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João Ayres
Gajendran Raveendranathan

Inter-American Development Bank
Department of Research and Chief Economist

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João Ayres*
Gajendran Raveendranathan**

* Inter-American Development Bank
** McMaster University

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Abstract*

We analyze a general equilibrium model of firm dynamics to study the effects of shocks to productivity, labor wedge, and collateral constraint (credit shock) on firm exit. We find that only the credit shock increases firm exit. This result is robust to the magnitude of shocks and different model specifications. Calibrating the model to match the behavior of output, employment, and firm debt during the Great Recession (2007-2009) in the United States, we find that the credit shock accounts for the observed rise in firm exit and its concentration among young firms. Furthermore, it accounts for 20 percent of the drop in output and employment.

JEL classifications: D21, D22, E24, E32
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1 Introduction

In this paper, we ask the following question: how do aggregate shocks affect firm exit? To answer this question, we build a general equilibrium model of firm dynamics with financial frictions and analyze the implications of shocks to productivity, collateral constraint (credit shock), and the labor wedge.[1] We show that in general equilibrium, only the credit shock increases firm exit, and that this result is robust to the magnitude of the shocks as well as to different model specifications. Next, we calibrate the model to match the observed behavior of output, employment, and firm debt during the Great Recession (2007–2009) in the United States. We show that the credit shock not only accounts for the overall rise in firm exit, but also accounts for the heterogeneous behavior of firm exit across age groups, with young firms accounting for most of the rise. In this exercise, the credit shock accounts for 20 percent of the decline in output and employment during the Great Recession.

Our model economy builds on Khan and Thomas (2008, 2013) and Clementi and Palazzo (2016). We enrich Clementi and Palazzo (2016)'s model of firm entry and exit by incorporating financial frictions and solving the model in general equilibrium, as in Khan and Thomas (2008, 2013). More specifically, we add debt decisions with collateral and non-negative dividend payments constraints to the firm's problem, and savings and labor choices to the representative consumer's problem. The inclusion of debt accumulation by firms, together with collateral and non-negative dividend payments constraints, allows us to study the implications of credit shocks. The savings and labor choices close the economy, allowing us to solve for interest and wage rates in general equilibrium.

Our results are derived from two exercises. In the first exercise, we separately analyze the transition dynamics following negative shocks to productivity, labor wedge, and collateral constraint, with a focus on the dynamics of firm exit. The temporary shock is unexpected in period one and, after that, agents have perfect foresight on the evolution of the economy. The magnitude and persistence of the shocks are chosen to match the average drop in U.S. GDP in the last four recessions (1982, 1990, 2001, and 2007) as well as the average time it took for U.S. GDP to complete half of the recovery since the beginning of the recession. Our results show that, among these three shocks, only the credit shock increases firm exit. The effects of productivity and labor wedge shocks on firm exit are quantitatively negligible.

The intuition for these results are as follows. Everything else constant, a negative productivity shock reduces firms' revenues. That lowers the value of operating for any given firm while keeping the value of exit constant. Hence, it should lead to an increase in firm exit. However, in general equilibrium, the negative productivity shock leads to

[1] The labor wedge refers to a shock from the business cycle accounting literature that generates a larger fall in labor relative to output.

lower wage and interest rates, which offset the impact of the negative productivity shock on the value of operating, and consequently, the rate of firm exit remains approximately unchanged. In turn, the labor wedge shock is modeled as in Chari, Kehoe, and McGrattan (2007), where the shock directly impacts the household's labor supply decision. The shock does not affect the firm's fundamentals directly, so it could only impact firm's exit decision through general equilibrium effects. Since the labor wedge shock reduces labor supply, it puts upward pressure on the wage rate. However, in our model, most of the adjustment for a labor wedge shock comes through lower firm entry, which dampens the upward pressure on the wage rate, leaving the rate of firm exit approximately the same.

In contrast, a shock to the collateral constraint increases firm exit for two reasons. First, it constrains the ability of firms to borrow and accumulate capital, specially among the young ones. This reduces their value of operation and they choose to exit. Second, firms that come into the period with debt that matures in the current period might not be able to issue enough new debt to pay non-negative dividends. Those firms are forced to exit. In our second exercise, where we calibrate the model to the Great Recession in the U.S., around 80 percent of the increase in firm exit results from firms choosing to exit even though they could pay non-negative dividends. That means that the first reason dominates. Therefore, while general equilibrium offsets the effect of the productivity and labor wedge shocks on firm exit, it only partially dampens the effect of the shock to the collateral constraint. This result is robust to the magnitude of the shock and to different model specifications (e.g., fixed operating costs in units of the final good as opposed to units of labor, GHH preferences as opposed to standard log preferences, and GHH preferences with habit formation).[2]

In our second exercise, we jointly calibrate productivity, labor wedge, and collateral constraint shocks to match the behavior of output, employment, and firm debt in the U.S. during the Great Recession (2007–2009), and compare the model with all three shocks (including the credit shock) to a counterfactual one with only the productivity and labor wedge shocks (excluding the credit shock). We find that only the model with the credit shock increases firm exit. The model without the credit shock actually decreases firm exit, which is at odds with the data. Furthermore, the model with the credit shock accounts for the increased firm exit concentrated among young firms. We view this result as additional evidence that a credit shock played a significant role during the Great Recession. Finally, comparing the models with and without the credit shock, we find that the drop in both output and employment in 2009 would have been 20 percent lower if there were no credit shock.

Related literature Our paper contributes to several strands of the literature: the

[2] Osotimehin and Pappadà (2017) find that negative productivity and financial shocks increase establishment exit in a partial equilibrium model of firm dynamics. While this result is also true in our model, only the credit shock increases firm exit in general equilibrium.

literature on firm entry and exit, the literature on firm dynamics and credit shocks, the literature on business cycle accounting, and the empirical literature on firm dynamics statistics. The paper that is most closely related to ours is Clementi and Palazzo (2016). They extend Hopenhayn (1992) to analyze how a shock to aggregate productivity propagates to changes in output in models with and without firm entry and exit. They find that incorporating firm entry and exit leads to higher persistence and volatility of output. The main difference between their analysis and ours is that we focus on implications of shocks for firm exit rather than how firm entry and exit affect aggregate fluctuations. Furthermore, our modeling choices differ from Clementi and Palazzo (2016) in other aspects, as we assume a general equilibrium model with endogenous interest rates, financial frictions, and firm entry with an unbounded mass of ex-ante identical entrants. The unbounded mass of ex-ante identical entrants implies that, in our model, the zero profit condition for entry holds with equality for all entrants. In Clementi and Palazzo (2016), potential entrants are bounded and ex-ante heterogeneous. Hence, in their model, the zero profit condition for entry does not hold with equality for all entrants. This feature of our model generates entry that is more cyclical than exit, a feature of the data documented by Lee and Mukoyama (2015).

Our paper contributes to the literature that uses firm dynamics models to study aggregate fluctuations. Khan and Thomas (2013) study productivity and credit shocks in a firm dynamics model with collateral constraints and partial irreversibility of investment. Khan, Senga, and Thomas (2016) study productivity and credit shocks in a firm dynamics model with endogenous default. Both papers argue that credit shocks are important to account for the behavior of aggregates and employment among small and large firms during the Great Recession. Clementi, Khan, Palazzo, and Thomas (2015), Sedláček (2019), and Siemer (2016) study how the decrease in firm entry during the Great Recession affected the slow recovery, which they term the "missing generation effect". Buera, Fattal-Jaef, and Shin (2015) analyze productivity shocks and credit shocks in a model with frictions in both the labor and the financial markets. A credit shock decreases employment among both young firms or small firms and increases employment among old and large firms. Mehrotra and Sergeyev (2019) target changes in job flows across firm age categories to calibrate their model of firm dynamics with financial frictions. The identification for the credit shock comes from lower job creation. They find that the credit shock accounts for 15 percent of the drop in total employment during the Great Recession. These papers have primarily emphasized the effect of credit shocks on firm entry and on young and small firms. We contribute to this literature by emphasizing the importance of a credit shock to account for firm exit during the Great Recession.

We also contribute to the literature on business cycle accounting. This literature estimates productivity, investment, labor, and government wedges to exactly match aggregates such as output, investment, consumption, and labor (Chari, Kehoe, and McGrattan,

2007). The idea is that upon estimation, the researcher could use these wedges to identify potential shocks. Brinca, Chari, Kehoe, and McGrattan (2016) estimate wedges in the standard real business cycle model and find that the labor wedge shock played a large role during the Great Recession. Furthermore, they emphasize that a credit shock might show up as a productivity or labor wedge or investment wedge shock in the standard real business cycle model depending on the underlying economic environment. This finding is further emphasized in Buera and Moll (2015), who find that a shock to the collateral constraint could show up as a shock to productivity or the labor wedge or the investment wedge depending on the underlying form of firm heterogeneity. In our model, even after controlling for the credit shock, we find that the labor wedge played a large role during the recession. Our calibrated value for the increase in the labor wedge is more than 3 percentage points. While this complements the finding in Brinca, Chari, Kehoe, and McGrattan (2016), it also suggests that the large labor wedge that they estimated was not driven primarily by a credit shock. These results also complement Kehoe et al. (2019a) and Kehoe et al. (2019b), who emphasize the role of tightening household credit rather than firm credit during the Great Recession.

Finally, we contribute to the empirical literature on firm dynamics. In particular, Siemer (2019) compares the performance of firms with high and low external financial dependence during the Great Recession using confidential data on the universe of firms in the U.S., and finds that financial constraints affected firm employment growth of young firms primarily through firm entry and exit. Fort, Haltiwanger, Jarmin, and Miranda (2013) and Decker, Haltiwanger, Jarmin, and Miranda (2014b) emphasize the importance of firm age in addition to firm size in their analyses. Our finding that a credit shock accounts for the increased firm exit across different age groups complements these empirical studies and emphasizes the importance of firm age in addition to firm size. This is because in the presence of financial frictions and firm entry and exit, age is one of the determinants of a firm's idiosyncratic state (productivity, capital, and debt in our model).[3]

This paper is organized as follows. Section 2 presents empirical evidence on firm exit during recessions in the United States. Section 3 describes the model economy, and Section 4 presents its calibration. Section 5 discusses the properties of the model in the stationary equilibrium, and Section 6 shows the results. Section 7 presents our final remarks.

