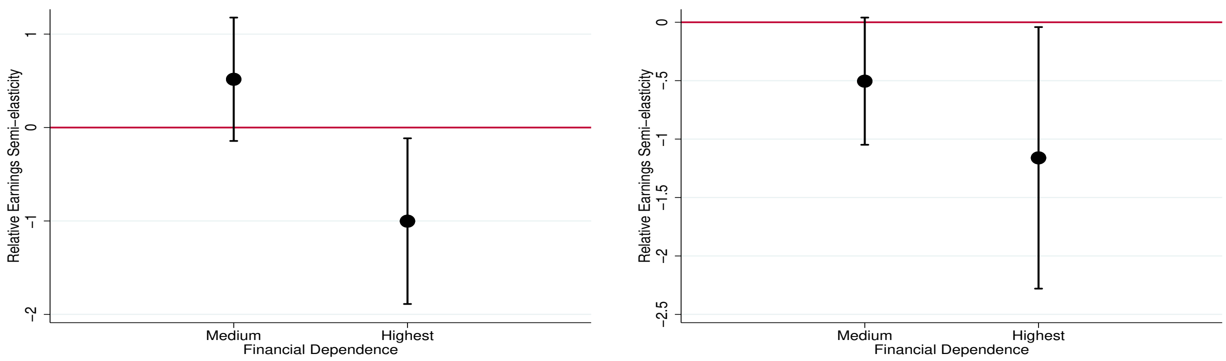

Figure 18: Earnings responses by firm size

Note: This figure reports the estimated semi-elasticity of earnings growth to national unemployment rate for workers in industries with medium and highest level of financial dependence. Both elasticities are relative to those with the lowest level of financial dependence. Both panels use fixed effect model as specified previously. Panel (a) is for workers working at small firms (less than 100 employees) and Panel (b) is for workers working at large firms (more than 100 employees). The data is from SIPP, wave 1 to the latest available wave 16. The sample is restricted to those workers who continuously work for the same employer. For the definitions of other variables, please see the data appendix for sample selection and variable constructions.

Table 12: Real earnings and Industry Financial Dependence: worker types

Log(Real Earnings)	Non-managers	Managers	No union	Union	Public sector	Private sector
Highest Financial Dependence × U. rate	-1.403***	-0.911	-1.077***	-1.114	-0.318	-0.919**
	(0.373)	(1.034)	(0.392)	(0.821)	(1.236)	(0.407)
Medium Financial Dependence × U. rate	-0.246	0.130	0.0278	-0.225	0.504	0.234
	(0.241)	(0.556)	(0.257)	(0.443)	(0.373)	(0.300)
Unemployment rate	-0.402**	-0.617	-0.729***	0.121	-0.0306	-0.935***
	(0.204)	(0.465)	(0.221)	(0.328)	(0.239)	(0.268)
Observations	346,448	35,821	332,993	49,276	83,233	299,036
Number of Workers	46,303	5,904	44,907	7,436	12,140	41,229
Industry dummies	YES	YES	YES	YES	YES	YES
Fixed Effects	YES	YES	YES	YES	YES	YES
Individual Controls	YES	YES	YES	YES	YES	YES
R-squared overall	0.186	0.0187	0.174	0.0676	0.108	0.220
R-squared within	0.0250	0.0256	0.0242	0.0168	0.0195	0.0224

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

NOTE: The data is from SIPP, wave 1 to the latest available wave 16. The sample is restricted to those workers who continuously work for the same employer. For the definitions of variables, please see the data appendix for sample selection and variable constructions. We use a fixed-effect model for different types of workers: $Log(Real\ Earnings)_{i,t} = \alpha_i + \delta\ Individual\ Controls_{i,t} + \beta_0 U.\ rate_t + \beta_1 \mathbb{I}\{Medium\ Financial\ Dependence\} \times U.\ rate_t + \beta_2 \mathbb{I}\{Highest\ Financial\ Dependence\} \times U.\ rate_t + \epsilon_{i,t}$. Robust standard errors are reported in parentheses below the coefficients. Robust standard errors are reported in parentheses below the coefficients.

