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Financial Markets and Fluctuations in Uncertainty*

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ABSTRACT

Researchers have documented that in the recent financial crisis the large decline in economic activity and credit has been accompanied by a large increase in the dispersion of growth rates across firms. We build a quantitative general equilibrium model in which financial frictions interact with increases in uncertainty at the firm level to generate a contraction in economic activity and a large increase in the dispersion of growth rates across firms. More generally, we find that for the post 1970 data our model can generate output which is about 70% as volatile as that in the data. A promising feature of our model is that it generates large labor wedges, a feature of the recent data on business cycles.

*The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

1. Introduction

The recent financial crisis has been accompanied by severe contractions in economic activity and credit as well as large increases in the cross section dispersion of firm growth rates (Bloom, Floetotto and Jaimovich 2009). Motivated by these observations we build a quantitative general equilibrium model with heterogeneous firms and financial frictions in which increases in uncertainty at the firm level lead to an increase in the cross section dispersion of firm growth rates and a contraction in economic activity.

The basic mechanism is that in the presence of imperfect financial markets an increase in firm level uncertainty leads firms to contract the size of their projects to avoid default. The increase in uncertainty also has an amplification effect on firms' output through tighter credit. Firm level credit is more restricted because of the rise in default risk that comes with higher firm level uncertainty.

We then quantify our model and ask, Can an increase in firm level uncertainty that generates the observed increase in the cross section dispersion in the recent crisis lead to a sizable contraction in economic activity? We find that it can generate a fall in output of similar size that is seen in the data, although the timing of the fall in the model is several quarters later than in the data. More generally, we compare our model's implications to the data post 1970 for the average peak to trough changes and business cycle statistics. We find that the model generates output which is about 70% as volatile at that in the data.

Recently, Chari, Kehoe and McGrattan (2007) have decomposed business cycles into the components due to various wedges and have argued that labor wedges can account for 2/3 of the fluctuations in output. A striking feature of the recent recession that started in 2007 is that it was associated mainly with a worsening of the labor wedge. A promising feature of our model is that it can generate a substantial worsening of the labor wedge during the episode. More generally, in our model with financial frictions changes in the dispersion of firm level shocks manifest themselves in aggregate data as movements in the labor wedge.

Our model has three key ingredients. First, firms must choose the scale of their projects with a decreasing returns to scale technology in advance. Second, the loans to firms cannot depend on their idiosyncratic shocks and firms default if they have insufficient funds to pay for their debt. Third, since firms must pay a fixed cost to enter, in equilibrium they make positive expected profits in each period that they do not default. The cost of default is the loss of future expected profits.

Given these ingredients, when firms choose their project size they face a trade off between expected return and risk. As firms increase their size they increase the expected return conditional on not defaulting but they also increase the probability of default. For a given variance of idiosyncratic shocks, they choose their optimal size to balance off the increase in expected return against the losses from default. At a given project size, when the variance of the idiosyncratic shocks increases the probability of default increases. Thus, in the face of such an increase in variance, firms become more cautious and decrease the size of their projects. At the aggregate level, these firm level responses imply that when the dispersion of idiosyncratic shocks increases aggregate output and employment fall.

Note that the result that firms decrease the size of their projects when the variance of idiosyncratic shocks increases depends critically on the lack of complete markets. If firms had access to complete markets then (with i.i.d. idiosyncratic shocks) an increase in the variance of these shocks would lead to no change in their optimal size. With such complete markets they would face no tradeoff between expected return and default risk. When the variance of shocks increases, firms keep their preferred size and then restructure the pattern of payments across states so that they never default.

In our model output declines not only because the size of each incumbent declines but also because the number of entering firms declines. High dispersion makes potential new entrants less willing to enter because conditional on entering a smaller scale is optimal and at this smaller scale the value of operating a firm is lower. For a given fixed cost of entry as the value a firm decreases the number of operating firms also decreases.

We consider a quantitative version of the model in which idiosyncratic firm productivity shocks have stochastic volatility. We choose the parameters of this shock process so that the model produces the time variation in cross section dispersion of the growth rate of sales observed in a panel of Compustat firms. As we have noted, the model produces output which is about 70% as volatile as that in the data. The model also produces a relative volatility of labor and the labor wedge to that of output similar to that in the data.

The algorithm we use to compute the equilibrium extends the solution methods of Kahn and Thomas (2008) that handle idiosyncratic and aggregate shocks to allow for free entry and endogenous debt contracts with default risk. Allowing for free entry in a decentralized model of heterogenous firms adds a substantial complication in the solution method as the entry decision has to be solved for in the simulation part of the algorithm.

In terms of the literature, this work is related to a growing literature that studies time varying volatility. Bloom, Floetotto, and Jaimovich (2009) and Bloom (2009) show that in the presence of adjustment costs, firms drop their investment and hiring when hit by a high uncertainty shock. [1] A key difference between our approach and that of Bloom et al. is that

[1] Other papers that study the effects of uncertainty on invesment in the presence of adjustment costs

in our work the financial frictions manifest themselves as labor wedges and the fixed cost frictions in the Bloom et al. paper manifest themselves as TFP shocks. Christiano, Motto, and Rostagno (2009) also explore the business cycle implications of uncertainty shocks. They show that in a DSGE model with nominal rigidities and financial frictions uncertainty shocks to investment account for a significant portion of the fluctuations in output.

Our work is also related to the work on heterogenous firms and financial frictions. For example, Cooley and Quadrini (2001) develop a model of heterogenous firms with incomplete financial markets and default risk and explore its implications for the dynamics of firms growth and exit. It is also related to the work of Cooley, Marimon, and Quadrini (2004) who find in a general equilibrium setting that limited enforceability of financial contracts amplifies the effects on output of technology shocks.

2. Model

Consider a dynamic model of a continuum of heterogeneous firms and a continuum of identical households. Firms use a decreasing returns technology with labor as an input to produce consumption goods. This technology is subject to both aggregate shocks and idiosyncratic productivity shocks. Households provide labor services to firms and trade assets that are contingent on the aggregate shock. They own all firms and receive lump sum transfers.

As we have noted, our model has three key ingredients. First, firms must choose the scale of their projects with a decreasing returns to scale technology in advance of the realization of shocks that affect the variance of idiosyncratic productivity. Second, the loans

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include Bernanke (1983), Abel and Eberly (1996), and Caballero and Engel (1999).

to firms cannot depend on their idiosyncratic shocks and firms default if they have insufficient funds to pay for their debt. Third, since firms must pay a fixed cost to enter, in equilibrium they make positive expected profits in each period that they do not default. The cost of default is the loss of future expected profits.

The timing of decisions is as follows. In the beginning of each period idiosyncratic and aggregate shocks are realized. After observing shocks, incumbent firms choose to repay their debts or default and new entrants decide on entry. Households then consume, work and decide on new asset holdings. Firms at this stage decide whether to default or not. Continuing firms produce, pay their workers and their debts, decide on new project sizes and new debt holdings, pay taxes and distribute dividends. Defaulting firms exit.

A. Firms

A continuum of firms produce output y_t with a stochastic decreasing returns technology using labor ℓ_t as an input

$$y_t = z_t \ell_t^{\theta}$$

where z_t is an exogenous idiosyncratic productivity shock. Firms commit to the scale of the project before the realization of their shocks. Specifically, they commit to an employment level ℓ_t in period $t-1$ that is not contingent on the realization of either the aggregate or the idiosyncratic shocks at t. The idiosyncratic productivity shock z_t follows a Markov process with transition function $\pi_z(z_t|z_{t-1}, \sigma_t)$ where σ_t is an aggregate shock that controls the dispersion (or standard deviation) of firm productivity. The aggregate shock follows a

Markov process with transition function $\pi_\sigma(\sigma_t|\sigma_{t-1})$.

Firms have access to one period debt contracts which are contingent on aggregate shocks but not on idiosyncratic shocks. Firms begin period t with some debt due $b_t(\sigma_t)$. Hence at the beginning of period t, each firm is indexed by $v_t = (\ell_t, b_t(\sigma_t), z_t)$ which records their labor commitments, their debt due, and their current idiosyncratic shock. We let Υ_t denote the measure of v_t across firms. The aggregate state is denoted $S_t = (\Upsilon_t, \sigma_t)$.

In each period t, each firm chooses a debt contract in which, conditional on not defaulting, promises to pay $b_{t+1}(\sigma_{t+1})$ for each aggregate shock σ_{t+1} at $t+1$. The price of such claim is given by a price schedule $q(\sigma_{t+1}|S_t, z_t, \ell_{t+1}, b_{t+1}(\sigma_{t+1}))$ that depends on the current aggregate state S_t, the firms' current idiosyncratic shock z_t and current decisions of the firm, namely, its labor commitment ℓ_{t+1} and its contingent borrowing level $b_{t+1}(\sigma_{t+1})$. Note that $b_{t+1}(\sigma_{t+1})$ can be negative so that firms can save.

