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Abstract*

We analyze shocks to productivity, collateral constraint (credit shock), firm operation, and labor disutility in a model of firm dynamics with entry and exit. Shocks to firm operation and labor disutility capture COVID-19 lockdowns. Compared to the productivity shock, the credit and the lockdown shocks generate larger changes in firm entry and exit. The credit shock accounts for lower entry, higher exit, and concentration of exit among young firms during the Great Recession. The lockdown shocks predict a large fall in entry and rise in exit followed by a sharp rebound. In both recessions, changes in entry and exit account for 10–20 percent of the fall in output and hours. Finally, we discuss how the modeling of potential entrants matters for the quantitative results.

JEL classifications: D21, D22, E24, E32.

Keywords: Firm dynamics, Recession, COVID-19, General equilibrium model, Credit shock, Lockdown.

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1 Introduction

In this paper, we ask the following question: how do aggregate shocks affect firm entry and exit, and consequently, how do responses in firm entry and exit affect the evolution of macro aggregates? To answer this question, we build a general equilibrium model of firm dynamics with financial frictions and analyze the implications of aggregate shocks that generate recessions. We analyze shocks to aggregate productivity, collateral constraint (also referred to as a credit shock), firm operation, and labor disutility. Shocks to firm operation and labor disutility are shocks that capture a lockdown experienced during COVID-19. The firm operation shock imposes a temporary shutdown on some firms. The labor disutility shock captures the inability of some workers to go to work.

First, we show that in comparison to a standard productivity shock, the credit and the two COVID-19 lockdown shocks generate larger changes in firm entry and exit. Second, we use the model to analyze the Great Recession with productivity and credit shocks, and a COVID-19 lockdown with firm operation and labor disutility shocks. In our analysis of the Great Recession, the credit shock accounts for lower entry, higher exit, and concentration of exit among young firms. In our analysis of a COVID-19 lockdown, the model predicts a large fall in entry and rise in exit followed by a sharp rebound. In both recessions, lower entry and higher exit account for roughly 10–20 percent of the fall in output and hours. Finally, we discuss how the elasticity of the supply of potential entrants matters for the quantitative results.

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 nonnegative 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 nonnegative 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.

After calibrating our model to the U.S. economy and showing that it accounts for various non-targeted firm dynamics statistics by age and size, we derive our main findings from three exercises. In the first exercise, we separately analyze the transition dynamics following negative shocks to productivity, collateral constraint, firm operation, and labor disutility. The temporary shock is unexpected in period one, and thereafter, 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 four recessions from 1978 to 2018 (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 from the impulse responses in the baseline model show that, in comparison to a productivity shock, shocks to credit, firm operation, and labor disutility lead to larger changes in firm entry and exit. The intuition for these results is as follows. Everything else constant, a negative productivity shock reduces revenues for both incumbents and potential entrants. That lowers the value of operating while keeping the value of exit constant. Hence, it should lead to a fall in entry and rise in exit. However, in general equilibrium, the negative productivity shock leads to lower wage and interest rates, which dampen the impact of the negative productivity shock on the value of operating. Consequently, general equilibrium dampens the fall in firm entry and the rise in firm exit.

In contrast, a shock to the collateral constraint decreases firm entry and increases firm exit because it constrains the ability of firms to borrow and accumulate capital. This especially impacts potential entrants and young incumbent firms by reducing their value of operation. Potential entrants choose not to enter and young incumbents choose to exit.

The firm heterogeneity in our model allows us to study a novel shock to firm operation, where we set the idiosyncratic productivity of some firms to zero temporarily. This captures restrictions imposed by the government, which prevent some firms from operating during a COVID-19 lockdown. Unlike a productivity shock which reduces the productivity of all firms equally, a firm operation shock severely impacts the productivity of a specific set of firms. Hence, a firm operation shock, although calibrated to match the same fall and recovery in output as the productivity shock, leads to a significantly larger increase in firm exit.

Finally, the labor disutility shock directly impacts the household's labor supply decision. The shock does not affect the firm's fundamentals directly. It could only impact a firm's exit decision through general equilibrium effects. Since the labor disutility shock reduces labor supply, it puts upward pressure on the wage rate. The higher wage rate leads to a fall in firm entry and a rise in firm exit.

In our second exercise, we analyze the Great Recession. We calibrate credit shocks to match the behavior of firm debt while feeding in productivity deviations from the data. Comparing the model with both the credit and productivity shocks to a counterfactual with only a productivity shock, we show that the credit shock generates a fall in firm entry, rise in firm exit, and concentration of firm exit among young firms similar to that observed during the Great Recession. We view this result as additional evidence that a credit shock played a significant role during the Great Recession.¹

A natural question is whether these variations in entry and exit matter for the evolution of macro aggregates. Therefore, we perform simulations in both the model economy subject to credit and productivity shocks and one that is not subject to shocks, and we

¹Although the productivity shock in the Great Recession exercise does not generate significant movements in entry and exit, it could if the shock were large enough. In a separate analysis of the 1980s double-dip recession, also characterized by pronounced changes in entry and exit, we show that the productivity shock was large enough to generate significant changes in entry and exit.

compute the contribution of differences in entry and exit for macro aggregates. Lower firm entry and higher firm exit generate 19 and 24 percent of the observed fall in output and hours in the first two years of the Great Recession (2008 and 2009), respectively.

In our third and final exercise, we simulate a COVID-19 lockdown like the one observed in 2020. We analyze shocks to firm operation and labor disutility. The model predicts a large drop in entry and rise in exit followed by a sharp rebound. Although we do not have data from the Business Dynamics Statistics (BDS) on entry and exit in 2020, the implications for entry are qualitatively consistent with patterns observed for new business applications during 2020. [Dinlersoz et al. \(2021\)](#) document an initial decline and then a sharp rebound during COVID-19 in new business applications. Lower entry and higher exit account for 17 and 8 percent of the fall in output and hours (2020 Q2 to 2021 Q1), respectively.

Finally, we discuss how the modeling of potential entrants is important to account for entry responses in the data. In our baseline model we assume an inelastic supply of potential entrants. In contrast, if we assume a perfectly elastic supply of potential entrants as in [Hopenhayn and Rogerson \(1993\)](#), the model leads to entry responses that are too volatile compared to the data.

Related literature Our paper contributes to several strands of the literature: the literature that uses structural models of firm dynamics to study entry and exit over the business cycle and credit shocks during the Great Recession, the recent literature that uses structural models to study COVID-19 lockdowns, and the empirical literature on firm dynamics statistics. The two papers that are most closely related to ours are [Clementi and Palazzo \(2016\)](#) and [Khan, Senga, and Thomas \(2016\)](#). [Clementi and Palazzo \(2016\)](#) 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. In contrast to [Clementi and Palazzo \(2016\)](#), we analyze shocks to credit, firm operation, and labor disutility. We emphasize the larger impact of these shocks on firm entry and exit, the role of a credit shock for entry and exit dynamics during the Great Recession, and the impact of entry and exit adjustments on macro aggregates. For our analysis, we also make different modeling choices from [Clementi and Palazzo \(2016\)](#). We assume a general equilibrium model with endogenous interest rates and financial frictions.

[Khan, Senga, and Thomas \(2016\)](#) analyze the Great Recession in a model of firm dynamics where the novel features are endogenous entry and exit and financial frictions. While our studies intersect in the modeling of entry and exit, we differ in the modeling of financial frictions. Our model assumes non-defaultable debt with a collateral constraint, whereas they assume defaultable debt. In their model, a credit shock worsens firms' cash on hand by requiring larger dividend transfers to the household. This reduces the underlying value of collateral and increases the cost of borrowing. In our model, a credit

shock is captured by a shock to the collateral constraint. Our studies suggest that the magnitudes of the responses in entry and exit are sensitive to the nature of the credit shock. In their analysis, a credit shock leads to larger changes in entry and exit compared to that observed during the Great Recession. In our analysis, the credit shock generates changes in entry and exit that is less volatile and more in line with the data.

In addition to [Khan, Senga, and Thomas \(2016\)](#), several other papers use a model of firm dynamics to study shocks to credit and firm entry during the Great Recession. [Khan and Thomas \(2013\)](#) study productivity and credit shocks in a firm dynamics model with collateral constraints and partial irreversibility of investment. They argue that credit shocks are important in accounting for the behavior of aggregates and employment among small and large firms during the Great Recession. [Clementi, Khan, Palazzo, and Thomas \(2015\)](#), [Sedláček \(2020\)](#), 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 make two contributions to this literature. First, we show that modeling potential entrants as perfectly inelastic rather than perfectly elastic leads to entry behavior that is consistent with the data. Second, we highlight the importance of a credit shock to account for firm exit during the Great Recession.

Several papers study the impact of the COVID-19 lockdown. For example, [Glover, Heathcote, Krueger, and Ríos-Rull \(2020\)](#) introduce disease progression into a life cycle model with heterogeneous consumers. [Arellano, Bai, and Mihalache \(2020\)](#) incorporate epidemiological dynamics into a sovereign default model. While we do not introduce epidemiological dynamics into our model, we exploit the heterogeneity across firms to study the implications of lockdowns for a subset of firms.

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 \(2014\)](#) 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).²

2 Data

In this section, we discuss the patterns of total firm entry and exit during U.S. recessions from 1978 to 2018. 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 2018. It is based on administrative records and covers most of the private non-agricultural sector of the economy. 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 chose the firm as the main economic unit of our analysis because the firm makes the relevant decisions regarding the economic activities of its establishments.³

Figure 1a plots the observed entry and exit rates together with their linear trends. Figure 1b plots the deviations of both entry and exit rates from their trends. Following the methodology used in the BDS, entry/exit rate is computed as the total number of firm births/deaths divided by the average of the total number of firms in years t and $t - 1$. The shaded areas in the figures correspond to recession periods according to the NBER classification of U.S. business cycles. Figure 1b shows that firm entry decreased during the 1980 double dip recession, the 1990 recession, and the 2007 Great Recession. Firm exit increased during every recession from 1978 to 2018.

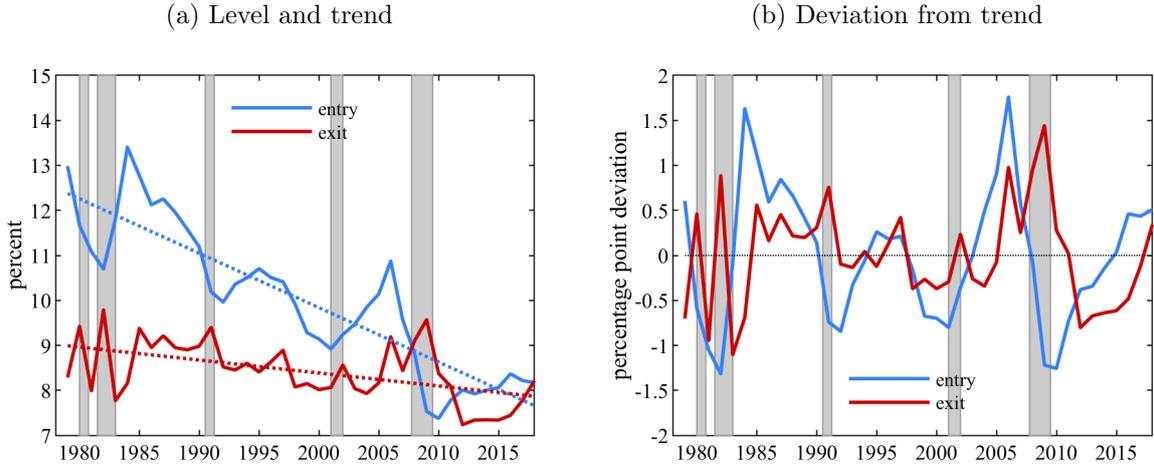
Next, we use the pronounced increase in firm exit during the Great Recession (2007-2009) and the availability of comprehensive data on firm age for the most recent years to study the behavior of firm exit by firm age in this particular episode. Figure 2 shows the time series of exit rates by firm age. The figure shows that the increase in exit rates in 2007-2009 was concentrated among younger firms (ages 1 to 5).⁴

²Other papers related to our study are [Ottonello and Winberry \(2020\)](#), [Winberry \(2021\)](#), and [Xiao \(2020\)](#), [Sedláček and Sterk \(2017\)](#), [Bloom et al. \(2018\)](#), [Arellano et al. \(2019\)](#), [Gilchrist et al. \(2014\)](#), [Dyrda \(2017\)](#), [Jermann and Quadrini \(2012\)](#), [Moscarini and Postel-Vinay \(2012\)](#), [Gomes and Schmid \(2010\)](#), [Gavazza et al. \(2018\)](#), [Crouzet and Mehrotra \(2020\)](#), [Lee and Mukoyama \(2018\)](#), [Schott \(2015\)](#), and [Adrian et al. \(2012\)](#).

³An 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.

⁴In the BDS, when an entrant exits, that is classified as an exit of a 1-year-old firm and so on.

Figure 1: Firm Entry and Exit



Notes: Figure 1a plots the levels and linear trends for firm entry and exit rates. Figure 1b plots percentage point deviations from linear trends for firm entry and exit rates from 1978-2018. The entry and exit rates are computed as the number of firm births (firm age = 0) and deaths normalized by the average of the number of firms in year t and $t - 1$, respectively. The shaded areas in the figures correspond to recession periods according to the NBER classification of U.S. business cycles. Sources: BDS and NBER.

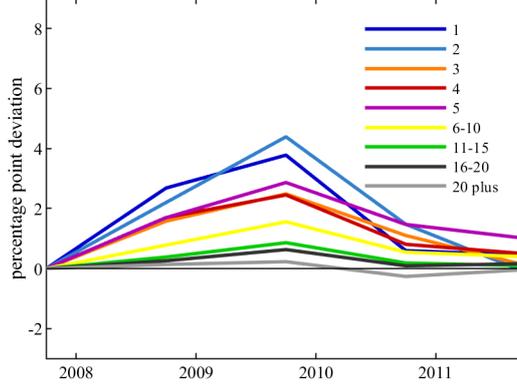
The figures above show that recessions are characterized by pronounced changes in entry and exit rates of firms, with some recessions showing larger variations than others. Based on that, Section 3 develops a quantitative macroeconomic model featuring firm entry and exit to analyze the implications of aggregate shocks for firm entry and exit rates, and the significant impact of the variation in firm entry and exit rates on the evolution of main macro aggregates.

3 Model

Our model economy consists of a representative household, heterogeneous incumbent firms, and potential entrants. The representative household owns 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. 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 se-

Figure 2: Firm Exit by Age during the Great Recession (2007-2009)



Notes: Figure 2 decomposes firm exit rates by age during the Great Recession, computed as the number of firm deaths in each age group divided by the total number of firms in the respective group. The figure plots the percentage point change in firm exit rate by age group from 2007. Source: BDS.

quence of budget, feasibility, and no-Ponzi-scheme constraints:

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

$$C_t + q_t A_{t+1} \leq w_t H_t + A_t + \Pi_t + T_t, \quad (1)$$

$$C_t \geq 0, \quad A_t \geq -\bar{A}, \quad A_0 \text{ given,}$$

where $U(C_t, H_t) = \log C_t - \psi_t \frac{H_t^{1+\phi}}{1+\phi}$. $\beta \in (0, 1)$ denotes the discount factor, ψ_t the labor disutility parameter, ϕ the inverse of Frisch elasticity, w_t the wage rate, q_t the bond price, and T_t the lump-sum transfers. Furthermore, we assume the representative household owns the firms and receives dividend payments Π_t in each period.

Incumbent firms: let $V_t^{inc}(k, b, \epsilon, \eta)$ 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 components ϵ and η . ϵ is a standard AR(1) component. $\eta \in \{0, 1\}$ is productivity during a COVID-19 lockdown. A firm that is allowed to operate will have $\eta = 1$, and a firm that is not allowed to operate will have $\eta = 0$. In the beginning of each period, after observing the idiosyncratic productivities, the firm chooses whether to exit ($d = 0$) or to operate ($d = 1$) to maximize its value:

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

in which $V_t^{op}(k, b, \epsilon, \eta)$ 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 nonnegative dividend payment and collateral constraints. The dividend payment of a firm is equal to its revenues net of operational costs, investment in physical capital, capital adjustment costs, principal payments on its current debt/savings, plus revenue from new debt issuance. It is expressed as

$$D_t(k', b', l, k, b, \epsilon, \eta) = f(k, l, \epsilon, \eta; Z_t) - w_t(l + f^o) - x(k', k) - \zeta(k', k) - b + (q_t - \mathbb{1}_{\{b' > 0\}} \tau^b) b',$$

where $f(k, l; \epsilon, \eta, Z_t)$ 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 bond price (borrowing wedge) for positive amounts of debt.⁵ Given the initial capital stock k , investment is determined by the choice of next-period capital k' according to $x(k', k) = k' - (1 - \delta^k)k$, in which δ^k is the depreciation rate of capital. As in [Hopenhayn \(1992\)](#), idiosyncratic productivity ϵ follows a first-order Markov process, in which $F^\epsilon(\epsilon'|\epsilon)$ denotes the distribution of ϵ' conditional on the realization of ϵ . Analogously, the distribution for η' given η is $F^\eta(\eta'|\eta)$. The value of the incumbent firm that decides to operate is

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

where $r_{t+1} \equiv 1/q_t - 1$. 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, pay the capital adjustment costs, and pay any debt entirely:⁶

$$V_t^{exit}(k, b) = (1 - \delta^k)k - \zeta(0, k) - b. \tag{4}$$

⁵Both 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 \(2013\)](#). Appendix A.9 shows that the results are not sensitive to having fixed costs in units of the final good.

⁶Following [Khan and Thomas \(2013\)](#), we do not allow firms to default on their debt in our baseline model. This 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. In the equilibrium of our calibrated model, none of the firms exit because of inability to repay their debt. In Section A.9, we consider implications of allowing for default.

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: our baseline model assumes a constant mass of potential entrants m , with each entrant drawing idiosyncratic productivities ϵ and η from the initial distributions G^ϵ and G^η . Furthermore, we assume these potential entrants enter with a positive stock of physical capital k^e and zero debt. Given the tuple $(k^e, 0, \epsilon, \eta)$, potential entrants decide whether to enter the economy by paying fixed costs f^e in units of labor and k^e in units of the final good.⁷

Let $V_t^{entry}(\epsilon, \eta)$ denote the value of entry. In the beginning of each period, after observing the initial idiosyncratic productivity, the potential entrant chooses whether to enter ($d^e = 1$) or not ($d^e = 0$) to maximize their value:

$$V_t^{entry}(\epsilon, \eta) = \max_{d_t^e(\epsilon, \eta) \in \{0, 1\}} d_t^e(\epsilon, \eta) \times [-w_t f^e - k^e + V_t^{inc}(k^e, 0, \epsilon, \eta)] + (1 - d_t^e) \times 0, \quad (5)$$

in which $[-w_t f^e - k^e + V_t^{inc}(k^e, 0, \epsilon, \eta)]$ is the value of entering and 0 is the value of not entering.

Dividend payments: let $\Omega_t(k, b, \epsilon, \eta)$ 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:

$$\begin{aligned} \Pi_t = & \int D_t(k'_t(k, b, \epsilon, \eta), b'_t(k, b, \epsilon, \eta), l_t(k, b, \epsilon, \eta), k, b, \epsilon, \eta) d_t(k, b, \epsilon, \eta) \Omega_t(dk \times db \times d\epsilon \times d\eta) \\ & + \int \left[(1 - \delta^k) k - \zeta(0, k) - b \right] (1 - d_t(k, b, \epsilon, \eta)) \Omega_t(dk \times db \times d\epsilon \times d\eta) + \\ & m \int \left[\begin{array}{c} D_t(k'_t(k^e, 0, \epsilon, \eta), b'_t(k^e, 0, \epsilon, \eta), l_t(k^e, 0, \epsilon, \eta), k^e, 0, \epsilon, \eta) \\ -w_t f^e - k^e \end{array} \right] d_t^e(\epsilon, \eta) G^\epsilon(d\epsilon) G^\eta(d\eta) \end{aligned} \quad (6)$$

⁷The assumption of an inelastic supply of potential entrants is similar to [Clementi and Palazzo \(2016\)](#). It contrasts to the perfectly elastic supply of entrants in [Hopenhayn \(1992\)](#), stemming from an unbounded mass of ex ante identical entrants. In Sections 6.1 and 6.2 and Appendices A.5 and A.7, we compare both and show that our assumption generates entry behavior that is consistent with the data.

