INTRODUCTION

The COVID-19 pandemic has caused hundreds of millions of infections and has wreaked havoc on the global economy since January 2020. In response to this health and economic crisis, many countries have committed to massive fiscal stimulus. For instance, the United States appropriated $293 billion for tax rebates and $268 billion for unemployment benefits in April 2020. Its federal debt scaled a historic peak as a percentage of GDP and has even exceeded GDP by the third quarter of 2021.

This paper contributes to the growing body of theoretical literature about fiscal responses to the pandemic by capturing two salient facts. First, shelter-in-place effectively mitigates viral transmission and saves lives (Fenichel, 2013; Friedson et al., 2021), but individuals tend to ignore external health benefits of their adaptive behaviors (see the discussions of infection externality by Fenichel et al., 2011; Bethune & Korinek, 2020; Eichenbaum et al., 2021). Second, in light of the lives versus livelihoods tradeoff, discretionary fiscal support plays a crucial role in the practice of social distancing (Faria-e-Castro, 2021; Guerrieri et al., 2022; Hall et al., 2020; Kaplan et al., 2020). We develop a model suggesting that fiscal stimulus in response to the pandemic not only smooths consumption but also prompts workers to substitute current work with future work, which improves population health and social welfare.
The analysis of fiscal policy in a dynamic framework has deep roots in the economics literature. Hall (1971) develops a pioneering model characterizing the intertemporal competitive equilibrium in which forward-looking individuals make plans under different fiscal policies. Barro (1979) postulates that the governments that aim to finance a temporary increase in their spending should issue public debts keeping the expected constancy in tax rates. Ohanian (1997) shows that issuing debts increases output and social welfare to a larger extent than increasing taxes in wartime. Our paper is closely related to Faria-e-Castro’s (2021) study, which investigates the effects of the pandemic outbreak and different fiscal remedies in a dynamic model and then conducts a quantitative assessment for the U.S. economy. This paper is complementary to Faria-e-Castro’s (2021) analysis in that we focus more on the micro foundations of fiscal policy.

In this paper, Section 2 lays out a simple two-period model where a mass of individuals make a choice along their labor-leisure constraint during and after an epidemic. In addition to the conventional labor-leisure tradeoff, infection externalities arise as working during the epidemic increases the mortality rate. Under laissez-faire, rational individuals choose to work less and stay longer at home, which in turn threatens their livelihood. We consider that the government borrows consumption goods from abroad and distributes them among the population on an equal basis and pays off the debt by collecting lump-sum taxes on labor earnings from living workers after the epidemic. The introduction of fiscal stimulus not only compensates workers for lost earnings but also saves their lives by allowing them to substitute future labor supply for current labor supply to a greater extent. We characterize a condition for fiscal stimulus to improve social welfare, which depends critically on time preference, intertemporal interest rate, and willingness to stay home.

We then consider that production processes exhibit scale economies based on labor division and specialization (Dixit & Stiglitz, 1977). In this case, some workers’ withdrawal from workforce due to the pandemic causes an immediate fall in the average labor productivity and wage rates (e.g., Eichenbaum et al., 2022). We label this intratemporal wage-decreasing effect as static pecuniary externality, which reflects that some workers’ decision to stay at home undermines scale economies and therefore lowers other workers’ earnings. Reduced work interactions during the pandemic help to mitigate mortality rates and improve population health, which translates into higher labor efficiency and wages in the long run. We label this intertemporal spillover effect of the epidemic-induced decrease in labor supply as dynamic pecuniary externality: workers’ current confinement contributes to preserving a healthy workforce and strengthening the post-epidemic productivity. In short, working amid the epidemic involves a contemporary gain in labor efficiency and a future loss. We analyze fiscal policies against the static and dynamic pecuniary externalities as well as the infection externality in a joint framework.

Section 3 outlines the labor-leisure tradeoff and the risk of infection into an infinite-horizon framework of scale economies. A monopolistic competition model, which emphasizes the epidemic-induced changes in labor supply, helps rationalize the comovement of macroeconomic aggregates (Eichenbaum et al., 2022). We first demonstrate the laissez-faire equilibrium, in which employment contraction resulting from the potential health risks leads to a lower wage rate, depressing aggregate demands and aggravating economic slack. Yet individually rational choices may not be efficient due to the failure to account for externalities. We then formulate labor supply decision-making as a social planner’s problem wherein working time during the crisis is set by the government. To correct the static pecuniary externality requires an increase in labor supply, yet to internalize the infection and dynamic pecuniary externalities necessitates a stay-at-home advisory. If the government activates fiscal policies, the belief that all workers stay home is self-fulfilling so that the entire labor force will be locked out. But the belief that some workers go to work may give rise to multiple equilibria; the highest labor supply equilibrium may Pareto dominate other possible equilibria. Therefore, fiscal stimulus alone is not enough, and the government needs to overcome coordination failure by retaining adequate employment.