After shocks are realized existing firms decide whether to repay or default, denoted $\phi = 1$ or $\phi = 0$ respectively. Firms that repay continue while firms that default exit. The dividends for a continuing firm are

$$(1) \quad d_t = (1-\tau^c)(z_t\ell_t^\theta - w_t\ell_t) - (1-\tau^d)b_t(\sigma_t) + \sum_{\sigma_{t+1}} q(\sigma_{t+1}|S_t, z_t, \ell_{t+1}, b_{t+1}))b_{t+1}(\sigma_{t+1})$$

where τ^c denotes corporate taxes and τ^d denotes a tax discount from their interest income. Dividends are restricted to be nonnegative, $d_t \geq 0$. We incorporate these taxes to make it attractive for firms to borrow so that it is not optimal for them to build up a large amount of savings in order to completely avoid the possibility of default.

The state of a firm at t is (v_t, S_t). Given the state, the budget set is defined as

$$\Gamma(v_t, S_t) = \{d_t | \; d_t \geq 0\}.$$

where d_t is given by (1). Note that firms with large enough debt have an empty budget set which forces them to default. That is, given the bond price schedules $q(\sigma_{t+1}|S_t, z_t, \ell_{t+1}, b_{t+1}(\sigma_{t+1}))$ for borrowing for new debt $b_{t+1}(\sigma_{t+1})$, there is a large enough inherited debt b_t at t such that no new debt contract can deliver non-negative dividends. For such a configuration the only option for the firm is to default. Such a firm then exits. We capture this formally by requiring that if $\Gamma(v_t, S_t) = \varnothing$ then firms default by setting $\phi(v_t, S_t) = 0$. In our model this is the only time a firm will default.

Let $V(v_t, S_t)$ denote the value of firm. For any individual state (v_t, S_t) such that the budget set is empty let $V(v_t, S_t)$ equal zero. For all other states in which the budget set is nonempty, $V(v_t, S_t)$ equals the value conditional on repaying today and acting optimally from now on. In each period, continuing firms choose new project sizes ℓ_{t+1}, a vector of state contingent loans $b_{t+1}(\sigma_{t+1})$, and dividends d_t. For states in which the budget set is nonempty, the value of $V(v_t, S_t)$ equals

$$\max_{\{d_t, b_{t+1}(\sigma_{t+1}), \ell_{t+1}\}} d_t + \sum_{z_{t+1}, \sigma_{t+1}} \{Q\left(\sigma_{t+1}|S_t\right) V(v_{t+1}, S_{t+1}) \pi_z(z_{t+1}|z_t, \sigma_{t+1}) \pi_\sigma(\sigma_{t+1}|\sigma_t)\}$$

subject to the budget constraint

$$d_t = (1 - \tau^c)(z_t \ell_t^\theta - w_t \ell_t) - (1 - \tau^d) b_t(\sigma_t) + \sum_{\sigma_{t+1}} q(\sigma_{t+1}|S_t, z_t, \ell_{t+1}, b_{t+1}) b_{t+1}(\sigma_{t+1})$$

a non-negative dividend condition $d_t \geq 0$, and the law of motion for aggregate states, where $Q(\sigma_{t+1}|S_t)$ is the price in state S_t for one unit of goods in period $t+1$ when the aggregate shock is σ_{t+1}. This law of motion has two parts. The aggregate shock σ_{t+1} evolves according to $\pi_\sigma(\sigma_{t+1}|\sigma_t)$ while the measure over firms idiosyncratic states evolves according to

$$(2) \qquad \Upsilon_{t+1}(\sigma_{t+1}) = H(S_t, \sigma_{t+1})$$

This problem gives the decision rules for new sizes of projects $\ell(v_t, S_t)$, borrowing $b(\sigma_{t+1})(v_t, S_t)$, repayment $\phi(v_t, S_t)$, and dividends $d(v_t, S_t)$.

When a firm defaults, it is liquidated, so society loses the built up knowledge inherent in z_t. However, defaulting firms produce and pay their workers whenever operating profits are positive $z_t\ell_t^\theta - w_t\ell_t \geq 0.$ Bond holders receive any residual goods from such firms. If $z_t\ell_t^\theta - w_t\ell_t < 0$ for defaulting firms, so that at their chosen scale in $t-1$ they make negative operating profits, they hire no labor and are liquidated immediately. Let $\kappa_t(v_t, S_t)$ be an indicator function for the firm that equals 1 if $z_t\ell_t^\theta - w_t\ell_t \geq 0$ and 0 otherwise.

Consider next firm entry. There is a continuum of identical potential projects every period. To enter, firms have to pay an entry cost ξ in period t and decide on the size of the project ℓ_{t+1}^e for the following period. The idiosyncratic shocks of new entrants z_{t+1} are drawn from a distribution with transition function $\pi_e(z_{t+1}|\sigma_{t+1})$. The value function of entrants is given by

$$V^e(S_t) = \max_{\{\ell_{t+1}^e\}} -\xi + \sum_{z_{t+1},\sigma_{t+1}} \left[Q(\sigma_{t+1}|S_t)\, V(\ell_{t+1}, 0, z_{t+1}, S_{t+1})\pi_e(z_{t+1}|\sigma_{t+1})\pi_\sigma(\sigma_{t+1}|\sigma_t)\right]$$

subject to the evolution of the aggregate states. This problem gives project sizes for new entrants $\ell^e_{t+1}(S_t)$. Let $M(S_t)$ denote the measure of new entrants.

Consider next the bond price schedules faced by firms. Each firm borrows from a financial intermediary. The intermediary offers firms bond price schedules such that each debt contract compensates for the expected loss in the case of default. To develop the expression for the value of a contingent loan to a firm, suppose the current aggregate state is S_t and that a firm with current idiosyncratic shock z_t and new scale ℓ_{t+1} buys a contingent bond $b_{t+1}(\sigma_{t+1})$. At $t+1$ when the aggregate shock is σ_{t+1} and the idiosyncratic shock is z_{t+1}, that firm repays completely whenever the repayment indicator $\phi(\ell_{t+1}, b_{t+1}(\sigma_{t+1}), z_{t+1}, S_{t+1})$ is one, and when this indicator is zero it repays $\max\{z_{t+1}\ell^{\theta}_{t+1} - w_{t+1}\ell_{t+1}, 0\}$, which is all of its operating profits . The intermediary values these contingent repayments using the price for contingent claims $Q(\sigma_{t+1}|S_t)$. Hence, the value for such a contingent loan is given by

$$q(\sigma_{t+1}|S_t, z_t, \ell_{t+1}, b_{t+1})b_{t+1}(\sigma_{t+1}) =$$

$$Q\left(\sigma_{t+1}|S_t\right)\left[\sum_{z_{t+1}} \pi_z(z_{t+1}|z_t, \sigma_{t+1})\phi(\ell_{t+1}, b_{t+1}(\sigma_{t+1}), z_{t+1}, S_{t+1})\right] b_{t+1}(\sigma_{t+1})$$

$$+Q\left(\sigma_{t+1}|S_t\right)\left[\sum_{z_{t+1}} \pi_z(z_{t+1}|z_t, \sigma_{t+1})(1 - \phi(\ell_{t+1}, b_{t+1}(\sigma_{t+1}), z_{t+1}, S_{t+1}))\max\{z_{t+1}\ell^{\theta}_{t+1} - w_{t+1}\ell_{t+1}, 0\}\right]$$

B. Households

Households are identical, discount the future at rate β, and have a period utility function $u(c_t, h_t)$ where c_t and h_t are consumption and labor in period t. Households provide labor h_t to firms at t for wage w_t, and receive aggregate dividends D_t and a lump sum transfer T_t. Households have access to one period securities $B_{t+1}(\sigma_{t+1})$ that are contingent on the aggregate shock σ_{t+1} at $t+1$, with prices $Q(\sigma_{t+1}|S_t)$.

The recursive problem for households, taking as given the wage, state contingent prices, aggregate dividends, and lump sum transfers, is the following

$$V^H(B_t(\sigma_t), S_t) = \max_{\{c_t, h_t, B_{t+1}(\sigma_{t+1})\}} u(c_t, h_t) + \beta \sum_{\sigma_{t+1}} \pi_\sigma(\sigma_{t+1}|\sigma_t) V^H(B_{t+1}(\sigma_{t+1}), S_{t+1})$$

subject to the budget constraint

$$c_t + \sum_{\sigma_{t+1}} Q(\sigma_{t+1}|S_t) B_{t+1}(\sigma_{t+1}) = w_t h_t + D_t + T_t + B_t(\sigma_t),$$

the no Ponzi scheme condition $B_{t+1}(\sigma_{t+1}) \geq -\bar{B}$, and the law of motion for aggregate states. Note that the transfers to consumers in period t are simply the taxes collected from firms in that period.