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

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

where ϵ and η denote the firm's idiosyncratic productivities, 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 wedges work like taxes, and they are rebated to the household as lump-sum transfers. Total transfers are given by

$$T_t = \tau^b \left[\int \mathbb{1}_{\{b'_t(k, b, \epsilon, \eta) > 0\}} b'_t(k, b, \epsilon, \eta) \Omega_t(dk \times db \times d\epsilon \times d\eta) + m \int \mathbb{1}_{\{b'_t(k^e, 0, \epsilon, \eta) > 0\}} b'_t(k^e, 0, \epsilon, \eta) d_t^e(\epsilon, \eta) G^\epsilon(d\epsilon) G^\eta(d\eta) \right].$$

3.1 Equilibrium

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

- (i) given A_0 , $\{w_t\}$, $\{q_t\}$, $\{\Pi_t\}$, $\{T_t\}$, $\{\tau_t^h\}$, 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, η) , given $V_{t+1}^{inc}(k, b, \epsilon, \eta)$, q_t , w_t , Z_t , and θ_t , the allocations $l_t(k, b, \epsilon, \eta)$, $k'_t(k, b, \epsilon, \eta)$, $b'_t(k, b, \epsilon, \eta)$, and $d_t(k, b, \epsilon, \eta)$ solve the incumbent firm problem in (2), (3), and (4), with the respective maximum values equal to $V_t^{inc}(k, b, \epsilon, \eta)$, $V_t^{op}(k, b, \epsilon, \eta)$, and $V_t^{exit}(k, b)$;

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

$$\begin{aligned}\Omega_{t+1}(k', b', \epsilon', \eta') &= \int \mathbb{1} \{k'_t(k, b, \epsilon, \eta) \leq k', b'_t(k, b, \epsilon, \eta) \leq b'\} d_t(k, b, \epsilon, \eta) \\ &\quad F^\epsilon(\epsilon'|d\epsilon) F^\eta(\eta'|d\eta) \Omega_t(dk \times db \times d\epsilon \times d\eta) \\ &\quad + m \int \mathbb{1} \{k'_t(k^e, 0, \epsilon, \eta) \leq k', b'_t(k^e, 0, \epsilon, \eta) \leq b'\} d_t^e(\epsilon, \eta) \\ &\quad F^\epsilon(\epsilon'|d\epsilon) F^\eta(\eta'|d\eta) G^\epsilon(d\epsilon) G^\eta(d\eta); \end{aligned}$$

(iv) for each t , $\{d_t^e(\epsilon, \eta)\}$ solves the entry problem in (5), with the maximum value equal to $V_t^{entry}(\epsilon, \eta)$;

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

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

$$\begin{aligned}H_t &= \int [l_t(k, b, \epsilon, \eta) + f^o] d_t(k, b, \epsilon, \eta) \Omega_t(dk \times db \times d\epsilon \times d\eta) \\ &\quad + m \int [l_t(k^e, 0, \epsilon, \eta) + f^o + f^e] d_t^e(\epsilon, \eta) G^\epsilon(d\epsilon) G^\eta(d\eta); \end{aligned}$$

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

$$\begin{aligned}A_{t+1} &= \int b'_t(k, b, \epsilon, \eta) d_t(k, b, \epsilon, \eta) \Omega_t(dk \times db \times d\epsilon \times d\eta) \\ &\quad + m \int b'_t(k^e, 0, \epsilon, \eta) d_t^e(\epsilon, \eta) G^\epsilon(d\epsilon) G^\eta(d\eta); \end{aligned}$$

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

$$\begin{aligned}C_t &+ \int [k'_t(k, b, \epsilon, \eta) - (1 - \delta^k) k + \zeta(k'_t(k, b, \epsilon, \eta), k)] \Omega_t(dk \times db \times d\epsilon \times d\eta) \\ &+ m \int [k^e + k'_t(k^e, 0, \epsilon, \eta) - (1 - \delta^k) k^e + \zeta(k'_t(k^e, 0, \epsilon, \eta), k^e)] d_t^e(\epsilon, \eta) G^\epsilon(d\epsilon) G^\eta(d\eta) = \\ &+ \int f(k, l_t(k, b, \epsilon, \eta), \epsilon, \eta; Z) d_t(k, b, \epsilon, \eta) \Omega_t(dk \times db \times d\epsilon \times d\eta) \\ &+ m \int f(k^e, l_t(k^e, 0, \epsilon, \eta), \epsilon, \eta; Z) d_t^e(\epsilon, \eta) G^\epsilon(d\epsilon) G^\eta(d\eta). \end{aligned}$$

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 1 shows the parameters that are calibrated outside the stationary equilibrium. We assume a period is equal to one quarter. As BDS reports statistics annually, we aggregate the statistics in the model as in the BDS to generate the respective annualized values. The discount rate β is 0.99 so that the annualized interest rate in the stationary equilibrium 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 0.32 percent, which is equivalent to the annualized average of the Moody’s Seasoned Aaa Corporate spread since 1983 ([Appendix A.9](#) shows results are robust to a larger spread). The quarterly depreciation rate of capital δ^k is set to 1.53 percent, which implies an annual depreciation rate of 6 percent. Both the fixed entry cost f^e and aggregate labor productivity Z are normalized to one.

The idiosyncratic productivity ϵ is assumed to follow a log $AR(1)$ process given by $\log \epsilon' = \rho_\epsilon \log \epsilon + \iota'$, in which the innovation ι' is iid and follows a Normal distribution with zero mean and variance σ_ι^2 . The persistence parameter ρ_ϵ is set to 0.9627, which implies an annualized persistence of 0.859 as in [Khan and Thomas \(2008\)](#). We discuss the calibration of the variance parameter σ_ι^2 below. The productivity process is discretized to a Markov chain with 31 grid points following the method described in [Tauchen \(1986\)](#). Regarding the idiosyncratic productivity η , we shut it down for the calibration of the initial steady state. That is, we assume that in the initial steady state none of the firms are in lockdown nor do they anticipate one.⁸

Table 1: Parameters Determined outside of the Stationary Equilibrium

Parameter	Source	Value
Discount rate (β)	McGrattan and Prescott (2003)	0.9902
Labor elasticity (ϕ)	Rogerson and Wallenius (2009)	0.5000
Borrowing spread (τ^b)	Moody’s Aaa Corporate spread	0.0032
Span of control (ν)	Khan and Thomas (2008, 2013) , Bloom et al. (2018) , and Clementi et al. (2015)	0.8363
Depreciation rate of physical capital (δ^k)	Standard	0.0153
Persistence of idiosyncratic productivity (ρ_ϵ)	Khan and Thomas (2008)	0.9627
Fixed entry cost (f^e)	Normalization	1
Aggregate labor productivity (Z)	Normalization	1

Table 2 presents the nine remaining parameters, which are jointly calibrated so that

⁸That implies $\eta = 1$ for all firms (both entrants and incumbents).

the model matches nine 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-annual-GDP ratio in 1948–2015, 46 percent, based on data from the U.S. Financial Accounts from the Board of Governors of the Federal Reserve System. The labor disutility parameter ψ is related to the fraction of total employment. As in [Arellano et al. \(2019\)](#), we calibrate the model such that average hours per worker is equal to one. The capital share α is related to the labor share, and we use its average from 1970–2015, 65 percent, as a target.

Our specification of the capital adjustment cost function allows our model to match moments of the distribution of the annual-investment rates (annual investment/capital) of individual firms reported in [Cooper and Haltiwanger \(2006\)](#). The investment irreversibility parameter γ is related to the fraction of firms with annual investment rates below 1 percent in absolute value, referred to as the inaction region in the literature, while the quadratic adjustment cost λ is related to the fraction of firms with annual-investment rate above 80 percent. The variance of innovations to idiosyncratic productivity σ_t^2 is related to the standard deviation of annual-investment rates.⁹ We target the standard deviation of annual investment rates to be consistent with other papers such as [Khan and Thomas \(2013\)](#) and [Clementi and Palazzo \(2016\)](#), but we validate the model with BDS firm dynamics statistics on employment by firm age and firm size in the next section.

Table 2: Parameters Determined Jointly in Equilibrium and Targeted Moments

Parameter	Value	Target	Data	Model
Collateral constraint (θ)	0.40	Non-finance business debt / Annual-GDP	0.46	0.47
Labor disutility (ψ)	0.79	Hours per worker = 1	1.00	1.00
Capital share (α)	0.45	Labor share	0.65	0.65
Std. dev. idiosync. prod. (σ_t)	0.08	Std. dev. annual-investment rate	0.34	0.33
Investment irreversibility (γ)	0.01	Fraction firms absolute annual-investment rate < 1%	0.08	0.08
Quadratic adjustment cost (λ)	1.08	Fraction firms annual-investment rate > 80%	0.02	0.03
Entry capital (k^e)	13.48	Firms 5 years / Firms 0-5 years	0.11	0.10
Fixed operating cost (f^o)	0.78	Entry rate	0.11	0.11
Mass of potential entrants (m)	0.19	Fraction firms 20-plus years	0.23	0.24

Finally, the entry capital k^e , fixed operating cost f^o , and mass of potential entrants m are related to the entry rate, the survival rate of young firms, and the share of old firms. For the survival rate of young firms, we target the ratio of the number of 5-year-old firms to the number of 0-5 year-old firms. For the share of old firms, we target the ratio of 20-plus-year-old firms to all firms. The targeted moments in the data and their respective

⁹[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 annual investment statistics based on the restricted sample of firms that survive for the entire period.

values in the model are listed in [Table 2](#).¹⁰

5 Properties of the Initial Stationary Equilibrium

In this section, we analyze the lifecycle properties of firms in the stationary equilibrium under the baseline calibration and validate the model against non-targeted moments in the data. [Figures 3a](#) and [3b](#) 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 they accumulate capital up to an age at which it stabilizes, around 30 years old on average. Employment follows a similar pattern. In fact, given the firm's idiosyncratic state, the employment decision is a static one derived by equating the marginal product of labor to its marginal cost:

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

This equation implies that employment is increasing in firms' capital, idiosyncratic productivities, and aggregate productivity, decreasing in the wage rate, and does not depend on the level of debt. Furthermore, [Figure 3a](#) shows that the baseline model accounts for employment growth observed in the BDS data in the first five years of a firm's life cycle.¹¹

There are several features in the model that explain the growth pattern of young firms. Firms rely on retained earnings and debt issuance to finance investment. However, the low initial capital stock makes it difficult for firms to raise enough operating revenues and issue enough debt to achieve their desired stock of capital. The capital adjustment costs pose additional difficulties for firms to adjust their capital stock by large amounts. Due to these frictions, firms smooth investment over time. [Figures 3c](#) and [3d](#) show that firms leverage themselves with debt to finance investment in the early years. Average net debt b increases up to age 11 and decreases thereafter, reaching negative values for firms older than 20 years. This is because older firms begin to save to avoid hitting the nonnegative dividend constraint in the future.¹² [Figure 3e](#) plots the distribution of debt, $\max(b, 0)$, by firm age and shows that younger firms account for the largest share of debt.^{13,14}

¹⁰We described a relationship between each parameter and one moment, but it is important to emphasize that they are all estimated jointly because they affect the other targeted moments as well.

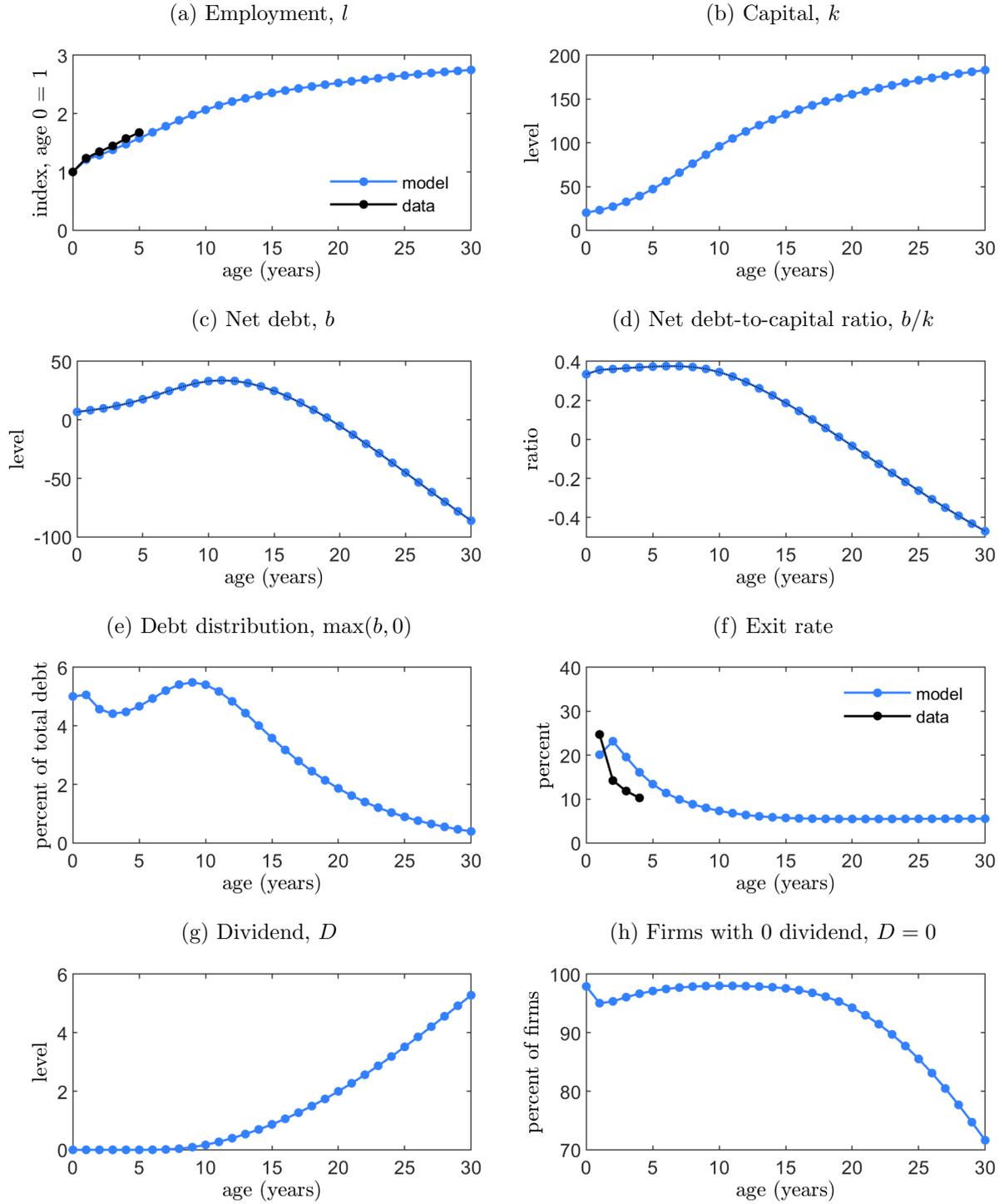
¹¹Although our model is quarterly and BDS is annual, we aggregated and annualized firm dynamics statistics in our model to be consistent with the BDS.

¹²As in [Khan and Thomas \(2013\)](#), to prevent firm savings from exploding, we solve for the unconstrained firm's problem and a minimum savings function.

¹³The share of debt decreases after age 1 due to the higher exit rates for younger firms ([Figure 3f](#)), then it increases as firms accumulate capital and relaxes the collateral constraint. It decreases again after firms accumulate enough capital and start to save to avoid the nonnegative dividend payment constraint.

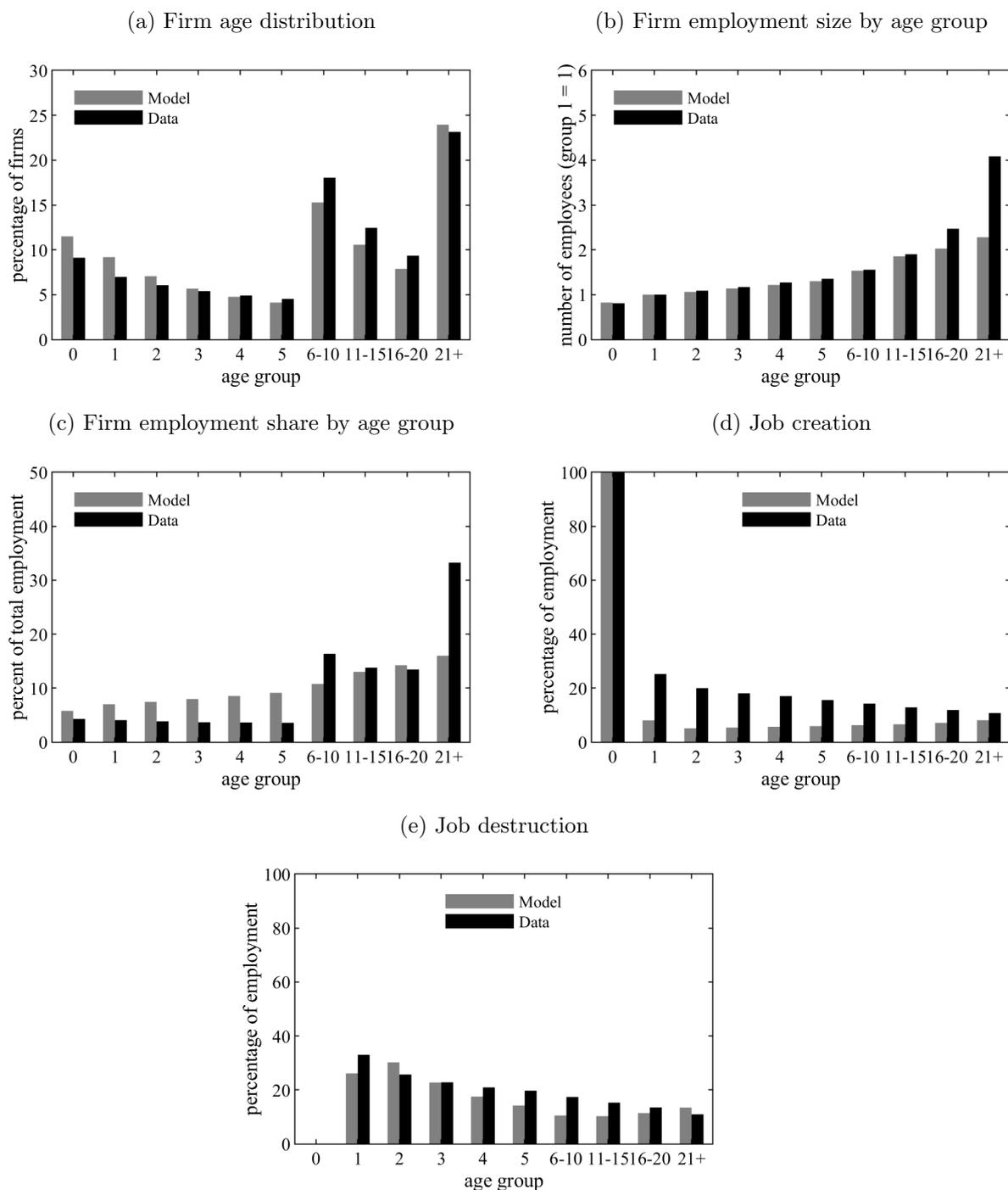
¹⁴The patterns of financing in the initial years are broadly consistent with the data. In our model, firms

Figure 3: Life Cycle Properties



Notes: Figure 3 plots firm dynamics life cycle properties from the initial stationary equilibrium of the baseline model and data where available. Figure 3a plots average employment by age (age 0 normalized to 1). Figure 3b plots average capital by age. Figure 3c plots average net debt by age. Figure 3d plots average net debt by age divided by average capital by age. Figure 3e plots share of firm debt by age. Figure plots 3f percent of firm exits by age. Figure 3g plots average dividends of operating firms by age. Figure 3h plots percent of firms with 0 dividends by age.

Figure 4: Firm Age Distribution, Firm Employment Size, Employment Share, and Job Flows by Age group



Notes: Figure 4 plots firm dynamics statistics by age in the baseline model and data. Figure 4a plots share of firms by age. Figure 4b plots average employment size by age (age 1 normalized to 1). Figure 4c plots share share of employment by firm age. Figure 4d plots job creation by firm age as a percent of employment by firm age. Figure 4e plots job destruction by firm age as a percent of employment by firm age. 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.

In our model, firms choose not to pay dividends until they have accumulated enough capital and savings. That is, firms will save and return zero dividends to the household if there is a high enough probability of facing a binding nonnegative dividend constraint in the future. Figure 3g plots the average dividend payments by age of incumbent firms that choose to operate. Dividends are zero up to around age 8 and begin to increase thereafter. This implies that all the revenues from sales and debt issuance are used for capital investment in the initial years. Figure 3h shows the percentage of firms for which the nonnegative dividend constraint is binding. The constraint binds for more than 90 percent of firms that are less than 20 years old and subsequently decreases.¹⁵

Figure 4 compares the properties of the stationary equilibrium to the data. Figure 4a plots the distribution of firms across age group, Figure 4b plots the average employment size of firms by age group, and Figure 4c plots the employment share of firms by age group. Figures 4d and 4e plot rates of job creation and destruction by age groups. The model statistics match the data reasonably well even though none of these moments were targeted except two. In Figure 4a, we targeted the ratio of the mass of firms that are 5 and 0-5 years old and the share of firms that are 21+ years.

Table 3 shows that the model does reasonably well in matching the size distribution of firms in the data. It accounts for the share of firms with more than 20 employees, although it underestimates the share of smaller firms (less than 9 employees) with respect to medium-sized ones (10–19 employees). The model also does reasonably well in accounting for the size distribution of firms that enter and exit the economy. More than 94 percent of firms that enter or exit the economy have 9 employees or less, both in the model and data.¹⁶

The properties of the initial stationary distribution discussed above depend on both financial and investment frictions (irreversible investment and quadratic adjustment cost). In Appendix A.2, we show how the non-targeted moments vary when we eliminate each of these frictions.

enter with initial capital k^e . After that, they use retained earnings and banks for financing. The 2017 Report to the Congress on the Availability of Credit to Small Businesses, which uses data from the 2014 Annual Survey of Entrepreneurs, shows that most young firms rely on owner funding in their early years (initial capital k^e and fixed entry cost f^e in our model). As firms become older, ASE shows that they use more bank credit. For example, in 2014, only 23 percent of firms that are 2 years or less had borrowed more than 250,000. *More than 50 percent of firms that are 16 years or older borrowed more than 250,000* (Table 3, page 22).

¹⁵Among the total mass of firms in the economy, the nonnegative dividend constraint binds for 88 percent of firms.

¹⁶In the data, approximately 1.91 percent of firms enter with more than 20 employees. None of the firms enter with more than 20 employees in the model. The same holds true for firm exit. That is, roughly 2 percent of firms that exit in the data have more than 20 employees. None of the firms that exit in the model have more than 20 employees.

