A Theory of Credit Cycles under Pandemic*

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Abstract

We develop a tractable dynamic theory linking endogenous credit cycles with conditions in the labor market, in which a pandemic may cripple credit markets and even cause a credit collapse by freezing the labor supply. We execute the idea in a general equilibrium framework with banks and financially constrained heterogeneous firms. In the static model, a modest pandemic disrupts the credit markets only at the intensive margin by decreasing the labor supply. A worsening pandemic can trigger a credit crisis, followed by a discontinuous sharp fall in aggregate output. By extending to a dynamic general equilibrium setting, we show that this mechanism can generate endogenous boom-bust credit cycles. Credit injection *per se* cannot adequately stabilize the economy. The lockdown policy combined with subsidizing firms turns out to be an efficient policy package to curb pandemic-induced recession.

Keywords: Endogenous Credit Cycles, Pandemic Induced Recession, Lockdown Policy, Credit Policy

JEL codes: E31 E32 E41 E51 E52

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1 Introduction

The COVID-19 pandemic is an unexpected and large-scale macroeconomic shock. Motivated by the response to the Great Recession and the lessons from the Great Depression, monetary and fiscal authorities around the world have quickly adopted unprecedented policies to alleviate the economic trauma caused by the virus. Economics researchers have also offered many timely policy recommendations. See Eichenbaum et al. (2020), Brunnermeier et al. (2020), Gourinchas (2020), Guerrieri et al. (2020), etc., for theoretical and quantitative analysis and Fang et al. (2020) among many others for empirical discussion.

The fast-growing literature has mainly addressed the implications of lockdown, vaccine and fiscal policy amid the COVID-19 crisis. There has been a relative lack of discussion on how credit policy should respond to the pandemic. To this end, we present a dynamic tractable framework that links endogenous credit cycles with labor market conditions. We show that the pandemic may cripple credit markets and even cause a credit collapse by freezing the labor supply. We implement the idea in a general equilibrium framework with banks and financially constrained heterogeneous firms. We aim to answer the following questions. How does a dysfunctional labor market affect credit markets? How does credit expansion affect the macroeconomy during the COVID-19 crisis? What kind of macroeconomic policy is more effective?

We provide a novel perspective on the aggregate consequences of the pandemic. Our model is built on the endogenous credit-cycle theory in Dong and Xu (2020).[1] In the model economy, firms are heterogeneous in terms of their productivities. A typical firm can obtain external finance from a bank in the credit market. A bank as a lender cannot observe a borrower's quality due to the information asymmetry. There exists a moral hazard problem between borrowers and lenders. The firm as a borrower has an incentive to divert its bank loans and invest in a storage technology. As a result, the bank imposes an incentive compatibility (IC) constraint on the firm that determines an endogenous leverage ratio. Amid the pandemic, the spread of the virus dampens the labor supply and deteriorates the average quality of projects. The lowered quality of projects exacerbates the moral hazard problem between borrowers and banks, thereby worsening the external financing condition and reducing the aggregate output. We further show that when the infection rate is sufficiently high, banks have little incentive to provide liquidity to borrowers due to the severe moral hazard problem. Consequently, the credit market freezes, and the economy collapses to a panic equilibrium, where the dysfunctional credit market triggers a financial crisis followed by a sharp and discontinuous drop in the aggregate output.

We extend the model to a dynamic general equilibrium setting and introduce susceptible-

[1] The model in Dong and Xu (2020) is a heterogeneous-firm version of credit crisis theory developed by Boissay et al. (2016).

infectious-recovered (SIR) dynamics of the epidemic. We show that the outbreak of a pandemic can generate an endogenous boom-bust credit cycle. A credit expansion policy may lead to a backfire effect on the financial market. This is because in the early stage of a pandemic when the infection rate is modest, a large scale of credit expansion causes more low-quality projects to be financed. The lowered average quality of projects in the economy largely exacerbates the moral hazard problem between borrowers and lenders. The credit market becomes more vulnerable and eventually collapses when the infection rate surges. We also show that the quantitative easing policy that directly injects liquidity to the firms fails to curb the recession when the financial system is dysfunctioning. Therefore, credit expansion policy *per se* cannot adequately stabilize the economy in response to the outbreak of the pandemic.

We also evaluate alternative policy packages in the dynamic model. We find that a lockdown policy combined with a subsidization policy for firms can sufficiently curb the pandemic-induced recession. A short-period lockdown policy that effectively flattens the SIR curve can mitigate the disruptive effect on the labor market induced by the spread of the virus. Moreover, the subsidization policy extenuates the adverse impact of the pandemic on the quality of projects and thus alleviates the moral hazard problem between the lenders and the borrowers. Consequently, the improved external financing conditions faced by firms prevents the credit market from collapsing amid the pandemic.

Related Literature There has been a large and fast-growing volume of literature on the pandemic and its economic consequences using the SIR model since the outbreak of COVID-19. The tractable SIR model was originally proposed by Kermack and McKendrick (1927) and serves as an important workhorse in the epidemiological literature. We do not intend to offer a comprehensive review of the SIR model or COVID-19 here. Instead, we focus on the macroeconomic analysis of the COVID-19 crisis. To begin with, most papers are on the generalized SIR model with a policy of either lockdown or vaccination, including Gourinchas (2020), Alvarez et al. (2020), Atkeson (2020), Acemoglu et al. (2020), etc., Berger et al. (2020), Eichenbaum et al. (2020), and Garriga et al. (2020). Closer to our study, Eichenbaum et al. (2020) present the *aggregate* implications of COVID-19 by conducting optimal policy analysis within the SIR framework. Faria-e Castro (2021) then studies the fiscal policy as a response to the COVID-19 outbreak in a nonlinear DSGE model. Furthermore, Kaplan et al. (2020), Glover et al. (2020) and Bonadio et al. (2020) show the *distributional* effects of pandemic within and across countries. Moreover, Guerrieri et al. (2020) examines the aggregate and sectoral effect of the pandemic as a labor supply shock in a two-sector incomplete market model. However, to the best of our knowledge, there is a relative lack of research on the connection between financial markets and pandemics, with the exception of Bigio et al. (2020). Bigio et al. (2020) focuses on the comparison between the policy of lump-sum transfers and that of a credit policy in a continuous-time framework. Our major difference from Bigio et al. (2020) is that we take a different approach to modeling the dynamic general equilibrium effect of credit policy. It allows us to clearly evaluate the unintended consequences of credit cycles due to the combination of financial friction and miscellaneous policy recommendations.

In section 2 and 3, we model and characterize a static model to illustrate the key mechanism. We then use section 4 to present our quantitative findings following several policy responses. Section 5 concludes.

2 A Static Model

We start with a stylized static model to formalize the basic idea. We follow Boissay et al. (2016) to model the credit market and real economy. The model economy is populated by a unit measure of firms/investors. Each firm is endowed with K units of capital. The firm can invest their own capital in the production sector or deposit in a bank. The bank will channel the deposit to other firms that want to borrow in the credit market. When the epidemic breaks out, the population has three types of agents (workers): susceptible (S), infected (I) and recovered (R). In the static model, we simplify the analysis by assuming that the population of three types of agents are constant, denoted by $J = \{S, I, R\}$. In the dynamic setup, we will introduce the canonical SIR structure to characterize the epidemic dynamics.

2.1 Labor Supply

We assume that there is a representative household whose members are workers with unit measure. Each worker inelastically provides one unit of time. The household decides that $a \in [0, 1]$ fraction of family members will continue working at the workplace and the remaining $1 - a$ fraction will remain at home. For simplicity, we assume that the productivity of working at home is zero. Therefore, the effective labor that can work is a. Note that since the total hours are normalized to be one, the variable a reflects the labor efficiency. Throughout the paper, a refers to labor productivity.

The household's total income comes from each worker, which is Wa where W is the wage rate for the effective labor. We assume working outside the home increases the risk of being infected. We assume the total number of family members that are infected, i, is increasing in the fraction of the population working outside the home, a. Given the population structure of SIR in the whole economy, we assume that the newly infected number of the individual household satisfies

$$i = baSAI, \tag{1}$$

where $b \in (0,1)$ indicates the probability of being infected as a result of working outside; A is the aggregate effective labor; S and I are respectively, the existing population of susceptible and infected agents in the economy.[2] Eq. (1) reflects the newly infected agents as an outcome of the interaction between the susceptible aS and the infected AI occurred in the workplace.

We specify the household's utility function as $u(c,i) = \log c - vi$, where the term vi $(v > 0)$ captures the disutility caused by the infection. The household treats each family member identically and aims to choose the consumption, c, and the number of family members working outside the home, a, to maximize the utility $u(c,i)$ subject to the budget constraint $c \leq Wa$.

To guarantee an interior solution for $a \in [0,1]$, we assume that the infection population is above a threshold such that $I > \frac{1}{vbS}$. The optimal condition for the number of family members that work outside is given by

$$\frac{1}{a} = vbSAI. \tag{2}$$

Then the equilibrium condition $a = A$ yields

$$A = \left(\frac{1}{vbSI}\right)^{\frac{1}{2}}. \tag{3}$$

The last condition indicates that aggregate labor productivity A decreases with the infection population I. The condition $I > \frac{1}{vbS}$ implies that the outbreak of the pandemic reduces the number of effective workers and thus the aggregate labor productivity ($A < 1$).

2.2 Production Sector

There is one unit measure of heterogeneous firms. Each firm is endowed with K units of capital and can meet one project. A typical project uses capital k and efficient labor n to produce goods. We assume that the production function follows a Cobb-Douglas form $y = (zk)^{\alpha} n^{1-\alpha}$, where $\alpha \in (0,1)$, and z is idiosyncratic efficiency with CDF $\mathbf{F}(z)$ on the support $[z_{\min}, z_{\max}]$ with mean μ and standard deviation σ. Note that k is not necessarily equal to the endowed capital, K, because of the presence of the credit markets.

We assume the firms can fully observe their own efficiency z and need to pay wages at market rate W to the hired workers. The optimal labor decision is the solution of the static problem $\Pi(z) = \max_{n \geq 0} \left\{(zk)^{\alpha} n^{1-\alpha} - Wn\right\}$. The first-order condition implies that the labor demand satisfies

$$n(z) = \left(\frac{1-\alpha}{W}\right)^{\frac{1}{\alpha}} zk. \tag{4}$$

[2] Here, the number of newly infected individuals for each household/family is an outcome of working outside the home. Accordingly, i is an endogenous choice variable for households. Also note that in the equilibrium, we have $a = A$. However, when the individual households make their decisions, they take A as given.

Due to the constant return-to-scale technology, capital income $\Pi(z)$ can be expressed as $\Pi(z) = \pi z k$, where the average marginal rate of return π satisfies

$$\pi = \alpha \left(\frac{1-\alpha}{W} \right)^{\frac{1-\alpha}{\alpha}}. \tag{5}$$

Thus, the investor's marginal return of capital by investing in the firm with z is given by πz.

We also assume the firm has an option to a linear storage technology in which it does not produce final goods but obtains a return ψk, where $\psi > 0$. One example of storage technology is holding gold or safe assets, which are not productive.

2.3 Investors and Credit Market

There is a credit market in which individual investors/firms can supply or obtain credit. The bank in our model is passive, in the sense that it simply channels the deposit to the loans in the competitive market. Thus, the deposit rate is equal to the loan rate. We denote r^f as the competitive interest rate prevalent in the credit market. Given K units of endowed capital, an individual firm with idiosyncratic productivity z can choose to (i) deposit in the bank to obtain interest rate r^f or (ii) borrow from the credit market with r^f and invest in the production sector with the rate of return πz.

Let m denote the ratio of loans to the firm's endowed capital. Then, mK is the quantity of loans the firm borrows from the credit market. If the firm decides to invest in the real sector, the overall capital available is $(1+m)K$. The net rate of return is $\pi z(1+m) - r^f m$. Instead, if the firm chooses to deposit capital in the bank (equivalent to lending all the capital to other firms), the rate of return is simply r^f.

Following Boissay et al. (2016), we assume that the borrowers may divert $\theta \in (0,1)$ proportion of the loans, combining all of their resources (endowed capital plus loans) together and resorting to a linear storage technology with marginal return ψ. Thus, the total amount of capital that the borrower can divert is $K + \theta m K$. Due to the linearity of the storage technology, the marginal rate of return per unit of the borrower's own capital after switching to storage technology is $\psi(1+\theta m)$.

The rate of return of the firm with z under the aforementioned options can be summarized as

$$r(z) = \max\left\{ r^f, \quad \pi z(1+m) - r^f m, \quad \psi(1+\theta m) \right\}. \tag{6}$$

Due to the moral hazard problem, the bank (representing the lenders) wants to deter the borrowers from diverting the loans. To do so, it can limit the quantity of loans that the marginal borrowers (those indifferent to the first and the second options) can borrow such that they have no interest in diverting:

$$\psi(1+\theta m) \leq r^f. \tag{7}$$

It can be shown that the above incentive compatibility (IC) condition holds with equality at the optimum. Thus, the market funding ratio in the credit market can be expressed as

$$m = \frac{r^f - \psi}{\theta\psi}. \tag{8}$$

The market funding ratio m increases with the market interest rate r^f and decreases with the rate of return on the storage technology ψ and the severity of the moral hazard problem, θ. As discussed in Boissay et al. (2016), the positive relationship between m and r^f reflects the positive selection effect of the loan rate on borrowers. That is, when r^f rises, only those investors with efficient projects (z is high) intend to borrow, which in turn mitigates the moral hazard problem and therefore induces a higher market funding ratio m.