C. Equilibrium

Equilibrium in the goods market require that the total consumption of households equals the total output produced by non-defaulting firms and defaulting firms net of the cost of new entrants

$$(3) \quad c(S_t) = y(S_t) - M(S_t)\xi.$$

where total output is defined as

$$(4) \quad y(S_t) = \int [\phi(v_t, S_t) + (1 - \phi(v_t, S_t))\kappa(v_t, S_t)] z_t \ell_t^\theta d\Upsilon_t(v_t; \sigma_t)$$

Labor market clearing implies that households labor supply in $t+1$ equals the period t labor commitments of operating firms in $t+1$, so that for each σ_{t+1}

$$\int [\phi(v_t, S_t) + (1 - \phi(v_t, S_t))\kappa(v_t, S_t)] \ell(v_t, S_t) d\Upsilon_t(v_t; \sigma_t) + M(S_t)\ell^e(S_t) = h(B(\sigma_{t+1}), S_{t+1}).$$

Finally, the total borrowing by firms equals the total savings by consumers

$$\int \phi(v_t, S_t) q(\sigma_{t+1}|S_t, z_t, \ell_{t+1}, b_{t+1}) b_{t+1}(\sigma_{t+1}) d\Upsilon_t(v_t; \sigma_t) = Q(\sigma_{t+1}|S_t) B_{t+1}(\sigma_{t+1})$$

The measure of firms evolves over time as firms enter, exit, and change their labor and borrowing choices. Given the state $S_t = (\Upsilon_t(\sigma_t), \sigma_t)$, the transition function is given by

$$(5) \quad H(v_{t+1}; S_t, \sigma_{t+1}) = \int \Lambda(v_{t+1}, v_t, \sigma_{t+1}|S_t) \Upsilon_t(v_t; \sigma_t) dv_t + M(S_t) \Lambda^e(v_{t+1}, \sigma_{t+1}|S_t).$$

where, given $v_{t+1} = (\ell_{t+1}, b_{t+1}(\sigma_{t+1}), z_{t+1})$, the function $\Lambda(v_{t+1}, v_t, \sigma_{t+1}|S_t)$ equals

$$\begin{cases} \pi_z(z_{t+1}|z_t, \sigma_{t+1}) & \text{if } \ell_{t+1} = \ell(v_t, S_t),\ b_{t+1}(\sigma_{t+1}) = b(\sigma_{t+1})(v_t, S_t),\ \text{and } \phi(v_t, S_t) = 1 \\ 0 & \text{otherwise} \end{cases}$$

and the function $\Lambda^e(v_{t+1}, \sigma_{t+1}|S_t)$ equals

$$\begin{cases} \pi_e(z_{t+1}|\sigma_{t+1}) & \text{if } \ell_{t+1} = \ell^e(S_t) \\ 0 & \text{otherwise} \end{cases}$$

To interpret these transition functions note that $\Lambda(v_{t+1}, v_t, \sigma_{t+1}|S_t)$ specifies that the probability that a firm with some $v_t = (\ell_t, b_t(\sigma_t), z_t)$ transits to $v_{t+1} = (\ell_{t+1}, b_{t+1}(\sigma_{t+1}), z_{t+1})$ in aggregate state S_t equals $\pi_z(z_{t+1}|z_t, \sigma_{t+1})$ when such firm chooses the particular ℓ_{t+1} and b_{t+1} in v_{t+1}.

We now define the equilibrium of this economy. Given the initial distribution Υ_0 and an initial aggregate shock σ_0, a recursive equilibrium consists of policy and value functions of firms $\{d(v_t, S_t),\ b(v_t, S_t, \sigma_{t+1}),\ \ell(v_t, S_t),\ \phi(v_t, S_t),\ V(v_t, S_t)\}$, households policy functions for consumption $c(B_t, S_t)$, hours $h(B_t, S_t)$ and savings $B(\sigma_{t+1}, S_t)$, the wage rate $w(S_t)$ and discount bond price $Q(\sigma_{t+1}, S_t)$, bond price schedules $q(\sigma_{t+1}|S_t, z_t, \ell_{t+1}, b_{t+1})$, the mass of new entrants $M(S_t)$, and (vi) the evolution of aggregate states $\Upsilon_t(\sigma_t)$ governed by the transition function $H(S_t, \sigma_t)$, such that for all t: (i) The policy and value functions of firms satisfy their optimization problem, (ii) households decisions are optimal, (iii) loan contracts reflect the expected default losses such that every contract breaks even in expected value, (iv) domestic good, labor, and credit markets clear, (v) the free entry condition holds

$$V^e(S_t)M(S_t) = 0,$$

and (vi) the evolution of the measure of firms is consistent with the policy functions of firms, households and shocks.

D. Sketch of the Computation Algorithm

Solving the model requires keeping track of the measure of firms $\Upsilon_t(v_t;\sigma_t)$ as it changes with the idiosyncratic and aggregate shocks. We first combine the problem of households, firms, and the financial intermediary. In recursive notation, optimization from households imply that wages and intertemporal prices equal

$$Q(\sigma'|\sigma,\Upsilon) = \beta\pi_\sigma(\sigma'|\sigma)\frac{u_c(c',h')}{u_c(c,h)}$$

$$w(\sigma,\Upsilon) = \frac{u_h(c,h)}{u_c(c,h)}$$

The firms problem can be simplified further by noting that the only relevant individual states for the firm decisions are the idiosyncratic shock and the total after tax profits net of total debt $x = (1-\tau^c)(z\ell^\theta - w\ell) - (1-\tau^d)b$. Using households' first order condition we can then write in recursive form the combined program of firms and the financial intermediary as follows.

First for a given state (x,z,σ,Υ) the firm default if its budget set is empty: If

$$\{x + \sum_{\sigma'} q(\sigma'|\sigma,\Upsilon,z,\ell',b')b'(\sigma) < 0 \forall\{\ell',b'\}\}$$

then $\phi(z,x,\sigma,\Upsilon) = 0$ and $V(x,z,\sigma,\Upsilon) = 0$.

Conditional on having a non-empty budget set then the firms' problem is

$$(6) \qquad V(x,z,\sigma,\Upsilon) = \max_{\ell',b'(\sigma')} d + \sum_{\sigma'} Q(\sigma'|\sigma,\Upsilon)\sum_{z'}\pi_z(z'|z,\sigma')[V(x'(.),z',\sigma',\Upsilon')]$$

where the choices of $\ell', b'(\sigma')$ map into the future firm state x' as follows

$$x' = (1-\tau^c)(z'\ell'^{\theta} - w'(\sigma,\Upsilon)\ell') - (1-\tau^d)b'(\sigma)$$

subject to the budget constraint

$$d = x + \sum_{\sigma'} q(\sigma'|\sigma,\Upsilon,z,\ell',b')b'(\sigma),$$

non-negative dividend condition.

$$(7)\quad x + \sum_{\sigma'} q(\sigma'|\sigma,\Upsilon,z,\ell',b')b'(\sigma) \geq 0$$

the break even conditions for the financial intermediary for all σ'

$$\begin{aligned} & q(\sigma'|\sigma,\Upsilon,z,\ell',b')b'(\sigma) = \\ & \quad Q\left(\sigma\prime|\sigma,\Upsilon\right)\left[\sum_{z'} \pi_z(z'|z,\sigma')\phi(x'(.),z',\sigma',\Upsilon')\right] b\prime(\sigma\prime) \\ & \quad +Q\left(\sigma\prime|\sigma,\Upsilon\right)\left[\sum_{z'} \pi_z(z'|z,\sigma')(1-\phi(x'(.),z',\sigma',\Upsilon')) \max\{z\prime\ell'^{\theta} - w'\ell', 0\}\right] \end{aligned}$$

and the evolution of the aggregate states where σ' evolves according to $\pi_\sigma(\sigma\prime|\sigma')$ while the measure over firms idiosyncratic states evolves according to

$$(8)\quad \Upsilon'(\sigma') = H(\Upsilon(\sigma),\sigma')$$

Following the algorithms of Krusell and Smith (1998) and Kahn and Thomas (2008) we parameterize the measure of firms with a small number of moments and solve the firm's problem. In particular we approximate the measure of firms with the number of operating firms N, and the last period aggregate shock, σ_{-1}. Given these 2 states, we construct forecasts functions for the next period's number of firms and aggregate consumption and labor

$$(9) \quad N' = f_N(N, \sigma_{-1}, \sigma), \ c = f_c(N, \sigma_{-1}, \sigma), \ h' = f_h(N, \sigma_{-1}, \sigma)$$