Table 3: Firm Size Distribution

Number of employees	Data	Model
	% of firms	
All firms: ≤ 9	76.2	52.5
All firms: 10 – 19	12.2	37.6
All firms: 20+	11.6	9.9
Entrants: ≤ 9	94.8	98.8
Entrants: 10 – 19	3.3	1.2
Entrants: 20+	1.9	0.0
Exits: ≤ 9	94.3	96.1
Exits: 10 – 19	3.5	3.9
Exits: 20+	2.1	0.0

6 Results

In this section, we perform three exercises. In the first one, in Section 6.1, we analyze the implications of aggregate shocks for firm entry and exit rates, and the impact of the variation in firm entry and exit rates on the evolution of main macro aggregates. In the second and third exercises, in Sections 6.2 and 6.3, we use the quantitative model to study the behavior of firm entry and exit and main macroeconomic aggregates during the Great Recession (2007-2009) and the current recession driven by lockdown measures implemented during the COVID-19 crisis, respectively.

We consider shocks to aggregate productivity, collateral constraint (also referred to as a credit shock), firm operation (also referred to as firm shutdown), and labor disutility. Shocks to labor disutility and firm operation are shocks that capture the lockdowns experienced during COVID-19. The labor disutility shock captures the inability of some workers to go to work, while the firm operation shock captures a temporary shutdown for some firms. In this case, we assume that a fraction χ of incumbent firms and potential entrants are subject to a shutdown in the period of announcement. During shutdown, they are not allowed to operate ($\eta = 0$), and they remain in shutdown in the subsequent period with probability ρ_χ . Those firms that exit shutdown or that do not enter shutdown in the period of announcement have zero probability of facing a shutdown in the future. In this setup, χ captures the size of the shutdown when it is announced, and ρ_χ captures its persistence.

6.1 Aggregate Shocks, Firm Entry, and Firm Exit

In our first exercise, we analyze impulse responses in the baseline model with a particular emphasis on firm entry and exit. Starting from the stationary equilibrium under

the baseline calibration, we study the impulse responses from shocks to aggregate productivity, collateral constraint, firm operation, and labor disutility. These shocks are unexpected one-time events, but once they occur agents have perfect foresight of how these variables will evolve over time. 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 target two moments: (1) the average drop in U.S. real GDP normalized by the working age population from peak to trough in the four recessions from 1978 to 2018, 4.1 percent, and (2) the average time that it takes for GDP to complete half of the recovery since the beginning of the recession, which is 14 quarters. Figure 5 plots the calibrated values of the shocks. To generate a 4.1 percent drop in output, shocks to productivity and labor disutility are around 4 and 8 percent, respectively, the mass of firms subject to temporary shutdown is roughly 5 percent, and the collateral constraint tightens by around 50 percent.

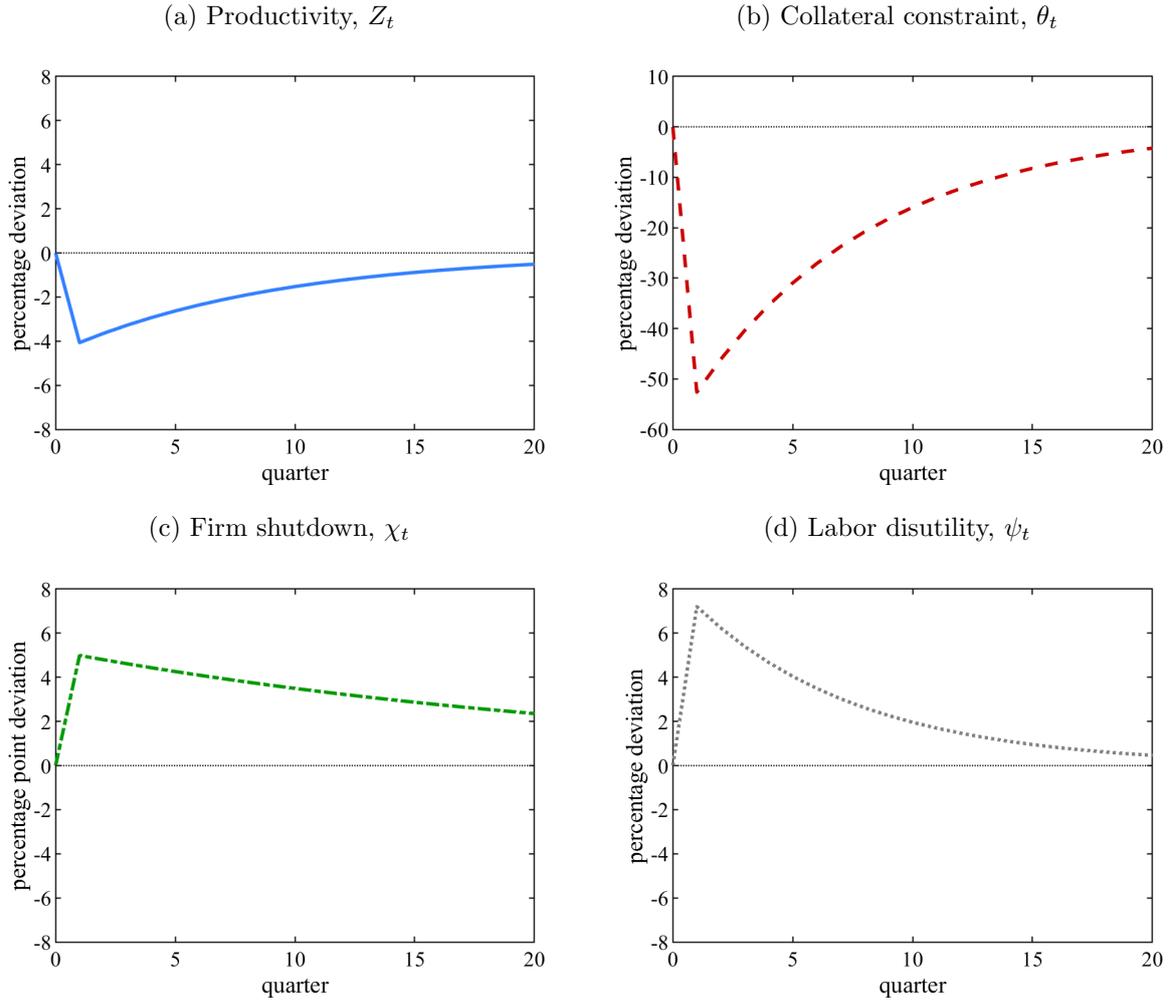
Macro aggregates, entry, and exit: Before turning to our discussion on firm entry and exit, we briefly discuss the implications of these shocks for the main macro aggregates. Figure 6 plots the impulse responses of GDP, hours of work, consumption, investment, and firm debt for each shock. Given our calibration strategy discussed above, the fall in GDP from peak to trough and the time to complete half of its recovery is the same across shocks (Figure 6a). Figures 6b and 6d show that all shocks lead to reductions in hours and investment, which also characterize recessions in the data. As in Khan and Thomas (2013), Figure 6 shows that credit shocks lead to a delayed fall in output, hours, and investment, an initial increase in consumption and then a drop in subsequent periods, a larger drop in firm debt, and a slower recovery of all these variables in comparison to productivity shocks. As in Chari, Kehoe, and McGrattan (2007), labor disutility shocks lead to a larger drop in hours than productivity shocks.¹⁷

The aggregate shock that is novel in our analysis is the firm shutdown shock. In comparison to a productivity shock, it leads to a larger drop in hours and investment. The recovery is faster in the initial periods but slows down afterwards. Furthermore, it also leads to an increase in consumption in the period of the shock. These differences are driven primarily by increased firm exit during a firm shutdown, which we discuss below.

In Figure 7, we plot changes in annual firm entry and exit rates resulting from each shock. The black lines represent the average of the percentage point deviations in firm entry and exit rates in the U.S. recessions in 1979, 1990, 2000, and 2007, computed with BDS data. The rates in the model are computed following BDS methodology. Therefore, we divide annual entry and exit by the average mass of firms in the current year and in the previous year. As Figure 7 shows, the implications for firm entry and exit rates

¹⁷Our labor disutility shock is similar to the labor wedge shock studied in Chari, Kehoe, and McGrattan (2007), with the difference that the latter is redistributed as lump-sum transfers to households.

Figure 5: Transition Dynamics of Exogenous Shocks



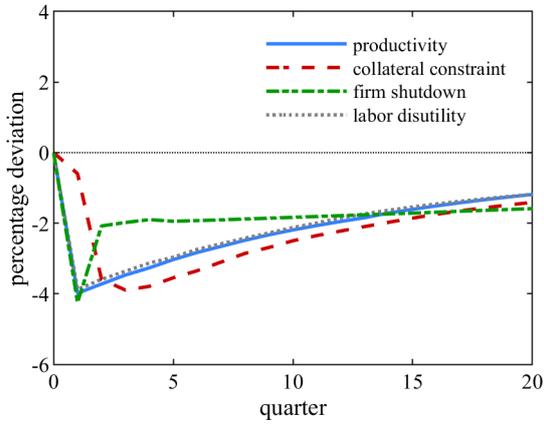
Notes: Figure 5 plots the transition dynamics of exogenous shocks to productivity, collateral constraint, firm shutdown, and labor disutility in the baseline model. The size and persistence of the shocks are jointly calibrated such that they generate the same drop and recovery in GDP. Target moments: (1) Average drop in U.S. real GDP normalized by the working age population from peak to trough in the four recessions from 1980 to 2010 = 4.1 percent, and (2) Average time that it takes for GDP to complete half of the recovery since the beginning of the recession = 14 quarters.

are qualitatively similar across shocks and the data: firm entry decreases and firm exit increases during recessions.¹⁸ The magnitudes, however, are different. In comparison to the productivity shock, the credit and labor disutility shocks generate a larger fall in firm entry, while the credit, firm shutdown, and labor disutility shocks generate a larger rise in firm exit. For the firm shutdown shock, 94 percent of the firms subject to a temporary shutdown end up exiting the economy permanently.

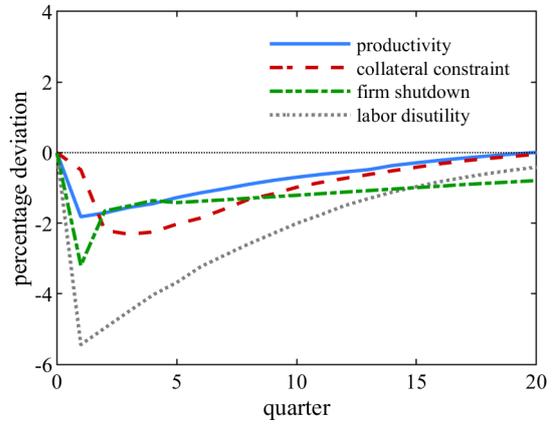
¹⁸In the case of a shutdown shock, firm entry drops on impact and increases substantially right after. The fall in firm entry on impact depends on the mass of potential entrants subject to the shock. Due to lack of data, we assumed the share is the same for both entrants and incumbents.

Figure 6: Transition Dynamics of Main Aggregates

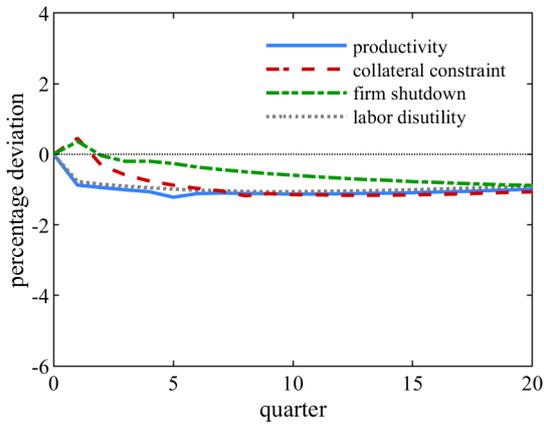
(a) GDP



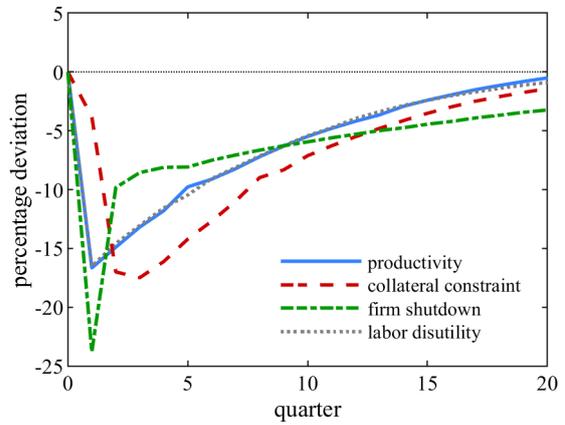
(b) Hours, H_t



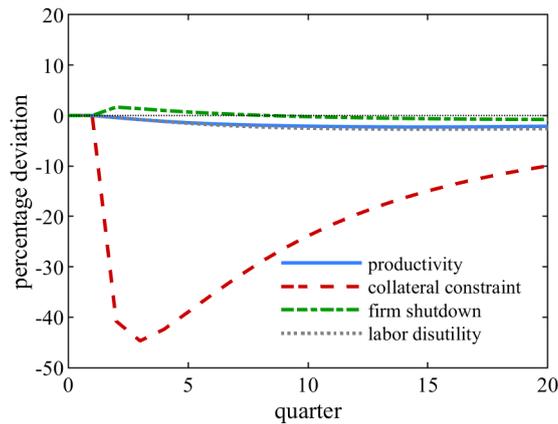
(c) Consumption, C_t



(d) Investment

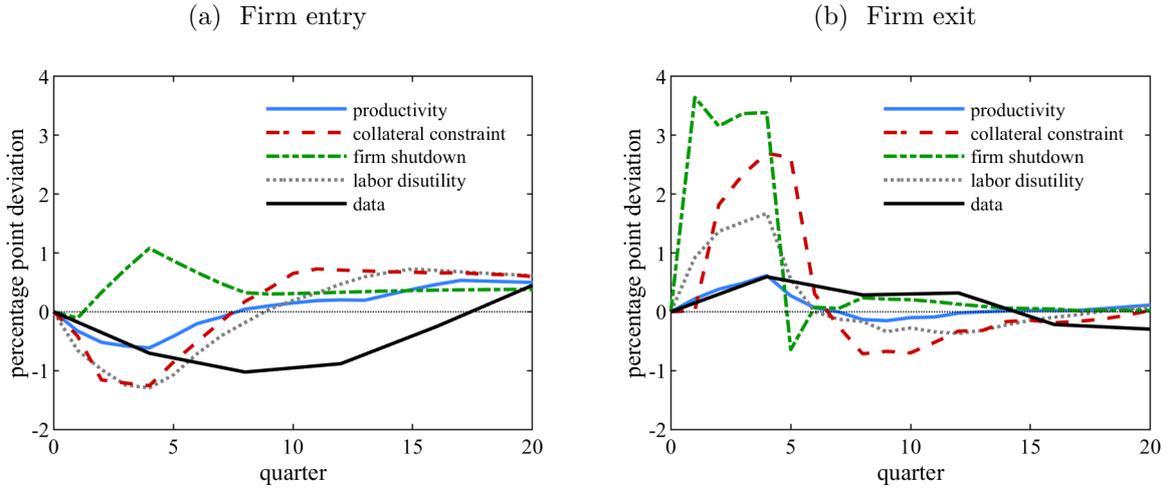


(e) Debt



Notes: Figure 6 plots the transition dynamics of GDP, hours, consumption, investment, and firm debt as percentage deviations given shocks to productivity, collateral constraint, firm shutdown, and labor disutility in the baseline model.

Figure 7: Transition Dynamics of Firm Entry and Exit



Notes: Figure 7 plots the transition dynamics of annual firm entry and exit rates as percentage point deviations given shocks to productivity, collateral constraint, firm shutdown, and labor disutility in the baseline model. The figure also overlays the average of percentage point deviations in firm entry and exit rates computed from the BDS for the U.S. recessions starting in 1979, 1990, 2000, and 2007. As in the BDS, we normalize annual entry and exit rates in a given period by the average of the mass of firms in a given year and the previous year.

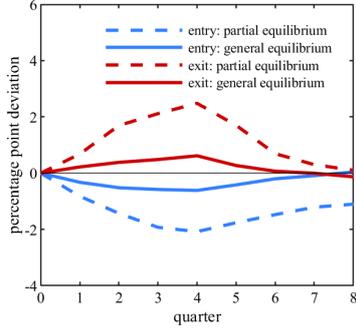
Partial versus general equilibrium effects: To better understand the entry and exit dynamics following each shock, Figure 8 breaks down the effects of each one into partial and general equilibrium effects. Figure 8 plots the entry and exit rates (left panels: 8a, 8d, 8g, and 8j) together with the changes in the wage rate (middle panels: 8b, 8e, 8h, and 8k) and the interest rate (right panels: 8c, 8f, 8i, and 8l). Let us start with the productivity shock. The blue and red dashed lines in Figure 8a show what the entry and exit rates would be if wages w_t and interest rates r_t remained fixed at their initial levels (this relaxes labor market clearing and assets market clearing).¹⁹ In partial equilibrium, the only change a firm observes is the lower aggregate productivity. This does not change the value of exit but implies lower revenues and therefore a lower value of operating. That explains the fall in the entry rate and the rise in the exit rate. However, once wages and interest rates are allowed to change (Figures 8b and 8c), they offset most of the impact of the productivity shock such that the overall changes in entry and exit rates become small.

Figure 8d analyzes the case of a credit shock. A credit shock mostly impacts young productive firms that are borrowing to accumulate capital. These are the firms that are financially constrained, and once the shock hits, there is a large decrease in entry and increase in exit. The main reason is that restricted access to credit implies a much

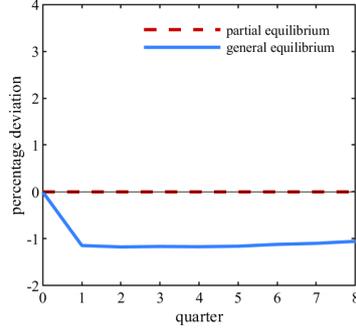
¹⁹We have also analyzed the case where we fix the entry decision of potential entrants. However, the impact of changes in the entry margin on firm exit is negligible for our baseline model.

Figure 8: Partial and General Equilibrium Effects

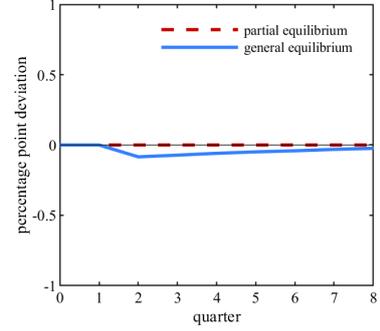
(a) Productivity: entry & exit



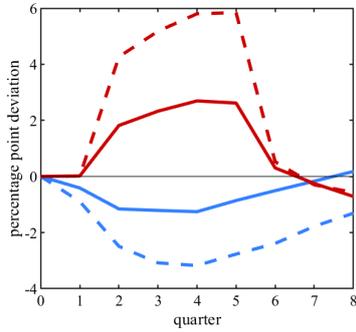
(b) Productivity: w_t



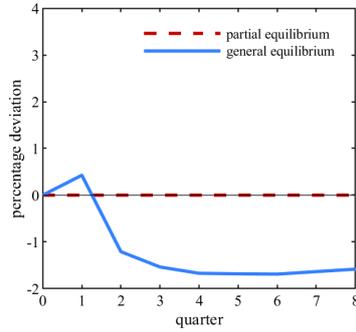
(c) Productivity: r_t



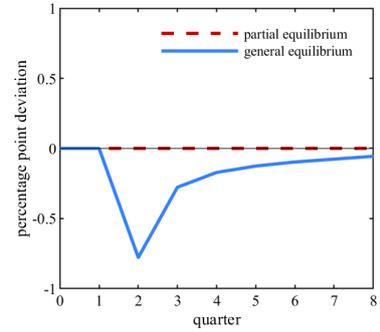
(d) Collateral cons.: entry & exit



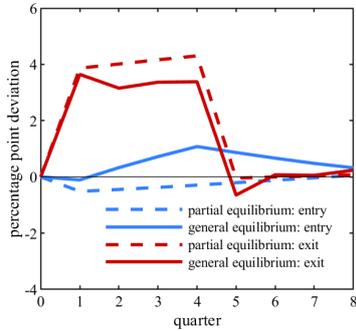
(e) Collateral cons.: w_t



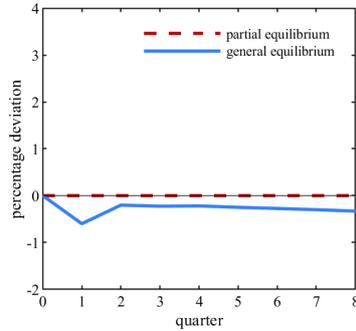
(f) Collateral cons.: r_t



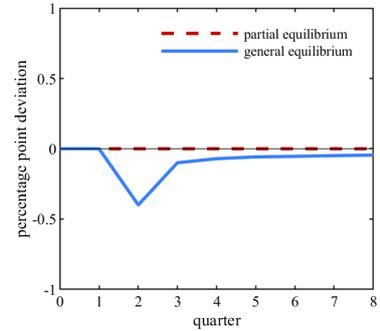
(g) Firm shutdown: entry & exit



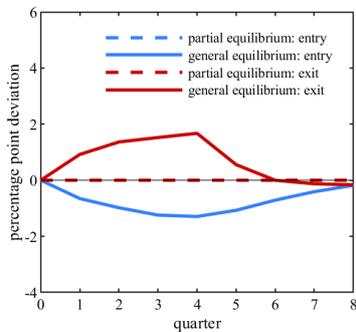
(h) Firm shutdown: w_t



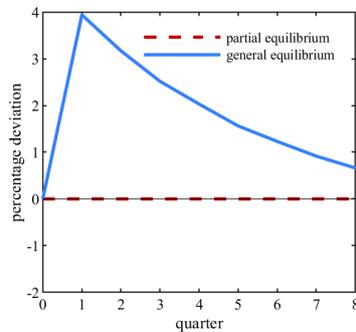
(i) Firm shutdown: r_t



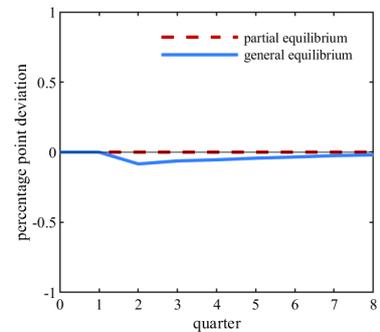
(j) Labor disutility: entry & exit



(k) Labor disutility: w_t



(l) Labor disutility: r_t



Notes: Figure 8 decomposes changes in entry and exit rates into general and partial equilibrium effects for each shock in the baseline model. The first column plots deviations in entry rates and exit rates in general equilibrium and partial equilibrium for each shock. The second and third columns plot the wage rate and interest rate in general equilibrium for each shock.

slower process of capital accumulation, and therefore, a slower rate of growth for profits. The slower accumulation of capital is further amplified due to the interaction with the collateral constraint.²⁰ The large fall in entry and rise in exit hold even when we allow for wages and interest rates to change.