Given that the IC condition (7) is satisfied, we now discuss the firm's optimal strategies on borrowing and lending. It is straightforward to show that a firm tends to borrow from the credit market if and only if the productivity z is above a threshold z^* that satisfies

$$z^* \equiv \frac{r^f}{\pi}, \tag{9}$$

where the average marginal return to capital, π, is given by (5). If $z < z^*$, investing is less profitable than lending to the credit market. As a result, the firm would strictly prefer the latter option. Otherwise, for the case of $z > z^*$, the firm would choose to invest in the real sector.

3 Characterizing Equilibrium

Before the discussion of credit market equilibrium, we first specify aggregate labor N and aggregate output, Y. Let $\chi(k)$ denote the distribution of the capital stock k in the economy such that the aggregate capital is given by $K = \int d\chi(k)$. From the individual labor demand (4), the aggregate labor N is given by

$$N = \int \int_{z \geq z^*} n(z)\, \mathrm{d}\mathbf{F}(z)\, \mathrm{d}\chi(k) = \left(\frac{1-\alpha}{W}\right)^{\frac{1}{\alpha}} \tilde{K}. \tag{10}$$

where $\tilde{K} \equiv K(1+m)\left[1-\mathbf{F}(z^*)\right] \mathbf{E}(z|z \geq z^*)$ is the effective capital used in the production sector, which depends on the quantity $K(1+m)\left[1-\mathbf{F}(z^*)\right]$ and the average quality $\mathbf{E}(z|z \geq z^*)$. For the aggregate output, we have $Y = \int_{z \geq z^*} y(z)\, \mathrm{d}\mathbf{F}(z) = \frac{1}{1-\alpha} WN$, where the second equality is due to the optimal condition of labor demand. Combining the last two equations leads to the aggregate production function as $Y = \tilde{K}^{\alpha} N^{1-\alpha}$. The epidemic will affect aggregate production through the effective capital $\tilde{K}$ and the effective labor N.

The optimal labor supply decision (3) implies in the equilibrium

$$N = A = \left(\frac{1}{vbSI}\right)^{\frac{1}{2}}. \tag{11}$$

Therefore, the marginal rate of return to capital is obtained by substituting (10) into (5)

$$\pi = \alpha \tilde{K}^{\alpha-1} A^{1-\alpha}, \tag{12}$$

where labor productivity A strictly decreases with the number of infections I.

To guarantee the transparency of the analysis, we assume for the rest of the paper that idiosyncratic productivity component z conforms to a Pareto distribution with CDF $\mathbf{F}(z) = 1 - (z/z_{\min})^{-\eta}$ and $\eta > 1$. We normalize the mean of z to be 1, therefore $z_{\min} = 1 - 1/\eta$.

3.1 Non-Panic Equilibrium

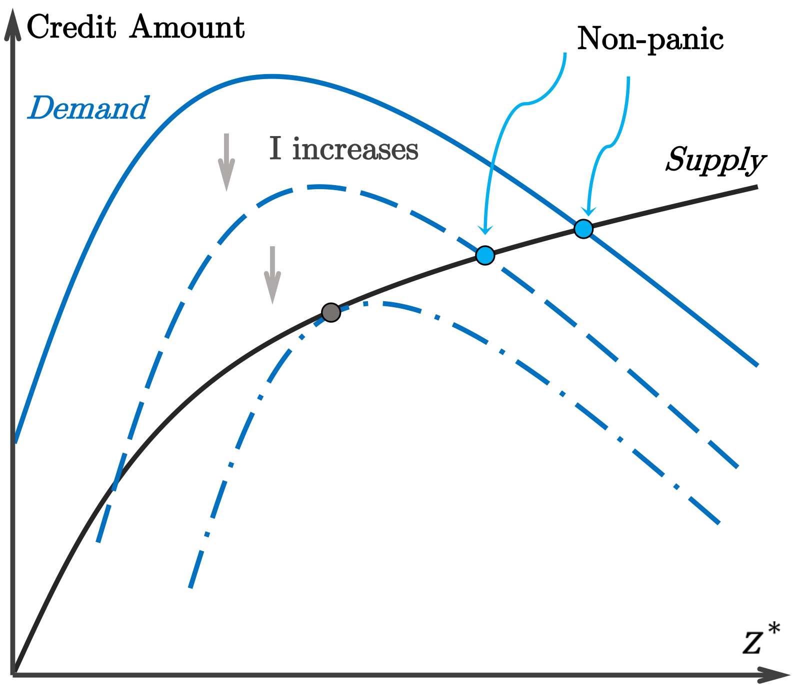
We start with the case in which the credit market is functioning. In this case, we must have $r^f > \psi$, and all capital, K, will be allocated to the production sector. The credit market clearing condition implies the demand for credit, $[1 - \mathbf{F}(z^*)] mK$, equals the supply of credit, $\mathbf{F}(z^*) K$. This equilibrium condition can be further expressed as

$$[1 - \mathbf{F}(z^*)] m = \mathbf{F}(z^*), \tag{13}$$

where the leverage m is given by (8). The RHS of the above equation indicates that the supply of loans only depends on the extensive margin $\mathbf{F}(z^*)$, which monotonically increases with the cutoff value z^*, whereas the LHS of the equation shows that the aggregate demand for loans consists of the extensive margin $1 - \mathbf{F}(z^*)$ and the intensive margin m. The extensive margin declines with the cutoff z^*. The intensive margin m is increasing in z^*. To see this, under the market clearing condition, the aggregate effective capital can be expressed as $\tilde{K} \equiv K(1+m)[1 - \mathbf{F}(z^*)] \mathbf{E}(z|z \geq z^*) = K\mathbf{E}(z|z \geq z^*)$, which is the product of the quantity of capital available to the firms and the average production efficiency. The second equality is due to the fact that $(1+m)[1 - \mathbf{F}(z^*)] = 1$ implied by the definition of $\tilde{K}$ and the market clearing condition (13). From (9) and (12), the equilibrium interest rate satisfies

$$r^f = \pi z^* = \alpha z^* \mathbf{E}^{\alpha-1}(z|z \geq z^*) A^{1-\alpha} K^{\alpha-1}. \tag{14}$$

Figure 1: Demand and Supply in the Credit Market



Notes: The blue lines indicate the credit demand under different values of infected population I: $[1 - \mathbf{F}(z^*)]m$, and the black line indicates the credit supply: $\mathbf{F}(z^*)$.

Note that with the Pareto distribution, we have $\mathbf{E}(z|z \geq z^*) = \frac{\eta}{\eta-1}z^*$. Thus, the equilibrium interest rate r^f strictly increases with z^*. The positive relationship between r^f and z^* reflects the positive selection of the market rate on the production efficiency. From the incentive compatibility constraint (8), m increases with r^f, implying that the leverage increases with z^* as well. Therefore, the relationship between the aggregate demand for credit $[1 - \mathbf{F}(z^*)]\, m$ and the cutoff value z^* could be nonmonotonic. A rise in the cutoff z^* would raise the borrowing capacity of banks—intensive margin; moreover, it reduces the number of firms that choose to borrow and produce—extensive margin.

To provide an intuitive illustration of the credit market equilibrium, Figure 1 plots the demand and supply schemes of credit against the cutoff value z^*. The demand curve (the blue lines) presents an inverted-U shape. The intersection point of the demand and supply curves corresponds to the equilibrium cutoff z^*. Note that the equilibrium condition (13) indicates that the severity of pandemic I only affects credit demand by impacting labor productivity A. To see this, the condition (14) implies that a decrease in labor productivity A caused by a larger infection ratio I reduces the interest rate r^f, resulting in a lower leverage ratio m. Therefore, a more severe pandemic (i.e., I becomes larger) may shift the demand curve downward. As the supply side $\mathbf{F}(z^*)$ does not depend on I, the population of infected workers essentially determines the properties of the equilibria. As shown in Figure 1, when the pandemic is not severe

(I is small), the demand and the supply intersect and credit market equilibrium exists, whereas if the infected rate becomes larger, the demand may not intersect with the supply, such that credit market equilibrium does not exist.[3] We will show later that in the latter scenario, there exists a unique panic equilibrium. The following proposition fully characterizes the relationship between the severity of pandemic and the existence of credit market equilibrium.

Proposition 1 *Under the assumption $\eta < \alpha/\theta$, there exists an endogenous threshold of the number of infected workers, I^*, such that*

i *if $I < I^*$, the credit market equilibrium exists;*

ii *if $I > I^*$, the credit market equilibrium cannot be supported.*

Proof. See Appendix A.1.

Part (ii) of Proposition 1 shows that once the pandemic becomes sufficiently severe, the credit market equilibrium cannot be supported. In other words, I^* reflects the lower bound of the infected population under which the credit market can be sustained. This finding implies that a pandemic outbreak may deteriorate the average quality of the projects in the whole economy, trigger a credit market crisis due to the discontinuity between different equilibria. We label the regime for the existence of the credit market (non-panic) equilibrium (i.e., $I < I^*$) as Regime 1 and the regime for credit market collapse (panic) equilibrium (i.e., $I > I^*$) as Regime 2. A small I^* indicates that the credit market is vulnerable to crises.

In the non-panic equilibrium, since all the capital is allocated to the production sector, the aggregate output Y is

$$Y = \left[\mathbf{E}\left(z|z \geq z^*\right) K\right]^{\alpha} A^{1-\alpha}. \tag{15}$$

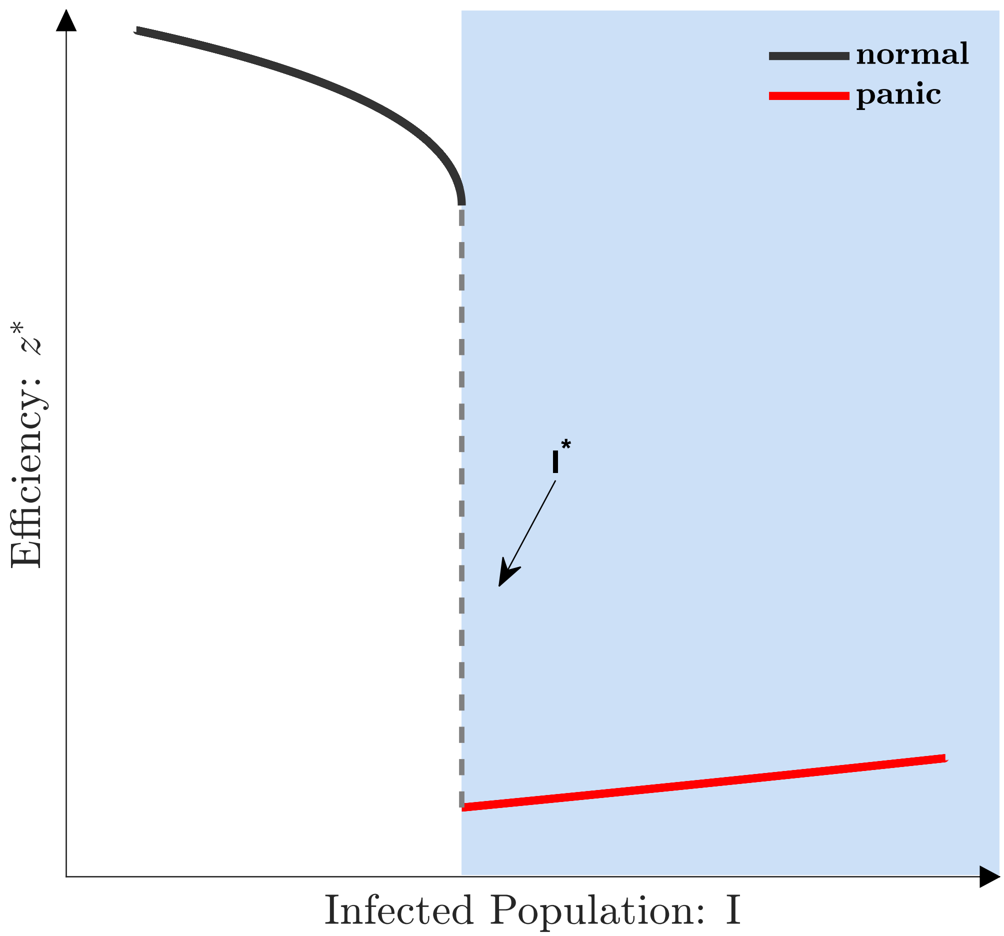
Appendix A.2 shows that the severity of pandemic I has an unambiguously adverse impact on output through two effects. On the one hand, it directly reduces labor productivity across all firms, A. On the other hand, it induces more low-efficiency projects prevailing in the real sector and thus reduces the average quality, i.e., $\mathbf{E}\left(z|z \geq z^*\right)$ declines.[4] As a result, given the capital stock K, the output level negatively responds to the change in the population of infected agents. The following proposition gives a full characterization.

Proposition 2 *Under Regime 1, where the credit market equilibrium is supported (i.e., $I < I^*$), the aggregate output strictly decreases with the population of infected agents.*

[3] Note that in the case of non-panic equilibrium, there exist two equilibria, i.e., the demand curve intersects the supply curve twice. One corresponds to a high value of productivity cutoff z^*, the other one corresponds to a low value of z^*. Since the low value equilibrium is essentially not tatonnement stable (Boissay et al., 2016) and is Pareto dominated by the high value equilibrium, our analysis only focuses on the high value equilibrium.