To solve the equilibrium of the model, we start with candidate forecasts functions (9) and solve the program (6). Solving such problem requires finding fixed points for both the value function $V(x, z, \sigma, N, \sigma_{-1})$ and the repayment decision $\phi(z, x, \sigma, N, \sigma_{-1})$. The solution gives policy rules for firms $\ell(x, N, \sigma_{-1}, \sigma)$, borrowing $b(\sigma')(x, N, \sigma_{-1}, \sigma)$, repayment $\phi(x, N, \sigma_{-1}, \sigma)$, and dividends $d(x, N, \sigma_{-1}, \sigma)$. Using these policy rules we simulate the model. Given initial N in every period of the simulation, we find the number of firms the next period N' such the free entry condition holds:

$$\xi = \sum_{z\prime, \sigma_{t+1}} \left[Q\left(\sigma' | \sigma, N, \sigma_{-1}\right) V(\ell^e(N, \sigma_{-1}), 0, z', N', \sigma) \pi_e(z' | z, \sigma') \pi_\sigma(\sigma' | \sigma) \right]$$

During each period we also compute aggregate consumption and labor such that the market clearing conditions hold. After the simulation we compute new forecasting functions (9) using the equilibrium sequences fo N, c, and h for given the sequence of σ shocks. We repeat this procedure until the forecasting functions converge. In the final stage, all forecasting functions have an $R^2 > 0.98$.

3. Quantitative Analysis

A. Parametrization

We use features of the time variation in the cross section distribution of firms in the United States to help inform the choice of some key parameters. Many of the parameters of preferences and technology are fairly standard and are chosen to reflect commonly used values.

Consider first the setting of some standard parameters. The utility function is assumed to take the form $u(c,h) = \log(c) - \xi \frac{h^{1+\nu}}{1+v}$. We set $\nu = 0.5$ which implies a labor elasticity of 2. This estimates are in the range of elasiticities used in macroeconomics as reported by Rogerson and Wallenius (2009). The exponent of the production function θ is set to the labor share 0.7 times the decreasing returns to scale parameter 0.975. The decreasing returns parameter is taken from Basu and Fernald (1997). The corporate tax τ_c is set to 25% which is the average effective corporate tax from 2002 to 2006 from the Monthly Treasury Statement published by the Treasury Department.

Consider next the parameterization of the Markov processes over idiosyncratic productivity shocks and aggregate shocks. The Markov process over firms' idiosyncratic productivity shock is parameterized as follows. In each period a fraction δ of firms receive a productivity shock $z_t = 0$ which is absorbing. The productivity process of the remaining firms is assumed to follow the process

$$\log z_t = \rho_z \log z_{t-1} + \sigma_t \varepsilon_t$$

where $\varepsilon_t \sim N(0,1)$. The innovations ε_t are independent across firms. The aggregate shock follows the process

$$\log \sigma_t = (1 - \rho_\sigma) \log \mu_\sigma + \rho_\sigma \log \sigma_{t-1} + \upsilon_t$$

where $\upsilon_t \sim N(0, \varphi)$.

Our data source for firm data is Compustat. We set the parameters governing the aggregate and idiosyncratic shocks $\mu_\sigma, \varphi, \rho_\sigma,\ \rho_z$, to match the time variation of both the distribution and average annual sales growth in the data. The four moments we target are the mean, standard deviation and autocorrelation of the cross section interquartile range of annual sales growth, and the mean firm autocorrelation of sales growth across firms from 1970 to 2009, which equals 0.65. Using quarterly data, annual sales growth is computed as $sales_t/0.5(sales_{t-4} + sales_t)$ with sales deflated by CPI for firms in Compustat with at least 160 quarters of observations. The debt tax discount τ_d is chosen to match an average debt to output ratio since 1990 among firms in Compustat. The fraction δ is parameterized to the average U.S. failure rates and the entry cost ξ is calibrated so that the number of firms relative to output 3.4. The resulting parameters are $\mu_\sigma = 0.19$, $\varphi = 0.22$, $\rho_\sigma = 0.76$, $\rho_z = 0.7$, $\delta = 0.025$, $\tau_d = 0.0017$ and $\xi = 2.66$.

Table (1) presents the calibration results and some additional moments of the model and the data. The model can match well the average and time variation of the cross section dispersion among firms in the U.S. Both in the data and the model the average growth dispersion across firms is large with an average interquartile range of 0.15 and 0.16 respectively and a standard deviation over time of 3.3 in the data and 3.7 in the model.

As the table shows, underlying the dispersion and time variation of sales growth across firms is the dispersion of the firm's leverage ratios both in the data and the model. The mean leverage ratios across firms are close to 3.6 the data and 5 in the model. Moreover the mean leverage ratio is very volatile over time with a standard deviation of 49 in the data and over 100 in the model. Moreover at any point in time, firms differ in their leverage ratios significantly. The average interquartile range of leverage equal 2.5 in the data while it is equal to 1.9 in the model. This heterogeneity in the cross section of leverage is also time varying with a standard deviation of 83 in the data and 66 in the model. Overall, the model is consistent with the data in terms of the large variability in firms' leverage ratios across time and across firms.

B. Impulse Response to a Dispersion Shock

Here we discuss the impulse response of both firm level variables and aggregate variables to an increase in dispersion. We use these responses to help provide intuition for the model's mechanism.

Specifically, to set the initial conditions we consider a long enough sequence of realizations in which the low dispersion shock is realized so that all aggregates do not change from one period to the next. We then use as an initial condition the resulting measure over individual states. Starting from this distribution we suppose that in time period 3 the dispersion shock changes from low to high and then stays there for then onwards.

The shock in the impulse response is an increase in σ_t from 14% to 20% which corresponds to one standard deviation of the σ_t process. To help interpret the magnitude of the shock, the IQR of sales growth increases from 0.13 to 0.14 with this shock.

We start with the responses of an individual firm with some particular individual state

(z, ℓ, b). We choose the level of z to be the mean level. Note that this level of z has the property that when the dispersion shock increases the conditional mean of future idiosyncratic shocks in unaffected. We choose the levels of ℓ and b for an average firm in the distribution.

In Figure 1 we plot the labor ℓ' and debt choices $\sum_{\sigma'} q(\sigma')b'(\sigma')$ of this firm for 10 quarters. We see that when dispersion increases the firm decreases the scale of production by about 3% and decreases the value of its borrowing by about 2.5%. The intuitive idea is that at the original scale of production, when dispersion increases firms would be forced into default more often. When firms default they lose the future stream of positive expected profits. To avoid losing this stream the firm decreases the size of the project.

The intuition for this result is that since the firm has decreasing returns to scale $(\theta < 1)$, the scale of operation controls the tradeoff between expected return and risk. A smaller scale lowers expected profits for the next period but lowers the risk, namely the probability that the firm will have to default.

Now consider our firm with the mean idiosyncratic productivity. When the dispersion shock increases, the conditional mean of the idiosyncratic productivity shock is unchanged but the conditional variance of this shock increases. This change increases the risk more than the expected return and hence the firm finds it optimal to choose a lower scale for the project. For a similar reason the firm decreases it outstanding debt.

To get a feel for the importance of financial frictions at the firm level we consider what a firm with no financial frictions would do when faced with an increase in dispersion. Specifically, we consider the choices of a single firm with access to a complete set of financial markets with complete enforcement of debt contracts that faces the same prices as in our economy and with idiosyncratic productivity equal to the mean level. In particular, this firm has access to debt which allows it to pay back different amounts depending on the level of its idiosyncratic shock. This firm chooses the scale of labor ℓ_{CM} so that the expected marginal product of labor equals the expected wage rate weighted by the stochastic discount factor

$$\sum_{z_{t+1},\sigma_{t+1}} Q\left(\sigma_{t+1}|S_t\right)\pi_z(z_{t+1}|\sigma_{t+1},\sigma_t)\theta z_{t+1}\ell_{CM}^{\theta-1} = \sum_{\sigma_{t+1}} Q\left(\sigma_{t+1}|S_t\right)w_{t+1}.$$

Figure 2 plots the labor choices for such a firm as well as the choices of labor for a firm in our economy. The scale of firms with no financial frictions are always higher than the scale of firms in our model. In fact, the distance between these two choices of labor is a measure of the financial distortions at the level of the individual firm. When dispersion is low, the size of the firm with no financial frictions is about 70% larger than a similar firm in our model. When dispersion increases, financial distortions are amplified and the difference in size between these two firms reaches 100%.