Figure 8g analyzes the case of a firm shutdown. While the productivity shock reduces the average productivity of all firms, a shutdown severely impacts the productivity of a given mass of firms, which leads to a significantly larger increase in firm exit. In this case, the drop in wages and interest rates is not enough to reduce it.

Finally, Figure 8j analyzes the entry and exit rates following the labor disutility shock. The labor disutility shock does not enter the firm’s problem. Hence, it could affect entry and exit only through general equilibrium effects. That explains why the firm entry and exit rates do not respond in partial equilibrium. Once we allow the wage rate and interest rate to change, we observe a fall in entry and a rise in exit. This is because the higher labor disutility leads to a lower supply of labor leading to higher wages (Figure 8k).

Firm exit by age: Next, we decompose the implications of these shocks for firm exit by age.²¹ For each shock, Figure 9 plots the percentage point change in firm exit rates for firms that are 1-5 years, 6-10 years, and 11 years and older. The productivity shock and labor disutility shock increase firm exit across all ages, in particular among young firms. This is not surprising because younger firms have less capital and more debt, and hence are closer to the exit threshold. The credit shock leads to a disproportionate increase in exit among young firms, while the exit rate among older firms decreases. This is because older firms are not hurt by a tighter collateral constraint, but they gain from a lower interest and wage rates. A firm shutdown leads to a disproportionate rise in firm exit among older firms, unlike the other three shocks. The reason is that older firms are less likely to exit in normal times (Figure 3f). However, during a firm shutdown the relative exit probability of older firms increases significantly. Young firms are more likely to exit in normal times. Hence, the relative increase in their exit probabilities is smaller during a firm shutdown.

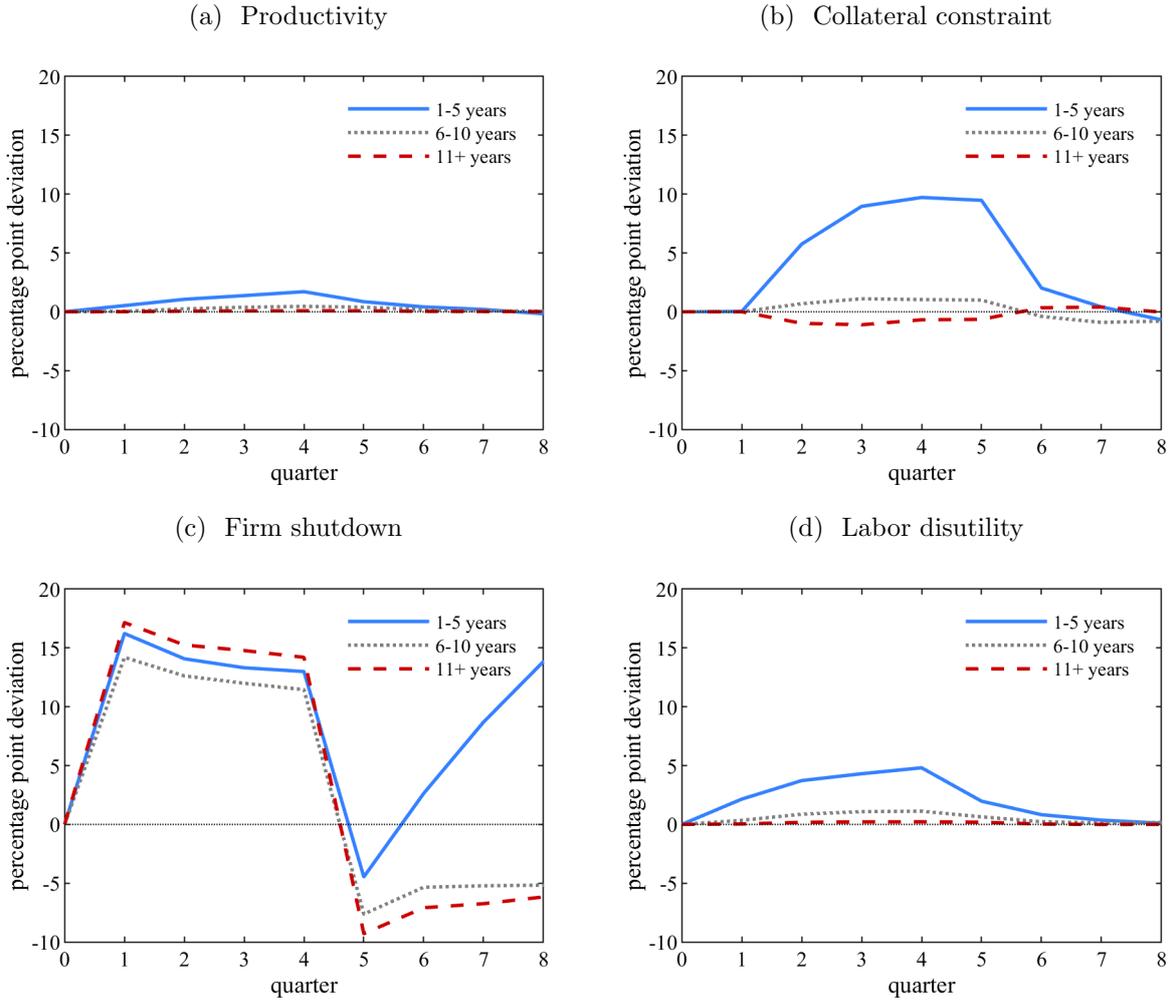
In summary, the shocks we considered lead to heterogeneous responses in entry and exit. In particular, the credit shock and the two COVID-19 shocks lead to larger movements in the extensive margin (firm entry or exit). A natural question to ask is whether these differences in firm entry and exit matter for the evolution of macro aggregates.

Implications of firm entry and exit for macro aggregates: For each shock, we now

²⁰In principle, firms could also be forced to exit. That is, 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, some of them might be forced to exit because they are unable to generate nonnegative dividends. In our calibration, none of the exiting firms are forced to exit.

²¹In Appendix A.3, we also decompose the heterogeneous responses in firm investment by age.

Figure 9: Firm Exit by Age

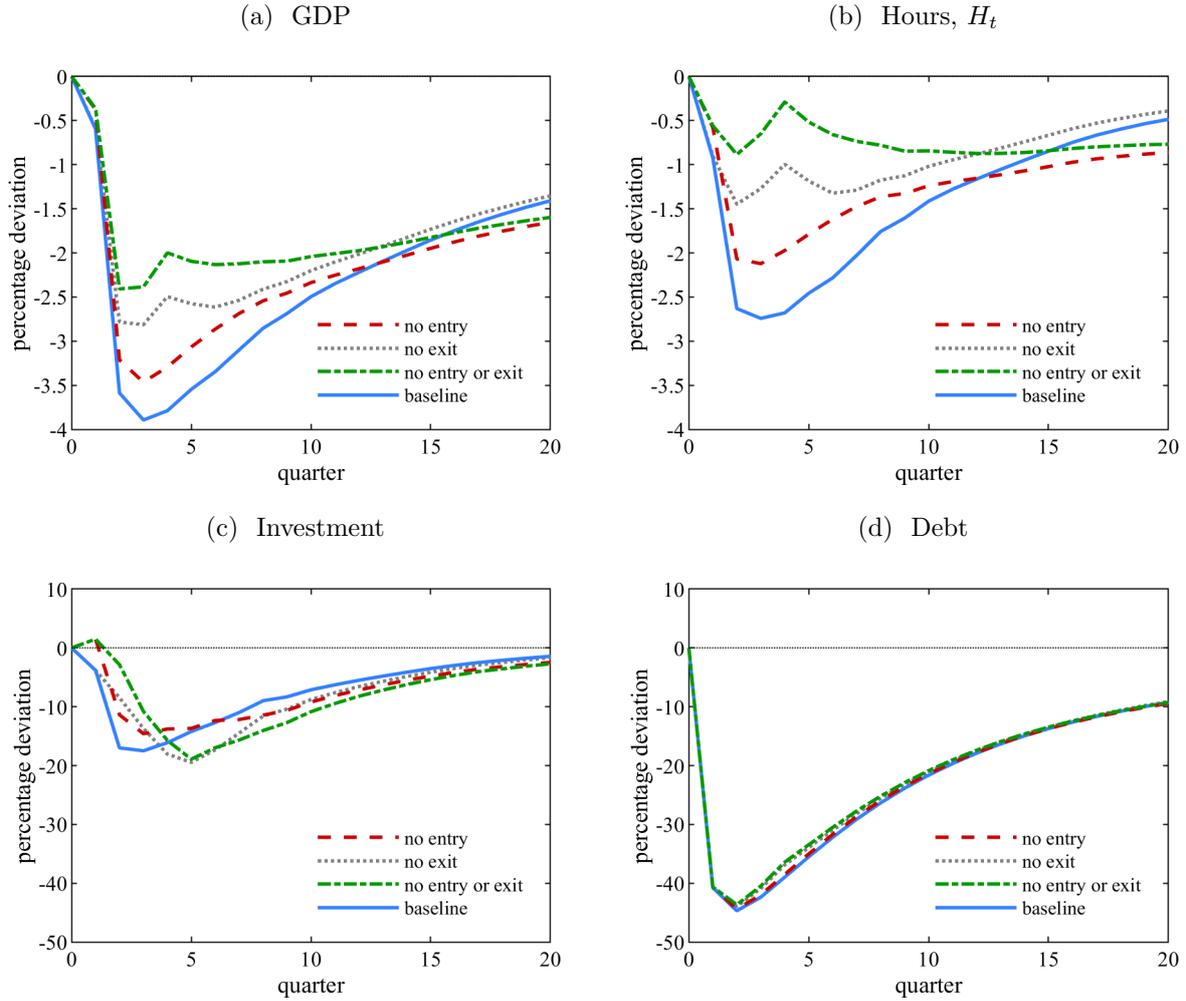


Notes: Figure 9 plots percentage point changes in firm exit rates by age groups for each shock in the baseline model.

compute the impact of differences in entry and exit in the economy subject to a shock versus an economy not subject to a shock (initial steady state) for the evolution of macro aggregates. Given that the credit and the firm shutdown shocks lead to the largest rise in firm exit, we focus on those two shocks in this section. In Appendix A.4, we show the results for the productivity and labor disutility shocks.

To compute the impact of differences in firm entry on macro aggregates, we proceed as follows. We first identify two groups of firms: the ones that enter the economy subject to the shock, but do not enter the economy not subject to the shock (group 1), and firms that enter the economy not subject to the shock, but do not enter the economy subject to the shock (group 2). We identify these firms for every period of the transition. For group 1, we compute for each period their contribution to output, hours, investment, and firm debt by simulating them in the economy subject to the shock. For group 2, we compute their contribution to output, hours, investment, and firm debt by simulating them in the

Figure 10: Collateral Constraint: Decomposition of Aggregates by Entry and Exit



Notes: Figure 10 decomposes the evolution of GDP, hours, investment, and firm debt due to differences in firm entry and exit in the case of a shock to the collateral constraint in the baseline model. “no entry” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry between the economy subject to the shock versus the economy not subject to it. Similarly, “no exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm exit in the first four quarters of the shock and “no entry or exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry and exit.

economy not subject to the shock. The difference between the contribution of group 2 net of group 1 is the loss in output/hours/firm investment/firm debt due to differences in entry in the economy subject to the shock.²²

To compute the impact of differences in firm exit on macro aggregates, we proceed

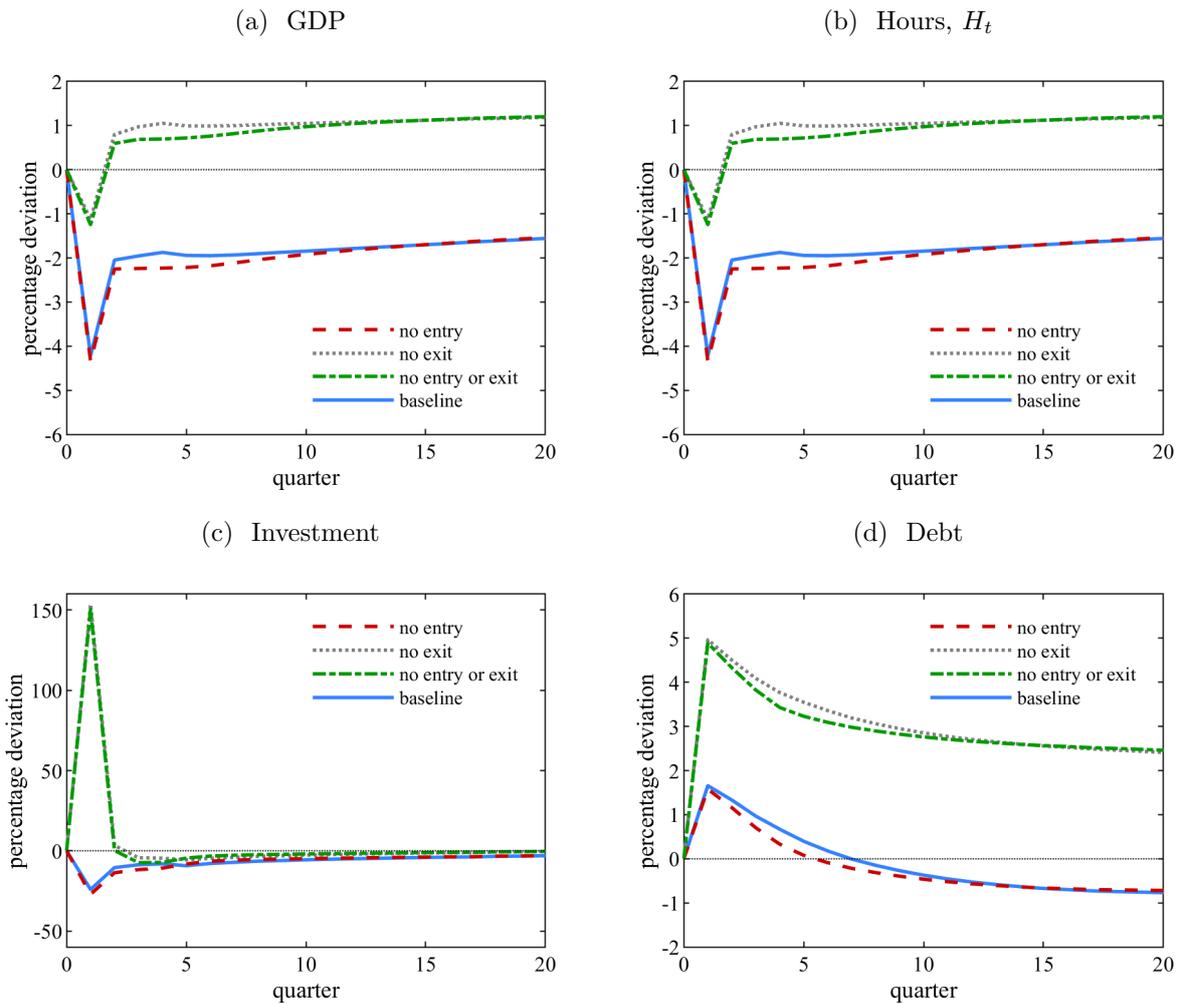
²²As an example, consider two potential entrants: potential entrant x and potential entrant y . Suppose potential entrant x enters the economy subject to a credit shock, but not the economy without a credit shock. We compute its contribution to macro aggregates in the economy subject to the credit shock. Suppose potential entrant y enters the economy without a credit shock, but not the economy with a credit shock. We compute its contribution to macro aggregates in the economy without the credit shock. The difference between the contribution of potential entrant y net of potential entrant x is the loss in aggregates in the economy with a credit shock due to differences in entry.

as follows. In both the economy with the shock and without the shock, we consider the distribution of incumbent firms in the period of the shock and the firms that enter in both economies. Hence, these are all the firms that were not considered in the calculation from above. For all of these firms, we keep track of the history of idiosyncratic shocks in addition to the initial capital stock, debt, and productivity (for incumbents, this would be their state in period 1 and for entrants this would be their state in the period in which they enter). Again, we identify two groups of firms: the ones that exit the economy subject to the shock, but do not exit the economy not subject to the shock (group 1), and firms that exit the economy not subject to the shock, but do not exit the economy subject to the shock (group 2). For group 1, starting from the periods in which there is a difference in exit, we compute for each period the non-exiting firms' contribution to output, hours, investment, and firm debt by simulating them in the economy not subject to the shock. For group 2, starting from the periods in which there was a difference in exit, we compute the non-exiting firms' contribution to output, hours, investment, and firm debt by simulating them in the economy subject to the shock. The difference between the contribution of group 1 net of group 2 is the loss in output/hours/firm investment/firm debt due to differences in exit in the economy subject to the shock. Because we have to keep track of the history of shocks for this analysis, we compute differences resulting from exit in the first four quarters of the shock.

After computing the net impact on macro aggregates resulting from differences in firm entry and exit, in Figure 10 we plot the evolution of macro aggregates for a credit shock if one ignores these margins. The contribution of both firm entry and exit to output, hours, and investment is large. For example, the contributions of lower entry and higher exit to the fall in GDP, hours, and investment in the first four quarters of the shock are 40, 73, and 49 percent, respectively. Furthermore, both entry and exit add persistence to the recovery of output and hours in the initial periods after the shock. After roughly 15 quarters though, entry contributes to a faster recovery of the economy. The overall impact of differences in entry and exit on firm debt is small. This implies that most of the fall in firm debt is driven by incumbent firms (labeled no entry or exit) rather than differences in firm entry and exit.

Figure 11 decomposes the evolution of GDP, hours, investment, and firm debt with and without firm entry and exit when there is a firm shutdown. The impact of the rise in firm exit on macro aggregates during a shutdown is large. If we ignore firm exit, in the first quarter of the shock, GDP falls by roughly 1 percent. If we include it, GDP falls by 4 percent. The impact on total hours is similar. In the first four quarters of the shock, the contribution of higher firm exit to the fall in output and hours is more than 100 percent. This is because, if we ignore firm exit, the lockdown increases output and hours among incumbent firms due to general equilibrium effects (lower interest and higher wage rates in Figures 8i and 8h). General equilibrium effects also significantly increase investment

Figure 11: Firm Shutdown: Decomposition of Aggregates by Entry and Exit



Notes: Figure 11 decomposes the evolution of GDP, hours, investment, and firm debt due to differences in firm entry and exit in the case of a shock to firm operation in the baseline model. “no entry” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry between the economy subject to the shock versus the economy not subject to it. Similarly, “no exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm exit in the first four quarters of the shock and “no entry or exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry and exit.

and firm debt among incumbent firms.

6.2 Great Recession

In this section, we show that a credit shock generates a fall in firm entry, a rise in firm exit, and a concentration of firm exit among young firms consistent with empirical patterns observed during the Great Recession in the United States. We also quantify the impact of the credit shock on output and hours, and we decompose the impact of lower firm entry and higher firm exit on the evolution of output and hours.

Given that the recession started in December 2007 (NBER), we treat the first quarter of 2008 as the first period of the shock. Figures 12a and 12b plot the values of shocks to the collateral constraint and productivity. We calibrate the shock to the collateral constraint with two parameters: the size of the shock in the first quarter of 2008 and its persistence. The parameters are calibrated jointly to target the fall in firm debt from peak to trough (16 percent) and its level below trend after 15 quarters (14 percent). The calibration yields a 16 percent drop in the collateral constraint in the first quarter of the shock and an annualized persistence of 0.9. Figure 12c plots firm debt in the model and data. Even with only two parameters for the credit shock, the model does reasonably well in generating observed empirical patterns. For the productivity shock, we feed in the deviations from trend in output per hour.²³

Figure 13 plots changes in firm entry and exit rates in the model with only the credit shock, the model with only the productivity shock, the model with both shocks, and the data.²⁴ The model with both shocks accounts for more than 50 percent of the fall in firm entry (pre-recession to trough) and more than 75 percent of the rise in firm exit (pre-recession to peak). Furthermore, changes in firm entry and exit rates are relatively small in the model with only the productivity shock. The credit shock drives most of the adjustments in entry and exit.²⁵

It must be noted that our model might overstate the impact of the credit shock on firm exit because we abstract from aggregate uncertainty. If there were an aggregate stochastic process, firms might save more/borrow less for precautionary reasons, in which case the impact of the credit shock on firm exit might be dampened. However, the quantitative impact is likely to be small for the following reasons. First, the 2007 financial crisis was a rare event. Second, firms in our model already face idiosyncratic risk, which allows them to internalize shocks that lower productivity, and hence, operating profits. Even during the credit shock in our model, none of the firms exit due to accidental default, i.e., inability to repay debt.