[4] See the black line in Figure 2 for a graphic illustration or Appendix A.2 for a formal proof.

Figure 2: Efficiency in Different Equilibria



Notes: This figure illustrates the equilibrium relationship between the efficiency and the infected population. The area for $I < I^*$ is the regime where credit market equilibrium exists. The area for $I > I^*$ is the regime where the economy has a unique panic equilibrium.

Proof. See Appendix A.2.

Proposition 2 indicates that in the credit market (non-panic) equilibrium, the pandemic impedes the aggregate economy through the credit channel. If the pandemic becomes sufficiently severe, the credit market will freeze, inducing a financial crisis. The former negative impact of the pandemic is due to the within-sector misallocation, and the latter is mainly due to the shutdown of the whole market. We will discuss this scenario shortly.

3.2 Panic Equilibrium

We now consider Regime 2, where the credit market equilibrium cannot be supported, i.e., $I > I^*$. We label this scenario as panic equilibrium. Because of the collapse of the credit market, investors cannot finance from outside; thus, $m = 0$. The investors' investment options are reduced to two: investing either in the production sector or in storage technology. The marginal rates of return for these two options are πz and ψ, respectively. The bank's investment decision rule follows the trigger strategy: invest in the real economy if $z > z^*$ and invest in storage technology otherwise. The cutoff z^* equates two marginal rates of return, i.e.,

$$\pi z^* = \psi. \tag{16}$$

Thus, the aggregate capital allocated to the production sector is given by $K\left[1 - \mathbf{F}\left(z^*\right)\right]$. Compared to the credit market equilibrium where all the capital is allocated to the production sector, in the panic equilibrium, cross-sector misallocation emerges. To determine the equilibrium cutoff z^*, from (16) and the definition of π, we have $\alpha A^{1-\alpha}\tilde{K}^{\alpha-1}z^* = \psi$, where the effective capital satisfies $\tilde{K} = K\left[1 - \mathbf{F}\left(z^*\right)\right]\mathbf{E}\left(z|z \geq z^*\right)$. In the Appendix, we show that there exists a unique panic equilibrium when the pandemic is sufficiently serious, i.e., $I > I^*$. We can further prove that the cutoff z^* in the panic equilibrium strictly increases with I, as shown in Figure 2. This is because a larger I implies a lower labor productivity A. As a result, only those investors with a higher value of idiosyncratic shock z choose to invest in the real sector.

Regarding the aggregate output, the impact of I on the aggregate output now consists of three effects. First, a higher I reduces the number of investors that invest in the real sector, i.e., $1 - \mathbf{F}(z^*)$ declines, so it exacerbates the adverse impact on the extensive margin. Second, a higher I decreases the within-sector misallocation because of a larger cutoff z^*. Finally, a higher I directly reduces the productivity A. Appendix A.3 shows that the negative effect dominates the positive effect. Therefore, in the panic equilibrium, the aggregate output strictly decreases with the infection rate I.

Discontinuity Thus far, we have analyzed the impact of the pandemic on aggregate output for different equilibria. To give a complete and rigorous characterization of the relationship between the output level and the infected population I, we need to discuss the discontinuity of the aggregate output around the threshold I^*.

Proposition 3 *The equilibrium cutoff z^* and the aggregate output are discontinuous for Regime 1 and Regime 2 at $I = I^*$, i.e.,*

$$\begin{aligned} z^*_{\textbf{\textit{Normal}}}\left(I = I^*\right) &> z^*_{\textbf{\textit{Panic}}}\left(I = I^*\right), \\ Y_{\textbf{\textit{Normal}}}\left(I = I^*\right) &> Y_{\textbf{\textit{Panic}}}\left(I = I^*\right). \end{aligned}$$

Proof. See Appendix A.4.

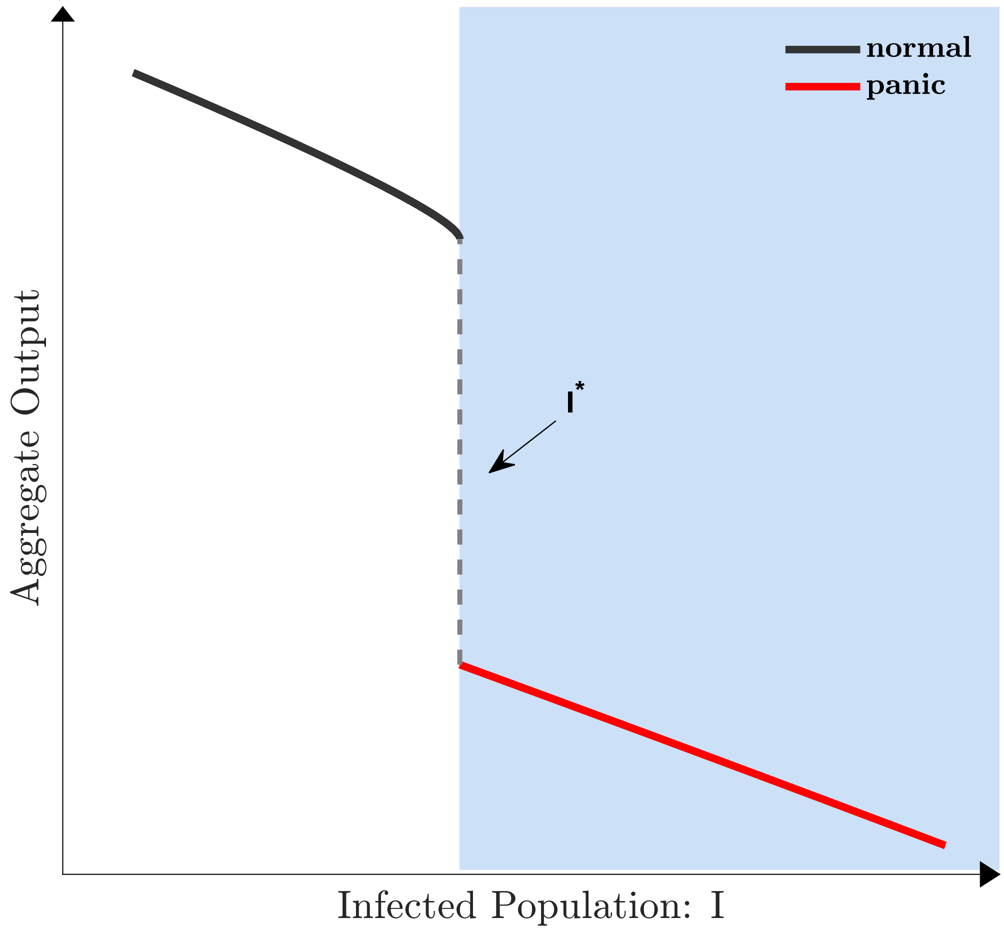
The proposition indicates that the spread of virus that causes I to exceed the threshold I^* will induce a discontinuous drop in allocation efficiency z^* and in aggregate output. Now, we can fully characterize the relationship between aggregate output and the pandemic. Figure 3 presents a graphic description.

The threshold I^* divides the space into two areas. The area less than I^* corresponds to the normal credit market equilibrium. The area larger than I^* corresponds to the unique panic equilibrium. According to the previous discussion, the output levels in both regimes are monotonically decreasing with the size of the infected population. In addition, Proposition 3 suggests the output level presents a discontinuous drop at $I = I^*$ between two equilibrium regimes.

Figure 2 presents a graphic description for the relationship between the allocation efficiency (or cutoff z^*) and I^*. It shows that in the normal regime, a pandemic outbreak (I increases) deteriorates efficiency. While in the panic regime where the credit market collapses, the average quality of the projects increases with I^* because of the selection effect, i.e., only those investors with sufficiently large productivity choose to invest. Moreover, Proposition 3 implies that when I exceeds the threshold I^*, efficiency experiences a sharp decline.

From Normal to Panic Proposition 3 also conveys an important message that when the economy switches from a non-panic regime to a panic regime, the output level experiences a sharp reduction. In this sense, our model provides a credit channel through which a pandemic may lead to excessive aggregate volatility. For instance, given the threshold I^*, if the spread of the virus causes the I that is originally less than but close to I^* exceeding I^*, the aggregate output will experience a large drop instead of a continuous decline due to the regime switch between the normal and the panic equilibrium.

Figure 3: Aggregate Output in Different Equilibria



Notes: This figure uses the Pareto distribution to illustrate the equilibrium relationship between the aggregate output and the infected population. The area for $I < I^*$ is the regime where credit market equilibrium exists. The area for $I > I^*$ is the regime where the economy has a unique panic equilibrium.

4 A Model with Pandemic Dynamics

We now extend our baseline static model to a dynamic circumstance by introducing an SIR pandemic dynamics. Under the dynamic environment, we will show that pandemic dynamics may cause financial crises and endogenous business cycles. We first follow Eichenbaum et al. (2020) to introduce an SIR dynamic structure.

4.1 Pandemic Dynamics

Each period, the susceptible agents can become exposed agents and resistant agents. The total number of susceptible agents S_t evolves as

$$\Delta S_t = -\beta_a A_{t-1} I_{t-1} A_{t-1} S_{t-1} - \beta I_{t-1} S_{t-1}, \tag{17}$$

where I_t is the population of infected agents, A_t is the number of workers working at the workplace. In the household's optimization problem, we will explicitly derive the condition for A_t from the optimal labor supply. The first term in the LHS of (17) indicates the newly infected population as a result of interaction that occurred in the workplace; the second term indicates the newly infected cases due to general activities (Eichenbaum et al., 2020).

The infected agents can be recovered with probability γ. Given the infection population I_{t-1}, the total number of newly infected agents evolves as

$$\Delta I_t = -\gamma I_{t-1} + \beta_a A_{t-1} I_{t-1} A_{t-1} S_{t-1} + \beta I_{t-1} S_{t-1}. \tag{18}$$

Resistant agents consist of those recovered from infected agents and those from susceptible agents. The total number of resistant agents has the dynamics

$$R_t = 1 - I_t - S_t. \tag{19}$$

4.2 Economic Activities

4.2.1 Households

We consider a representative household, which consists of one unit measure of hand-to-mouth workers. Similar to the static model, the household chooses the consumption c_t, the number of family members at the workplace a_t, and the number of family members infected i_t to maximize lifetime utility $\sum_{t=0} \rho^t (\log c_t - v i_t)$, where $\rho \in (0, 1)$ is the discount rate. The constraints faced by the household are the budget constraint $c_t \leq W_t a_t$ and the dynamics of the number of newly infected family members

$$\Delta i_t = -\gamma i_{t-1} + \beta_a a_{t-1} S_{t-1} A_{t-1} I_{t-1} + \beta I_{t-1} S_{t-1}. \tag{20}$$

Let μ_t denote the Lagrangian multiplier for (20). The optimal conditions for a_t and i_t are

$$\frac{1}{a_t} = -\beta_a \rho \mu_{t+1} S_t A_t I_t, \tag{21}$$

$$v + \mu_t = \rho (1-\gamma) \mu_{t+1}. \tag{22}$$

The last equation implies that μ_t is a constant that satisfies $\mu_t = \mu_{t+1} = -\frac{v}{1-\rho(1-\gamma)}$. In the equilibrium, we have $a_t = A_t$, then

$$A_t = a_t = \min\left\{ (\Phi S_t I_t)^{-\frac{1}{2}}, 1 \right\}, \tag{23}$$

where $\Phi = \frac{\beta_a v \rho}{1-\rho(1-\gamma)}$.

4.2.2 Investors

The investors and production sector in the dynamic model are essentially the same as those in the static model. To introduce the dynamics, we assume that the investors accumulate capital. The workers again inelastically provide labor. To simplify the analysis, we assume that the workers do not have access to the capital market and are hand-to-mouth. They consume all their labor income each period. The idiosyncratic productivity z_t is assumed to follow a Pareto distribution and i.i.d. across individuals and over time.

The investor that meets a firm in the real sector with idiosyncratic productivity z_t chooses consumption $\tilde{c}_t$ and capital stock in the next period k_{t+1} to maximize the life utility $\sum_{t=0}^{\infty} \rho^t \log \tilde{c}_t$, where $\rho \in (0,1)$ is the discount rate. The investor's budget constraint is

$$\tilde{c}_t + k_{t+1} - (1-\delta) k_t = r_t (z_t; I_t) k_t,$$

where $r_t (z_t; I_t)$ is the rate of return to the capital that is defined as that in (6), which satisfies

$$r_t (z_t; I_t) = \max \left\{ r_t^f, \quad \pi_t z_t (1 + m_t) - r_t^f m_t, \quad \psi (1 + \theta m_t) \right\}, \tag{24}$$

where r_t^f is the lending rate in the credit market, π_t is the sectoral marginal product of capital satisfies (5), and decreasing in sectoral labor productivity A_t, m_t is the leverage ratio defined from IC condition (8), ψ is the return of storage technology, θ reflects the extent of the moral hazard problem between the lender and the bank. Since sectoral labor productivity A_t strictly decreases with I_t, the rate of return r_t depends on the infection population I_t.

Because of the log utility, the optimal capital decision satisfies

$$k_{t+1}(z_t, k_t; I_t) = \rho [r_t(z_t; I_t) + (1-\delta)] k_t. \tag{25}$$

The optimal decision $k_{t+1}(z_t, k_t; I_t)$ indicates that the pandemic has an impact on individual savings, which works through the general equilibrium channel by affecting the rate of return to capital, $r_t(z_t; I_t)$. When the population is severely infected by the virus, the credit market collapses and $r_t(z_t; I_t) = \max\{\pi_t z_t, \psi\}$. Consequently, even though the individual decision does not involve the *risk* of market collapse, the infection rate I_t still affects both supply and demand in credit markets, and thus the market rate r^f in the equilibrium.