Moreover, our simulations illustrate that the increased borrowing helps to save more lives and increase consumption, although it tends to dampen labor supply, lower wage rates, and make more firms exit. A sufficiently large fiscal stimulus effectively serves as a full lockdown policy. Larger borrowing can boost the post-epidemic economy by stimulating labor supply, promoting worker productivity, and facilitating market specialization. Behind this long-run labor market prosperity, however, is a heavy tax burden. The design of the optimal fiscal policy involves a balance between current and future welfare. We suggest that the optimal borrowing level increases with production efficiency and industry markup because greater efficiency and markups mean higher income in each period, which raises the opportunity cost of work activities during the epidemic. In addition, the government tends to implement an aggressive fiscal relief when the viral disease is highly deadly and contagious. Our comparative static analyses find support from prior empirical studies (e.g., Benmelech & Tzur-Ilan, 2020).
THE BASIC MODEL

Consider a two-period small open economy populated by a unit mass of identical individuals, where an epidemic breaks out in the first period \((t = 0)\) and dissipates in the second period \((t = 1)\). Possible infection only occurs at \(t = 0\), and all of the infected die at the end of this period. At the beginning of period \(t\), each living individual is endowed with one unit of time, which can be spent either in the workplace \((L_t)\) or at home \((H_t)\). Her time constraint requires

\[ L_t + H_t = 1. \tag{1} \]

The more an individual’s exposure in the workplace at \(t = 0\), the higher likelihood she has to be infected. The mortality probability at the end of the first period is given by

\[ z = \xi L_0 (\bar{L}_0)^\lambda, \tag{2} \]

where \(\xi, \lambda > 0\) are the severity of the disease and the viral transmission through person-to-person contact, and \(\bar{L}_0\) is the fraction of time spent in the workplace on average in period \(t\). Equation \((2)\) suggests that an individual is more likely to survive if she works less during the epidemic and will always survive if she stops working; moreover, she faces a higher health risk if others work more.\(^5\)

By assuming away population growth, we expect the post-epidemic workforce size to be \(1 - z\).

In period \(t\), each individual obtains an instantaneous utility of \(V_t\) if she is living and zero utility otherwise. Her lifetime utility is time separable and amounts to

\[ U = V_0 + \delta (1 - z)V_1, \tag{3} \]

where \(\delta > 0\) indicates her intertemporal preference, while \(V_t\) is derived from consumption of the unique final goods \((C_t)\) and leisure (i.e., staying at home \(H_t\)):

\[ V_t = \ln C_t + \varphi \ln H_t, \quad \varphi > 0. \tag{4} \]

Let the real wage rate be \(\omega\) in both periods. If each individual spends all her disposable income on consumption in period \(t\), then

\[ C_t = \omega L_t - X_t, \tag{5} \]

where \(X_t\) is a lump-sum tax (in terms of final goods) if positive and a transfer payment if negative.

2.1 | Laissez-faire

We begin with the case where each individual optimally plans her time allocation in the absence of a government \((X_t = 0)\). By substituting Equations \((1)\), \((2)\), \((4)\) and \((5)\) into Equation \((3)\), we derive an individual’s expected intertemporal utility as

\[ U = \ln (\omega L_0) + \varphi \ln (1 - L_0) + \delta \left[ 1 - \xi L_0 (\bar{L}_0)^\lambda \right] \left[ \ln (\omega L_1) + \varphi \ln (1 - L_1) \right]. \tag{6} \]

The first order conditions with respect to \(L_0\) and \(L_1\) obtain

\[ \frac{\partial U}{\partial L_0} = \frac{1}{L_0} - \frac{\varphi}{1 - L_0} - \delta \xi (\bar{L}_0)^\lambda \left[ \ln (\omega L_1) + \varphi \ln (1 - L_1) \right] = 0, \]
\[ \frac{\partial U}{\partial L_1} = \delta \left[ 1 - \xi L_0 (\bar{L}_0)^\lambda \right] \left( \frac{1}{L_1} - \frac{\varphi}{1 - L_1} \right) = 0. \]

Because \(L_0 = \bar{L}_0\) by symmetry, the levels of labor supply during and after the epidemic in laissez-faire equilibrium \((L_0^N\) and \(L_1^N\), where the superscript \(N\) stands for “no intervention”) satisfy

\[ \frac{1}{(L_0^N)^\lambda} \left( \frac{1}{L_0^N} - \frac{\varphi}{1 - L_0^N} \right) = \delta \xi \ln \frac{\omega \varphi \varphi}{(1 + \varphi)^{1+\varphi}}, \quad L_1^N = \frac{1}{1 + \varphi}. \tag{7} \]
The next lemma contrasts the equilibrium labor supply during and after the epidemic:

**Lemma 1** Under laissez-faire, individuals optimally reduce their working time when the epidemic breaks out \( (L_0^N < L_1^N) \).