In the model, a firm's choice of its scale depends on that firm's debt, as well as on the aggregate and idiosyncratic. All else equal, highly indebted firms choose smaller scales. The left panel of Figure 3 illustrates this generic negative relationship between project size and debt for two aggregate shocks while holding constant operating profits at the mean level. Firms with large debt choose smaller scales because debt increases the risk of default and hence these firms find it optimal to reduce such risk with a more conservative scale. Specifically, given the debt schedules, large debt due shrinks firms' budget sets especially for low idiosyncratic shocks. Firms prefer to become smaller and expand the budget set in those idiosyncratic shocks to avoid default. As the figure shows, when debt is large enough, firms' budget set is empty and they default and exit.[2] As the figure also shows, high debt is disproportionately disruptive in times of high dispersion as the level of debt for which the firm shrinks its scale and defaults is lower with high dispersion.

Default in the model happens when firms cannot roll-over their debt even though the firm has a positive value. Hence, default happens due to *liquidity* as opposed to *solvency* problems. The right panel of Figure 3 shows the value of the firm as a function of debt for the two aggregate shocks. Clearly, the higher the debt of a firm is the lower its value and once the debt gets high enough, the firm's value is zero. The interesting part of the relation is that at a critical value of the debt the value of the firm discretely jumps down to zero. At this critical value the firm is just able to borrow enough to pay off its existing debt. Hence, for slightly higher values of debt the firm cannot borrow enough and must default. The reason the value function jumps at this critical value is that by defaulting the firm loses a strictly positive discounted stream of expected future profits. This leads to the question, Why can the firm with a positive value not borrow more? The reason is that the firm cannot borrow freely at the contingent prices used in the valuation of the future dividends. In particular, the firm cannot borrow contingently on its idiosyncratic shock. Because of this restriction the firm cannot pledge resources based only on the expected stream of profits. Hence, it is possible for a firm to be illiquid, in that it cannot borrow, even though it is solvent, in that it has positive value.

We now turn to the impulse responses at the aggregate level. In Figure 4a we plot the impulse response of the main aggregates, output, labor, and consumption, for 10 quarters.

[2] Many model of firm dynamics and financial frictions such Hopenhayn and Albuquerque (2003), Cooley and Quadrini (2001), and Arellano, Bai, and Zhang (2010) share this feature with our model.

In the period when the shock hits, the *impact* period, consumption falls about 0.5% and continues to slowly fall. On impact, output and labor do not change because the size of the projects have been set in the previous period. In the period after the shock hits, output falls about 1.5% and labor falls more than 2.5%. The reason why aggregate output and labor fall is that incumbent firms shrink their scale with higher dispersion and there is less entry of new firms. To get a longer perspective in Figure 4b, we plot these impulse responses for 100 quarters. We see that consumption and output continue to fall and eventually settle down to be about 1.7% lower than their starting points. After its initial drop, labor slowly rises and eventually settles down to be about 2.3% lower than their starting points.

In Figure 5a, we plot uncontingent interest rates (in levels relative to the initial one) and wage rates[3]. Except for the impact period, interest rates barely change. The wage rate drops more than 2% on impact and, as we see in Figure 5b, continues to decline until it is about 3% below its original level. The decline in wages after then shock hits is the main reason why aggregate labor slowly rises after the initial decline.

In Figure 6a we see that the measure of firms in the economy increases a tiny bit the period after the shock and then slowly decreases. The long impulse response in Figure 6b shows that this measure eventually settles down to about 1.7% below its original level. High dispersion is associated with a smaller measure of firms which is driven by the incentives to enter. As seen above, high dispersion exacerbates the financial frictions and leads firms to choose small scales. Hence during high dispersion times, it becomes less attractive to pay the fixed cost and enter. Since the resources spent on fixed costs to set up firms represent

[3]The uncontingent interest rate is the rate on claim in period t that delivers 1 unit of consumption in all states in period $t+1$.

a type of investment we have that investment decreases in high dispersion times. After the increase in dispersion the measure of firms declines slowly as consumers find it optimal to smooth their consumption.

In Figures 7a and 7b we graph the labor wedge and TFP. These are two commonly used measures in business cycle analysis. We define the labor wedge as

$$(10)\quad 1-\tau_l=-\frac{U_{ht}}{U_{ct}}/(\theta y_t/h_t).$$

and define TFP as output y_t divided by $h_t^{\theta}N_t^{1-\theta}$ where N_t is the measure of firms[4]. Interestingly, we see that the labor wedge falls over 3% after the dispersion shock is realized while TFP (and, clearly labor productivity y_t/l_t) increases a modest amount, about .5%.

Note that even with complete financial markets the labor wedge would not be zero. That is true because firms must commit to their scale before the realization of shocks. Hence, we think of (10) as a simple statistic that is often computed in the data and is used to evaluate models. Nonetheless, this labor wedge moves around substantially more in our model than it would in the complete markets version of our model. The reason it does so is that in our model the financial frictions make it not optimal for firms to equate the value marginal product of labor to the value of the wage as seen in Figure 2.

In the model, measured TFP rises a small amount because high dispersion in idiosyncratic productivity increases the reallocation possibilities across firms given the decreasing returns to scale in production.

[4] Here N_t is the measure of firms. We note that in the economy with complete markets the aggregate production function would be $h_t^{\theta}N_t^{1-\theta}$. (NEED A SECTION ON COMPLETE MARKETS)

C. Business Cycle Implications

So far we have investigated the implications for our model following a one time shock to dispersion. Next, we consider the type of business cycle statistics that the model generates. In examining these statistics it is important to keep in mind that in our benchmark results we have purposefully abstracted from other shocks to highlight the quantitative importance of dispersion shocks.

The data is quarterly from 1970: 1 to 2009:4 and logged and detrended with separate linear trends. We consider both changes in aggregates from peak to trough, business cycle statistics and explore in detail the episode of the 2007 financial crisis. (For details see the appendix.)

Peak Trough Analysis

Table (2) shows that a sizable fraction of the business cycle fluctuations can be rationalized by dispersion shocks interacting with financial frictions. Consider first the changes in aggregates from peak to trough. In the data, the average contraction of GDP from peak to trough is 5% while in the model the contraction is 3.5%. In this sense our model can explain about 70% of the contraction in aggregate output. In the data and in the model the contraction in aggregate output is largely due to a decline in labor. In the data, on average labor falls by 5.1% from peak to trough while in the model it declines by 6.7%. The model thus generates a recession mostly from movements in labor and hence predicts that labor declines more than output declines. In the data from peak to trough labor and output contract by about the same amount.

Probably the most important feature of the model is that it generates an average decline in the labor wedge in recessions of 7% which is close to the observed in the data of 5.8%. Thus, our model with financial frictions and dispersion shocks generate movements in aggregate variables which during downturns show up as a collapse in the labor wedge.

During this period TFP falls modestly from peak to trough. Specifically TFP falls on average about 1.3% while output falls about 5%. In the model, we have a moderate increase in TFP of 1.2%.

Bloom, Floetotto and Jaimovich (2009) show that in a model with adjustment costs for capital and labor high dispersion generates a TFP decline. In their model high dispersion also generates a contraction in aggregate output but through a different margin from ours. In their environment, the contraction in output is accounted by an endogenous decline in TFP, while in our model the contraction is accounted mainly by a decline in the labor wedge.

Business Cycle Statistics in the Benchmark Model

Turning to second moments statistics, our model with only dispersion shocks generates about 70% of the volatility of output in the data. The model also generates, as in the data, higher volatility of labor and the labor wedge relative to output although these relative volatilities are a bit higher. The relative volatility of labor in the model is 2 whereas in the data it is 1.3; the relative volatility of the labor wedge in the model is 2.5 whereas in the data it is 1.7. The labor and the labor wedge are also positively correlated with GDP in the model and data, though in the model those correlations are higher than in the data.

Classic business cycle models with only TFP shocks do not generate the higher volatility of labor relative to output observed in the data because in those models the labor wedge is constant. As noted above, Chari, Kehoe and McGrattan (2007) show that fluctuations in the labor wedge modeled as an exogenous stochastic process can account for about 2/3 of the fluctuations in output. In our model, financial frictions at the firm level and dispersion shocks increase the volatility of aggregate labor which results in a volatile labor wedge.

The variation of TFP in the model is modest and contrary to the data its fluctuations are negatively correlated with GDP. Adding TFP shocks in the model brings the volatility and correlation of TFP closer to the data. This is an extension we explore below.

The 2007 Financial Crisis

The next experiment we do in this section is analyze how much of the movement in aggregates in the current recession can be accounted for by our model.