Let $\chi_t(k)$ denote the distribution of the capital stock k in the economy. The aggregate capital satisfies $K_{t+1} = \int\int k_{t+1}(z_t, k_t; I_t) \, \mathrm{d}\mathbf{F}(z_t) \, \mathrm{d}\chi_t(k_t)$. Since z_t is i.i.d., the aggregate capital K_{t+1} can be expressed as

$$K_{t+1} = \rho \left[\int r_t(z_t; I_t) \, \mathrm{d}\mathbf{F}(z_t) + (1-\delta) \right] K_t = \rho \left[\alpha Y_t + (1-\delta) K_t \right]. \tag{26}$$

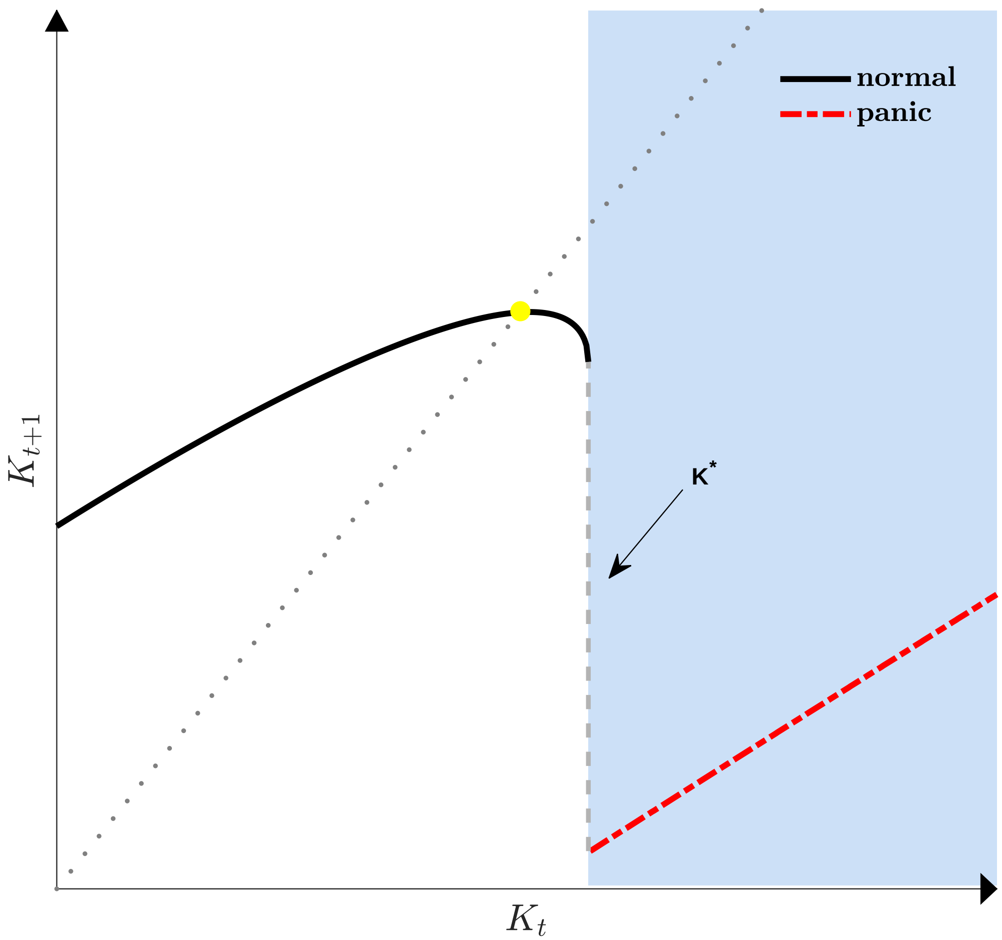
The second equality holds because aggregate capital wealth consists of the income from the real sector and the value after depreciation.

In the appendix, we present the full dynamic system of the model. The capital stock in next period K_{t+1} is shown to be a function of K_t under either **Normal** or **Panic** equilibria, which can be denoted as $g(K_t)$. According to Dong and Xu (2020), we can prove that the policy function $g^{\textbf{Normal}}(K_t)$ is strictly concave in K_t, and $g^{\textbf{Panic}}(K_t)$ strictly increases with K_t. Analogous to the analysis for the static model, in the appendix, we further show that there exists a threshold of aggregate capital K_t^* that depends on the infection rate I_t, such that (i) if $K_t < K_t^*$, there exists a normal equilibrium and (ii) if $K_t > K_t^*$, there exists a panic equilibrium. Figure 4 provides an illustrative example of the phase diagram of the capital stock K_t.

We now discuss the steady state of the dynamic system. From the capital accumulation equation, we have $\tilde{r}K = \alpha A^{1-\alpha} [\mathbf{E}(z|z \geq z^*) K_h]^\alpha$, where $\tilde{r} = 1/\beta - (1-\delta)$. The steady state capital K is determined by the equation $K = g(K)$. It turns out that the level of steady-state capital K depends on productivity A. In the steady state, there is no pandemic, i.e., $A = 1$ (see Eq. 23). Therefore, steady-state capital is irrelevant to infection population. According to Dong and Xu (2020), if the return on the storage technology ψ is sufficiently low, the steady state is unique and normal.[5] The intuition is that under a sufficiently low return on the storage technology, ψ, the moral hazard problem between the bank and the borrowers is less severe since the borrowers have less incentive to run away. Thereby, the credit market is functioning,

[5]In particular, the condition is $\psi < \frac{(\eta-\alpha)\tilde{r}z_{\min}}{\eta(1-\theta)}$.

Figure 4: Phase Diagram for Aggregate Capital



Notes: This figure illustrates the phase diagram of the aggregate capital stock K_t under fixed productivity. In Appendix B, we show that there exists a threshold of capital K^* such that the area for $K_t < K^*$ is the regime where the economy has the unique **Normal** equilibrium. The area for $K_t > K^*$ is the regime where the economy has the unique **panic** equilibrium. The intersection between the curve and the 45-degree line is the steady state.

and the normal equilibrium can be supported.[6]

4.3 Dynamics

In the dynamic model, productivity and thus the infected population I_t would affect the policy function $g(K_t)$. Therefore, the pandemic dynamics implied by the SIR structure can influence credit market dynamics by changing the labor productivity. In this section, we document the dynamic impact of the severity of the pandemic based on some numerical analysis.

We first parameterize the structural parameters in the baseline model. One period corresponds to one week. The total population is normalized to one. As the setup of the credit market in our model is in line with that in Dong and Xu (2020), we calibrate the credit market-related parameters according to their calibration values. In particular, we set the moral hazard parameter $\theta = 0.08$, the shape parameter in the Pareto distribution $\eta = 2.2166$. For other standard parameters, we simply follow the business cycle literature. We set the capital share in production function $\alpha = 0.35$, the depreciation rate $\delta = 0.1/52$, the discount rate $\rho = 0.999$. For the sectoral labor productivity A, we normalize it to be 1. For the return on the storage technology, ψ, we set it to be 0.0017 such that the initial steady state is the normal equilibrium. The value of ψ implies that the initial steady-state capital is below but close to the threshold of regime switch K^*.

For those parameters in SIR dynamics, we follow Eichenbaum et al. (2020) to set the recover rate $\gamma = 7/18$. We calibrate β and β_a such that the fraction of infection related to work ($\frac{\beta_a A^2}{\beta_a A^2+\beta}$) is 1/6 and the recovered number in the long run accounts for 60% of the total population (Eichenbaum et al., 2020). We eventually obtain $\beta = 0.514$ and $\beta_a = 0.103$. The number of infected workers I_0 (the pandemic shock) in the first period is assumed to be 0.001. Finally, we set the parameter in the disutility of infection, v, such that $\Phi = 50$. This parameter determines the magnitude of the response of labor supply after the outbreak of the pandemic.

Market Collapse amid Pandemic We now discuss the aggregate consequences induced by the pandemic. We numerically show how pandemic dynamics may affect the credit market stability and cause the economic slump. In our numerical exercise, the economy is initially in the steady state. A shock to the infected population hits the economy ($I_0 = 0.001$). We use this shock to mimic the outbreak of COVID-19. The infected population evolves over time according to the SIR dynamics presented in Eq. (17) to (19). The red line in the first panel of Figure 5 illustrates the pandemic dynamics. As the virus quickly spreads, the infected population I_t

[6]Note that the condition of ψ that guarantees the existence of normal equilibrium does not depend on sectoral productivity A; thus, the situation of pandemic along the dynamic path (i.e., I_t) would not change the property of the intersection point between the policy function $g(K)$ and the 45 degree line. In our baseline model, $g(K)$ is always cross the 45 degree line in the Regime 1.

surges, resulting in a sharp and rapid decline in the labor supply and the productivity. The pandemic-induced supply shock triggers a credit market collapse by pushing the initial normal equilibrium to the panic equilibrium. The economic intuition is as follows. The disastrous shock greatly deteriorates the efficiency (z^*) and the quality of the borrowers' projects and thereby exacerbates the moral hazard problem between the bank and the borrowers. When the lending rate r_t^f that clears the credit demand and supply becomes sufficiently low (less than the return on storage technology, ψ), the credit market freezes and the economy falls into the panic equilibrium. The dynamic path of the aggregate output shown in Figure 5 indicates that the deep recession lasts a long period until the infection rate largely drops. The Appendix offers more discussion through phase diagram analysis. It is worth noting that the output overshoots during the recovery periods because of the average efficiency of investment project ($z_t^*/z_{\min}$) is significantly improved.[7]

Effects of Flattening the Curve Flattening the infection curve can mitigate the adverse impacts caused by the outbreak of Covid-19. To evaluate the corresponding aggregate consequences, we consider two flattened curves with a lower β.[8] In the first case of flattened curve, we consider $\beta = 0.45$. The dynamics (blue lines) in Figure 5 shows that the pandemic still causes severe economic recession, though the magnitude of the slump decreases. In the second case, we consider an even more flattened infection curve with $\beta = 0.41$. The dynamics (green lines) show that the pandemic causes an even smaller drop in productivity. The flattened curve also shortens the duration of the credit market collapse and mitigates the adverse impact of the pandemic on the aggregate economy.[9]

Impact of Uncertainty The empirical evidence shows that economic uncertainty surges after a pandemic outbreak (Baker et al., 2020). To evaluate the adverse impact of the surge of economic uncertainty, we introduce a time-varying dispersion of idiosyncratic productivity shock z. In particular, we assume that the standard deviation of z, denoted by σ_t, temporarily increases amid the pandemic.[10] Figure 6 shows that high uncertainty makes the credit market more vulnerable to the outbreak of pandemic.[11] The intuition is as follows. A bank in the credit

[7] In the appendix, we show that the cutoff (z^*) positively depends on the marginal product of capital (MPK), which decreases with the capital stock. When the equilibrium switches from panic to normal during the recovery, z^* will present an overshooting pattern due to the high MPK.

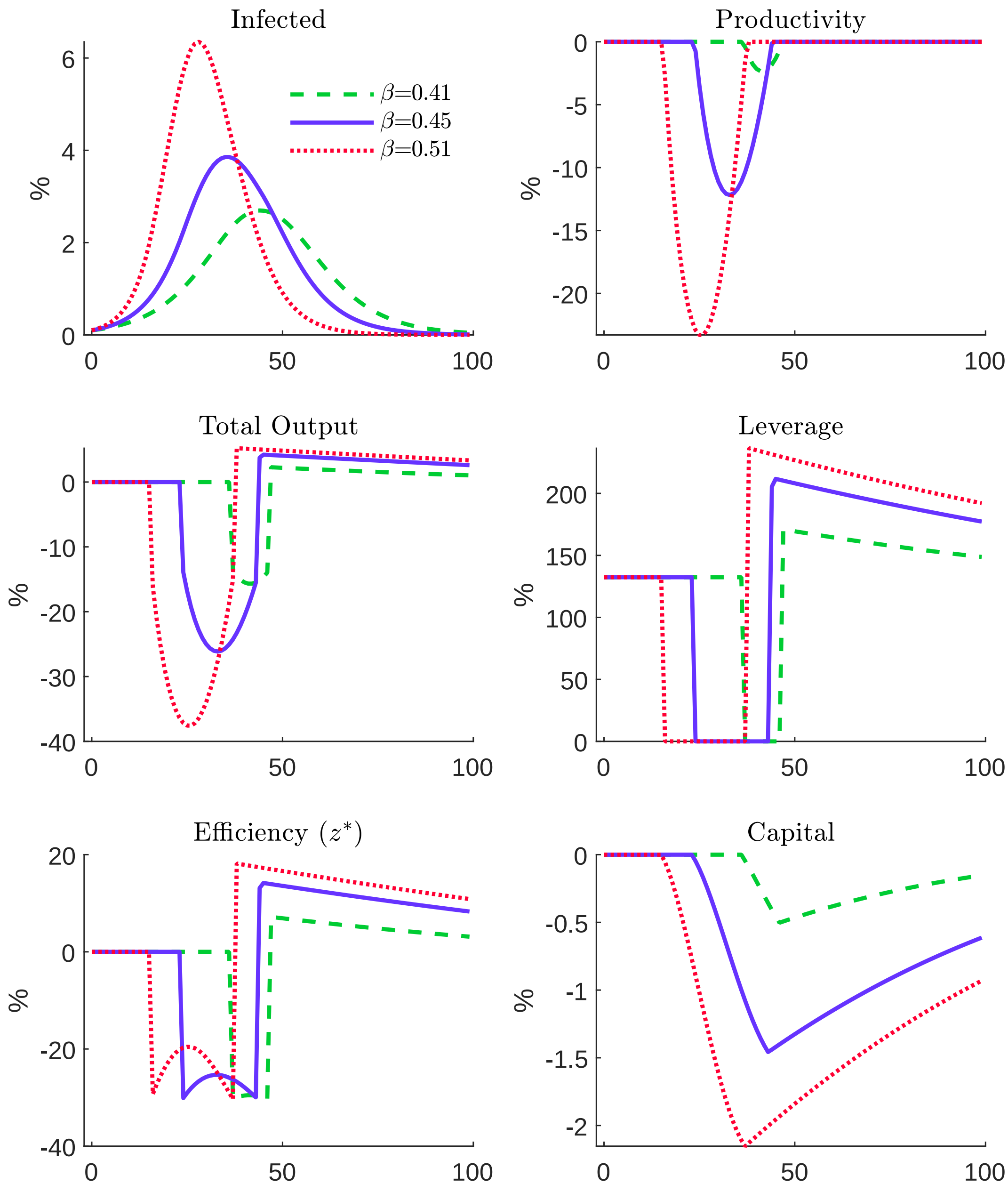
[8] Given β, we set the parameter value of β_a such that $\frac{\beta_a A^2}{\beta_a A^2 + \beta} = \frac{1}{6}$.