Table 13: Monthly probability of transition into unemployed during the 2008 recession

Transit into Unemployment$_{t-1\to t}$	(1) Basic	(2) Firm size	(3) More HHs controls	(4) Not employed
Highest Financial Dependence × U. rate$_{i;t-1}$	0.172**		0.189***	0.177**
	(0.0682)		(0.0685)	(0.0815)
Medium Financial Dependence × U. rate$_{i;t-1}$	0.0727		0.0781	0.0596
	(0.0474)		(0.0476)	(0.0565)
Small Firms × Highest Financial Dependence × U. rate $_{i;t-1}$		0.148*		
		(0.0855)		
Small Firms × U. rate $_{i;t-1}$		0.0365		
		(0.0852)		
Small Firms × Highest Financial Dependence $_{i;t-1}$		0.00539		
		(0.0172)		
Small Firms$_{i;t-1}$		-0.00340		
		(0.0107)		
Unemployment rate $_{i;t-1}$	0.135***	0.116*	0.127***	0.261***
	(0.0440)	(0.0607)	(0.0442)	(0.0531)
Age$_{i;t}$	0.00426**	0.00425**	0.00458**	0.00319
	(0.00214)	(0.00214)	(0.00217)	(0.00290)
Age Squared$_{i;t}$	-3.46e-05	-3.44e-05	-3.84e-05	-2.49e-05
	(2.40e-05)	(2.40e-05)	(2.44e-05)	(3.11e-05)
Tenure for Current Job$_{i;t-1}$	0.00244***	0.00245***	0.00238***	0.00315***
	(0.000311)	(0.000310)	(0.000301)	(0.000374)
Education$_{i;t}$	-0.00217	-0.00217	-0.00228	-0.00250
	(0.00241)	(0.00241)	(0.00240)	(0.00296)
Race$_{i;t}$	-0.00867	-0.00870	-0.00874	-0.00762
	(0.00564)	(0.00564)	(0.00556)	(0.00708)
Sex$_{i;t}$	-0.0239	-0.0237	-0.0220	-0.0305
	(0.0189)	(0.0189)	(0.0190)	(0.0186)
Married$_{i;t}$			-0.00524	
			(0.00382)	
No. of HH members$_{i;t}$			0.00457	
			(0.00429)	
Log(HH income) $_{i;t-1}$			0.0112***	
			(0.000825)	
Log(Property income)$_{i;t-1}$			-0.00169**	
			(0.000824)	
Observations	208,785	208,771	208,785	208,785
Number of Worker Id	24,992	24,992	24,992	24,992
Industry Dummies	YES	YES	YES	YES
Full Interaction of Dummies	YES	YES	YES	YES
Fixed Effects	YES	YES	YES	YES
R-squared overall	0.000130	0.000121	0.000203	0.000248
R-squared within	0.00509	0.00509	0.00690	0.00557

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

NOTE: The data is from SIPP 2008 panel, up to the end of the recession, June 2009. The sample is restricted to those private workers, and at least we should observe two points for a given worker. For workers who transited into unemployment from time $t-1$ to t, they are denoted as $Y_{i,t-1} = 0$ and $Y_{i,t} = 1$. Please see the data appendix for variable constructions. "Small Firms" equals 1 if the number of employees at the location the worker works is less than 100 (tempsiz1==1 or 2 in waves 1-10 and tempsiz1==1,2,3,or 4 in waves 11 and onward). The regression equation is a fixed-effect model, and there is a full interaction between the dummy variables $\mathbb{I}\{Small\ Firms\}$, $\mathbb{I}\{Financial\ Dependence\}$ and the continuous variable of $U.\,rate$ for column (3); the regression is: $Y_{i,t} = \alpha_i + \delta\ Individual\ Controls_{i,t} + \mathbb{I}\{Financial\ Dependence\} \times U.\,rate_{t-1} + \mathbb{I}\{Financial\ Dependence\} \times \mathbb{I}\{Firm\ Size\} \times U.\,rate_{t-1} + \epsilon_{i,t}$. Robust standard errors are reported in parentheses below the coefficients. We only report some of the coefficients that are of particular interests.