[3]Other papers related to our study are Ottonello and Winberry (2018), Winberry (2020), and Xiao (2018), Sedláček and Sterk (2017), Bloom et al. (2018), Arellano et al. (2018), Gilchrist et al. (2014), Dyrda (2016), Jermann and Quadrini (2012), Moscarini and Postel-Vinay (2012), Gomes and Schmid (2010), Gavazza et al. (2016), Crouzet and Mehrotra (2018), Lee and Mukoyama (2018), Schott (2015), and Adrian et al. (2012).

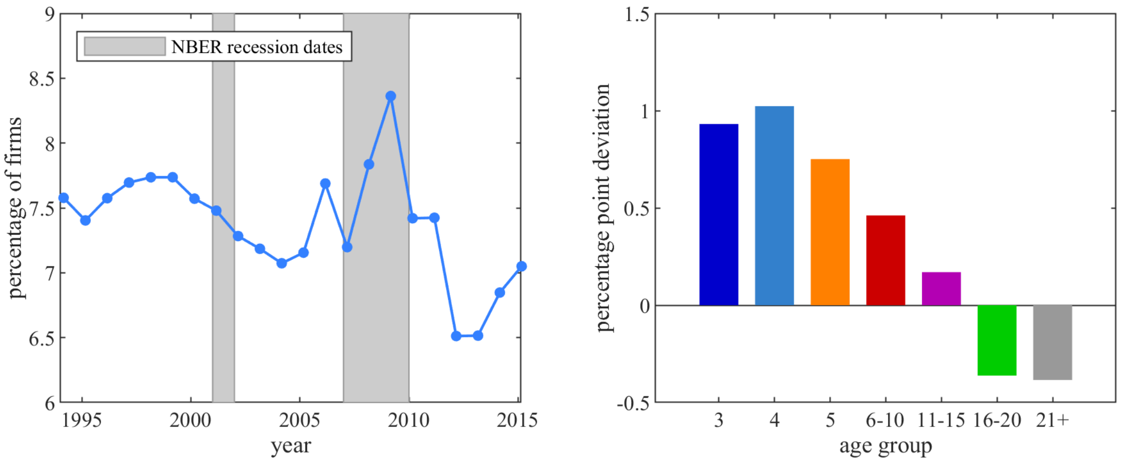
2 Data

In this section, we discuss the pattern of firm exit during the Great Recession (2007–2009) in the United States. The data are from the Business Dynamics Statistics (BDS), published by the Center of Economic Studies in the U.S. Census Bureau. This publicly available data set contains annual (mid-March) information on private businesses in the United States from 1977 to 2015. It is based on administrative records and covers most of the private non-agricultural sector of the economy. Furthermore, only employer firms are included (firms with at least one payroll employee). The main exclusions are self-employed individuals, employees of private households, agricultural production employees, and most government employees. Although information is available both at firm and establishment levels, we choose the firm as the main economic unit of our analysis because the firm makes the relevant decisions regarding the economic activities of its establishments.[4]

Figure 1: Firm exit during the Great Recession

(a) Firm exit rate: 3 years old and older

(b) Firm exit by age (2007-2009)



Sources: U.S. Census and NBER.

Figure 1a plots the exit rate of the group of firms that are three years old and older. It is defined as the total number of firms that exited the economy in that age group divided by the total number of firms in the same age group. The shaded areas in the figure correspond to recession periods according to the NBER classification of U.S. business cycles. Figure 1a shows that firm exit increased by 1.16 percentage points between 2007 and 2009. We focus on the exit rate of firms that are three years old or older because total firm exit lags firm entry. This follows from the fact that younger firms are more likely to exit than older firms. Therefore, by focusing on the exit rate of firms that are

[4] An establishment is defined as a single physical location where production takes place, whereas a firm corresponds to a group of establishments linked to each other by ownership. We refer to Haltiwanger, Jarmin, and Miranda (2002) and Jarmin and Miranda (2002) for a description of the data.

three years old or older, we control for the lagged effect of firm entry. For the rest of this paper, firm exit refers to exit rates of firms that are 3 years old and older.

Next, Figure 1b decomposes the rise in firm exit during the Great Recession across age groups. For this graph, we compute the number of firm exits for each age group as a percentage of total exits and plot the change in percentage points between 2007 and 2009. We see that the increase in firm exit during the Great Recession was concentrated among young firms (3 to 15 years old).

In Section 6.2, we show that only the credit shock in our model economy leads to an increase in firm exit, and it is also accounts for the concentration of exit among younger firms.[5]

3 Model

Our model economy consists of a representative household, heterogeneous incumbent firms, and ex-ante identical potential entrants. The representative household receives dividend payments from the firms and makes decisions regarding consumption, labor, and savings to maximize utility. Incumbent firms are heterogeneous with respect to their capital, debt/savings, and productivity. They make decisions on whether to operate or exit, as well as decisions on labor, investment, and borrowing (or saving) to maximize the present value of profits. Ex-ante identical potential entrants make decisions on whether to enter or not. Despite the idiosyncratic risk, the aggregate state of the economy evolves deterministically, and agents have perfect foresight. We describe the problem of each agent in detail below.

Households: the representative household chooses a sequence of consumption $\{C_t\}$, labor $\{H_t\}$, and asset holdings $\{A_{t+1}\}$ to maximize her lifetime utility subject to a sequence of budget, feasibility, and no-Ponzi-scheme constraints:

$$\max_{\{C_t,H_t,A_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t U\left(C_t, H_t\right), \quad \text{s.t.}$$

$$C_t + A_{t+1} \leq \left(1-\tau_t^h\right) w_t H_t + (1+r_t)A_t + \Pi_t + T_t, \tag{1}$$

$$C_t \geq 0, \quad H_t \in [0,1], \quad A_t \geq -\overline{A}, \quad A_0 \text{ given},$$

where $U\left(C_t, H_t\right) = \log C_t - \psi \dfrac{H_t^{1+\phi}}{1+\phi}$. $\beta \in (0,1)$ denotes the discount factor, w_t the wage rate, τ_t^h the labor wedge, r_t the interest rate, and T_t the lump-sum transfers. Furthermore, we assume the representative household owns the firms and receives dividend payments

[5] Firm exit increased during the 1980 Double Dip recession as well. However, data on firm exit by age group is not available for that period. Hence we focus on the Great Recession for our application.

Π_t in each period.

Incumbent firms: let $V_t^{inc}(k, b, \epsilon)$ denote the value of an incumbent firm in period t. The idiosyncratic state is given by the stock of physical capital k, the stock of debt/savings b ($b > 0$ refers to debt and $b < 0$ refers to savings), and the idiosyncratic productivity ϵ. In the beginning of each period, after observing the idiosyncratic productivity, the firm chooses whether to exit ($d = 0$) or to operate ($d = 1$) to maximize its value:

$$V_t^{inc}(k, b, \epsilon) = \max_{d \in \{0,1\}} d \times V_t^{op}(k, b, \epsilon) + (1 - d) \times V_t^{exit}(k, b), \tag{2}$$

in which $V_t^{op}(k, b, \epsilon)$ denotes the value of operating, and $V_t^{exit}(k, b)$ denotes the value of exiting. If the firm continues to operate, it chooses labor l, next-period capital k', and next-period debt/savings b' to maximize its value subject to non-negative dividend payment and borrowing constraints. The dividend payment of a firm is equal to its revenues net of operational costs, investment in physical capital, capital adjustment costs, interest payments on its current debt/savings, plus revenue from new debt issuance. It is expressed as

$$\begin{aligned} D_t(k', b', l, k, b, \epsilon) =& f(k, l, \epsilon; Z_t) - w_t(l + f^o) - x(k', k) - \zeta(k', k) \\ & - \left(1 + r_t + \mathbb{1}_{\{b>0\}}\tau^b\right) b + b', \end{aligned}$$

where $f(k, l; \epsilon, Z_t)$ denotes the production function, f^o the fixed operating cost (in units of labor), $x(k', k)$ the investment, $\zeta(k', k)$ the capital adjustment cost, and τ^b the exogenously given spread on the debt interest rate (borrowing wedge) for positive amounts of debt.[6] Given the initial capital stock k, investment is determined by the choice of next-period capital k' according to $x(k', k) = k' - \left(1 - \delta^k\right) k$, in which δ^k is the depreciation rate of capital. As in Hopenhayn (1992), idiosyncratic productivity follows a first-order Markov process, in which $F(\epsilon'|\epsilon)$ denotes the distribution of ϵ' conditional on the realization of ϵ. The value of the incumbent firm that decides to operate is

$$\begin{aligned} V_t^{op}(k, b, \epsilon) \quad &= \quad \max_{l,k',b'} D_t(k', b', l, k, b, \epsilon) + \frac{1}{1 + r_{t+1}} \int V_{t+1}^{inc}(k', b', \epsilon') F(d\epsilon'|\epsilon), \\ \text{s.t.} \qquad & D_t(k', b', l, k, b, \epsilon) \geq 0, \quad b' \leq \theta_t k. \end{aligned} \tag{3}$$

We assume a collateral constraint, in which next-period debt (borrowing) is limited to a fraction θ_t of the current capital stock of the firm. Exiting firms must sell their capital,

[6] Both operating and entry costs are in units of labor, so the model delivers stationary entry/exit rates and average employment size of firms in a balanced growth path. See Klenow, Li, and Bollard (2013). Section 6.1 shows that the results are not sensitive to having fixed costs in units of the final good.

pay the capital adjustment costs, and pay any debt entirely:[7]

$$V_t^{exit}(k,b) = \left(1-\delta^k\right)k - \zeta(0,k) - \left(1 + r_t + \mathbb{1}_{\{b>0\}}\tau^b\right)b. \tag{4}$$

The adjustment cost function is given by:

$$\zeta(k',k) = \begin{cases} \lambda\left(\frac{x(k',k)}{k} - \delta^k\right)^2, & x(k',k) \geq 0, \\ -\gamma x(k',k) + \lambda\left(\frac{x(k',k)}{k} - \delta^k\right)^2, & x(k',k) < 0, \end{cases}$$

with $\gamma, \lambda > 0$. The adjustment cost function incorporates both convex adjustment costs and investment irreversibility. The former is captured by the quadratic term, which implies that costs increase in a quadratic fashion as investment deviates from the level that would keep the capital stock constant. Investment irreversibility is captured by the linear term γx, which implies a higher cost for negative investment.