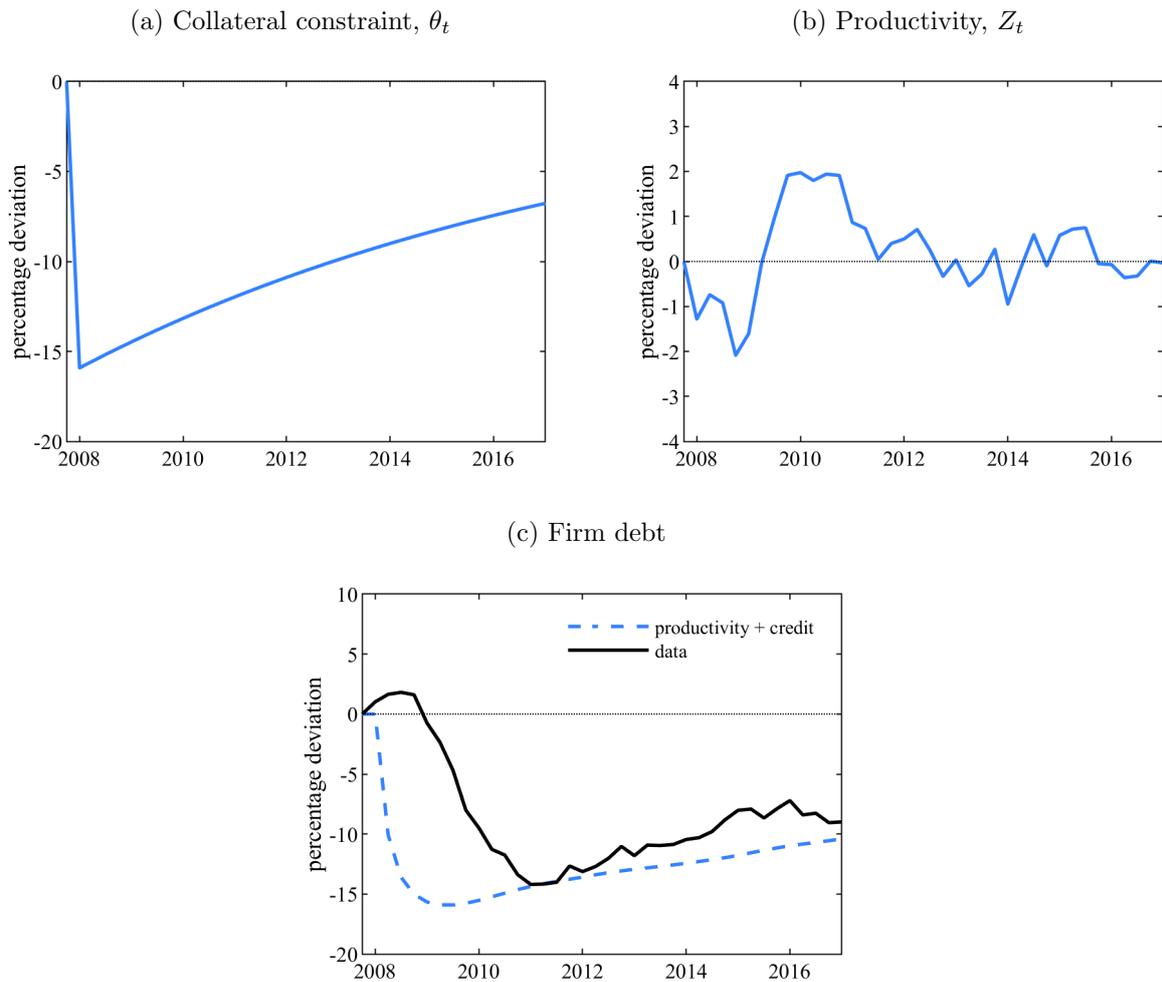
In Figure 14, we compare the change in firm exit rates by age group between model and data. In both the model and data, the increase in exit rates is concentrated among younger firms (ages 1 to 5). Nevertheless, there is larger variation in firm exit by age in the model. This is partly because, in the model, exit among older firms decreases due to general equilibrium effects. In the data, exit among older firms increases, although that

²³Unlike the neoclassical growth model, it is not possible to compute aggregate labor productivity Z with only aggregate data on output, investment, and hours in the model with heterogeneous firms. Instead, we used output per hour as an approximation. In Appendix A.6, Figure 26 shows that the model generates a similar pattern for output per hour as observed in the data.

²⁴For the model with only the credit shock, we feed in the calibrated values for the collateral constraint.

²⁵Although the productivity shock in the Great Recession exercise does not generate significant movements in entry and exit, it can if the shock is large enough. For example, in Appendix A.5, we analyze the 1980s double-dip recession, another recession characterized by pronounced changes in entry and exit, and show that productivity shocks generate significant changes in entry and exit.

Figure 12: Exogenous Shocks and Calibration Targets for the Great Recession



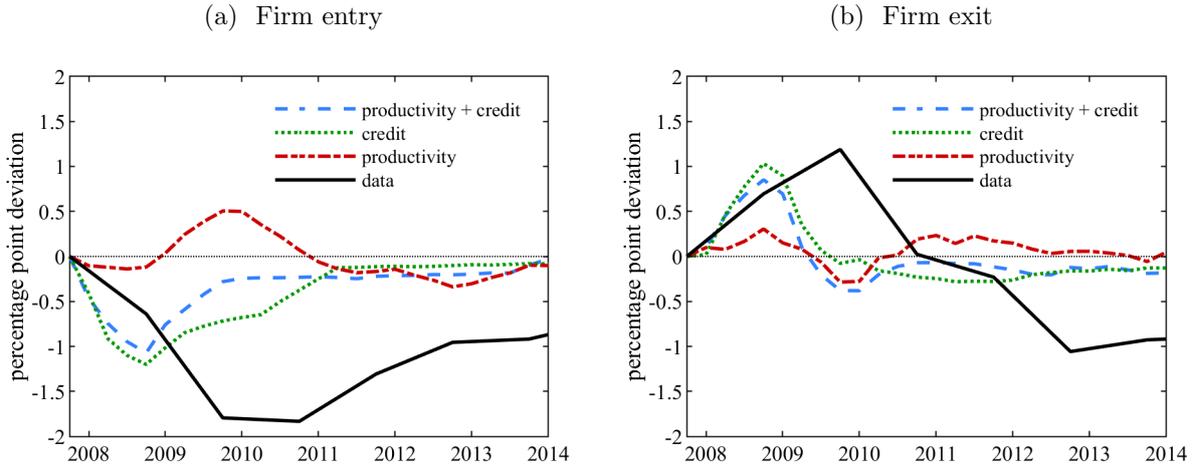
Notes: Figures 12a and 12a plot exogenous shocks to productivity and collateral constraint. Figure 12c plots firm debt in model and data. All variables are expressed as percentage deviations. For firm debt, we use non-financial business loans from the FRB Z1. We use BEA for GDP data. For total hours (used below), we used BLS. We constructed total hours by using BLS data on total employment and average weekly hours. For labor productivity, we used output per hour from the BLS. We log-HP-filtered annual data with a penalty parameter of 6.25 and quarterly data with a penalty parameter of 1,600.

increase is small.²⁶

In Figure 15, we plot non-targeted macroeconomic aggregates both in the model and data. In the model with the credit and productivity shocks, output and hours fall by 3.6 and 1.9 percent, respectively (pre-recession to trough). Analogously, in the model with only the productivity shock, output and hours fall by 2.3 and 1.0 percent, respectively. In the data, output and hours fell by 5.1 and 7.1 percent. Therefore, the credit shock accounts for 25 percent of the fall in output $((3.6-2.3)/5.1)$ and 13 percent of the fall in hours $((1.9-1.0)/7.1)$ observed in the data. Furthermore, Figure 15 shows that the credit

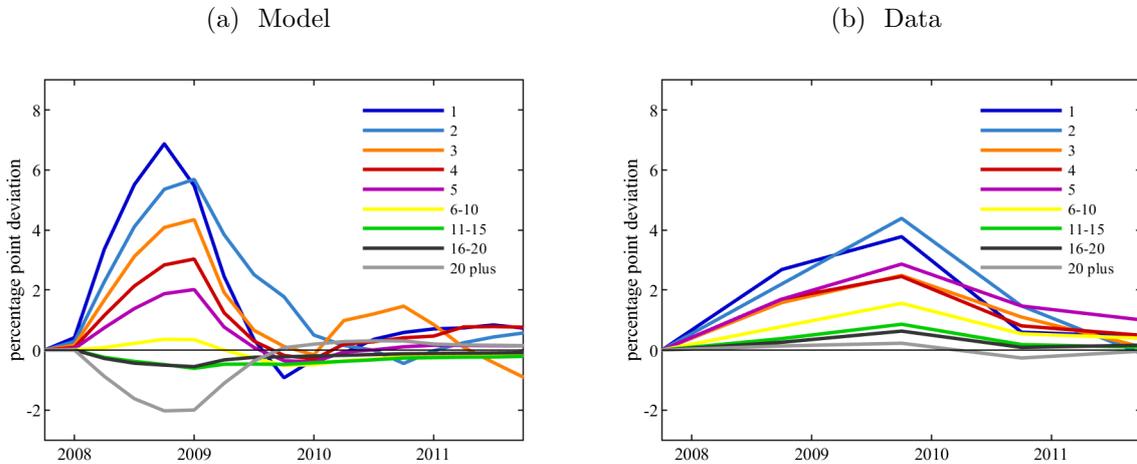
²⁶Appendix A.6 provides summary statistics on firms that exit during the Great Recession.

Figure 13: Great Recession: Transition Dynamics of Firm Entry and Exit



Notes: Figure 13 plots the transition dynamics of annual firm entry and exit rates as percentage point deviations for the Great Recession exercise. “productivity + credit” refers to the case with shocks to both productivity and the collateral constraint. “credit” refers to the case with shocks to only credit. “productivity” refers to the case with shocks to only productivity. The figure also overlays the percentage point deviations in firm entry and exit rates computed from the BDS for the Great Recession. As in the BDS, we normalize annual entry and exit rates in a given period by the average of the mass of firms in a given year and the previous year.

Figure 14: Non-Targeted Moments: Firm Exit by Age in the Model and Data

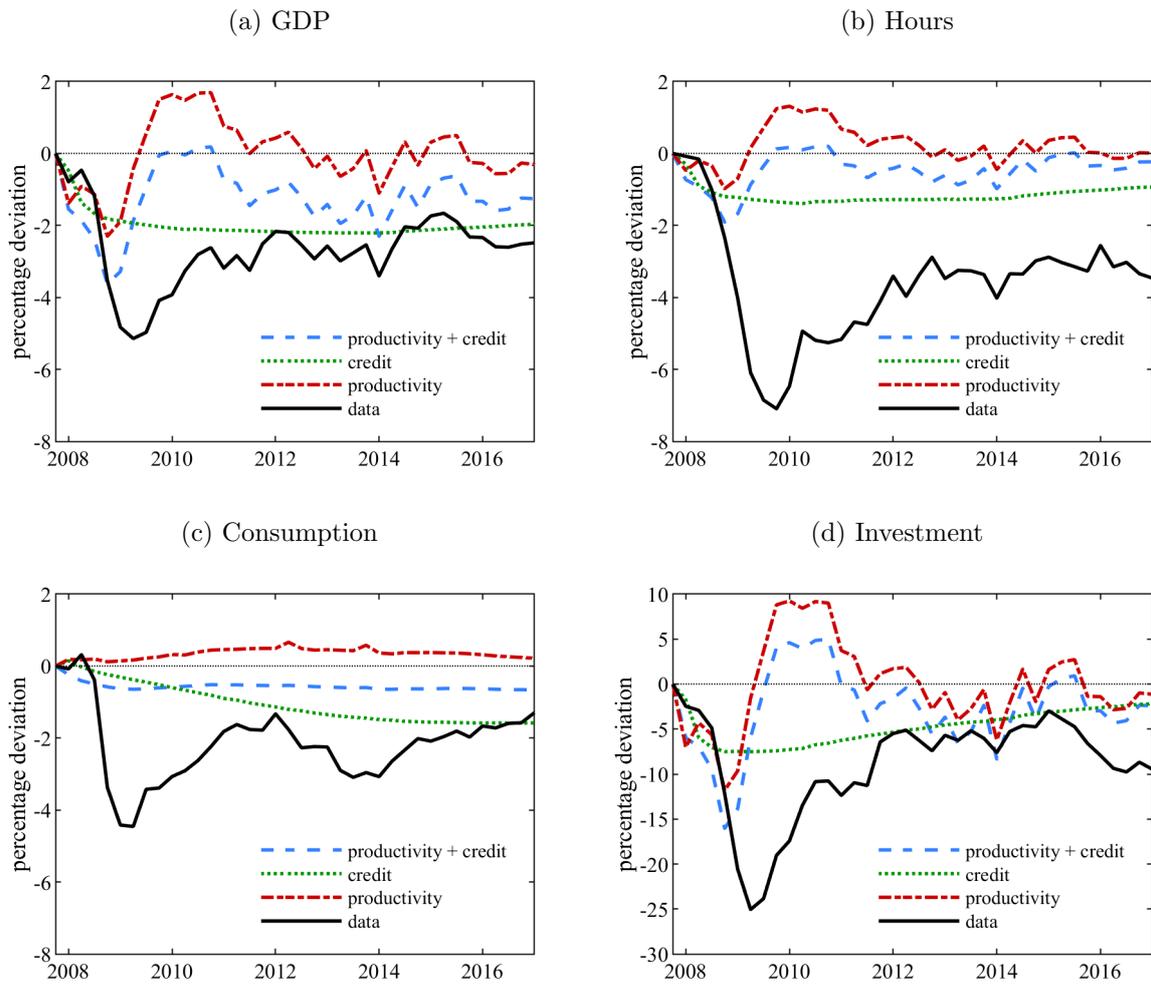


Notes: Figure 14 plots the percentage point change in exit rates by age group from 2007 to 2009 for the data (left) and the Great Recession exercise in the model (right).

shock also contributes significantly to the fall in investment.

A novel feature in our analysis is the adjustment in firm entry and exit. In Figure 16, we quantify the impact of these adjustments on the evolution of output and hours. As Figure 16 shows, both lower firm entry and higher firm exit contribute to the fall in output and hours. For example, lower entry and higher exit account for 31 and 61

Figure 15: Transition Dynamics of Main Aggregates during the Great Recession



Notes: Figure 15 plots the transition dynamics of GDP, hours, consumption, and investment as percentage deviations following shocks to productivity and collateral constraint in the model. It also overlays the deviations observed in the data. “credit” refers to the case with shocks to the collateral constraint. “productivity” refers to the case with shocks to productivity. “productivity + credit” refers to the case with both shocks.

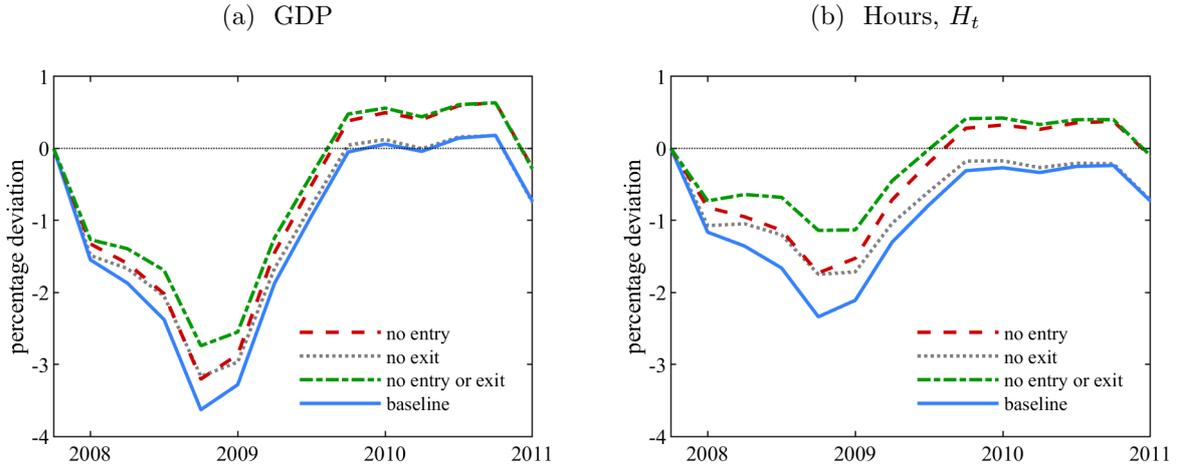
percent of the fall in output and hours during the first two years of the Great Recession in the baseline model with both shocks. That amounts to 19 and 24 percent of the fall in output and hours observed in the data (2008 and 2009), respectively.

6.3 COVID-19 Lockdown

In our third and final exercise, we simulate a lockdown similar to the one experienced during the second quarter of 2020. We do not introduce epidemiological dynamics into our model of firm dynamics. Instead, we use this exercise to quantify the impact of a fall in firm entry and a rise in firm exit during a lockdown on output and total hours.

Given that the recession started in February 2020 (NBER), we treat the second quarter

Figure 16: Great Recession: Decomposition of Aggregates by Entry and Exit



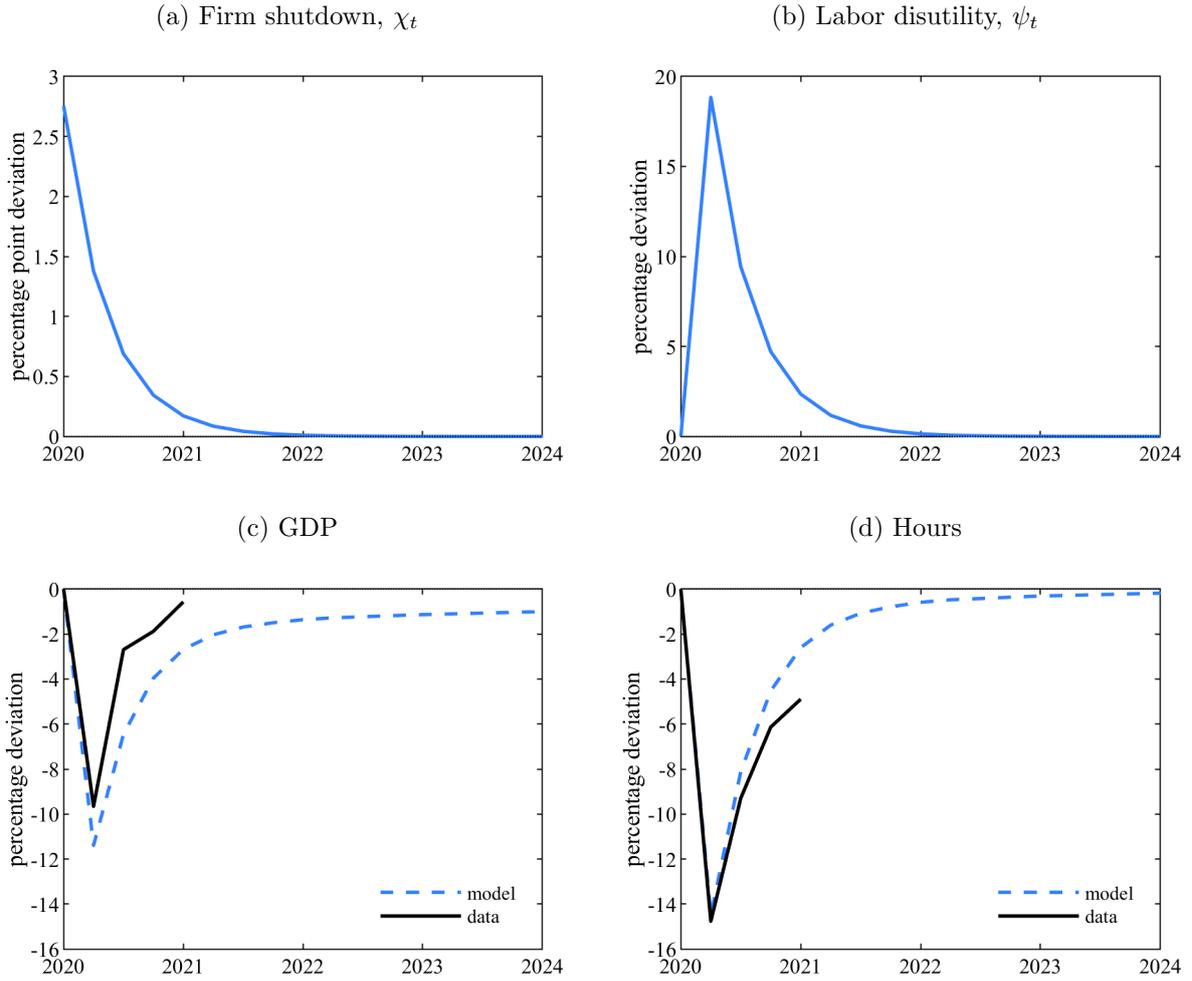
Notes: Figure 16 decomposes the evolution of GDP and hours due to differences in firm entry and exit in the Great Recession exercise. “no entry” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry between the economy subject to the Great Recession vs the economy not subject to the Great Recession. Similarly, “no exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm exit in the first four quarters of the shock and “no entry or exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry and exit.

of 2020 as the first period of the shock. We calibrate the model with two shocks: a shock to firm operation and a shock to labor disutility. The shock to firm operation captures restrictions imposed by the government which prevent some firms from operating temporarily. The shock to labor disutility captures the inability of some workers to go to work.