[9] In fact, if the infection curve is sufficiently flattened, i.e., the infected population I_t is extremely small, the household would optimally supply all the labor. In this case, the pandemic has no impact on the productivity and the real economy.

[10] For a Pareto distribution with mean 1, the standard deviation ($\sigma = 1/\eta/(\eta - 2)$) is strictly decreasing in the shape parameter η. An increase in σ is equivalent to a decrease in η.

[11] Dong and Xu (2020) theoretically prove that a higher uncertainty reduces the risk capacity of the credit market, below which the credit supply freezes.

Figure 5: Impact of the Pandemic under Different β



Notes: This figure reports the dynamics after the outbreak of the pandemic. The horizontal axes indicate the number of weeks. The vertical axes for economic variables indicate the percentage deviation from the initial state. The infection is measured by the percentage of the population. The leverage is the level in terms of percentage. Different colors correspond to the case with different values of β.

market cannot observe the true quality of the borrower's project. Therefore, the bank has to impose an incentive compatibility constraint to prevent the borrower from diverting loans to the storage technology. An increase in the variance of z raises the bottom tail risk (i.e., the fraction of low-quality projects). A higher bottom tail risk would further exacerbate the moral hazard problem faced by the bank and thus tightens the financing condition for borrowers. A deteriorated financing condition reduces the capacity at which the interbank market can absorb credit. As a result, the credit market is more vulnerable to collapse, taking the SIR dynamics as given. The figure shows that the economic recession due to market collapse has a longer duration than that in the baseline model with relatively low uncertainty. This result suggests that a surge in economic uncertainty amplifies the disastrous effects of the pandemic. Besides, the output in the case of high uncertainty presents oscillation dynamics because the economy periodically hits the normal and the panic equilibria amid the pandemic. Dong and Xu (2020) provides more discussion about the mechanism for endogenous credit cycles.

4.4 Evaluating Policies

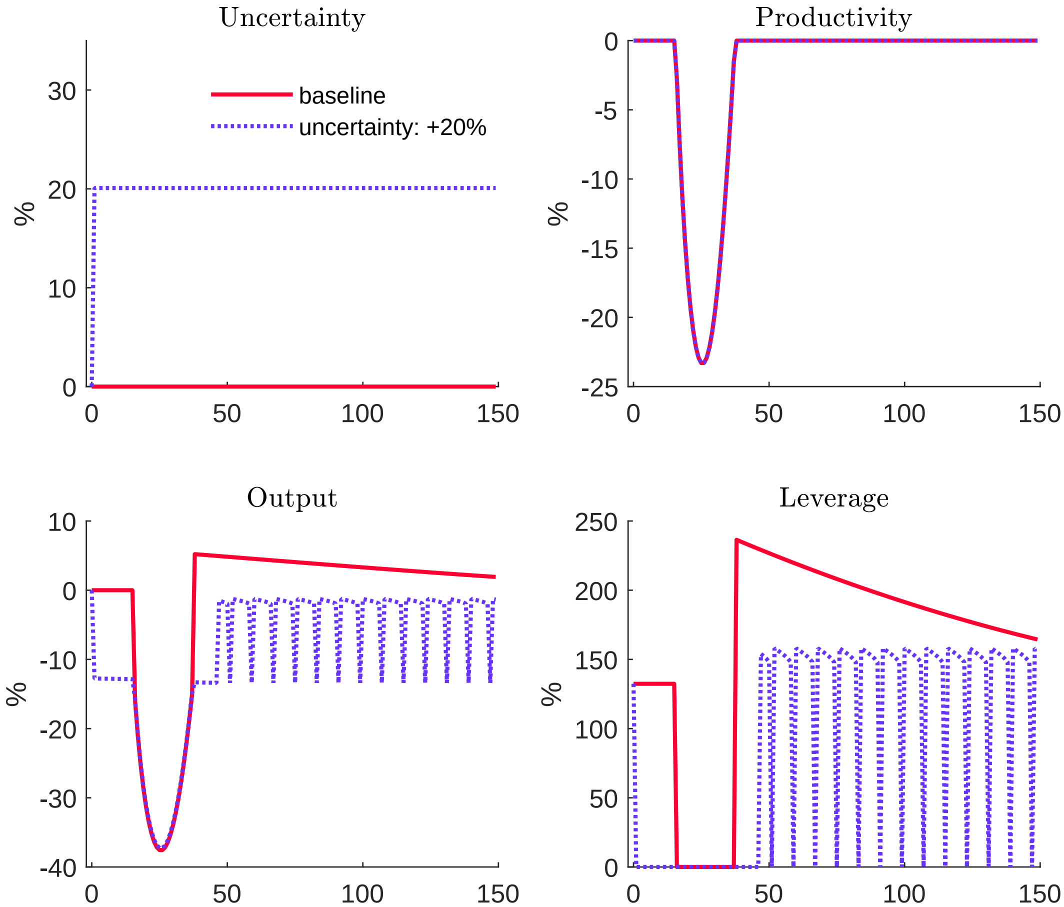
4.4.1 Credit Policies

When the COVID-19 outbreak occurred, the central banks around the world launched large-scale quantitative easing polices to curb the economic meltdown caused by the pandemic. To discuss the potential impacts of credit policies on the financial market and the real economy, we now introduce credit expansion policies.

Reserve Requirement We first consider a reserve requirement policy. We assume that the bank can only lend out $\xi_t \in (0, 1)$ fraction of its capital/deposit, the remaining $1 - \xi_t$ fraction of capital is used as reserved deposit. Appendix C provides more details about the model extension. In the quantitative exercise, we specify the parameter values and the SIR dynamics the same as those in the baseline model. For the reserve requirement policy, we assume that the government temporarily raises the rate ξ_t to combat the pandemic. In particular, $\xi_t = 1$ for $t \in [12, 35]$ and $\xi_t = 0.95$ otherwise. Figure 7 shows that the credit expansion during the pandemic exacerbates the vulnerability of the credit market. The credit expansion causes the economy to slide into the panic equilibrium in the earlier stage of the pandemic, while in the baseline case, the economy remains in normal equilibrium (see the shaded area in Figure 7).

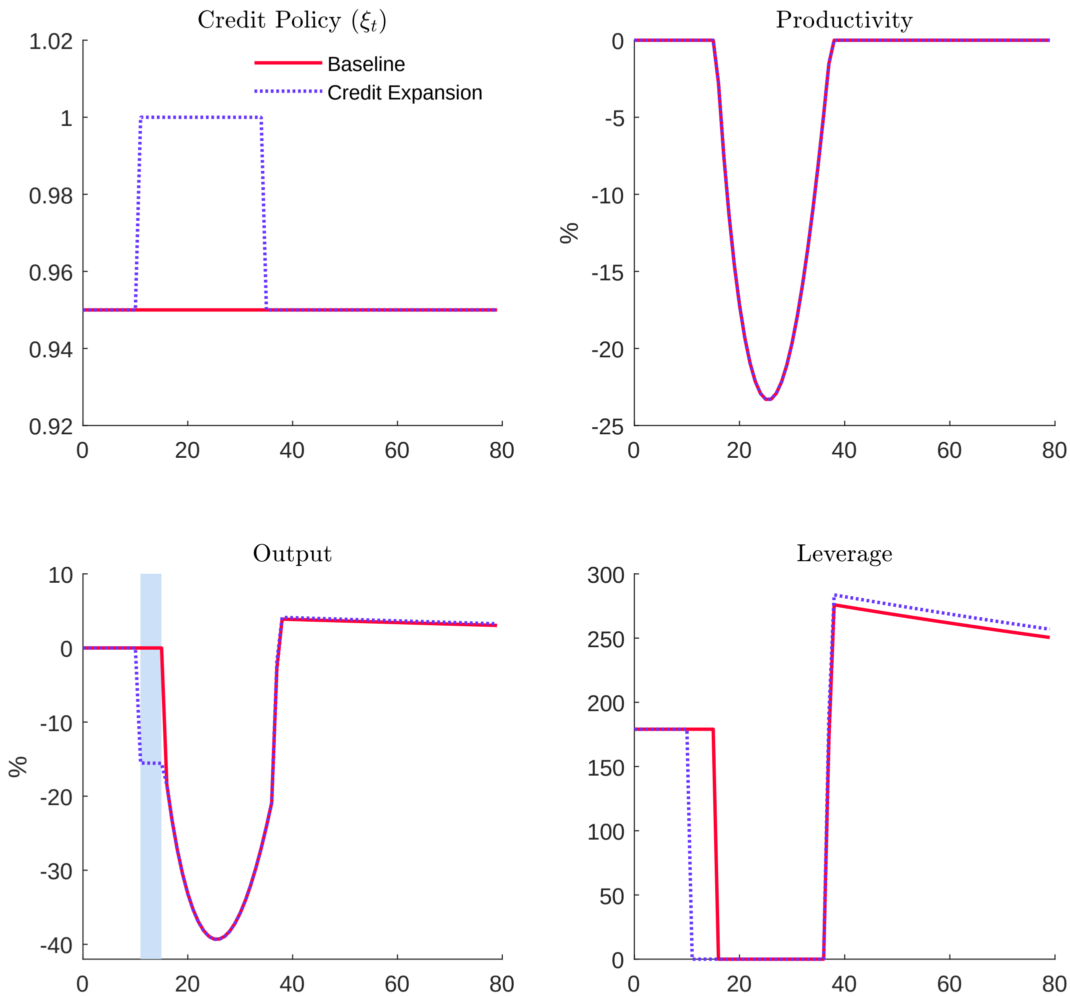
We now illustrate the intuition of the adverse effect of credit expansion. Appendix C provides a more detailed analysis through a static model. A larger credit expansion ξ_t reduces the interest rate. A lower interest rate induces more firms to invest and demand credit, resulting in a lower level of average quality of borrowers, which in turn exacerbates the moral hazard problem. The IC constraint (8) then implies that the leverage ratio declines. The credit market

Figure 6: Impact of the Pandemic under High Uncertainty



Notes: This figure reports the dynamics after the outbreak of the pandemic under an uncertainty shock. The horizontal axes indicate the number of weeks. The uncertainty, productivity and output are the percentage deviations from the initial state. The leverage is the level in terms of percentage. The red lines correspond to the baseline case, and the blue lines correspond to the high uncertainty case where the standard deviation of z increases 20%.

Figure 7: Impact of the Pandemic under the Reserve Requirement Policy



Notes: This figure reports the dynamics after the outbreak of the pandemic under credit expansion through the reserve requirement policy. The horizontal axes indicate the number of weeks. The output is the percentage deviation from the initial state. Infection was measured by the percentage of the population. The leverage is the level in terms of percentage. The red lines correspond to the baseline case where $\xi_t = 0.95$, and the blue lines correspond to the credit expansion case where $\xi_t = 1$ for $t \in [12, 35]$ and $\xi_t = 0.95$ otherwise. The shaded area indicates the scenario where credit expansion causes credit market collapse.

clearing condition implies that the credit expansion shifts the demand curve downward. As a result, the threshold of infected population I_t^* strictly decreases with the credit expansion policy ξ_t. That is, given the severity of pandemic I_t, the credit market becomes more vulnerable to collapse under the expansionary credit policy.