Entrants: we assume an unbounded mass of ex-ante identical potential entrants.[8] They enter with positive stock of physical capital k^e and zero debt. Upon entry, they pay a fixed cost f^e in units of labor and k^e in units of the final good, and draw an idiosyncratic productivity shock from the initial distribution G. The value of entry V_t^{entry} is given by

$$V_t^{entry} = -w_t f^e - k^e + \int V_t^{inc}(k^e, 0, \epsilon)\, G(d\epsilon). \tag{5}$$

Dividend payments: let $\Omega_t(k,b,\epsilon)$ denote the distribution of incumbent firms over the idiosyncratic states. Total dividend payments, Π_t, will be equal to the sum of the total dividend payments from incumbent firms that choose to operate, the total dividend payments from incumbent firms that choose to exit, and the total dividend payments from entrants:

$$\begin{aligned} \Pi_t = & \int D_t\left(k_t'(k,b,\epsilon), b_t'(k,b,\epsilon), l_t(k,b,\epsilon), k, b, \epsilon\right) d_t(k,b,\epsilon)\,\Omega_t(dk \times db \times d\epsilon) \\ & + \int \left[\left(1-\delta^k\right)k - \zeta(0,k) - \left(1 + r_t + \mathbb{1}_{\{b>0\}}\tau^b\right)b\right]\left(1 - d_t(k,b,\epsilon)\right)\Omega_t(dk \times db \times d\epsilon) \\ & + m_t \int D_t\left(k_t'(k^e,0,\epsilon), b_t'(k^e,0,\epsilon), l_t(k^e,0,\epsilon), k^e, 0, \epsilon\right) d_t(k^e,0,\epsilon)\, G(d\epsilon) \\ & + m_t \int \left[\left(1-\delta^k\right)k^e - \zeta(0,k^e)\right]\left(1 - d_t(k^e,0,\epsilon)\right) G(d\epsilon) - m_t\left(w_t f^e + k^e\right). \end{aligned} \tag{6}$$

[7]Following Khan and Thomas (2013), we do not allow firms to default on their debt, which implies that dividend payments might be negative upon exit. That is, if the stock of physical capital of an exiting firm is not sufficient to cover capital adjustment costs and debt repayments, the household must transfer to the firm the amount of final goods necessary to cover these costs.

[8]This is a key modeling difference from Clementi and Palazzo (2016). In their model, potential entrants are bounded and ex-ante heterogeneoues. Hence the zero profit condition may not hold with equality for all entrants. In our model, potential entrants are unbounded and ex-ante identical. Hence the zero profit condition holds with equality for all entrants. Our assumption generates larger movements in firm entry as observed in the data.

Production technology: each firm produces the homogeneous good using the following production technology:

$$f(k, l, \epsilon; Z) = (Z\epsilon)^{1-\alpha\nu} \left(k^{\alpha} l^{1-\alpha}\right)^{\nu},$$

where ϵ denotes the firm's idiosyncratic productivity, Z the aggregate productivity, k the physical capital input, and l the labor input. The capital-labor share is denoted by $\alpha \in (0,1)$, and $\nu \in (0,1)$ denotes the span of control parameter, as in Lucas (1978).

Lump-sum transfers: following the business cycle accounting literature, borrowing and labor wedges work like taxes, and they are rebated to the household as lump-sum transfers. Total transfers are given by

$$T_t = \tau^b \int \mathbb{1}_{\{b>0\}} b \; \Omega_t (dk \times db \times d\epsilon) + \tau_t^h w_t H_t.$$

3.1 Equilibrium

A *competitive equilibrium* consists of an initial level of asset holdings A_0, initial distribution over idiosyncratic states $\Omega_0(k, b, \epsilon)$, sequences of wage rate $\{w_t\}$, interest rate $\{r_t\}$, aggregate productivity $\{Z_t\}$, labor wedge $\{\tau_t^h\}$, collateral constraint $\{\theta_t\}$, consumption $\{C_t\}$, labor supply $\{H_t\}$, asset holdings $\{A_{t+1}\}$, dividend payments $\{\Pi_t\}$, lump-sum transfers $\{T_t\}$, mass of entrants $\{m_t\}$, distribution of incumbent firms over the idiosyncratic state $\{\Omega_t(k, b, \epsilon)\}$, operate/exit decision function $\{d_t(k, b, \epsilon)\}$, labor demand function $\{l_t(k, b, \epsilon)\}$, capital decision function $\{k_t'(k, b, \epsilon)\}$, debt decision function $\{b_t'(k, b, \epsilon)\}$, value of entry $\{V_t^{entry}\}$, value of incumbent function $\{V_t^{inc}(k, b, \epsilon)\}$, value of operating function $\{V_t^{op}(k, b, \epsilon)\}$, and value of exiting function $\{V_t^{exit}(k, b)\}$, such that:

(i) given A_0, $\{w_t\}$, $\{r_t\}$, $\{\Pi_t\}$, $\{T_t\}$, $\{\tau_t^h\}$, the allocations $\{C_t\}$, $\{H_t\}$, and $\{A_{t+1}\}$ solve the household problem in (1);

(ii) for each t and for each idiosyncratic state (k, b, ϵ), given r_t, w_t, Z_t, θ_t, and $V_{t+1}^{inc}(k, b, \epsilon)$, the allocations $l_t(k, b, \epsilon)$, $k_t'(k, b, \epsilon)$, $b_t'(k, b, \epsilon)$, and $d_t(k, b, \epsilon)$ solve the incumbent firm problem in (2), (3), and (4), with the respective maximum values equal to $V_t^{inc}(k, b, \epsilon)$, $V_t^{op}(k, b, \epsilon)$, and $V_t^{exit}(k, b)$;

(iii) for each t, the distribution of firms $\Omega_t(k, b, \epsilon)$ evolves according to:

$$\Omega_{t+1}(k', b', \epsilon') = \int \mathbb{1}\{k_t'(k, b, \epsilon) \leq k', b_t'(k, b, \epsilon) \leq b'\} \, d_t(k, b, \epsilon) \, F(\epsilon'|d\epsilon) \, \Omega_t(dk \times db \times d\epsilon)$$
$$+ m_t \int \mathbb{1}\{k_t'(k^e, 0, \epsilon) \leq k', b_t'(k^e, 0, \epsilon) \leq b'\} \, d_t(k^e, 0, \epsilon) \, F(\epsilon'|d\epsilon) \, G(d\epsilon);$$

(iv) for each t, the value of entry is equal to zero: $V_t^{entry} = 0$;

(v) for each t, the wedges are lump sum rebated to the household;

(vi) for each t, the labor market clears:

$$H_t = \int \left[l_t(k,b,\epsilon) + f^o\right] d_t(k,b,\epsilon)\Omega_t\left(dk \times db \times d\epsilon\right)$$
$$+ m_t f^e + m_t \int \left[l_t\left(k^e,0,\epsilon\right) + f^o\right] d_t\left(k^e,0,\epsilon\right) G^\epsilon\left(d\epsilon\right);$$

(vii) for each t, the asset market clears:

$$A_{t+1} = \int b'_t(k,b,\epsilon) d_t(k,b,\epsilon)\Omega_t\left(dk \times db \times d\epsilon\right)$$
$$+ m_t \int b'_t\left(k^e,0,\epsilon\right) d_t\left(k^e,0,\epsilon\right) G^\epsilon\left(d\epsilon\right);$$

(viii) for each t, the goods market clears:

$$C_t + m_t k^e + \int \left[k'_t(k,b,\epsilon) - \left(1-\delta^k\right)k + \zeta\left(k'_t(k,b,\epsilon),k\right)\right]\Omega_t\left(dk \times db \times d\epsilon\right)$$
$$+ m_t \int \left[k'_t\left(k^e,0,\epsilon\right) - \left(1-\delta^k\right)k^e + \zeta\left(k'_t(k^e,0,\epsilon),k^e\right)\right] G^\epsilon\left(d\epsilon\right) =$$
$$+ \int f\left(k, l_t(k,b,\epsilon), \epsilon; Z\right) d_t(k,b,\epsilon)\Omega_t\left(dk \times db \times d\epsilon\right)$$
$$+ m_t \int f\left(k^e, l_t(k^e,0,\epsilon), \epsilon; Z\right) d_t(k^e,0,\epsilon) G^\epsilon\left(d\epsilon\right).$$

Given the definition of a competitive equilibrium, the definition of a stationary competitive equilibrium is straightforward. A *stationary competitive equilibrium* is a competitive equilibrium in which the sequences of prices, allocations, and distributions, are constant across time (so time subscripts t can be dropped).

4 Calibration

Table 3 shows the parameters that are calibrated outside the stationary equilibrium. The statistics on firm dynamics are annual, so we assume a period to be one year. The discount rate β is 0.96 so that the interest rate in the stationary equilibrium $r = (1-\beta)/\beta$ is 4 percent, the estimate in McGrattan and Prescott (2003). We set the Frisch elasticity to 2, which implies ϕ equal to 0.5. This value of the Frisch elasticity is within the range used in macroeconomic models, between 2 and 4, as in Rogerson and Wallenius (2009). The span of control parameter ν is set to 0.836, which is the average of the estimates used in Khan and Thomas (2008, 2013), Bloom et al. (2018), and Clementi et al. (2015). The borrowing spread τ^b is set to 1.3 percent, the average of the Moody's Seasoned Aaa Corporate spread since 1983. The annual depreciation rate of capital δ^k is set to 6 percent. Both the fixed entry cost f^e and aggregate labor productivity Z are normalized

to one, and the labor wedge τ^h is set to zero.