In this experiment we let the initial number of firms be the one that arises in the limit after a long sequence of relatively low uncertainty shocks. We then choose the sequence of shocks so that the IQR of sales growth that the model produces is similar to that in the data. In Figure 8 we show the IQR of sales growth in the model and the data. We think of this procedure as backing out the dispersion shocks from data on dispersion of sales growth. Given our initial condition and this sequence of shocks we then simulate the model.

Figure 9 and 10 show the resulting movements in output and labor. From Figure 9 we see that over the period 2007:4 to 2009:3 the model generates about the same overall decline in output as in the data, although the decline in output in the model lags that in the data by several quarters. From Figure 10 we that the model produces a similar decline in labor as in the data, at least from 2007:4 to 2009:1, and then produces a somewhat larger decline at the trough of the recession.

Figures 11 and 12 show the resulting series for labor wedges and aggregate TFP. From

Figure 11 we see that the labor wedge in the model is similar to that in the data except for the last several quarters. From Figure 12 we see that the model produces a somewhat sizable increase in aggregate TFP, while in the data the TFP falls and then rises. Note that both in the model and in the data TFP rises by about 3 percentage points from 2008:4 to 2009:3. In this sense the main issue with TFP is that in the data TFP declines by almost 2% from 2008:1 to 2008:4 while in the model it increases a bit.

Business Cycles with Dispersion and Productivity Shocks

As in seen in the benchmark results of Table (2), dispersion shocks generate a greater volatility of labor relative to output as in the data. Nevertheless, our benchmark model produces TFP fluctuations that are negatively correlated with GDP. In this section we add aggregate productivity shocks in addition to dispersion shocks and find that having both shocks in our model can reproduce the aggregate business cycles statistics tightly.

Given that our model is highly non-linear, we add productivity shocks in a very parsimonious way. Specifically, we assume that productivity shocks are perfectly negative correlated with dispersion shocks and that an increase in one standard deviation of the dispersion shocks corresponds to a 1% decline in aggregate productivity. Such mapping from dispersion to productivity produces in our model a decline in TFP from peak to trough of about 1.2%, which mirrors the data TFP decline.

Table (3) shows the business cycle statistics and peak to trough deviations that our model produces with dispersion and aggregate productivity shocks. The model with both shocks can explain almost all of the fluctuations in output and labor. The model with both shocks continues to produce a highly volatile labor wedge, which enables the model to generate a highly volatile labor. Importantly, the model now matches the data in terms of the volatility of labor relative to output of 1.3. The relative labor volatility declines when the model faces productivity shocks because as in standard real business cycle models, the intertemporal labor choices together with persistent productivity shocks produces a low volatility of labor. In addition, the model now generates TFP comovements that are positively correlated with output, although this correlation is lower in our model than in the data. In terms of peak to trough movements, the model can reproduce the empirical output collapse during recessions driven mostly by a fall in labor.

4. Conclusion

[to be completed]

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Table 1: Calibration Results

	Data		Model	
	Mean	Std. Dev	Mean	Std.Dev
IQR Sales Growth	0.15	3.3	0.16	3.7
IQR Leverage	2.51	83.4	1.91	66.1
Mean Leverage	3.60	49.1	5.07	141.0
Other Moments				
Autocorrelation IQR Sales growth	0.84		0.72	

Table 2: Business Cycles with Dispersion Shocks

	Data				Model			
	Peak–Trough	$Std(x)$	$\frac{Std(x)}{Std(gdp)}$	$cor(x, gdp)$	Peak-Trough	$Std(x)$	$\frac{Std(x)}{Std(gdp)}$	$cor(x, gdp)$
GDP	-5.0	2.6			-3.5	1.8		
Labor	-5.1	3.4	1.3	0.79	-6.7	3.5	2.0	0.98
Consumption	-3.1	2.5	0.7	0.86	-0.6	1.1	0.6	0.76
Labor Wedge	-5.8	4.4	1.7	0.84	-7.1	4.4	2.5	0.96
TFP	-1.3	1.2	0.3	0.61	1.2	0.8	0.5	-0.90

Table 3: Business Cycles with Dispersion and Productivity Shocks

	Data				Model			
	Peak	$Std(x)$	$\frac{Std(x)}{Std(gdp)}$	$cor(x, gdp)$	Peak	$Std(x)$	$\frac{Std(x)}{Std(gdp)}$	$cor(x, gdp)$
GDP	-5.0	2.6			-5.4	2.9		
Labor	-5.1	3.4	1.3	0.79	-7.2	3.8	1.3	0.97
Consumption	-3.1	2.5	0.7	0.86	-1.5	1.6	0.5	0.84
Labor Wedge	-5.8	4.4	1.7	0.84	-6.9	3.8	1.4	0.98
TFP	-1.3	1.2	0.3	0.61	-1.2	0.8	0.2	0.18

Figure 1: Firm Dynamics

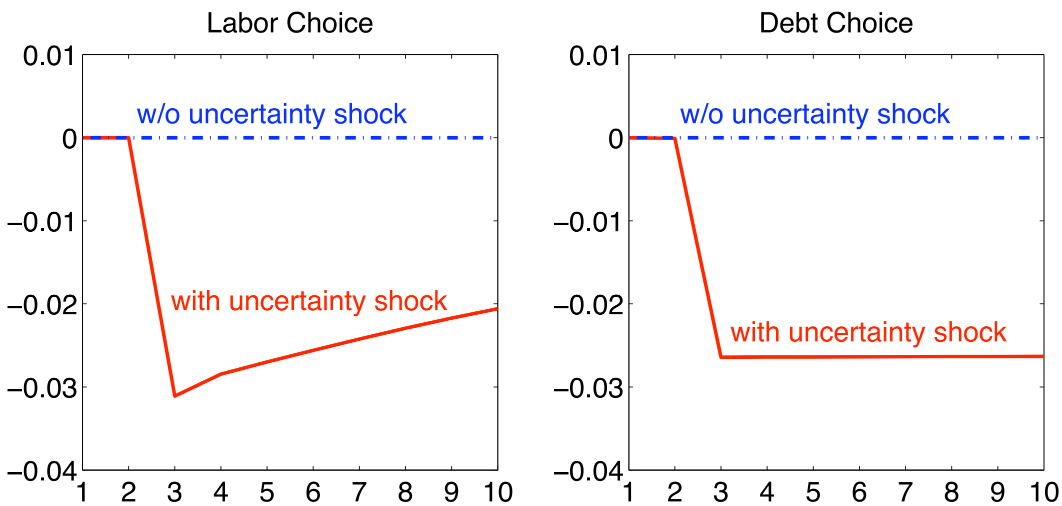


Figure 2: Model and Frictionless Labor Choice

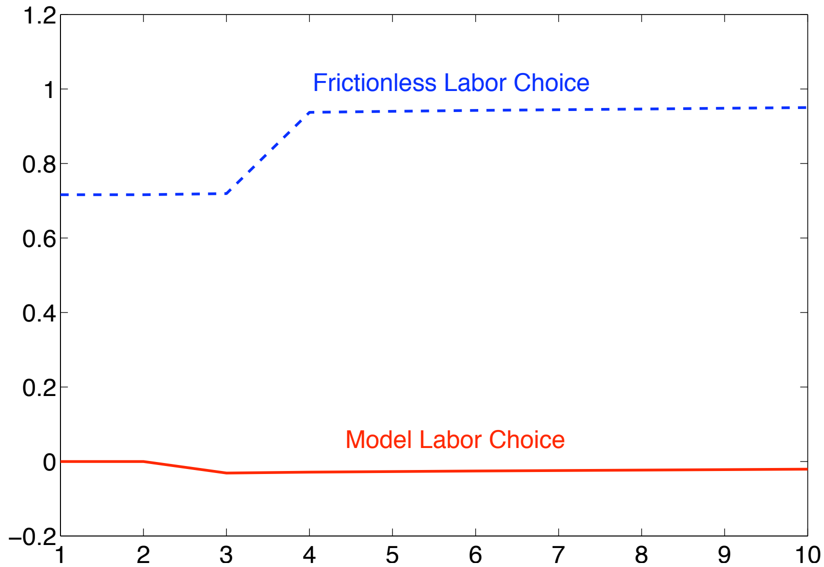
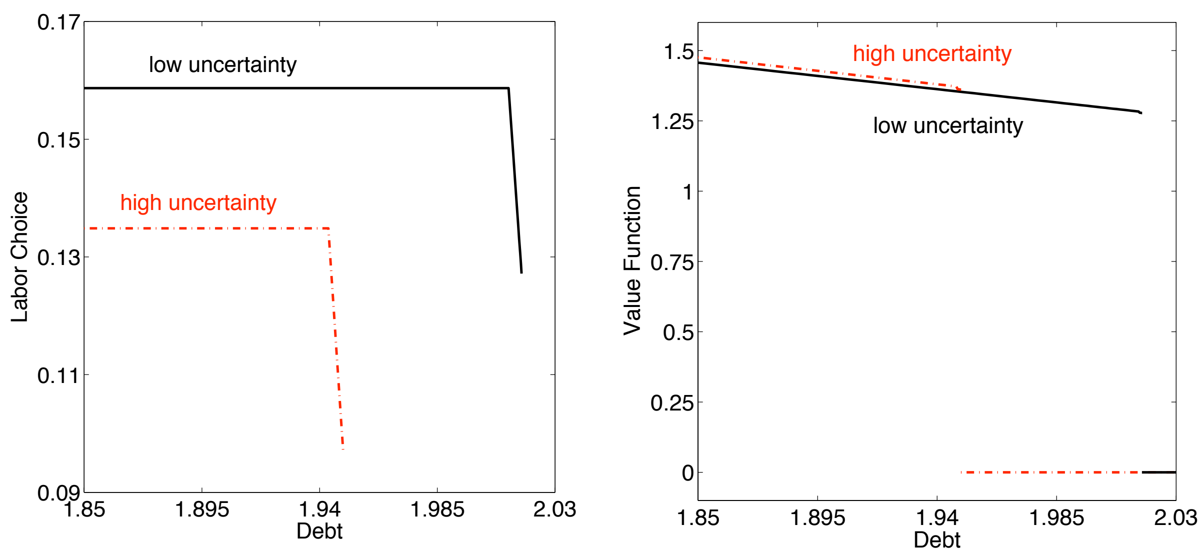