Lending Facility We consider another type of credit policy that takes the form of lending facility. Suppose the central bank can directly lend $\phi_t K_t$ to investors at the market interest rate, where $\phi_t \in (0,1)$ indicates the magnitude of credit expansion. We assume that the borrowers cannot divert the loan provided by the central bank, i.e., they always pay back loans to the central bank. In particular, the rate of return of the firm with idiosyncratic productivity shock z under the aforementioned options is given by

$$r_t(z) = \max\left\{r_t^f, \quad \pi_t z_t (1 + m_t + l_t) - r_t^f (m_t + l_t), \quad \psi (1 + \theta m_t)\right\}. \tag{27}$$

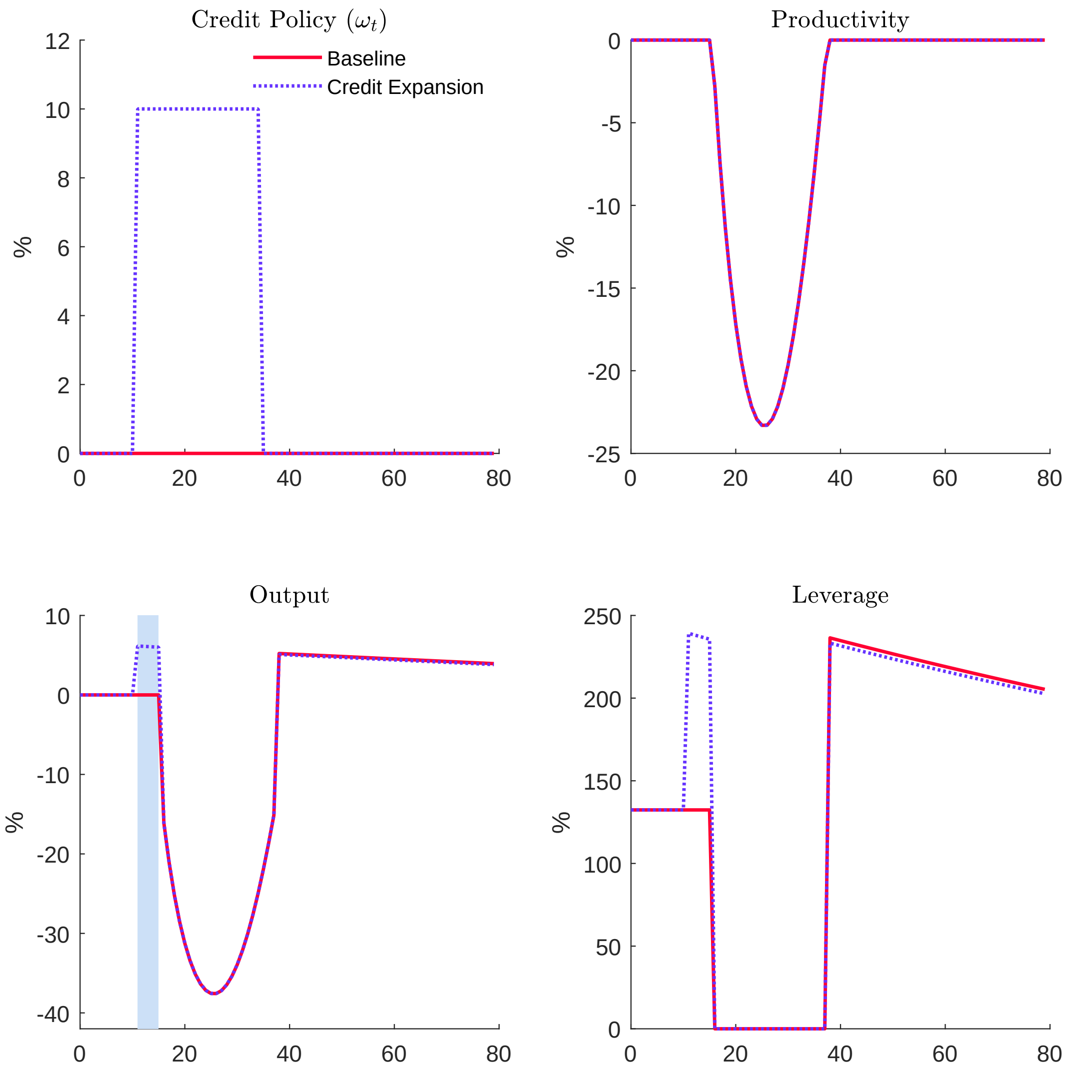
Since there is no moral hazard problem for the loans provided by the lending facility $l_t K_t$, the leverage ratio m_t still takes the same form as that in the baseline model. The credit market clearing condition implies $[1 - \mathbf{F}(z_t^*)](m_t + \phi_t) = \mathbf{F}(z_t^*)$. To facilitate the analysis, we further assume $\phi_t = \omega_t m_t$. Then we have

$$[1 - \mathbf{F}(z_t^*)](1 + \omega_t) m_t = \mathbf{F}(z_t^*), \tag{28}$$

where the leverage ratio satisfies $m_t = \frac{r_t^f - \psi}{\theta \psi}$. Combining last equation with the condition $r_t^f = \pi_t z_t^*$, we can obtain a condition to determine the cutoff z_t^*. Moreover, the last equation indicates that credit expansion through the lending facility policy (increasing ω_t) is equivalent to reducing the severity of moral hazard θ.

In the quantitative exercise, we specify the parameter values and the SIR dynamics the same as those in the baseline model. For the lending facility policy ϕ_t, we assume that the government temporarily expands the credit by raising the lending facility rate ω_t. In particular, $\omega_t = 0.1$ for $t \in [12, 35]$ and $\omega_t = 0$ otherwise. Figure 8 reports the impact of lending facility policy after the pandemic hits the economy. It shows that increasing the credit supply through lending facilities may lead to a short credit boom prior to the market collapse caused by the pandemic. However, this policy cannot stimulate the economy once the credit market is frozen due to the disastrous pandemic shock. This is because the lending facility policy only works when the credit market is functioning. Therefore, compared to the case of the reserve requirement policy, though the lending facility policy will not induce additional negative impact, it also fails to improve the credit market condition during the pandemic periods.

Figure 8: Impact of the Pandemic under the Lending Facility Policy



Notes: This figure reports the dynamics after the outbreak of the pandemic under credit expansion through the lending facility policy. The horizontal axes indicate the number of weeks. The output is the percentage deviation from the initial state. The leverage is the level in terms of percentage. The red lines correspond to the baseline case where $\omega_t = 0$, and the blue lines correspond to the credit expansion case where $\omega_t = 10\%$ for $t \in [12, 35]$ and $\omega_t = 0$ otherwise. The shaded area indicates the scenario where credit expansion causes the short-run credit boom.

4.4.2 Lockdown Policy

The above analysis does not consider the lockdown policy that prevents workers from working. In reality, the government may strictly lockdown the community to flatten the infection curve. Denote l_t as the tightness of lockdown policy. We consider a temporary lockdown policy with the time interval $[T_0, T_1]$ such that

$$l_t = \begin{cases} \bar{l} & \text{if } t \in [T_0, T_1] \\ 0 & \text{otherwise} \end{cases}, \tag{29}$$

where $\bar{l} \in [0, 1]$. We assume that under the lockdown, the household can send at most $1 - l_t$ fraction of the family members to work, i.e., $a_t \leq 1 - l_t$.

Moreover, the lockdown policy directly affects pandemic dynamics. Since only $1 - l_t$ fraction of population is active for economic/social activities, we follow Alvarez et al. (2020) to assume that the dynamics of susceptible and infected populations in the SIR model under lockdown are given by[12]

$$\Delta S_t = -\beta_a a_{t-1} S_{t-1} A_{t-1} I_{t-1} - \beta I_{t-1}(1 - l_{t-1}) S_{t-1}(1 - l_{t-1}), \tag{30}$$

$$\Delta I_t = -\gamma I_{t-1} + \beta_a a_{t-1} S_{t-1} A_{t-1} I_{t-1} + \beta I_{t-1}(1 - l_{t-1}) S_{t-1}(1 - l_{t-1}). \tag{31}$$

Similar to the baseline case, the optimal labor supply from the household implies that the labor productivity A_t is

$$A_t = a_t = \min\left\{ (\Phi S_t I_t)^{-\frac{1}{2}}, 1 - l_t \right\}, \tag{32}$$

where $\Phi = \frac{\beta_a v \rho}{1 - \rho(1-\gamma)}$.

Since the lockdown policy may curb the spread of virus, we assume the policy can reduce the value of parameter β. Therefore, in our setup the infected curve is flattened after the lockdown. One difference between the lockdown analysis here and the previous analysis related to flattening the curve is that the lockdown policy causes a large and temporary drop in the effective labor productivity. Therefore, it is expected that the flattened curve induced by the lockdown policy can avoid the collapse of the credit market due to the spread of the virus. However, the policy may also cause a market collapse immediately after the lockdown because of the free-fall of labor productivity.

Figure 9 compares the dynamics between the baseline model and two cases with lockdown policy. In the quantitative exercise for the lockdown cases, we assume that 20% of the labor force is locked down and cannot go to work, and the policy is implemented 20 weeks from

[12] In contrast to the SIR structure in (17) and (18), in the lockdown case, we replace S_t, I_t with $(1 - l_t) S_t$ and $(1 - l_t) I_t$.

period 1 to 20. That is, $l_t = 0.20$ for $t \leq 20$ and $l_t = 0$ otherwise. We assume that the lockdown reduces β from 0.514 (the baseline case) to 0.45 and 0.41, respectively. The figure shows that in contrast to the baseline scenario (red lines), if the lockdown policy can sufficiently flatten the infection curve (reducing β to 0.41), the outbreak of the pandemic (when the infected population surges) does not trigger a credit market collapse. However, the slump of the effective labor productivity due to the lockdown in the early stage of the pandemic still causes a market freeze, leading to an economic meltdown. The output quickly rebounds after the release of the lockdown policy. However, if the lockdown policy does not sufficiently flatten the infection curve (e.g., $\beta = 0.45$), there may emerge a second wave of the pandemic, which will cause credit market collapse. The blue lines in Figure 9 indicate this case.

The above analysis indicates that using aggressive policies such as lockdown to flatten the curve is not cost free. Note that the lockdown scenario we consider here to some extent is an optimistic case, since we assume that the policy can effectively mitigate the spread of the disease; i.e., β decreases permanently. However, if the COVID-19 surges back after the government reopens the community, i.e., l_t becomes 0 and β returns to a higher value, then the lockdown policy performs even worse because the market may collapse twice.

4.4.3 Subsidization Policy

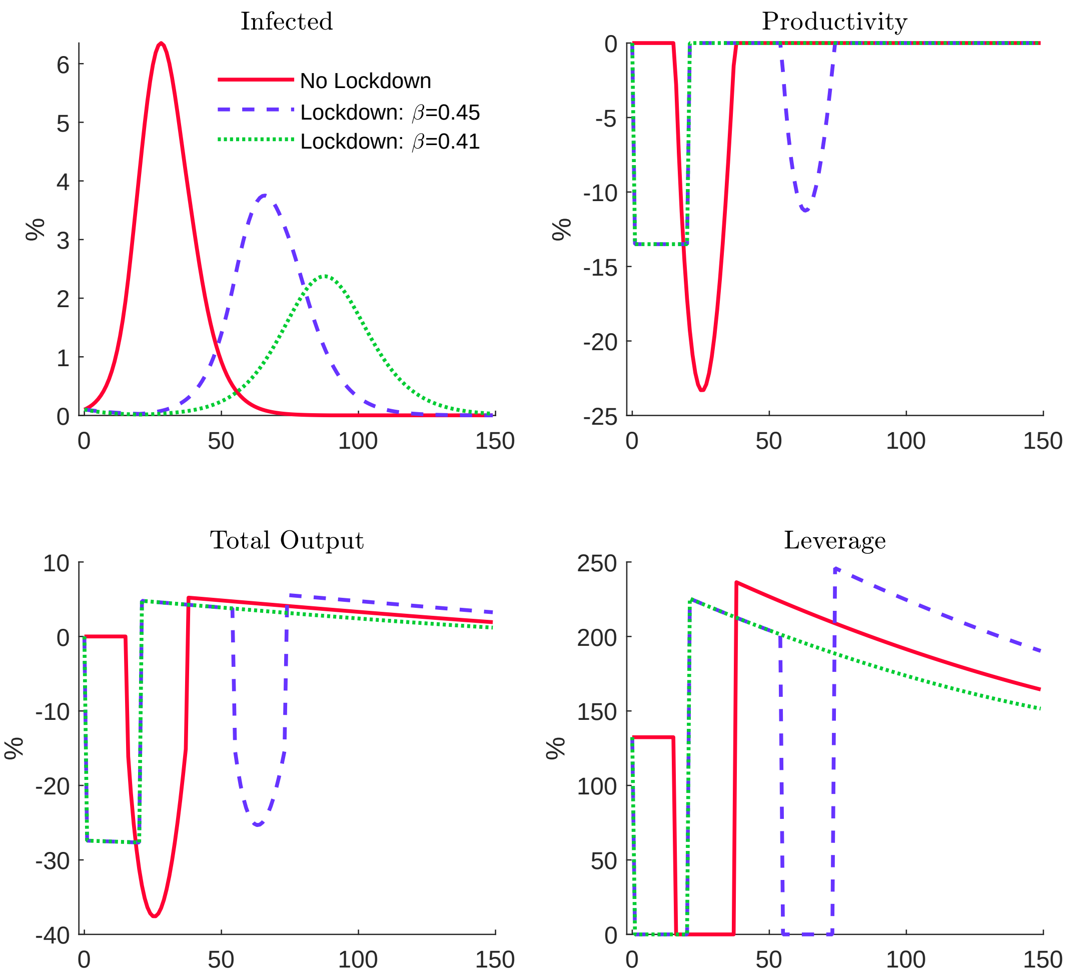
Credit expansion and lockdown policies turn out to be inefficient in the sense that they may increase credit market vulnerability. The market is more likely to collapse in response to the outbreak of pandemic under these policies. The pandemic is essentially a labor supply shock that may deteriorate productivity. Thereby, one straightforward stabilization policy is to subsidize the firms directly. This type of fiscal policy can mitigate the substantial drop in firm profit and thus prevent the economy from plunging into the panic equilibrium. To see this, we assume that the government subsidizes the firm with the rate τ_t. Therefore, the revenue for the firm becomes $(1 + \tau_t)\,(zk)^{\alpha}\, n^{1-\alpha}$.[13] In our quantitative exercise, we specify $\tau_t = \tau > 0$ if $t \in [T_0, T_1]$ and zero otherwise. The subsidy rate τ_t is set to completely offset the reduction of effective productivity a_t caused by the lockdown. Figure 10 compares the dynamics between the lockdown case and the case of lockdown with subsidy policy. This shows that the subsidization policy can effectively stabilize the aggregate economy under the lockdown policy.