Table 1: Parameters determined outside of the stationary equilibrium

Parameter	**Value**
Discount rate (β)	0.960
Labor elasticity (ϕ)	0.500
Borrowing spread (τ^b)	0.013
Span of control (ν)	0.836
Depreciation rate of physical capital (δ^k)	0.060
Persistence of idiosyncratic productivity (ρ_ϵ)	0.859
Fixed entry cost (f^e)	1
Aggregate labor productivity (Z)	1
Labor wedge (τ^h)	0

The idiosyncratic productivity ϵ is assumed to follow a log $AR(1)$ process given by $\log \epsilon' = \rho_\epsilon \log \epsilon + \eta'$, in which the innovation η' is iid and follows a Normal distribution with zero mean and variance σ^2_η. The persistence parameter ρ_ϵ is set to 0.859, following Khan and Thomas (2008). We discuss the calibration of the variance parameter σ^2_η below. The productivity process is discretized to a Markov chain with 30 grid points following the method described in Tauchen (1986). Entrants draw their initial productivities from the stationary distribution of the discretized Markov chain.

Table 2 presents the eight remaining parameters, which are jointly calibrated so that the model matches eight targeted moments in the stationary equilibrium. The choice of the targeted moments is based on the specific set of parameters we want to calibrate. The collateral constraint θ is related to the amount of debt firms have. We use as a target the average non-finance business debt-to-GDP ratio in 1948–2015 using data from the US Financial Accounts from the Board of Governors of the Federal Reserve System, which is 50 percent. The leisure share ψ is related to the fraction of total employment to working age population in the data, approximately 60 percent.[9] The capital share α is related to the labor share, and we use its average from 1970–2015 of 65 percent as a target.

Our specification of the capital adjustment cost function allows our model to match moments of the distribution of the investment rates (investment/capital) of individual firms reported in Cooper and Haltiwanger (2006). The investment irreversibility parameter γ is related to the fraction of firms with investment rates below 1 percent in absolute value, the inaction region, while the quadratic adjustment cost λ is related to the fraction of firms with investment rate above 80 percent, and the variance of innovations to idiosyncratic productivity σ^2_η to the standard deviation of investment rates.[10] Finally,

[9]Working age population is defined as the number of individuals between 16 and 64 years old.

[10]Cooper and Haltiwanger (2006) compute investment statistics using a balanced panel of large manufacturing plants that are continually in operation between 1972 and 1988. We account for that by simulating the initial stationary distribution for 30 years and computing the investment statistics based

Table 2: Parameters determined jointly in equilibrium and targeted moments

Parameter		**Value**
Collateral constraint (θ)		0.73
Leisure share (ψ)		1.75
Capital share (α)		0.37
Entry capital (k^e)		2.45
Fixed operating cost (f^o)		0.78
Variance of innovations to idiosyncratic productivity (σ_η^2)		0.08
Investment irreversibility (γ)		0.02
Quadratic adjustment cost (λ)		1.08
Target	**Data**	**Model**
Ratio of non-finance business debt to GDP	0.50	0.48
Total labor	0.60	0.60
Labor share	0.65	0.63
Entrants' 5-years survival rate	0.46	0.46
Entry rate	0.11	0.09
Standard deviation of investment rate	0.34	0.33
Fraction of firms with absolute investment rate below 1%	0.08	0.08
Fraction of firms with investment rate above 80%	0.02	0.03

the entry capital k^e and fixed operating cost f^o are related to the entry rate and the survival rate of young firms. Regarding the latter, we chose to target the entrants's 5-years survival rate. The targeted moments in the data and their respective values in the model are listed in Table 2.[11]

5 Properties of the initial stationary equilibrium

In this section, we analyze the lifecycle properties of firms in the stationary equilibrium under the benchmark calibration and validate the model against non-targeted moments in the data. Figures 2a and 2b plot the average employment and average capital stock of firms in each cohort, respectively. Firms start with the initial capital stock k^e at age 0 and begin to accumulate capital up to an age in which it stabilizes, around 15 years old on average. Employment follows a similar pattern. In fact, the employment decision is a static one, in which operating firms equalize the marginal product of labor to its marginal cost,

$$l_t(k,b,\epsilon) = \left(\frac{(1-\alpha)\,\nu\,(Z_t\epsilon)^{1-\alpha\nu}\,k^{\alpha\nu}}{w_t} \right)^{\frac{1}{1-(1-\alpha)\nu}}.$$

on the restricted sample of firms that survive for the entire period.

[11]Even though we described a relation between each parameter and a specific moment, it is important to emphasize that they are all estimated jointly because they affect the other targeted moments as well.

This implies that employment is increasing in firms' capital, idiosyncratic productivity, and aggregate productivity, decreasing in the wage rate, and does not depend on the level of debt.

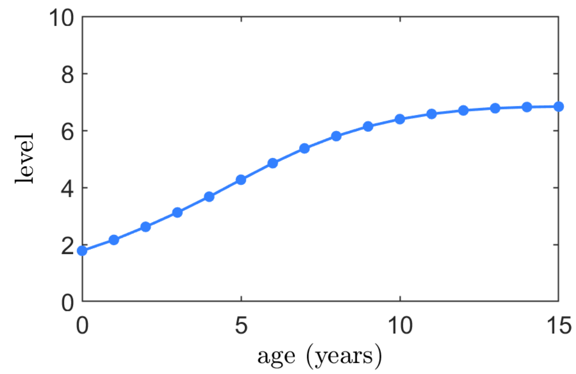
There are several features in the model that explain the growth pattern of young firms. The capital adjustment cost makes it costly for firms to adjust their capital stock by large amounts, so they smooth investment over time. The collateral and non-negative dividend payment constraints pose additional difficulties to capital accumulation. Firms rely on retained earnings and debt issuance to finance investment. However, the lower initial capital stock makes it difficult for firms to raise enough operating revenues and issue enough debt to achieve their desired stock of capital. Figures 2c and 2d show that firms leverage themselves with debt to finance investment in the early years. Average debt increases up to age 8 and decreases thereafter, reaching negative values for firms older than 13 years, which means that they begin to save to avoid hitting the non-negative dividend constraint in the future. Accordingly, firms choose to not pay dividends in their early ages until they have accumulated enough capital and savings. Figure 2e plots the average dividend payments by age of incumbent firms that choose to operate. Dividends are zero up to around age 7 and begin to increase thereafter, which means that all the revenues from sales and debt issuance are used for capital investment in the initial years.

Finally, firms also grow due to a selection effect. In our model, the only reason firms exit is because of low idiosyncratic productivity shocks. Some firms might be forced to exit because they cannot satisfy the non-negative dividend constraint, or they may choose to exit if the net present value of operation becomes lower than the value of exit. Consequently, the firms that are more likely to exit are the ones with lower capital and higher debt. In our model, these represent the young firms, which are trying to accumulate capital and have less space (low capital and high debt) to accommodate these negative shocks. Hence, the productivity threshold that triggers exit is higher for these firms. This adds to the higher exit rates at younger ages in Figure 2f. Therefore, the most productive firms survive in the initial years, implying that the average productivity increases, as Figure 2g shows. Interestingly, the life cycle profile of average productivity is not monotone. It starts to decrease after age 6. This is because by then firms have accumulated capital and start reducing their debt. Hence, they are more capable of accommodating low productivity shocks and the productivity threshold that triggers exit decreases.

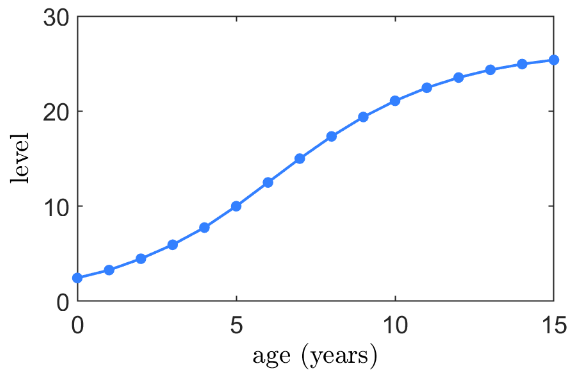
Figure 3 compares the properties of the stationary equilibrium to the data, and shows that the model accounts for several non-targeted moments. Figure 3a plots the distribution of firms across age groups and Figure 3b plots the average employment size of firms by age group. The model statistics closely match the data even though none of these moments were targeted except one. In Figure 3a, we implicitly targeted the ratio of the mass of firms that are 5 and 0 years old, because we calibrated the model to match the