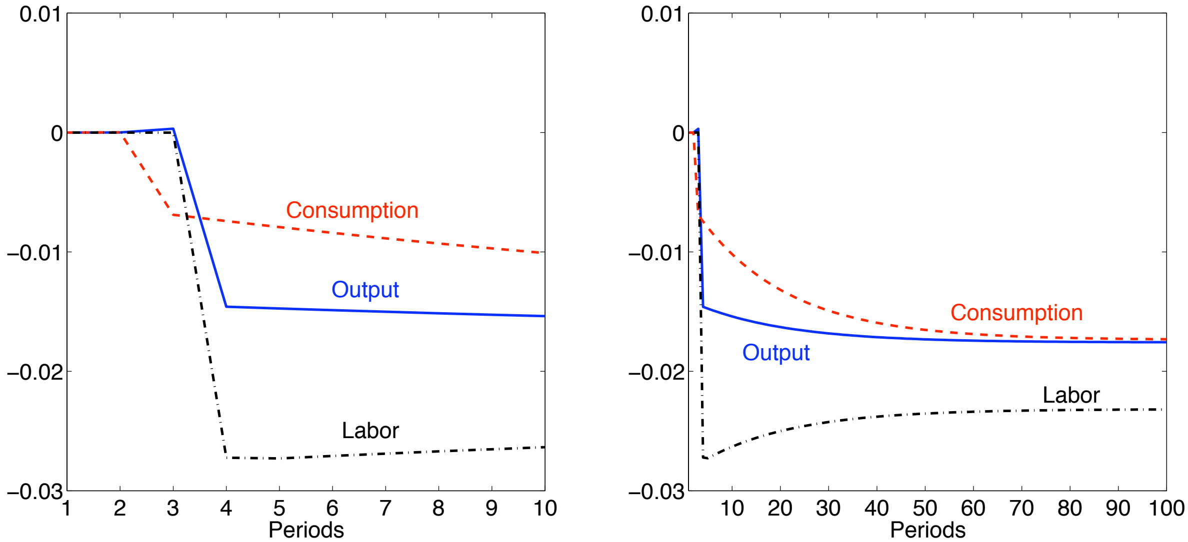
Figure 3: Policy and Value Function



(a)

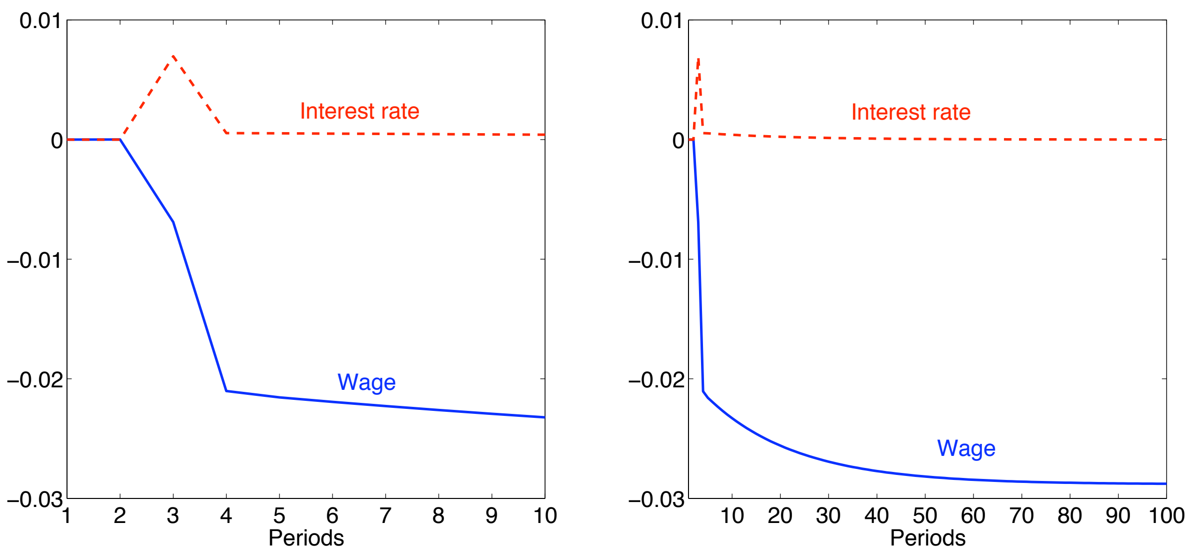
(b)

Figure 4: Impulse Responses for Output, Labor, and Consumption



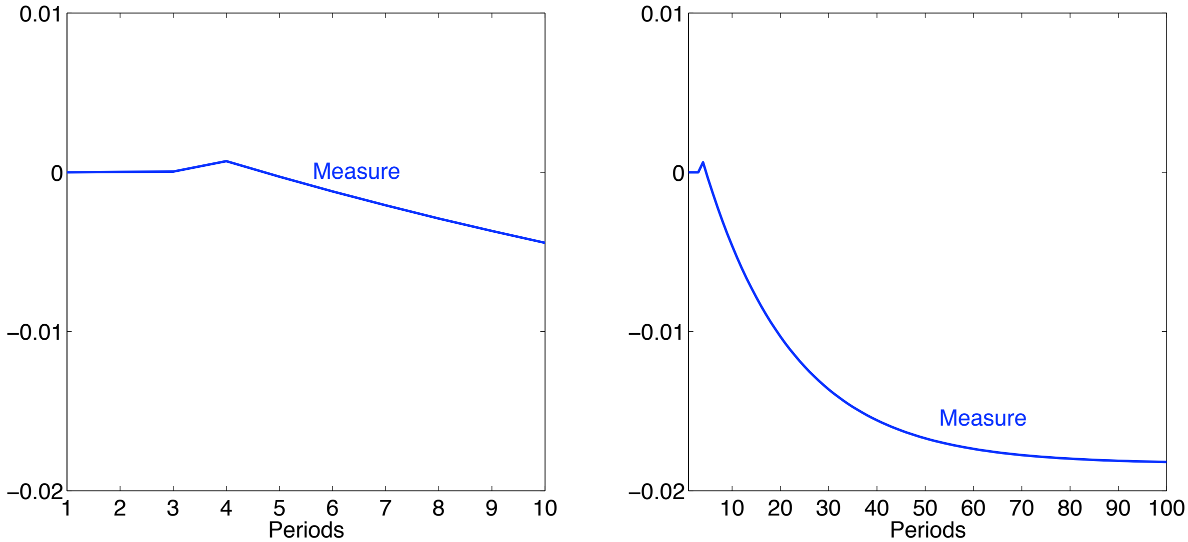
(a) (b)