5 Conclusion

The objective of this research is to show that a COVID-19-like pandemic can cripple credit markets and even cause credit collapse by freezing the labor supply. We then ask the following

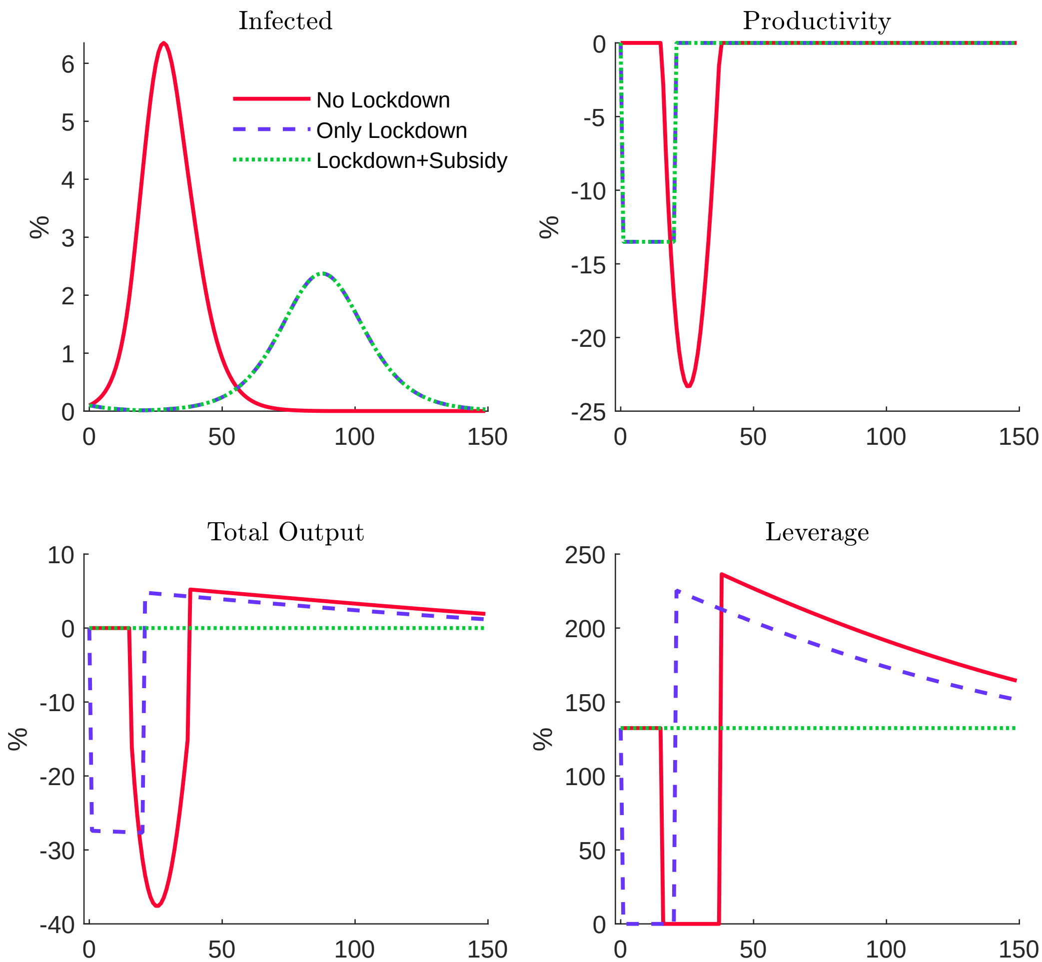
[13] We assume that the expenditure of subsidization policy is financed through a lump sum income tax.

Figure 9: Impact of the Pandemic under Lockdown



Notes: This figure reports the dynamics after the outbreak of the pandemic under different scenarios. The horizontal axes indicate the number of weeks. The output is the percentage deviation from the initial state. Infection was measured by the percentage of the population. The leverage is the level in terms of percentage. The red lines correspond to the baseline case where $\beta = 0.514$, the blue lines correspond to the lockdown case where $l_t = 0.2$ for $t \leq 20$ and $l_t = 0$ otherwise, and $\beta = 0.45$, the green dotted lines correspond to the lockdown case with a more flattened infection curve with $\beta = 0.41$.

Figure 10: Impact of the Pandemic under Lockdown and Subsidy



Notes: This figure reports the dynamics after the outbreak of the pandemic under lockdown with or without subsidies. The horizontal axes indicate the number of weeks. The vertical axes for economic variables indicate the percentage deviation from the initial state. The red lines correspond to the lockdown case without subsidies, and the blue lines correspond to the lockdown with subsidies, where $\tau_t = 0.2$ for $t \leq 20$ and $\tau_t = 0$ otherwise.

questions relevant for both researchers and policy makers: How does a dysfunctioning labor market affect the credit markets? How does credit expansion affect the macroeconomy during the COVID-19 crisis? What kind of macroeconomic policy is more effective? To rigorously address those questions, we develop a framework of endogenous boom-bust credit cycles with banks and financially constrained heterogeneous firms.

The key message that comes across the paper is that credit expansion *per se* cannot adequately stabilize the economy. Lockdown combined with subsidizing firms turns out to be an efficient policy package to curb the pandemic-induced recession. Moreover, we show that the outbreak of a pandemic can generate endogenous boom-bust credit cycles. The credit expansion policy may lead to a backfire effect on the financial market. This is because in the early stage of the pandemic when the infection rate is modest, a large scale of credit expansion causes more low-quality projects to be financed. The lowered average quality of projects in the economy exacerbates the moral hazard problem between borrowers and lenders. The credit market becomes more vulnerable and eventually collapses when the infection rate surges. We also show that the quantitative easing policy that directly injects liquidity to the firms fails to curb the recession when the financial system is dysfunctioning.

We then evaluate alternative policy packages in the dynamic model. In particular, we find that the lockdown policy combined with the subsidization policy for firms can sufficiently curb the pandemic-induced recession. The short-period lockdown policy that effectively flattens the SIR curve can mitigate the disrupting effect on the labor market induced by the wide spread of the virus. Moreover, the subsidization policy attenuates the adverse impact of the pandemic on the quality of projects and thus alleviates the moral hazard problem between lenders and borrowers. Consequently, the improved external financing condition faced by the firms prevents the credit market from collapsing amid the pandemic.

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Appendix

A Proofs

A.1 Proof of Proposition 1

From the credit market clearing condition (13) and the leverage constraint (8), we can solve the market interest rate as

$$r^f = \left[\theta \frac{\mathbf{F}(z^*)}{1-\mathbf{F}(z^*)} + 1\right]\psi. \tag{A.1}$$

Substituting last equation into (14) yields the equation that determines the cutoff z^*

$$\left[\theta \frac{\mathbf{F}(z^*)}{1-\mathbf{F}(z^*)} + 1\right]\psi = \alpha z^* \mathbf{E}^{\alpha-1}(z|z \geq z^*) A^{1-\alpha} K^{\alpha-1}. \tag{A.2}$$

Rearranging terms in last equation yields

$$\frac{\theta \frac{\mathbf{F}(z^*)}{1-\mathbf{F}(z^*)} + 1}{z^* \mathbf{E}^{\alpha-1}(z|z \geq z^*)} = \frac{\alpha}{\psi} A^{1-\alpha} K^{\alpha-1}, \tag{A.3}$$

where $A = \left(\frac{1}{vbSI}\right)^{\frac{1}{2}}$.

Define $\Gamma(z^*) = \frac{\theta \frac{\mathbf{F}(z^*)}{1-\mathbf{F}(z^*)}+1}{z^* \mathbf{E}^{\alpha-1}(z|z\geq z^*)}$. Lemma A.1 in Dong and Xu (2020) shows that under the condition $\eta < \alpha/\theta$, the function $\Gamma(z^*)$ is strictly convex in z^* over the support $(z_{\text{min}}, z_{\text{max}})$ and achieves its minimum at

$$\hat{z} = \left(1 + \frac{\alpha/\theta - \eta}{\eta - \alpha}\right)^{\frac{1}{\eta}}. \tag{A.4}$$

Recall that the productivity A is the number of workers that choose to work outside, which is given by $A = \left(\frac{1}{vbSI}\right)^{\frac{1}{2}}$. Thereby, (A.3) can be expressed as

$$\Gamma(z^*) = \frac{\alpha}{\psi}\left(\frac{1}{vbSI}\right)^{\frac{1-\alpha}{2}} K^{\alpha-1}. \tag{A.5}$$

Since $\alpha \in (0,1)$, the RHS of last equation is strictly decreasing in the infected population I. Define I^* that satisfies $\Gamma(\hat{z}) = \frac{\alpha}{\psi}\left(\frac{1}{vbSI^*}\right)^{\frac{1-\alpha}{2}} K^{\alpha-1}$, or equivalently

$$I^* = \frac{1}{vbS}\left[\frac{\Gamma(\hat{z})}{\alpha/\psi} K^{1-\alpha}\right]^{-\frac{2}{1-\alpha}}, \tag{A.6}$$

where $\hat{z}$ is defined by (A.4). It is straightforward that for any $I > I^*$, Eq. (A.3) has no solution, i.e., the normal equilibrium that the credit market is functioning cannot be supported. In contrast, for any $I < I^*$, Eq. (A.3) has a solution, i.e., the credit market equilibrium exists. We thus have proved Proposition 1.

A.2 Proof of Proposition 2

We first show that the cutoff z^* decreases with the infected population I. To see this, the convexity of $\Gamma(z^*)$ implies that for any $z^* > \hat{z}$, $\Gamma(z^*)$ is strictly increasing in z^*. Thereby, Eq. (A.3) implies that under the condition $I < I^*$, the solution of z^* is strictly decreasing in I. That is, when the pandemic becomes more severe, the more relatively low-quality projects demand external credit from the market, reducing the average quality, $\mathbf{E}(z|z \geq z^*)$, of projects being financed.

We now show the relationship between the aggregate output and the infected population I. From (15), the aggregate output in the non-panic equilibrium is $Y = [\mathbf{E}(z|z \geq z^*)K]^\alpha A^{1-\alpha}$, where z^* is determined by (A.3) and $A = \left(\frac{1}{vbSI}\right)^{\frac{1}{2}}$. Since both $\mathbf{E}(z|z \geq z^*)$ and A are decreasing in I, we immediately have $\frac{\partial Y}{\partial I} < 0$. The adverse impact of I on the output comes from the direct channel that reduces the effective labor productivity A and the indirect channel that lowers the average quality of projects being financed. We thus have proved Proposition 2.

A.3 Properties of Panic Equilibrium

We first prove that there exists a unique panic equilibrium when the infection is sufficiently severe such that $I > I^*$. As we discussed in Appendix A.1, when $I > I^*$, the non-panic equilibrium cannot be supported, as a result the credit market collapse. Under this case, the firms cannot access to the credit market to obtain external finance.

The marginal investor who is self-financed is indifferent with investing in the production sector and in the storage technology, i.e., $\pi z^* = \psi$. Using the definition of π, we have $\alpha A^{1-\alpha}\tilde{K}^{\alpha-1}z^* = \psi$. Since the effective capital is $\tilde{K} = K[1 - \mathbf{F}(z^*)]\mathbf{E}(z|z \geq z^*)$, we can further obtain

$$\frac{\alpha}{\psi}A^{1-\alpha}K^{\alpha-1} = \Phi(z^*) \equiv \frac{[1 - \mathbf{F}(z^*)]^{1-\alpha}}{[\mathbf{E}(z|z \geq z^*)]^{\alpha-1} z^*}, \tag{A.7}$$

where $A = \left(\frac{1}{vbSI}\right)^{\frac{1}{2}}$.

Under the Pareto distribution, we have $\Phi(z^*) = z_{\min}^{-(1-\alpha)(1-\eta)}(z^*)^{(1-\alpha)(1-\eta)-1}$, with the properties $\lim_{z^* \to z_{\min}} \Phi(z^*) = \lim_{z^* \to z_{\min}} \Gamma(z^*) = 1/z_{\min}$ and $\lim_{z^* \to +\infty} \Phi(z^*) = 0$. Since $\Phi(z^*)$ is a monotonic decreasing function, z^* strictly decreases with A or strictly increases with I. Note that to show the existence of unique solution of (A.7) is equivalent to show $\frac{\alpha}{\psi}A^{1-\alpha}K^{\alpha-1} < \Phi(z_{\min})$. This is indeed the case. Remember that under the assumption $\eta < \alpha/\theta$, we have $\Gamma(z_{\min}) > \Gamma(\hat{z})$ because $\hat{z}$ solve the problem $\min_z \Gamma(z)$. Moreover, since $\Phi(z_{\min}) = \Gamma(z_{\min})$, we have $\Phi(z_{\min}) > \Gamma(\hat{z})$. Since in the panic regime, the infected population I must satisfy $I > I^*$ or equivalently $\frac{\alpha}{\psi}A^{1-\alpha}K^{\alpha-1} < \Gamma(\hat{z})$. Then, we must have

$$\frac{\alpha}{\psi}A^{1-\alpha}K^{\alpha-1} < \Gamma(\hat{z}) < \Phi(z_{\min}).$$

Consequently, equation (A.7) has a unique solution.