As of now, we lack data to calibrate the mass of employer firms that were subject to a lockdown. However, we know that the most affected industries were arts, entertainment, recreation, accommodation, and food services. In 2018, these sectors accounted for 13.9 percent of firms in the BDS. For the firm shutdown shock (Figure 17a), we assume 20 percent of firms in these sectors (2.7 percent of all firms in our model) are subject to a lockdown. This leads to a fall in output similar to that observed in the data. Furthermore, the mass of firms subject to a lockdown in our model (2.7 percent) is close to estimates in Crane et al. (2020). They use data from ADP, which provides payroll processing services for businesses that account for 20 percent of total private sector employment. They find that the share of businesses that were closed (not issuing paychecks) for 70 days or more by April 20, 2020 was roughly 2 percentage points higher than the historical average from 2015–2019. The analogous statistic in our model is 2.7 percentage points, as we abstract from temporary closures.

For the labor disutility shock (Figure 17b), we calibrate it to target the fall in total hours observed in the second quarter of 2020. For both of these shocks, we set the

Figure 17: Exogenous Shocks, Output, and Total Hours for a COVID-19 Lockdown



Notes: Figure 17 plots the exogenous shocks and calibration targets for the COVID-19 lockdown exercise. Figures 17a and 17b plot exogenous shocks to firm operation (percent of firms not allowed to operate) and labor disutility. Figures 17c and 17d plot output and hours in model and data.

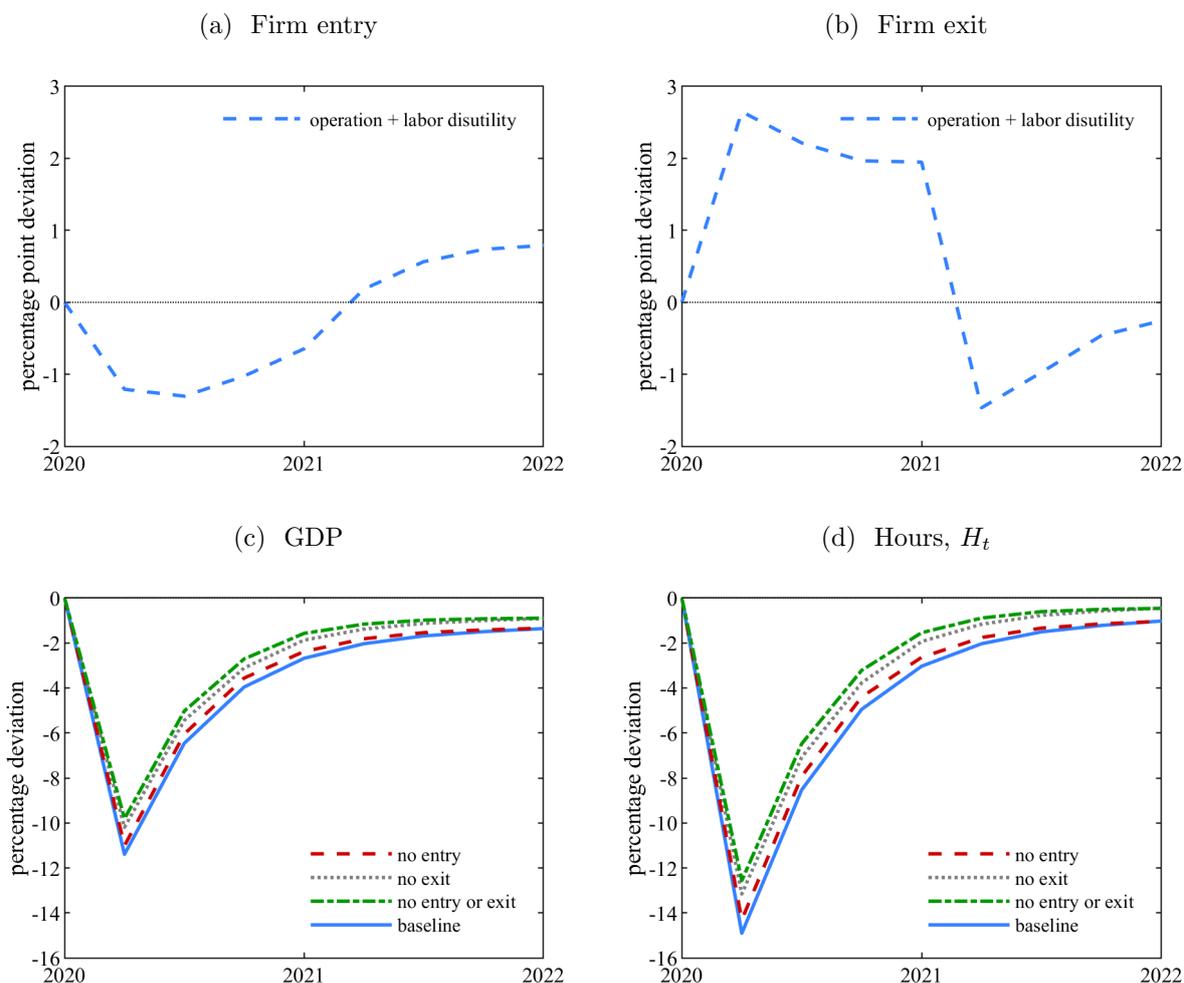
persistence to 0.5, which implies that the lockdown lasts on average for two quarters. This generates a recovery in output and total hours similar to that observed in the data (Figures 17c and 17d).²⁷

Figure 18 plots firm entry and exit responses in the model (18a and 18b) along with a decomposition of output and total hours with and without firm entry and exit (18c and 18d). The firm entry rate falls by more than a percentage point and the exit rate increases by more than 2.5 percentage points. Thirty-one percent of the firms subject to a temporary lockdown end up permanently exiting the economy. If we had assumed a more persistent lockdown, the magnitude of the rise in firm exit would be larger.

Furthermore, Dinlersoz et al. (2021) document a persistent decline in new business

²⁷Appendix A.8 shows the figures for consumption and investment.

Figure 18: COVID-19 Lockdown: Transition Dynamics of Firm Entry and Exit, and Decomposition of Output and Hours



Notes: Figures 18a and 18b plot the transition dynamics of annual firm entry and exit rates as percentage point deviations for the COVID-19 lockdown exercise. Figures 18c and 18d decompose the evolution of GDP and hours due to differences in firm entry and exit in the COVID-19 lockdown exercise. “no entry” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry between the economy subject to the COVID-19 lockdown vs. the economy not subject to the COVID-19 lockdown. Similarly, “no exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm exit in the first four quarters of the shock, and “no entry or exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry and exit.

applications after the Great Recession. In contrast, during COVID-19, there was an initial decline and then a sharp rebound. Our model implications are consistent with this pattern. The fall in entry in Great Recession exercise (Figure 13a) is persistent, whereas it is not in the COVID-19 lockdown exercise (Figure 18a).

Figures 18c and 18d show that changes in firm entry and exit have a significant impact on the fall in output and total hours. In the first four quarters of the lockdown, lower entry and higher exit account for 22 and 24 percent of the fall in output and hours. That

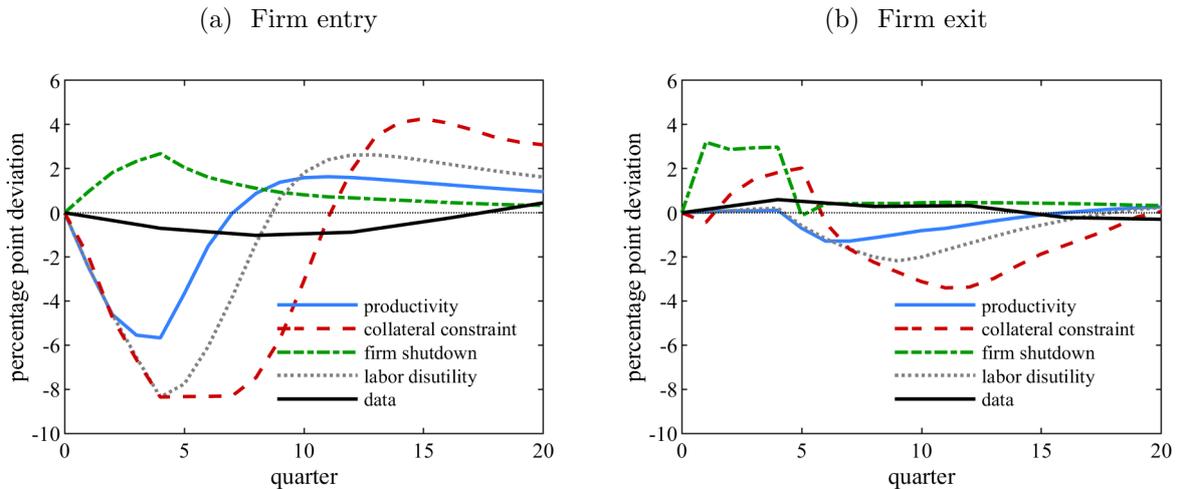
amounts to 17 and 8 percent of the fall in output and hours observed in the data (2020 Q2 to 2021 Q1), respectively.

6.4 Elasticity of Potential Entrants

The baseline model assumed that the mass of potential entrants is inelastic, as in [Clementi and Palazzo \(2016\)](#). An alternative approach is to assume a perfectly elastic supply of entrants as in [Hopenhayn \(1992\)](#), which stems from an unbounded mass of ex ante identical entrants. In this approach, the zero profit condition for entry holds with equality for all potential entrants and the mass of entrants is endogenous.

Figure 19 shows that this approach leads to responses in entry rates that are too volatile in comparison to the data.²⁸ This motivated us to model potential entrants as bounded for our baseline results. Nevertheless, the result that credit and firm shutdown shocks lead to a larger rise in firm exit in comparison to a productivity shock is robust even in this specification of the model.²⁹

Figure 19: Transition Dynamics of Firm Entry and Exit (elastic mass of potential entrants)



Notes: Figure 19 plots the transition dynamics of annual firm entry and exit rates as percentage point deviations given shocks to productivity, collateral constraint, firm shutdown, and labor disutility in the model with a perfectly elastic supply of potential entrants. The figure also overlays the average of percentage point deviations in firm entry and exit rates computed from the BDS for the U.S. recessions starting in 1979, 1990, 2000, and 2007. As in the BDS, we normalize annual entry and exit rates in a given period by the average of the mass of firms in a given year and the previous year.

²⁸We re-calibrate our baseline model with this modification. As this modified model has one less parameter (the mass of potential entrants), we drop one targeted moment: the share of firms that are 20-plus years old. We also re-calibrate the impulse responses for each shock.

²⁹Appendices A.5 and A.7 analyze the 1980s double-dip recession and the Great Recession with perfectly elastic potential entrants. Even in those exercises, entry is too volatile compared to the data.

7 Conclusion

In this paper, we studied how aggregate shocks affect firm entry and exit decisions, and how the responses in firm entry and exit affect the evolution of macro aggregates. We built a general equilibrium model of firm dynamics with financial frictions and analyzed the implications of aggregate shocks that generate recessions. We analyzed shocks to aggregate productivity, credit (collateral constraint), firm operation, and labor disutility. Shocks to firm operation and labor disutility are shocks that capture a lockdown experienced during COVID-19. The firm operation shock imposes a temporary shutdown on some firms, whereas the labor disutility shock captures the inability of some workers to go to work.

We showed that, in comparison to a standard productivity shock, the credit and the two COVID-19 lockdown shocks generate larger changes in firm entry and exit. Next, we used the model to analyze the Great Recession with productivity and credit shocks, and a COVID-19 lockdown with firm operation and labor disutility shocks. In our analysis of the Great Recession, the credit shock accounts for lower entry, higher exit, and concentration of exit among young firms. In our analysis of a COVID-19 lockdown, the model predicts a large fall in entry and rise in exit followed by a sharp rebound. In both recessions, lower entry and higher exit account for roughly 10–20 percent of the fall in output and hours.

The above results lead us to conclude that the nature of the shock matters for entry and exit responses and their impact on macro aggregates. Furthermore, these results illustrate the usefulness of models of heterogeneous firms with entry and exit to understand business cycle fluctuations.

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A Appendix

A.1 Algorithm to Compute Transitions

We solve the incumbent firm's problem as in [Khan and Thomas \(2013\)](#). Given prices, we first solve the unconstrained firm's problem using value function iteration. Using the policy functions of the unconstrained firm, we solve for a minimum savings function, i.e., minimum savings for each state such that the nonnegative dividend constraint never binds in the future. Given the minimum savings function, we solve the incumbent firm's problem using value function iteration. The next two subsections discuss how we compute transition paths in the model with perfectly inelastic potential entrants and perfectly elastic potential entrants.

A.1.1 Model with Perfectly Inelastic Mass of Potential Entrants (baseline)

- Guess sequence of w_t and r_t
- Solve for incumbent firm's and potential entrant's value and policy functions through backward induction
- Simulate transition path
- Backout sequence for Π_t from transition simulation
- Impose market clearing for the bond market and labor market and back out sequences for A_{t+1} and H_t
- Use budget constraint to solve for sequence for C_t
- Use intra-temporal consumption-labor first order condition and Euler-equation to update w_t and r_t and iterate until convergence

A.1.2 Model with Perfectly Elastic Mass of Potential Entrants

- Guess sequence of C_t and solve for sequence of r_t using Euler-equation
- Guess w_t starting from the period before the final steady state and solve for incumbent firm's value and policy functions; solve for sequence of w_t through backward induction such that $V_t^{entry} = 0$
- Backout sequence of H_t from household intra-temporal condition
- Solve for sequence of m_t such that labor market clears
- Backout sequence for Π_t from transition simulation

- Backout sequence for A_{t+1} from transition simulation by imposing bond market clearing
- Update C_t using budget constraint and iterate until convergence

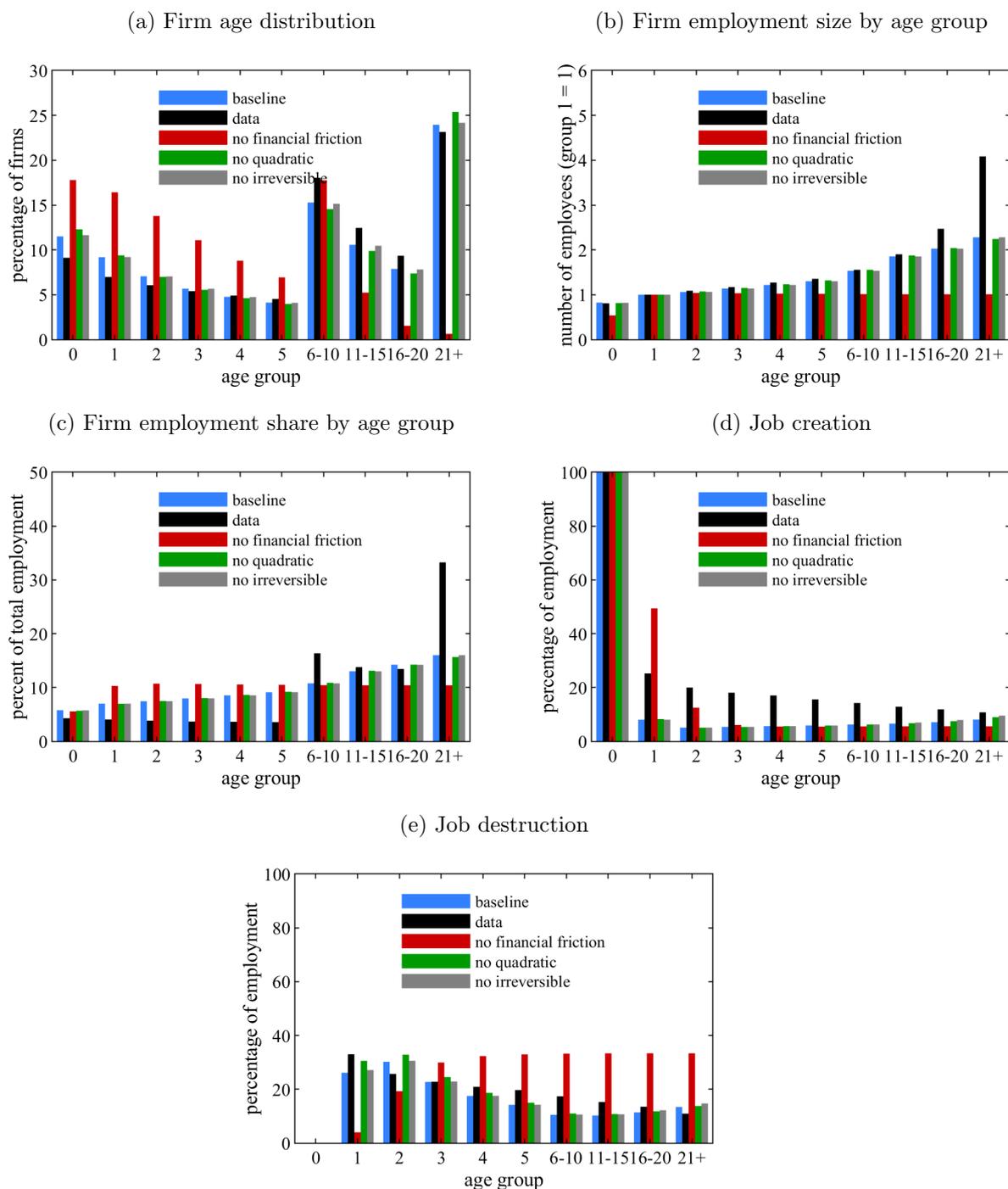
A.2 Role of Frictions for Non-Targeted Moments in Baseline Model

In Section 5, we showed that the baseline model accounts for several non-targeted moments in the data by firm age and firm size. Our baseline model incorporates both financial and investment frictions. In this section, we analyze implications for the non-targeted moments when we eliminate frictions. We consider the following cases: model without financial frictions (no nonnegative dividend constraint or collateral constraint), model without quadratic adjustment cost ($\lambda = 0$), and model without irreversible investment cost ($\gamma = 0$). For these cases, we eliminate the friction in the baseline model, but do not re-calibrate the model. Hence, the following analysis quantifies the role of each friction for our calibrated baseline model. It does not claim that a given friction is important in accounting for non-targeted moments in the general class of firm dynamics models.

Figure 20 plots non-targeted moments by firm age for the data, the baseline model, and each variation of the baseline model without frictions. It shows that, in our baseline model, the financial friction is important to quantitatively account for firm dynamics statistics by age. The blue bars (baseline model) are significantly different from the red bars (no financial friction). Capital adjustment costs (quadratic adjustment cost and irreversible investment) are not quantitatively important. The blue bars (baseline model) are roughly the same as the green bars (no quadratic adjustment cost) and the gray bars (no irreversible investment). Without the financial friction, young firms are not as constrained in accumulating capital. Hence, their employment size and employment shares are almost the same as among older firms (Figures 20b and 20c). Furthermore, young firms are less likely to exit without the financial friction leading to a larger share of young firms in comparison to the baseline model and the data (Figure 20a). Finally, in comparison to the data, the no financial friction model leads to higher job creation and lower job destruction among young firms. (Figures 20d and 20e).

Table 4 reports non-targeted moments by firm size for the data, the baseline model, and each variation of the baseline model without frictions. The financial friction is important to quantitatively account for firm dynamics statistics by size among all firms and exiting firms whereas the capital adjustment costs are not quantitatively important. The numbers reported in column (3) for the model without the financial friction are significantly different from those reported in column (2) for the baseline model. The numbers for columns (4) and (5) (no quadratic adjustment cost and no irreversible investment) are

Figure 20: Firm Age Distribution, Firm Employment Size, Employment Share, and Job Flows by Age Group



Notes: Figure 20 plots firm dynamics statistics by age in the baseline model, data, model without financial frictions, model without quadratic adjustment cost, and model without investment irreversibility. Figure 20a plots share of firms by age. Figure 20b plots average employment size by age (age 1 normalized to 1). Figure 20c plots share of employment by firm age. Figure 20d plots job creation by firm age as a percent of employment by firm age. Figure 20e plots job destruction by firm age as a percent of employment by firm age.

similar to those in the baseline model (column 2). Without the financial friction, there are more firms with 10-19 employees and fewer firms with 9 employees or less and 20+ employees. The elimination of the financial friction allows young firms to grow faster, leading to more firms in the middle. However, the elimination of the financial friction also leads to a higher equilibrium wage rate (2.0 in the baseline model and 2.5 in the no financial friction model). The higher wage rate leads to fewer firms with more than 20 employees. Finally, in all variations of the baseline model, firm entry is concentrated among small firms. This is because we assume firms enter with an initial stock of capital equal to k_e . Therefore, none of the frictions are important in accounting for the size distribution of entrants.