Figure 2: Life cycle properties

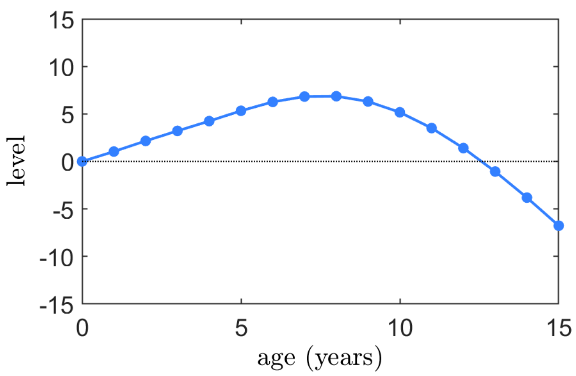
(a) Employment, l



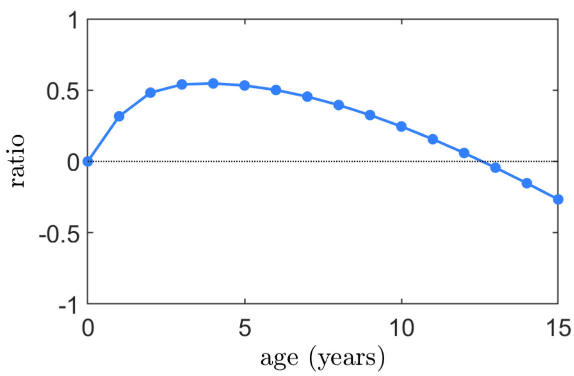
(b) Capital, k



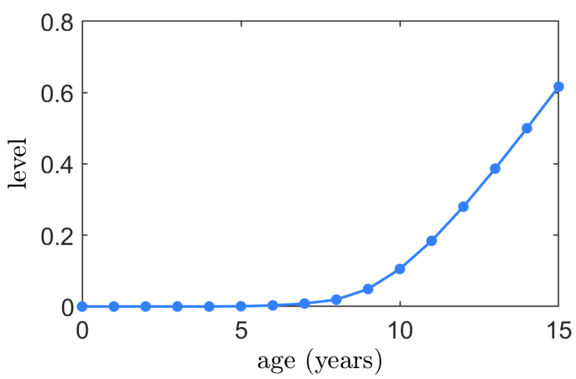
(c) Debt, b



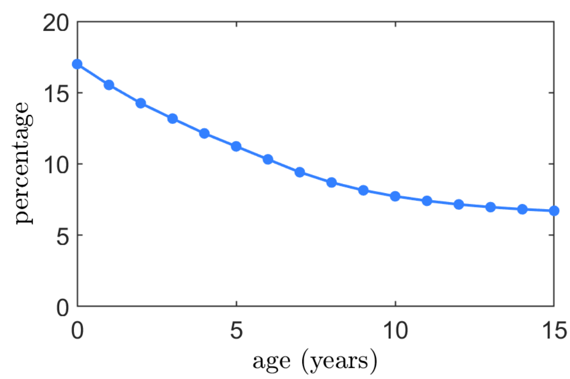
(d) Debt-to-capital ratio, b/k



(e) Dividend, D



(f) Exit rate



(g) Productivity, ϵ

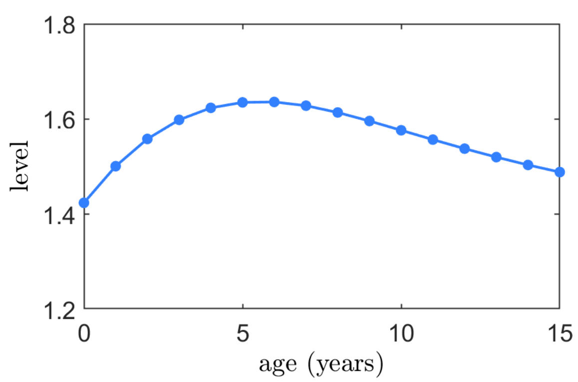
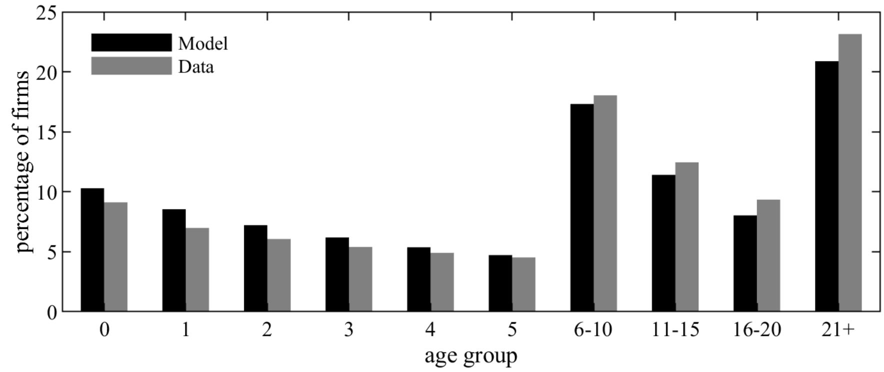
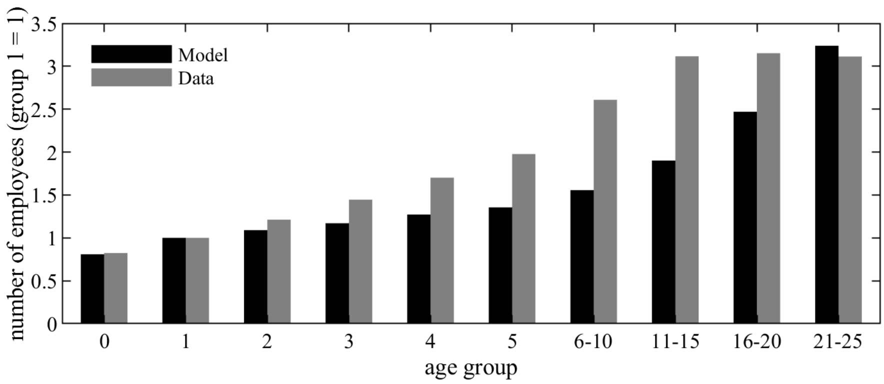


Figure 3: Firm age distribution, firm employment size, and job flows by age group

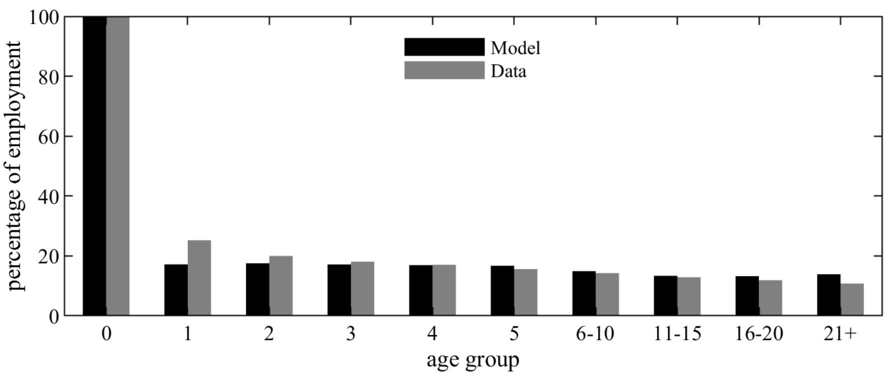
(a) Firm age distribution



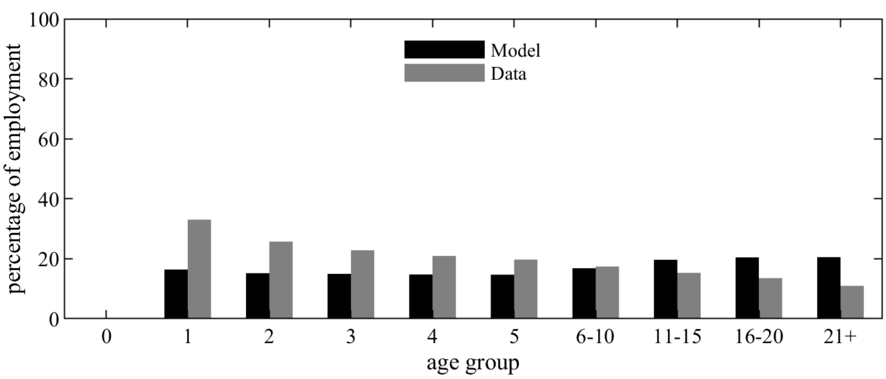
(b) Firm employment size by age group



(c) Job creation



(d) Job destruction



entrant's 5-years survival rate. The stationary equilibrium also matches the rates of job creation and destruction by age groups, presented in Figures 3c and 3d. The rates are computed as the fraction of jobs created/destructed over the total number of employees in the respective age group. This implies that age 0 firms have rates of job creation and destruction of 100 and 0 percent, respectively, both in the model and in the data.

6 Results

In this section, we perform two exercises. In the first exercise, in Section 6.1, we analyze the implications of negative shocks to aggregate productivity, labor wedge, and collateral constraint (also referred to as a credit shock) for firm exit. We show that only the credit shock increases firm exit in general equilibrium and that this result is robust to alternative model specifications. In the second exercise, in Section 6.2, we jointly calibrate the shocks to target the behavior of output, employment, and firm debt during the Great Recession (2007–2009) in the United States. We show that the credit shock not only accounts for the observed increase in firm exit, but it also accounts for the different behavior of exit rates across age groups. We also quantify its impact on aggregate output and employment.