We now show that the aggregate output in the panic equilibrium decreases with the size of infected population I. Once the equilibrium z^* is solved from (A.7), we can obtain the aggregate output. In particular, we have

$$Y = A^{1-\alpha}\left\{K\left[1-\mathbf{F}(z^*)\right]\mathbf{E}(z|z \geq z^*)\right\}^{\alpha}, \tag{A.8}$$

where the second equality is obtained by using (A.7). Meanwhile, substituting (A.7) into (A.8) implies that Y strictly decreases with I.

A.4 Proof of Proposition 3

According to the definition, the I^* satisfies $\frac{\alpha}{\psi}\left[A(I^*)\right]^{1-\alpha}K^{\alpha-1} = \Gamma\left(z^*_{\mathbf{Normal}}\right)$, where $z^*_{\mathbf{Normal}} = \arg\min_z \Gamma(z) = \hat{z}$. Let z^*_2 denote the equilibrium cutoff in panic equilibrium when $I = I^*$, i.e., $\frac{\alpha}{\psi}\left[A(I^*)\right]^{1-\alpha}K^{\alpha-1} = \Phi\left(z^*_{\mathbf{Panic}}\right)$. As discussed earlier $\Phi(z) < \Gamma(z)$ for any $z > z_{\min}$ and $\Phi(z)$ is monotonically decreasing in z, we must have $z^*_{\mathbf{Panic}} < z^*_{\mathbf{Normal}}$. So the equilibrium cutoff z^* is discontinuous at $I = I^*$.

We can further show that the aggregate output is discontinuous at the $I = I^*$. In particular, the aggregate output in non-panic (normal) and panic equilibria can be written as

$$Y_j = A^{1-\alpha}\left[K_j\mathbf{E}\left(z|z \geq z^*_j\right)\right]^{\alpha}, \; j = \{\text{Normal}, \text{Panic}\}$$

where K_j is the capital used in the production sector for j type of equilibrium satisfying

$$\begin{aligned} K_{\text{Normal}} &= K, \\ K_{\text{Panic}} &= K\left[1-\mathbf{F}\left(z^*_{\text{Panic}}\right)\right]. \end{aligned}$$

Notice that since $K_{\text{Normal}} = K$ is independent with z^*_{Normal}, we have

$$
\begin{aligned}
\frac{\partial Y_{\text{Normal}}}{\partial K_{\text{Normal}}} &= A^{1-\alpha} \alpha K^{\alpha-1}_{\text{Normal}} \left[\mathbf{E} \left(z | z \geq z^*_{\text{Normal}} \right) \right]^{\alpha} \\
&= \pi_{\text{Normal}} \mathbf{E} \left(z | z \geq z^*_{\text{Normal}} \right) \\
&> 0,
\end{aligned}
$$

where the second line holds due to the definition of π_{Normal} (see equation 12). Thus, we must have $\frac{\partial Y_{\text{Normal}}}{\partial K_{\text{Normal}}} > 0$. With this monotonicity property, we further have

$$
\begin{aligned}
Y_{\text{Normal}} &= A^{1-\alpha} \left[K_{\text{Normal}} \mathbf{E} \left(z | z \geq z^*_{\text{Normal}} \right) \right]^{\alpha} \\
&> A^{1-\alpha} \left[K_{\text{Panic}} \mathbf{E} \left(z | z \geq z^*_{\text{Normal}} \right) \right]^{\alpha} \\
&> A^{1-\alpha} \left[K_{\text{Panic}} \mathbf{E} \left(z | z \geq z^*_{\text{Panic}} \right) \right]^{\alpha} \\
&= Y_{\text{Panic}},
\end{aligned}
$$

where second line holds due to the fact $K_{\text{Normal}} > K_{\text{Panic}}$ and $\frac{\partial Y_{\text{Normal}}}{\partial K_{\text{Normal}}} > 0$, while the third line just applies $z^*_{\text{Normal}} > z^*_{\text{Panic}}$.

B Characterizing Dynamic System

We now characterize the full dynamic system. According to the analysis in the static model, the outputs are given by

$$
Y_t = A_t^{1-\alpha} \left[\mathbf{E} \left(z | z \geq z^*_t \right) K_{ht} \right]^{\alpha}. \tag{B.1}
$$

Recall that the cutoff values of z^*_t for the different regimes are determined by

$$
\frac{\alpha}{\psi} A_t^{1-\alpha} K_{ht}^{\alpha-1} = \begin{cases} \Gamma \left(z^*_t \right), & \text{if Normal} \\ \Phi \left(z^*_t \right), & \text{if Panic} \end{cases}, \tag{B.2}
$$

where $\Gamma \left(z^* \right) = \frac{\theta \frac{\mathbf{F}(z^*)}{1-\mathbf{F}(z^*)} + 1}{z^* \mathbf{E}^{\alpha-1}(z|z \geq z^*)}$ and $\Phi \left(z^* \right) = \frac{\left[1-\mathbf{F}(z^*)\right]^{1-\alpha}}{\left[\mathbf{E}(z|z\geq z^*)\right]^{\alpha-1} z^*}$.

Let K^*_t denote the critical value of capital stock for the switch between **Normal** and **Panic** equilibria, which satisfies

$$
\frac{\alpha}{\psi} A_t^{1-\alpha} \left(K^*_t \right)^{\alpha-1} = \Gamma \left(\hat{z}_t \right), \tag{B.3}
$$

where $\hat{z}_t = \arg \min_{z \in (z_{\min}, z_{\max})} \Gamma(z)$. Obviously, last equation implies that the threshold K^*_t increases with A_t or decreases with infected population I_t.

Analogously to the static model, we must have

$$K_{ht} = \begin{cases} K_t, & K_t < K_t^*, \text{ (Normal)} \\ K_t \left[1 - \mathbf{F}\left(z_t^*\right)\right], & K_t > K_t^*, \text{ (Panic)} \end{cases}. \tag{B.4}$$

In the end, the full dynamic system is described by (26) and (B.1) to (B.4).

Equations (B.2) to (B.4) imply that the RHS of (26) is a function of K_t under either **Normal** or **Panic** equilibria, which can be denoted as $g\left(K_t\right)$. Dong and Xu (2020) prove that $g^{\textbf{Normal}}\left(K_t\right)$ is strictly concave in K_t, and $g^{\textbf{Panic}}\left(K_t\right)$ strictly increases with K_t.

C Credit Policies

Reserve Requirement Policy We introduce the reserve requirement policy into a static model. The dynamic case is essentially the same. The bank can only lend out $\xi \in (0, 1)$ fraction of its capital. A competitive bank's profit maximization problem is

$$\max r\xi D + r^s \left(1 - \xi\right) D - r^f D, \tag{C.1}$$

where $D = \mathbf{F}\left(z^*\right) K$ is the total deposit; r^l is the lending rate; r^s is the interest rate for the reserved deposit; r^f is the deposit rate. We further assume that the bank earns a same interest rate for the reserved deposit $\left(1 - \xi\right) D$ as that of lending rate r^l, i.e., $r^l = r^s$. Under this setup, the zero profit condition implies that $r^l = r^f$.[14]

Under the credit expansion policy, the credit market clearing condition becomes $\left[1 - \mathbf{F}\left(z^*\right)\right] m = \xi \mathbf{F}\left(z^*\right)$. The equilibrium condition for the market interest rate (14) becomes

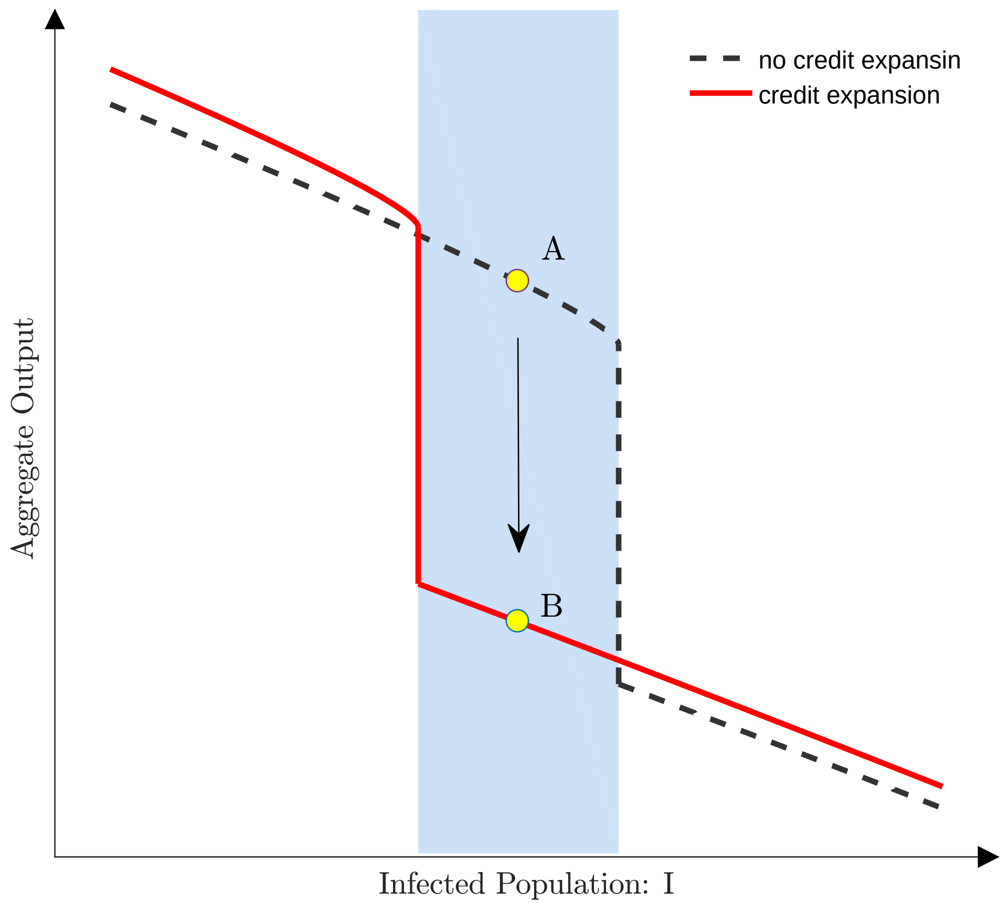
$$r^f = \alpha z^* \mathbf{E}^{\alpha-1}\left(z | z \geq z^*\right) A^{1-\alpha} \left\{\left[1 - \mathbf{F}\left(z^*\right)\left(1 - \xi\right)\right] \mathbf{E}\left(z | z \geq z^*\right) K\right\}^{\alpha - 1}, \tag{C.2}$$

where $A = \left(\frac{1}{vbSI}\right)^{\frac{1}{2}}$. It is straightforward to show that taking the cutoff z^* and the infected population I (thus A) as given, a larger credit expansion ξ reduces the interest rate. A lower interest rate induces more firms to invest and demand for credit, resulting in a lower level of average quality of borrowers, which in turn exacerbates the moral hazard problem. The IC constraint (8) then implies the leverage ratio declines. The credit market clearing condition implies that the credit expansion shifts the demand curve downward. We can show that the threshold of infected population I^* strictly decreases with the credit expansion policy ξ. This property of I^* conveys an important message that during the pandemic periods, an aggressive credit expansion policy (a large increase in ξ) may increase the vulnerability of the financial

[14] In the case where $r^s \neq r^l$, the credit policy may introduce an extra positive price effect on the equilibrium interest rate because of the zero profit condition. To exclude this effect, we focus on the case of $r^s = r^f$.

market. Even worse, during the pandemic periods when the infection population is below but close to the threshold I^*, an aggressive credit expansion may trigger a credit market panic by reducing the value of I^*. Figure C.1 gives a graph illustration. The figure shows that a credit expansion reduces the threshold for panic equilibrium I^* and shifts the Y-I^* curve to the left. Suppose the economy initially stays at a point on the Y-I^* curve (point A) in the blue area where the credit market is functioned. A credit expansion policy would cause a credit market crash by shifting the normal equilibrium to the panic one (point B), resulting in a plunge in the aggregate output. This perverse effect suggests that the credit policy needs to be contingent on the situation of pandemic. The credit expansion could cause unintended consequences on the real economy especially when the population of being infected is severe but still below the threshold I^*. Therefore, the priority of the government is to flatten the infection curve, and then the implement stimulus credit policy.

Figure C.1: Impact of Credit Expansion Policy



Notes: This figure illustrates the potential consequences of credit expansion on the credit market equilibrium and the aggregate economy. The black line is for the case where the credit expansion is in absent. The red line is for the case of credit expansion. The dashed line corresponds to the threshold I^* in each case. The blue shaded area represents the range for infection population I^* where the credit expansion may lead to a credit market crash (shifting point A to point B).