Figure 5: Impulse Responses for Wages and Interest Rates



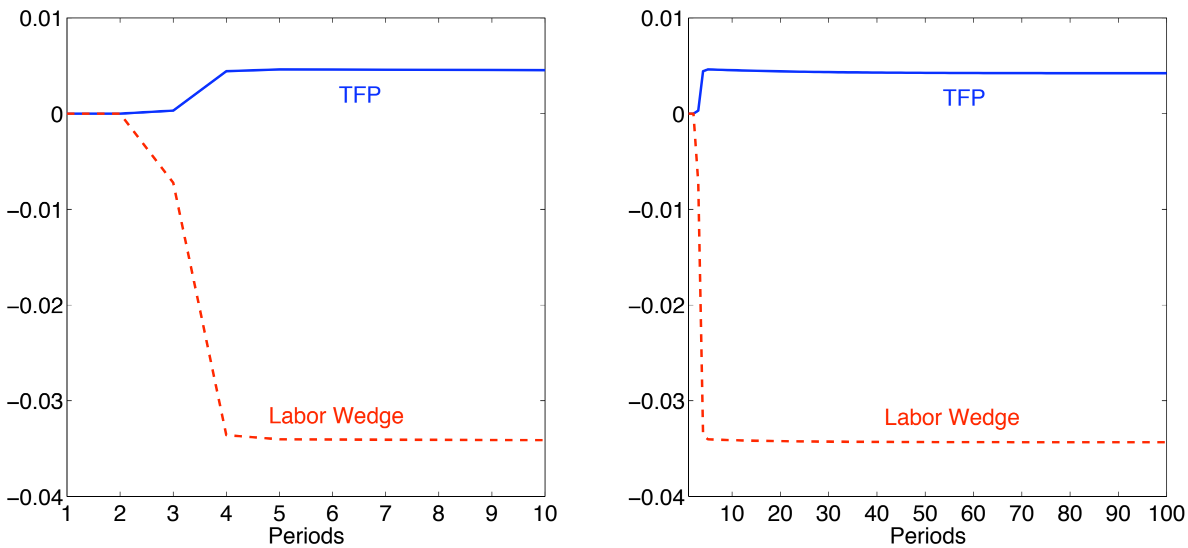
(a) (b)

Figure 6: Impulse Response for the Measure of Firms



(a) (b)

Figure 7: Impulse Responses for TFP and the Labor Wedge



(a) (b)

Figure 8: Financial Crisis: IQR Sales Growth

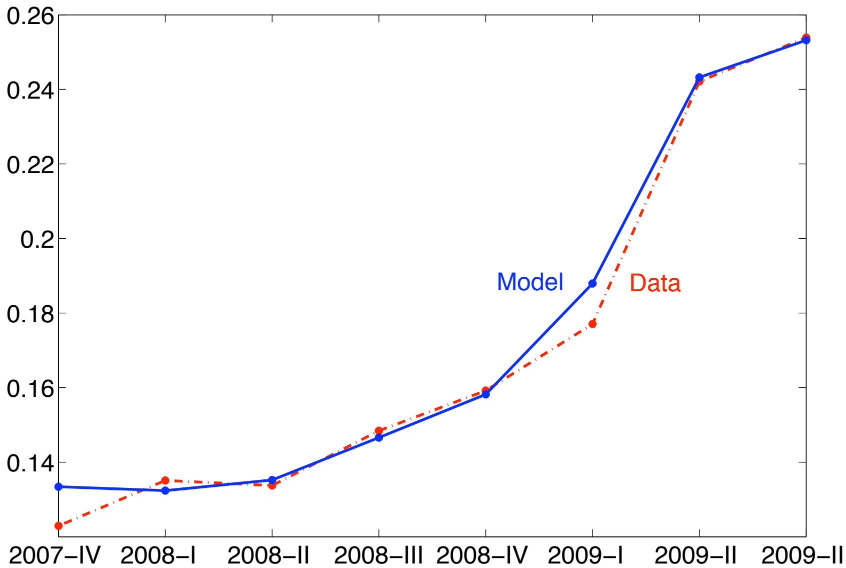


Figure 9: Financial Crisis: Output

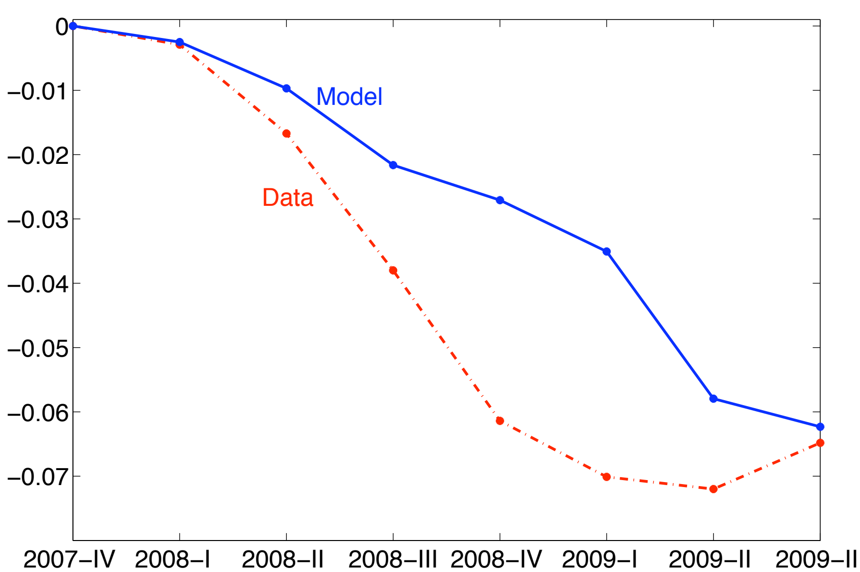


Figure 10: Financial Crisis: Labor

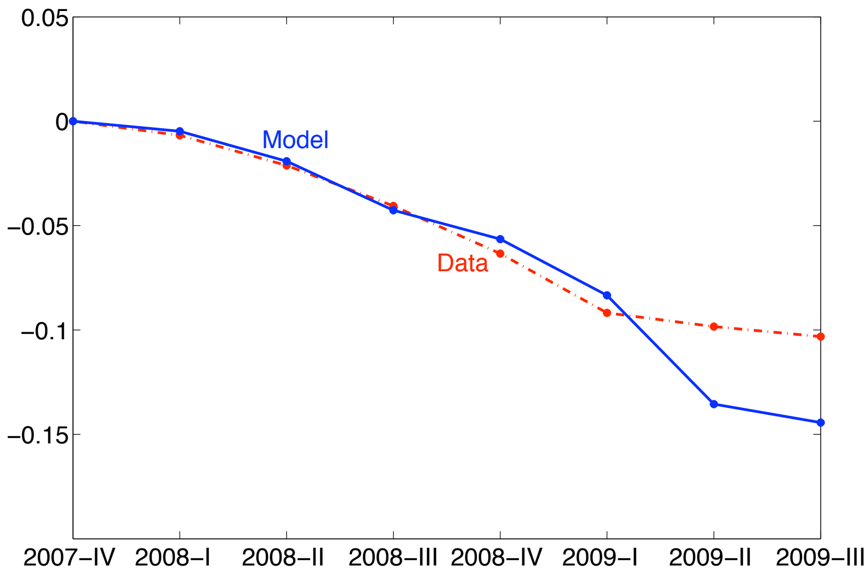


Figure 11: Financial Crisis: Labor Wedge

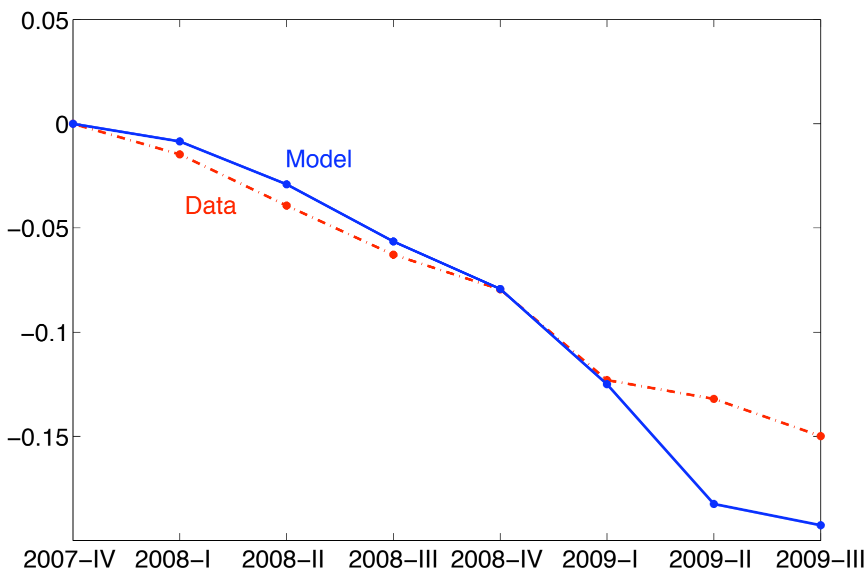


Figure 12: Financial Crisis: TFP