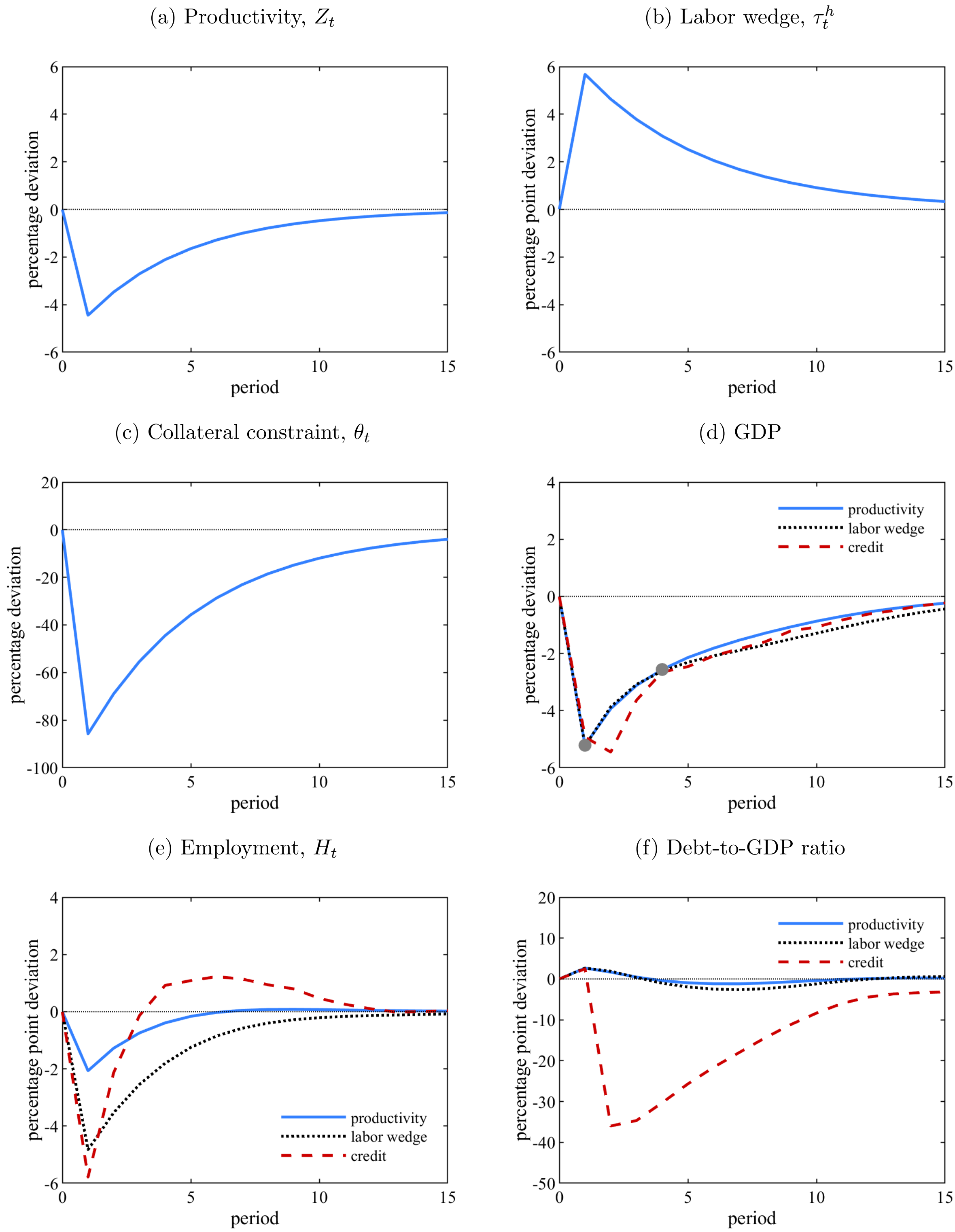
6.1 Aggregate shocks and firm exit

Starting from the stationary equilibrium under the benchmark calibration, we analyze the impulse response functions from temporary shocks to aggregate productivity, labor wedge, and collateral constraint. These shocks are unexpected one-time events, but once they occur agents have perfect foresight of how these variables will evolve over time.[12] In this exercise, we analyze each shock separately. The size and persistence of the shocks are jointly calibrated such that they generate the same drop and recovery in GDP. We match the average drop in US real GDP normalized by the working age population from peak to trough in the last four recessions, 5.2 percent, and the average time that it takes for GDP to complete half of the recovery since the beginning of the recession, 4 years.

Figure 4 shows the calibrated values of the shocks and the impulse response functions of main macroeconomic aggregates resulting from each shock. Given our calibration strategy discussed above, GDP is the same for all shocks in periods 1 and 4 as indicated by the gray markers in Figure 4d. In addition, Figure 4e shows that all shocks lead to reductions in employment, which also characterize recessions in the data. Figure 4f, which plots firm debt-to-GDP ratio, shows that firm debt-to-GDP decreases with the credit shock, but increases with the productivity and labor wedge shocks. The productivity and labor wedge shocks increase firm debt-to-GDP because they lead to a larger drop in

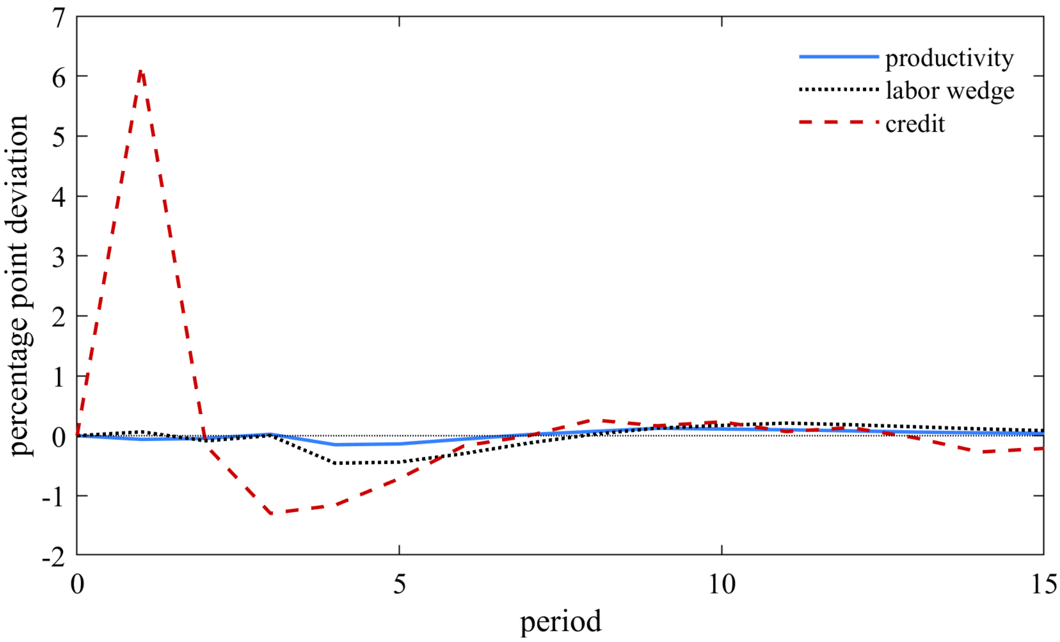
[12] We study transition dynamics as in Samaniego (2008).

Figure 4: Transition dynamics of main aggregates



GDP compared to the drop in firm debt. Given that these responses are qualitatively and quantitatively different across shocks, we will use these responses to jointly calibrate shocks during the Great Recession in our second exercise in Section 6.2. In this first exercise, we focus on firm exit. As Figure 5 shows, the implications for exit rates are very different across shocks. In particular, only the credit shock leads to a spike in the exit rate.[13]

Figure 5: Firm exit rate: 3 years old and older



To better understand the exit dynamics following each shock, Figure 6 breaks down the effects of each type of shock into partial and general equilibrium effects. It plots the exit rate together with the changes in the wage and interest rates. Let's start with the productivity shock. The red dashed line in Figure 6a shows what the exit rates would be if wages w_t, interest rates r_t, and entry rates m_t remained fixed at their initial levels (this relaxes labor market clearing, assets market clearing, and the zero profit condition). In this case, the only change an incumbent firm would observe is the lower aggregate productivity. This does not change the value of exit. However, it implies lower revenues and therefore a lower value of operating. That explains the rise in exit rates in period 1 for the dashed red line. However, once wages and interest rates are allowed to change, they offset most of the negative impact of the lower aggregate productivity for incumbent firms such that the overall changes in exit rates become negligible. This happens regardless of whether we keep entry rates fixed (relaxes the zero profit condition) and allow the wage and interest rates to change (black dotted line) or allow the entry, wage, and interest

[13]In the Appendix, Figure 11 shows that the entry rate decreases in all cases. Hence, in our model, lower firm entry is a response to all three shocks.

rates to change (benchmark general equilibrium—blue solid line).

Figure 6d analyzes the exit rate following the labor wedge shock. Note that the labor wedge does not enter the firm's problem. Hence, it could affect exit only through general equilibrium effects. That explains why the red dashed line (fixed wage, interest, and entry rates) does not respond. Once we allow wage and interest rates to change while keeping the mass of entrants fixed, the black dotted line, we observe an increase in exit rates. The reason is the following. The higher labor wedge leads to a lower supply of labor. Keeping entry rates fixed, but allowing the interest rate and wage rate to adjust leads to an adjustment in employment through incumbent firms. That leads to a large increase in wage rates, the black dotted line in Figure 6e. This makes firms demand less labor and pushes some of them to exit, which explains the rise in exit rates for the black dotted line. However, the higher wages make entry less attractive. Hence, at those wages, the firms that are entering would prefer not to. When we allow the entry rate to vary (zero profit condition holds), the lower mass of entrants lead to lower demand for labor. Consequently, the increase in the wage rate becomes much smaller in general equilibrium (blue solid line in Figure 6e) than when entry was fixed. This leads to almost no change in exit rates.

Finally, Figure 6g analyzes the case of a credit shock. As in the productivity shock case, the lower collateral constraint directly impacts firms. In fact, it mostly impacts young productive firms that are borrowing to accumulate capital as shown in Figure 2d. These are the firms that are financially constrained, and once the shock hits, there is a spike in exit rates. There are two main reasons for that. First, borrowing firms decided the amount of debt they brought into the period assuming that they would be able to borrow again. Once the issuance of debt unexpectedly becomes more difficult, and given that firms still have a low stock of capital, some of them are forced to exit because they are unable to generate non-negative dividends. Second, some exiting firms would be able to cut investment to generate positive dividends, but that would imply a much slower process of capital accumulation, which is further amplified due to the interaction with the lower collateral constraint. This leads some firms to choose to exit because it would take much longer for them to generate positive dividend payments. These two effects hold even when we allow for wages and interest rates to change, as well as the mass of entrants. General equilibrium only partially dampens the rise in firm exit. In the exercise in the next section in which we study the Great Recession, we further decompose changes in firm exit due to a credit shock.

The different behavior of exit rates following a credit shock is robust to the magnitude of the shock and to different specifications of the model. We show the behavior of firm exit in Figure 7 for a small shock and different model specifications. For the small shock, we consider the case where the shock is half of the calibrated value in Figure 4. Even then, the credit shock increases firm exit. For the different model specifications, we consider