Table 4: Firm Size Distribution

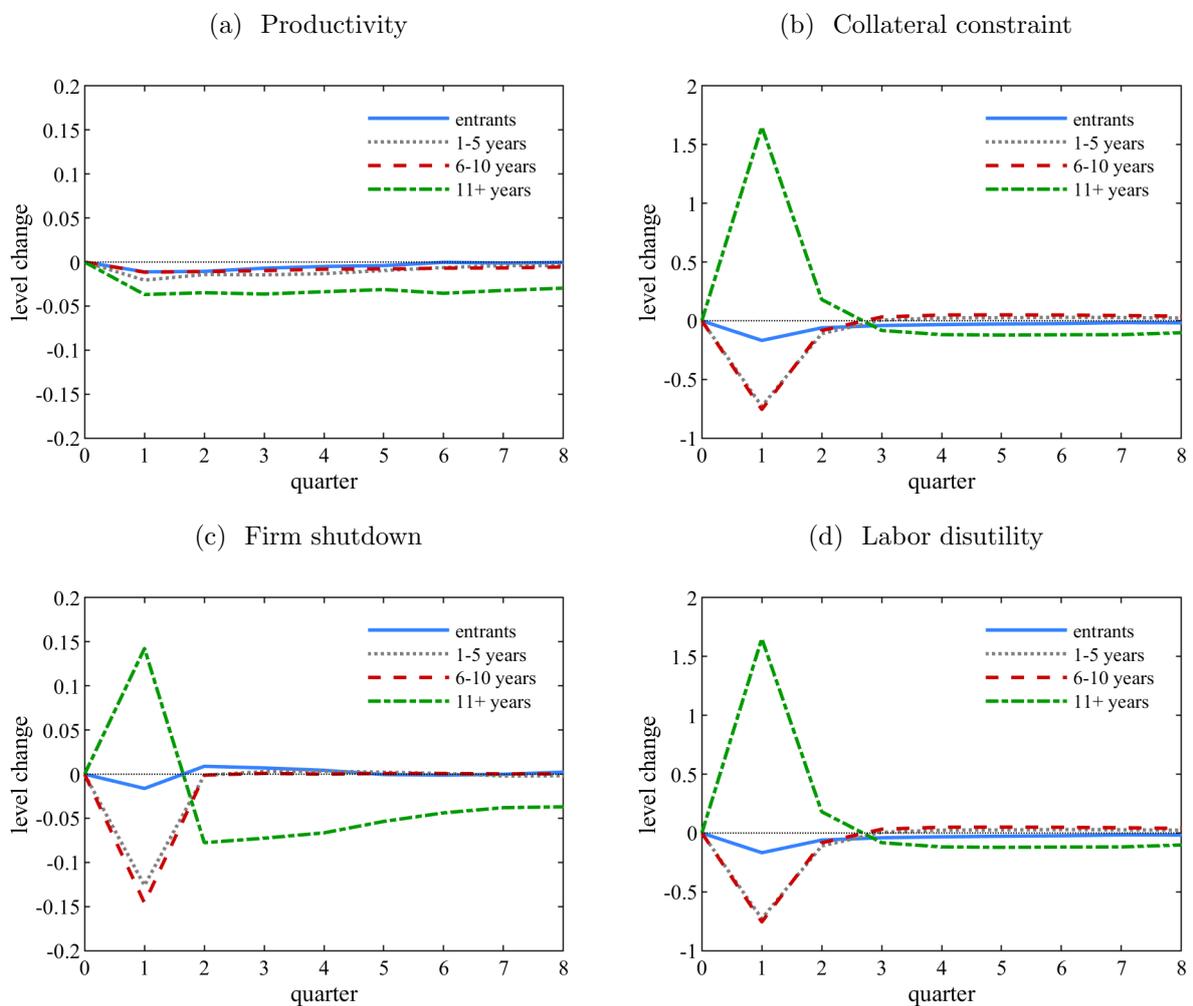
Number of employees	(1) Data	(2) Baseline	(3) No financial friction (unit = percent of firms)	(4) No quadratic adjustment cost	(5) No irreversible investment cost
All firms: ≤ 9	76.16	52.48	48.27	51.81	52.87
All firms: 10 – 19	12.19	37.64	47.33	37.82	36.97
All firms: 20+	11.65	9.89	4.41	10.37	10.15
Exits: ≤ 9	94.35	96.07	76.49	96.48	96.79
Exits: 10 – 19	3.52	3.93	23.50	3.52	3.21
Exits: 20+	2.13	0.00	0.00	0.00	0.00
Entrants: ≤ 9	94.79	98.80	95.67	98.38	98.68
Entrants: 10 – 19	3.30	1.20	4.33	1.62	1.32
Entrants: 20+	1.91	0.00	0.00	0.00	0.00

While the adjustment costs are not quantitatively important to account for the non-targeted moments by firm age and firm size, they are still important to pin down the variance of innovations to the idiosyncratic productivity process. One of the target moments in our calibration, the standard deviation of annual investment rates for firms that are 30 years and older is 0.34 in the data and 0.33 in the baseline model. Without the financial friction, the standard deviation is 0.33. It barely changes because most firms that are 30 years and older are not financially constrained in both models. Without the capital adjustment costs, the analogous standard deviation in investment rates is significantly higher. It is 0.39 without irreversible investment and explodes to an extremely large number without quadratic capital adjustment costs.

A.3 Firm Investment by Age for Impulse Responses in Baseline Mksodel

Figure 21 plots the level change in firm investment by age for the impulse responses from the baseline model discussed in Section 6.1. For the productivity shock, Figure 21a shows that investment falls across all age groups. For the credit shock, Figure 21b shows that investment falls for firms from ages 0-10, but rises for firms from ages 11 and above. The intuition for this result is the same as that discussed for higher exit among young firms and lower exit among older firms due to a credit shock (Figure 9b). Young firms invest less or even exit due to tighter credit, but older firms invest more due to general equilibrium effects.

Figure 21: Firm Investment by Age



Notes: Figure 21 plots percentage changes in firm investment by age groups for each shock in the baseline model (Section 6.1).

Figure 21c shows that a shock to firm operation also leads to lower investment among young firms and higher investment among older firms. Most of the fall in investment

for this shock is driven by higher exit (Figure 11). This explains the lower investment among young firms. Investment among older firms increases because due to general equilibrium effects (lower interest rate and wage rate, Figure 8). Finally, a shock to labor disutility also leads to lower investment among young firms and higher investment among older firms. The labor disutility shock leads to higher exit especially among young firms (Figure 9d), which explains the fall in investment among young firms. While the labor disutility shock leads to a higher wage rate, it also reduces the interest rate (Figure 8). This leads to higher investment among older firms.

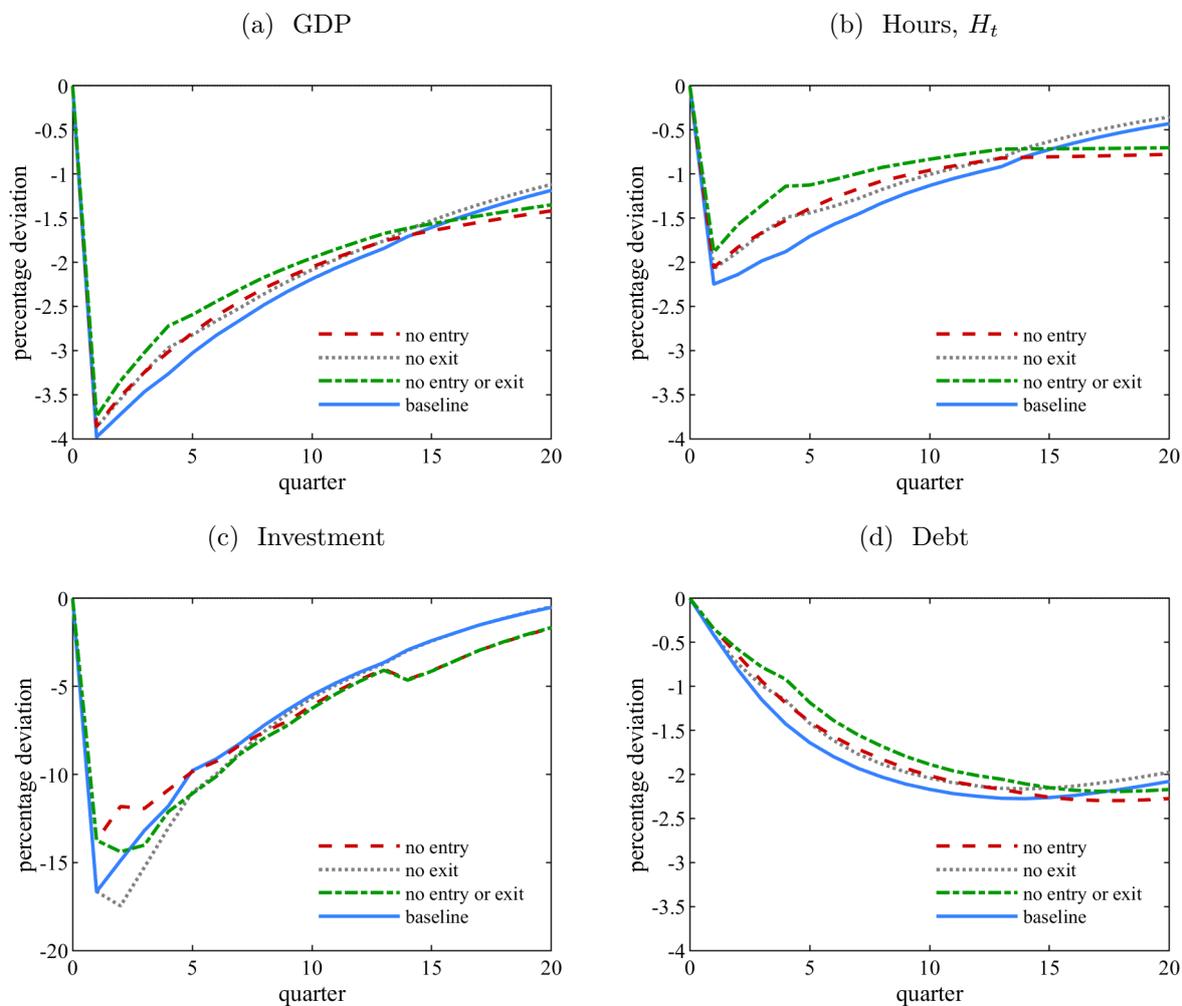
A.4 Evolution of Macro Aggregates with and without Firm Entry and Exit: Productivity and Labor Disutility Shocks

Figures 22 and 23 plot the evolution of aggregates controlling for differences in firm entry and exit for the impulse responses of the productivity shock and labor disutility shock from the baseline model discussed in Section 6.1.

For the productivity shock, the impact of differences in firm entry and exit on the evolution of macro aggregates (GDP, hours, investment, and firm debt) is small. This is because the magnitude of changes in firm entry and exit due to a productivity shock in our calibrated impulse response is small (Figure 7).

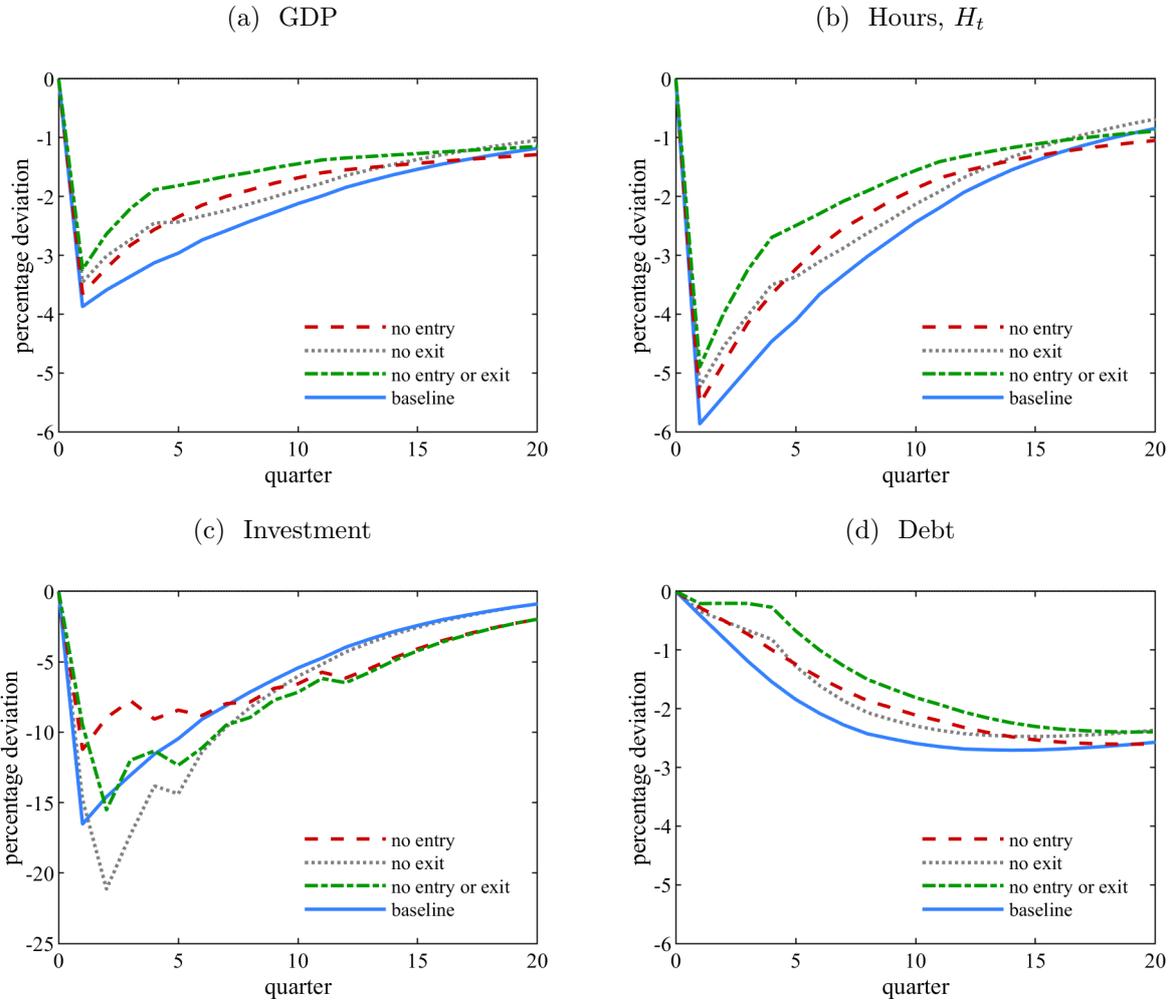
For the labor disutility shock, the impact of differences in firm entry and exit on the evolution of macro aggregates are large. This is because the labor disutility shock, which increases the wage rate, leads to a significant fall in firm entry and rise in firm exit (Figure 7). Lower firm entry and higher firm exit account for roughly 20-25 percent of the fall in output and hours.

Figure 22: Productivity: Decomposition of Aggregates by Entry and Exit



Notes: Figure 22 decomposes the evolution of GDP, hours, investment, and firm debt due to differences in firm entry and exit in the case of a shock to productivity in the baseline model. “no entry” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry between the economy subject to the shock vs. the economy not subject to the shock. Similarly, “no exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm exit in the first four quarters of the shock and “no entry or exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry and differences in firm exit.

Figure 23: Labor Disutility: Decomposition of Aggregates by Entry and Exit

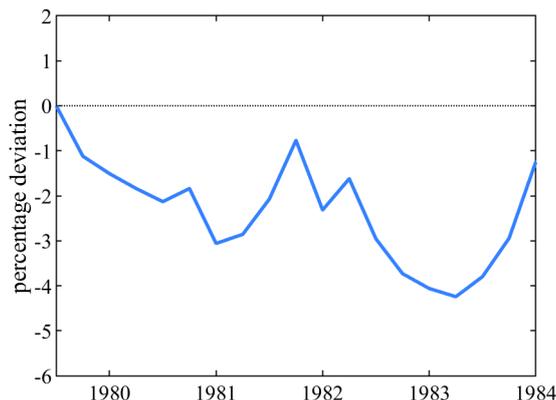


Notes: Figure 23 decomposes the evolution of GDP, hours, investment, and firm debt due to differences in firm entry and exit in the case of a shock to labor disutility in the baseline model. “no entry” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry between the economy subject to the shock vs the economy not subject to the shock. Similarly, “no exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm exit in the first four quarters of the shock and “no entry or exit” plots the evolution of macro aggregates if one excludes the impact of differences in firm entry and differences in firm exit.

A.5 1980s Double-Dip Recession

In this section, we feed in deviations output per hour observed during the 1980s double-dip recession as productivity shocks (Figure 24) and analyze implications for firm entry and exit (Figure 25). We perform this exercise in both the baseline model and the model with perfectly elastic mass of potential entrants.

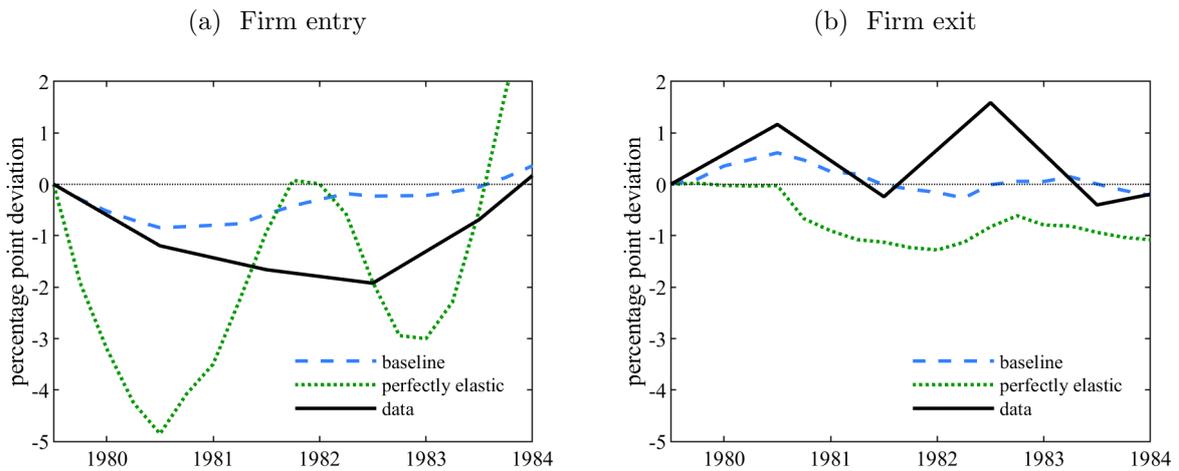
Figure 24: Productivity Shocks for 1980s Double-Dip Recession



Notes: Figure 24 plots shocks to productivity for the 1980s double-dip recession exercise.

Figure 25 shows that the baseline model, which assumes perfectly inelastic mass of potential entrants, generates some of the fall in entry and rise in exit observed during the 1980s double-dip recession. This suggests that if the productivity shocks are large and persistent, as shown in Figure 24, they can generate significant changes in entry and exit. Figure 25 also shows that the model with perfectly elastic mass of potential entrants leads to a significantly larger fall in entry compared to the data. Exit hardly changes.

Figure 25: 1980s Double-Dip Recession: Transition Dynamics of Firm entry and Exit



Notes: Figure 25 plots the transition dynamics of annual firm entry and exit rates as percentage point deviations for the 1980s double-dip recession exercise in both the baseline model and the model with perfectly elastic mass of potential entrants. The figure also overlays the percentage point deviations in firm entry and exit rates computed from the BDS for the 1980s double-dip recession.

A.6 Great Recession Exercise in Baseline Model

Figure 26 plots output per hour during the Great Recession in the model with both shocks to productivity and collateral constraint, model with shocks to productivity, and data. The model (“productivity + credit” or “productivity”) generates a pattern qualitatively similar to that observed in the data, although the fall in the model is significantly larger. We view this result as conservative because even in this calibration where output per hour falls more in the model, the productivity shock leads to only marginal changes in entry and exit. Furthermore, the credit shock’s impact on output per hour is marginal in the initial years, but significant in the following years.

Figure 26: Output per Hour during Great Recession

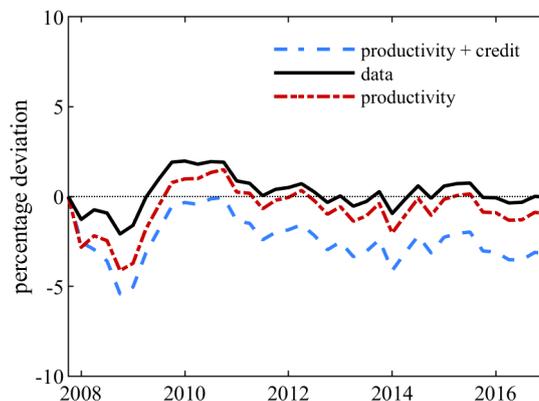


Table 5 provides summary statistics on the characteristics of firms that exit in the model with credit and productivity shocks in period 0 and period 4 (the period in which exits peak). We see that relative to period 0, firms that exit during the recession on average have higher productivity, higher net assets, and higher capital.

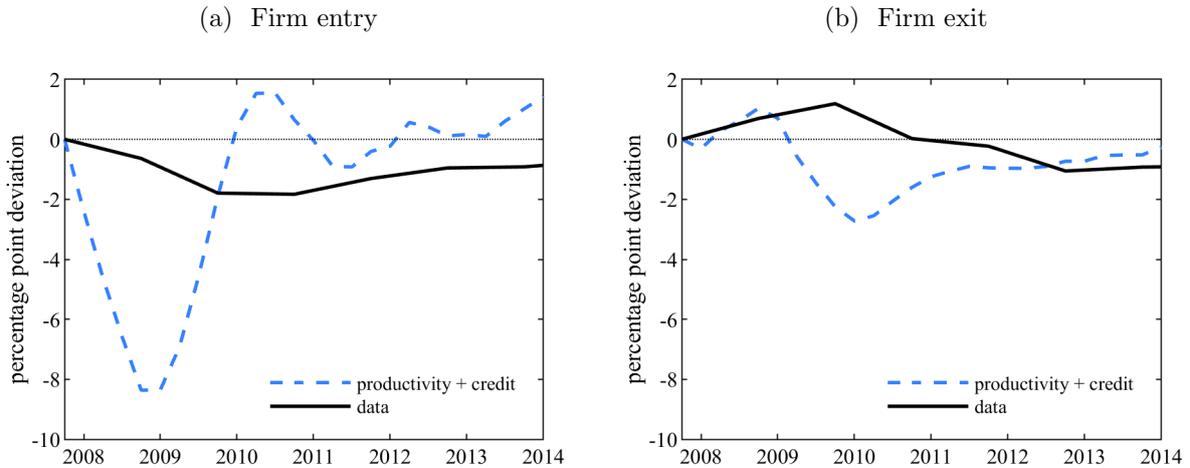
Table 5: Characteristics of Firms That Exit: Great Recession

Variable	Period 0 (%)	Period 4 (%)
Avg. productivity exiters / Avg. productivity all firms	78.7	81.3
Avg. capital exiters / Avg. capital all firms	3.9	9.7
Avg. net assets / Avg. net assets all firms	73.7	148.4

A.7 Great Recession in the Model with Perfectly Elastic Mass of Potential Entrants

In Section 6.2, we showed that the baseline model with shocks to the collateral constraint and productivity accounted generates entry and exit dynamics that is consistent with the data during the Great Recession. In this exercise, we perform the same exercise, but using the model with perfectly elastic mass of potential entrants (model presented in Section 6.4). We re-calibrate the model with the same targets used for the baseline model in the Great Recession exercise. In this case, the model with perfectly elastic potential entrants generates a fall in entry that is significantly larger than that observed in the data (Figure 27a). This further reiterates the point that the model with perfectly elastic mass of potential entrants generates entry that is too volatile in comparison to the data. Nevertheless, this model also partially accounts for the rise in exit observed in the data (Figure 27b).