Figure 6: Partial and general equilibrium effects

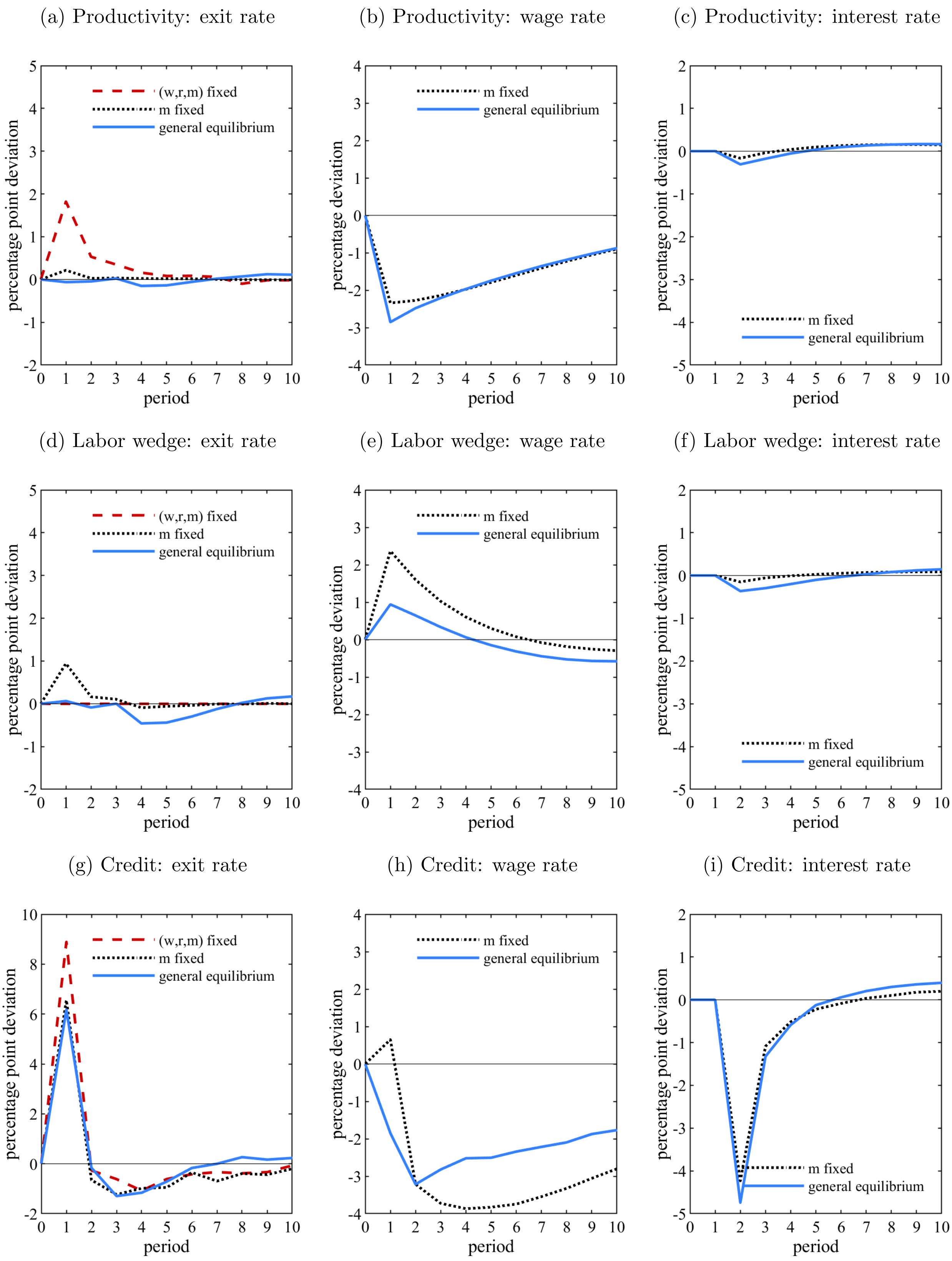
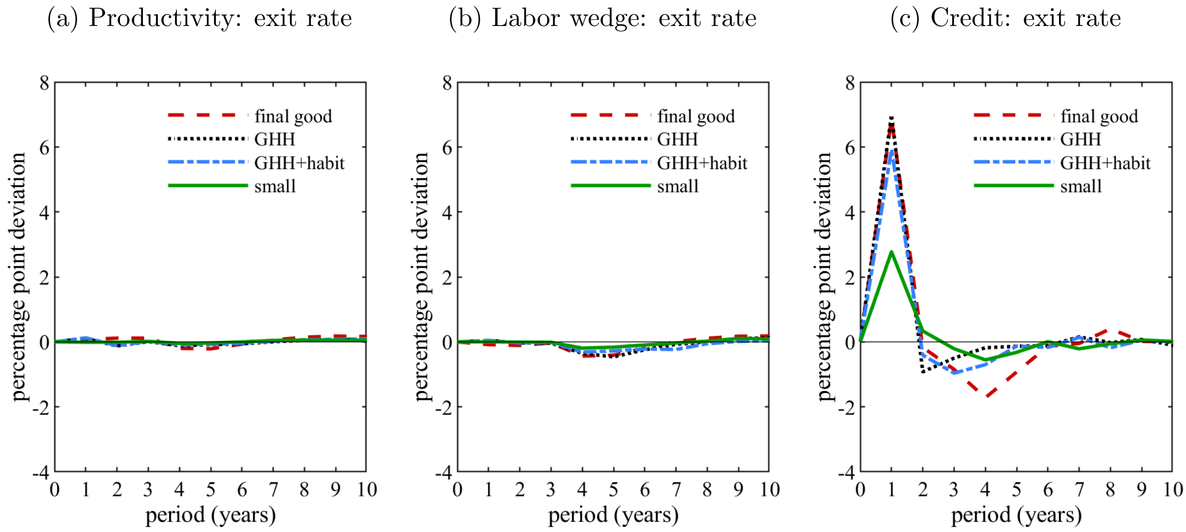


Figure 7: Firm exit with smaller shocks and other model specifications



the following cases: cost of operation in units of the final good, GHH preferences, and GHH preferences with habit formation as in Winberry (2020). Modeling cost of operation in units of the final good dampens the effects of lower wages due to a productivity shock. GHH preferences exclude wealth effects and hence dampen the fall in the wage rate (or amplify the rise in the wage rate). Habit formation, as studied by Winberry (2020), generates interest rate dynamics consistent with the data. For each of these cases, we recalibrate the model to match the same set of moments as in the benchmark calibration. Even with different specifications, only the credit shock increases firm exit.

6.2 Firm exit and the Great Recession

In our second exercise, we show that a credit shock accounts for the rise in firm exit and firm exit by age observed during the Great Recession in the United States. Furthermore, we quantify the impact of the credit shock on aggregate output and employment. To do that, we jointly calibrate shocks to productivity, labor wedge, and the collateral constraint to match the behavior of output, employment, and firm debt-to-GDP during the Great Recession. Given that the recession started in December 2007 (NBER), we treat 2008 as its first year.

Figure 8 plots the calibrated values of the shocks and the main macroeconomic aggregates both in the model and in the data. Data on GDP correspond to the deviation from a log linear trend of real GDP per working age person from 1948 to 2019. Employment data correspond to the ratio of employed people to total population between 16 and 64 years old. For firm debt, we use nonfinancial business loans from the FRB Z1. Given that output has not recovered since the Great Recession (Figure 8d), we assume one shock to productivity in 2008 and another shock to productivity in 2009 that is permanent (two

Figure 8: Great Recession calibration

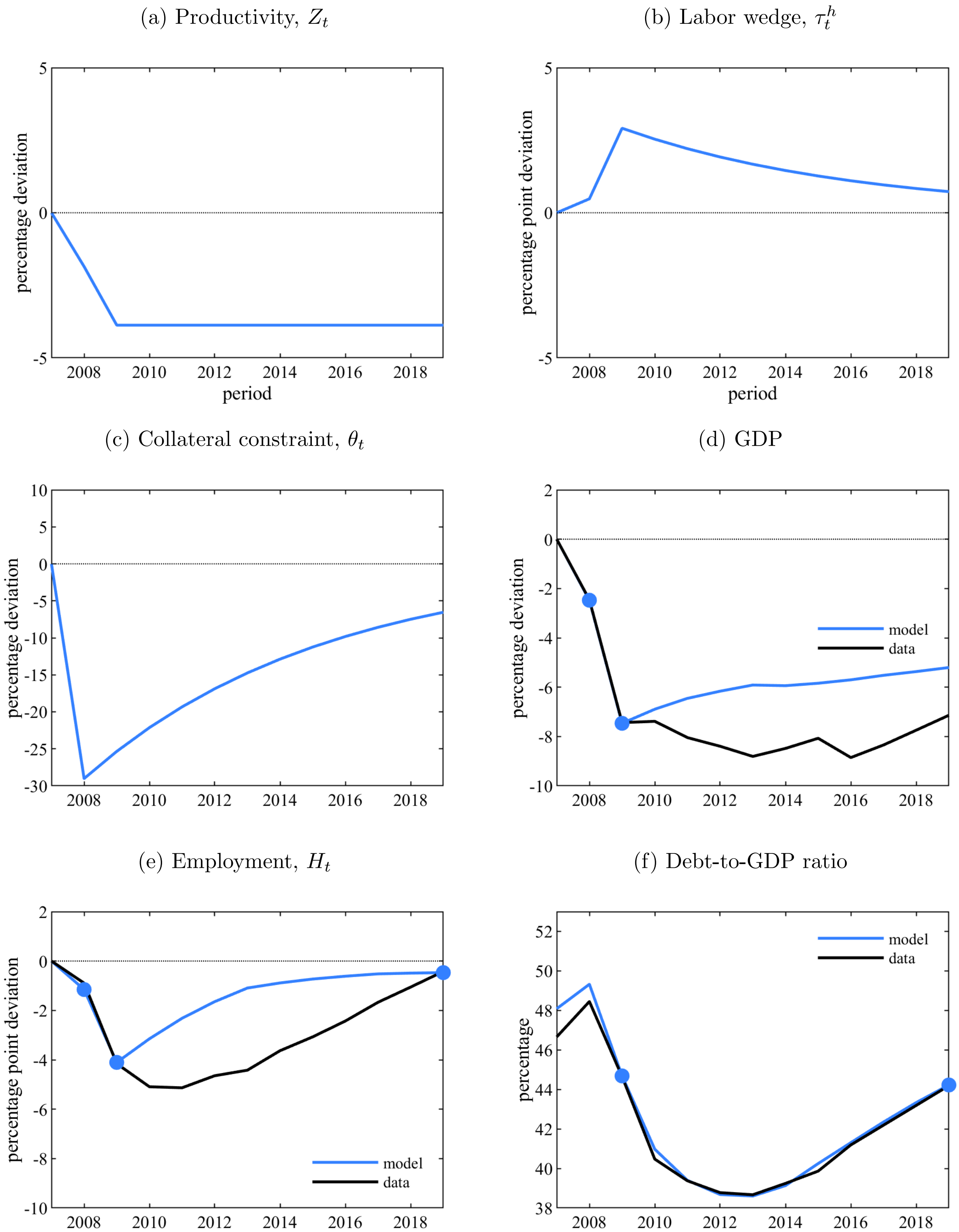
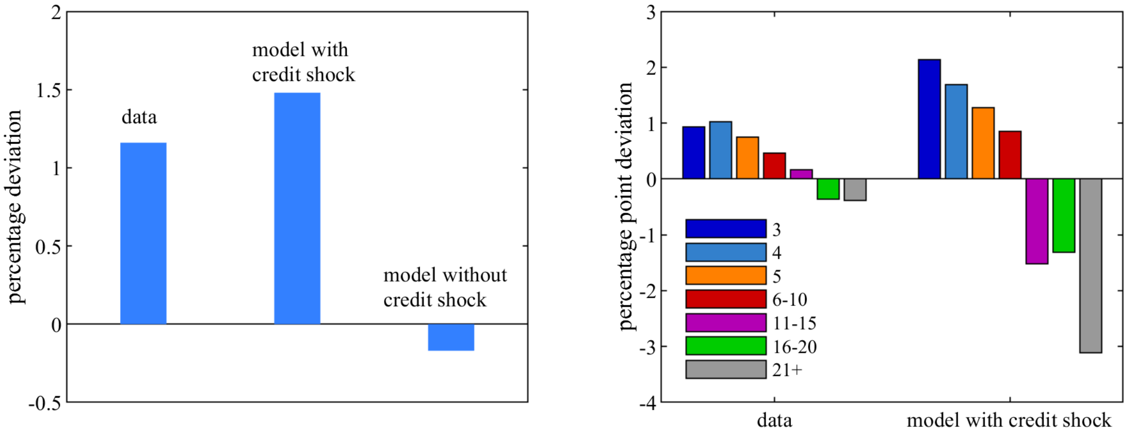