Figure 27: Great Recession with Perfectly Elastic Mass of Potential Entrants: Transition Dynamics of Firm Entry and Exit

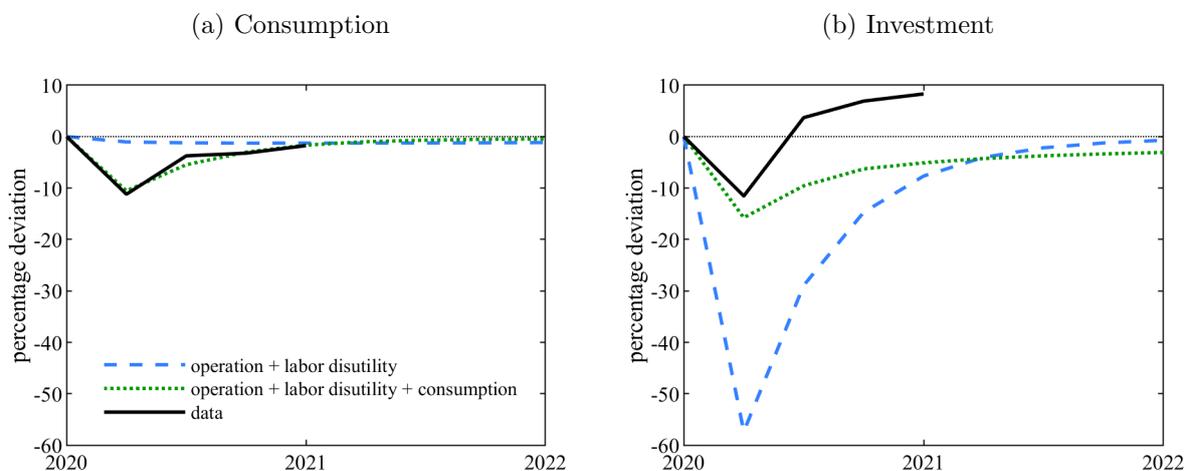


Notes: Figure 27 plots the transition dynamics of annual firm entry and exit rates as percentage point deviations for the Great Recession exercise in the model with perfectly elastic mass of potential entrants. “productivity + credit” refers to the case with shocks to both productivity and the collateral constraint.

A.8 COVID-19 Lockdown Consumption Responses

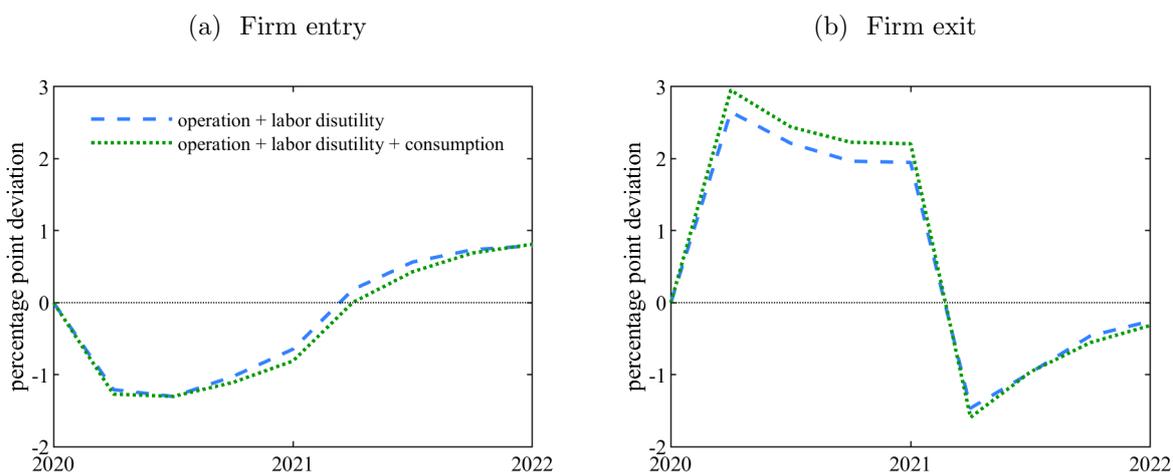
Figure 28 plots consumption and investment responses in the model with a COVID-19 lockdown (shocks to firm operation and labor disutility discussed in Section 6.3 referred to as “operation + labor disutility” in Figure 28) and the data from the first quarter of 2020. Although both consumption and investment fall in both data and model with only the shocks to firm operation and labor disutility, the model understates the drop in consumption and overstates the drop in investment. However, this shortcoming of the model is not a major concern for us with regard to implications for firm entry and exit. Suppose we introduce a third shock, a shock to the marginal utility of consumption, and re-calibrate the model to target the drop in consumption and the moments discussed in Section 6.3. In that case, the model with the three shocks (“operation + labor disutility + consumption”) accounts for the fall in consumption and investment observed in the data. However, the responses of firm entry and exit in the model with only the two shocks vs the model with three shocks are roughly the same (Figure 29).

Figure 28: Transition Dynamics of Consumption and Investment during a COVID-19 lockdown



Notes: Figure 28 plots the evolution of consumption and investment in the model for the COVID-19 lockdown exercises and the data. “operation + labor disutility” refers to the case with shocks to firm operation and labor disutility (exercise presented in Section 6.3). “operation + labor disutility + consumption” refers to the case with shocks to firm operation, labor disutility, and marginal utility of consumption.

Figure 29: COVID-19 Lockdown: Transition Dynamics of Firm Entry and Exit



Notes: Figure 29 plots the evolution of firm entry and exit rates in the model for the COVID-19 lockdown exercise. “operation + labor disutility” refers to the case with shocks to firm operation and labor disutility (exercise presented in Section 6.3). “operation + labor disutility + consumption” refers to the case with shocks to firm operation, labor disutility, and marginal utility of consumption.

A.9 Robustness to Different Model Specifications

One of our main findings is that in comparison to a productivity shock (controlling for the drop in output), the credit and the two lockdown shocks generate larger changes in firm exit. This section shows that this result is robust to different specifications of the model such as allowing for firm default, stochastic operating costs, fixed operating costs in units of the final good, GHH preferences, preferences with habit formation, and a larger spread. We discuss the motivation for each specification below.

A.9.1 Default

In our baseline model, firms do not default on their debt. This could be one possible reason for why firm exit does not increase as much for a productivity shock in our baseline model. If firms can default on their debt and lenders price that default risk, a productivity shock not only reduces operating revenue, but it could also increase the cost of borrowing by increasing default risk. Therefore, we incorporate default into our baseline model, re-calibrate it, and analyze the impulse response dynamics of firm exit for a productivity shock. The main takeaway is that, while a productivity shock does increase the cost of borrowing marginally, its marginal impact on firm exit in comparison to the baseline model is negligible.

When we introduce default to the baseline model, we make the following modifications to the baseline model. A firm that chooses to operate must repay its debt. The dividends for a firm that operates is given by the following equation:

$$D_t(k', b', l, k, b, \epsilon, \eta, \kappa) = f(k, l, \epsilon, \eta; Z_t) - w_t(l + \kappa f^o) - x(k', k) - \zeta(k', k) - b + (q_t(k', b', \epsilon, \eta) - \mathbb{1}_{\{b' > 0\}} \tau^b) b',$$

where κ is a variable that makes the cost of operation stochastic and $q_t(k', b', \epsilon, \eta)$ is a bond price schedule that prices default risk (more details below). We make the cost of operation stochastic to add more default risk. The value of operation is given by the following equation:

$$V_t^{op}(k, b, \epsilon, \eta, \kappa) = \max_{l, k', b'} D_t(k', b', l, k, b, \epsilon, \eta, \kappa) + \frac{1}{1 + r_{t+1}} \int \int \int V_{t+1}^{inc}(k', b', \epsilon', \eta', \kappa') F(d\epsilon' | \epsilon) F(d\eta' | \eta) F(d\kappa'),$$

s.t. $D_t(k', b', l, k, b, \epsilon, \eta, \kappa) \geq 0,$

There is no collateral constraint in the model with default. Instead, there is a bond price schedule, which shows up in the dividends equation.

The value of exit is given by the following equation:

$$V_t^{exit}(k, b) = \max [\chi^k k - \zeta(0, k) - b, \min[0, \chi k - \zeta(0, k)]],$$

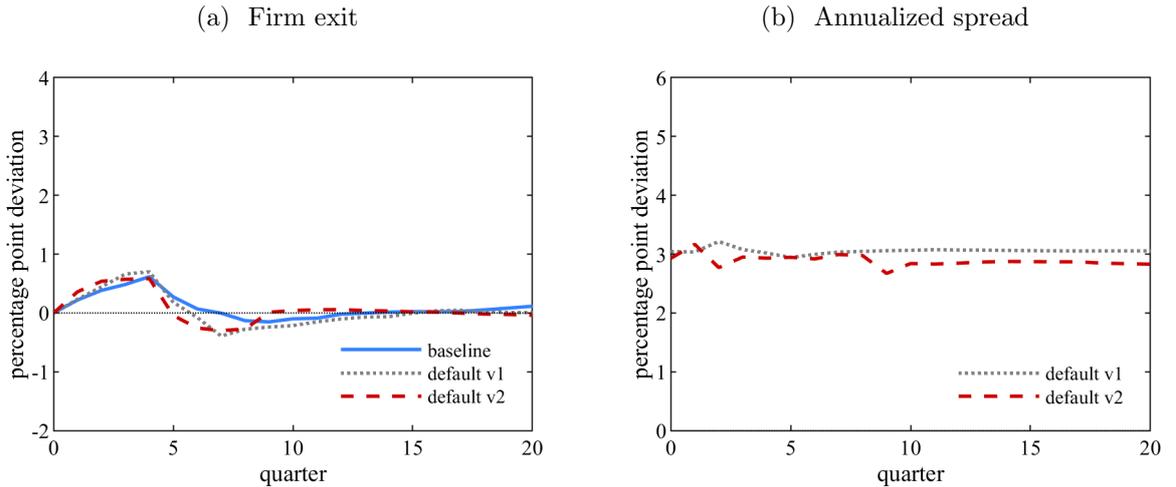
where χ is the parameter that dictates the resale value of capital upon exit. If $\chi k - \zeta(0, k)$ is less than 0 and b is positive, then the owner (the household) pays the cost $\chi k - \zeta(0, k)$, the firm defaults on b , and the value of exit is equal to $\chi k - \zeta(0, k)$. If $\chi k - \zeta(0, k)$ is less than 0 and b is negative, then the owner (the household) pays/receives $\chi k - \zeta(0, k) - b$, and the value of exit is equal to $\chi k - \zeta(0, k) - b$. If $\chi k - \zeta(0, k)$ is positive and greater than outstanding debt b , the firm repays all of its debt, and the value of exit is equal to $\chi^k k - \zeta(0, k) - b$. If $\chi k - \zeta(0, k)$ is positive and less than outstanding debt b , the firm repays $\chi k - \zeta(0, k)$ of its debt, defaults on the remaining amount, and the value of exit is equal to 0.

The bond price schedule is given by the following equation:

$$q(k', b', \epsilon, \eta) = \frac{1}{b'(1+r')} \int \int \int \left[d(k', b', \epsilon', \eta', \kappa') b' + (1 - d(k', b', \epsilon', \eta', \kappa')) \min [b, \max[0, \chi k - \zeta(0, k)]] \right] F(d\epsilon'|\epsilon) F(d\eta'|\eta) F(d\kappa').$$

If the firm operates in the next period, the lenders receive the full principal b' . If the firm exits, the lenders receive any outstanding debt after the firm sells its capital and pays the adjustment cost.

Figure 30: Model with Default: Transition Dynamics of Firm Exit and Spreads



Notes: Figure 30 plots the evolution of firm exit and the (cross-sectional) average spread. “baseline” refers to the model without default. “default v1” refers to the model with default where the probability of an extremely large operating cost is 0.01. “default v2” refers to the model with default where the probability of an extremely large operating cost is 0.005.

In this model, we no longer have the collateral constraint. Therefore, in our calibration we drop one target moment (ratio of the number of 5-year-old firms to the number of 0-5 year-old firms). We have an extra parameter χ . We include one more target moment related to this parameter, which is the average spread for Baa corporate bonds of 2.34 percent per year. We assume that the fixed cost scale parameter κ takes on a value of 1 or a very large number (1e38 in the numerical exercise). This implies that the firm surely exits for the second value. Figure 30a presents impulse response dynamics of firm exit for the model with default and the baseline model. Figure 30b plots the (cross-sectional) average spread in the model with default. For the probability of a large κ , we consider two variations by setting it equal to 0.01 and 0.005, respectively. The increase in spreads is marginal. The responses in exit are roughly the same in the model with default and the baseline model. Therefore, incorporating default into our baseline model does not significantly amplify exit responses to a productivity shock.

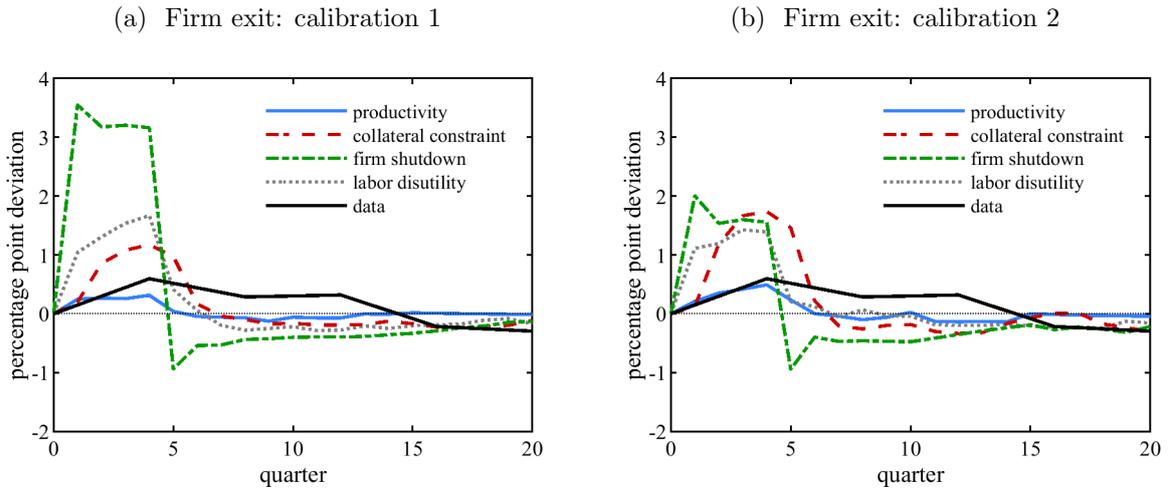
A.9.2 Stochastic Operating Cost

In this section, we show that impulse response dynamics of firm exit in the baseline are not sensitive to making the cost of operating stochastic. We make the fixed cost of operation stochastic as discussed in the previous section. We assume that the scale parameter for the fixed cost (κ) takes on a value of 1 or a very large number (1e38 in the numerical exercise). This implies that the firm surely exits for the second value. For the probability of a large κ , we consider two variations by setting it equal to 0.01 and 0.005, respectively. Figure 31 plots exit dynamics for each calibration of the baseline model with stochastic operating costs. In both cases, shocks to credit, firm operation, and labor disutility lead to larger changes in exit in comparison to a productivity shock.

A.9.3 Operating Cost in Final Good, Larger Spread, GHH, and habit Formation

In this section, we consider alternative specifications of the baseline model such as operating costs in units of the final good rather than labor, larger spread for borrowing, GHH preferences, and GHH preferences with habit formation. The last two specifications are widely used in the business cycle literature to better match the volatility of consumption and total hours. 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 (2021), generates interest rate dynamics consistent with the data. For the case with the larger spread, we set τ^b equal to the average spread for BAA corporate bonds, which implies an annual rate of 2.34 percent, rather than the average for Aaa corporate bonds used in the baseline model. For each of these

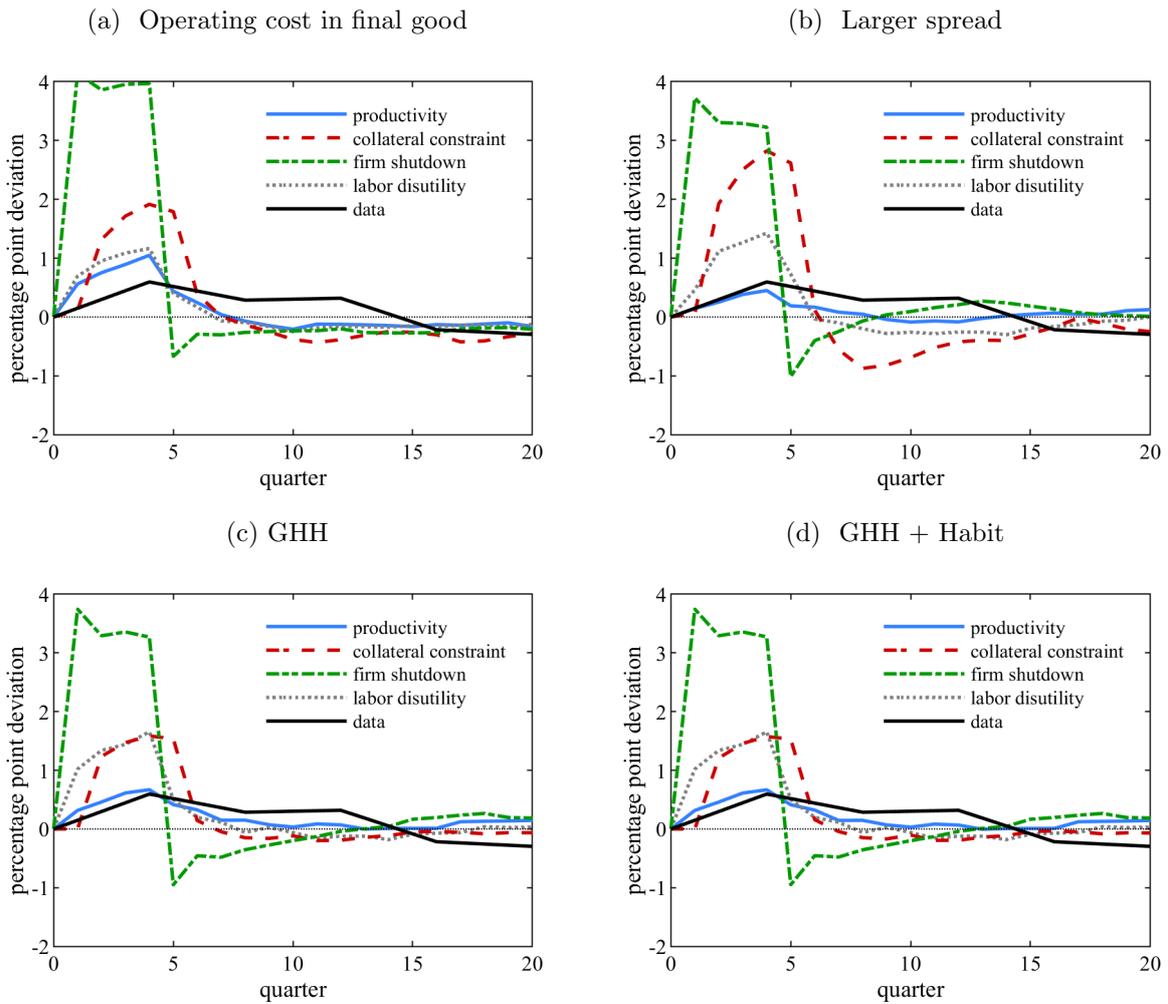
Figure 31: Transition Dynamics of Firm Entry and Exit



Notes: Figure 31 plots the transition dynamics of annual firm exit rates as percentage point deviations given shocks to productivity, collateral constraint, firm shutdown, and labor disutility in the baseline model with stochastic fixed operating costs.

cases, we re-calibrate the model to match the same set of moments as in the baseline calibration. Figure 32 plots exit dynamics for each variation. In all of these variations, shocks to credit, firm operation, and labor disutility lead to a larger increase in firm exit than a productivity shock.

Figure 32: Transition Dynamics of Firm Exit



Notes: Figure 32 plots the transition dynamics of annual firm exit rates as percentage point deviations given shocks to productivity, collateral constraint, firm shutdown, and labor disutility in four variations of the baseline model: 1) operating costs in units of the final good rather than labor, 2) larger spread for borrowing, 3) GHH preferences, and 4) GHH preferences with habit formation.