Figure 9: Non-targeted moments: firm exit in the model and data

(a) Firm exit rate: 3 years old and older

(b) Firm exit by age



parameters). We calibrate the labor wedge shock with 3 parameters: the shock in 2008, the shock in 2009, and the persistence parameter for the shock in 2009. We calibrate the credit shock with two parameters: the shock in 2008 and the persistence parameter for the shock in 2008. We jointly calibrate the 7 parameters to target the following 7 moments: output in 2008 and 2009, employment in 2008, 2009, and 2019, and firm debt-to-GDP in 2009 and 2019. They correspond to the blue markers in Figures 8d–8f. The calibration yields a 3.9 percent drop in productivity, a 2.9 percentage point increase in the labor wedge, and a 29.0 percent drop in the collateral constraint. Note that in Figure 8f, even though we only targeted the levels of firm debt-to-GDP in 2009 and 2019, the simulation accounts for the further decrease in firm debt-to-GDP observed in the initial years after 2009. In the model, the amplification of the drop is a result of the interaction between the collateral constraint and the capital stock.

To understand the role of the credit shock, we compare the model with all three shocks (*model with credit shock*) to a counterfactual one in which we feed in only the calibrated productivity and labor wedge shocks (*model without credit shock*). Figure 9 plots firm exit and a decomposition of firm exit by age groups in the model and data. In Figure 9a, we see that firm exit increases in the model with the credit shock as observed in the data (2007–2009). The model without credit shock actually decreases firm exit. In Figure 9b, we decompose firm exit across age groups in the data and in the model with the credit shock. We compute firm exit for each age group as a fraction of total exits and compute deviations from period 0 (2007 in the data). In both the model and data, the increase in firm exit is concentrated among young firms.

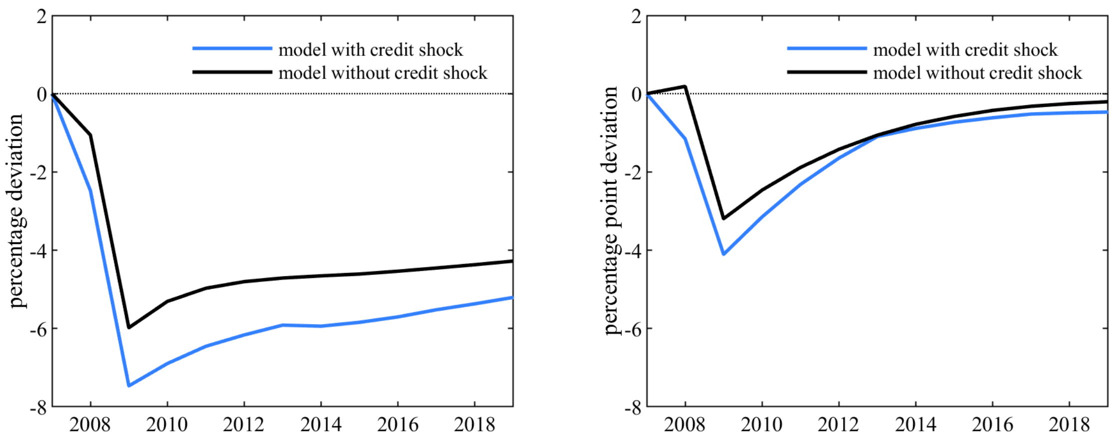
Table 3 provides summary statistics on the characteristics of firms that exit in the model with credit shock in period 0 and period 1. We see that relative to period 0, firms that exit in period 1 on average have higher productivity, lower net assets, and

Table 3: Characteristics of firms that exit: model with credit shock

Variable (only firms 3 years old and older)	**Period 0** (%)	**Period 1** (%)
Avg. productivity exiters / Avg. productivity all firms	47.4	51.5
Avg. capital exiters / Avg. capital all firms	30.9	29.0
Avg. net assets / Avg. net assets all firms	74.4	60.4
Firm exit 3 years and older / Firms 3 years and older	8.9	10.4
Firm exit 3 years and older (binding) / Firms 3 years and older	0.1	0.4

Figure 10: Output and employment with and without credit shock

(a) Output (b) Employment



lower capital. The increase in firm exit across firms that are 3 years old and older is 1.5 percentage points (10.4-8.9). The increase in firm exit across firms that are 3 years old and older as a result of them not being able to satisfy the non-negative dividend constraint is 0.3 percentage points (0.4-0.1). Hence, only 20 percent (0.3/1.5) of the rise in firm exit is a result of firms not being able to satisfy the non-negative dividend constraint, while the remaining 80 percent is a result of firms choosing to exit although they could pay non-negative dividends if they chose to operate.

Finally, we quantify the impact of the credit shock on output and employment in Figure 10. With the credit shock, output and employment fall by 7.5 percent and 4.1 percentage points in 2009, respectively. Without the credit shock, output and employment fall by 6.0 percent and 3.2 percentage points in 2009. Hence, the credit shock accounts for 20 percent of the fall in both output and employment during the Great Recession (1.0-6.0/7.5 and 1.0-3.2/4.1).

7 Conclusion

We analyze a general equilibrium model of firm dynamics to study the effects of shocks to productivity, labor wedge, and collateral constraint (credit shock) on firm exit. We find that only the credit shock increases firm exit. This result is robust to the magnitude of the shocks and different model specifications (fixed operating costs in units of the final good as opposed to units in labor, GHH preferences, and GHH preferences with habit formation).

Calibrating the productivity, labor wedge, and collateral constraint shocks to match the behavior of output, employment, and firm debt during the Great Recession, we find that the credit shock not only accounts for the rise in firm exit, but it also accounts for firm exit across different age groups. We view this result as additional evidence consistent with a credit shock during the Great Recession. Comparing the model with a credit shock to the model without it, we find that the credit shock accounts for 20 percent of the drop in output and employment during the Great Recession.

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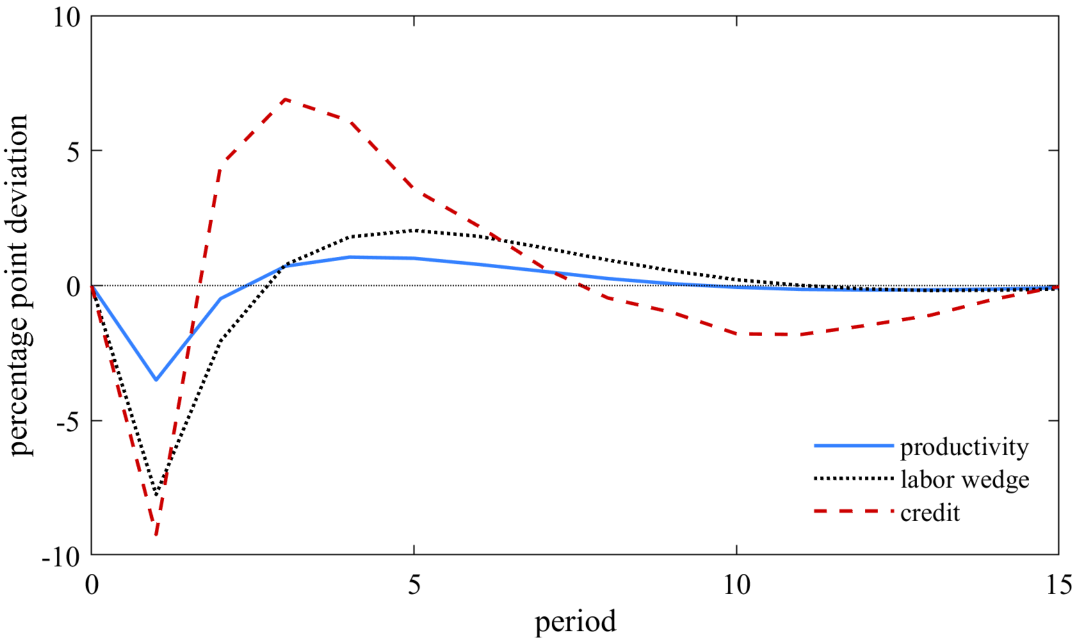
A Appendix

A.1 Firm entry

Figure 11 illustrates the behavior of firm entry for the three shocks analyzed in Section 6.1. It shows that all three shocks (shocks to productivity, labor wedge, and collateral constraint) lead to a drop in firm entry.

Figure 11: Firm entry rate



A.2 Algorithm to compute transitions

- Guess sequence of r_t
- Back out sequence of C_t given that $C_t = C_{t+1}/(\beta(1 + r_{t+1}))$
- Guess w_t and solve for incumbent firm's value and policy functions; solve for sequence of w_t through backward induction such that $V_t^{entry} = 0$
- Back out sequence of H_t from household intra-temporal condition
- Solve for sequence of m_t such that labor market clears
- Back out sequence for Π_t, A_{t+1}, and C_t
- Update r_t until convergence