**Proof** See Appendix. ■

Lemma 1 investigates the impact of a public health emergency on individual behaviors. When the outdoor environment is safe and healthy, individuals manage their time without concerns about infections. Yet the epidemic outbreak incurs a risk associated with social life. Taking into account the (extra) cost of potential mortality, they tend to stay longer at home and cut back work hours even without a lockdown policy or shelter-in-place order. This is also the point of the rational epidemics literature that individuals rationally increase self-protection through transmission-reducing actions. Empirical evidence on the COVID-19 pandemic validates this hypothesis: for example, Yan et al. (2021) find substantial voluntary avoidance behaviors in response to local infections and deaths in the US; Aum et al. (2021) find that while South Korea did not impose a lockdown against COVID-19, employment fell in the sole outbreak region to a greater extent than in other regions; Krueger et al. (2022) find that many Swedes stayed home on a voluntary basis, despite their government taking a lenient method.

Although individual adaptive behaviors help to slow down the spread of the virus and to lower the morality rate, they pose a threat to livelihoods. Since demands are endogenous to the epidemic-induced labor supply changes, individuals cut back consumption spending. We can infer from Equation (7) that all else being equal, a larger \( \xi \) results in a smaller \( L_0^N \) and therefore a smaller \( C_0^N \). Interpreted literally, individuals trade off income and consumption for health during the epidemic by taking more preventive measures against a more deadly disease. This result is consistent with Hall et al. (2020) finding that Americans are willing to give up more consumption to avoid deaths associated with COVID-19 when mortality risk is higher as well as Immordino et al. (2021) finding that fear of COVID-19 contagion raises the probability of consumption spending cut Italian households.

### 2.2 Fiscal stimulus

Motivated by the observation that governments worldwide have issued a considerable debt and provided substantial fiscal support to fight the COVID-19 pandemic, we now investigate the case in which the government borrows from abroad. As the epidemic occurs at \( t = 0 \), the government borrows \( B > 0 \) units of goods, which are then earmarked for household subsidies. To finance the debt at \( t = 1 \), the government collects a lump-sum income tax \( T > 0 \) in terms of goods on each living individual. With an exogenous interest rate \( r \), the government balances its intertemporal budget as expressed by \( (1 + r)B = (1 - z)T \). The net tax in period \( t \) can be written as

\[
X_t = \begin{cases} 
-B & \text{if } t = 0 \\
T & \text{if } t = 1 
\end{cases}
\] (8)

The interactions between the government and individuals proceed in two stages. The government moves first to announce the level of borrowing \( B \). By observing the fiscal policy, individuals optimally choose \( L_1^F \) where \( t = \{0, 1\} \) and the superscript \( F \) stands for “fiscal policy”. The next proposition presents the equilibrium outcome for the given government borrowing:

**Proposition 1** Given \( B > 0 \), \( (L_0^F, L_1^F) \) can be determined by

\[
L_1^F = \frac{1}{1 + \varphi} + \frac{(1 + r)\varphi B}{\omega(1 + \varphi) \left[ 1 - \xi (L_0^F)^{1 + \lambda} \right]},
\] (9)

\[
\delta \xi \left[ (1 + \varphi) \ln (1 - L_1^F) + \frac{\varphi L_1^F}{1 - L_1^F} + \ln \frac{\omega}{\varphi} - 1 \right] = \frac{1}{(L_0^F)^{\lambda}} \left( \frac{\omega}{\omega L_0^F + B} - \frac{\varphi}{1 - L_0^F} \right).
\] (10)
If the government increases its borrowing, individuals always work less in period 0 \( \left( \frac{\partial L_0^F}{\partial B} < 0 \right) \) and work more in period 1 \( \left( \frac{\partial L_1^F}{\partial B} > 0 \right) \) if and only if

\[
\varphi \frac{\omega L_0^F + B}{1 - L_0^F} > \frac{\xi(1 + \lambda) B (L_0^F)^{1+\lambda} - (\omega + \lambda)L_0^F - \lambda B}{(1 + \lambda)L_0^F - \lambda}.
\]

(11)

Proof See Appendix. ■

Given the government borrowing \( B > 0 \), it is straightforward to infer from Equations (7) and (9) that \( L_1^F > L_1^N \), which indicates that fiscal stimulus induces workers to increase labor supply after the epidemic. As transfer payments and wages are substitutes in the purchase of consumption goods, a more aggressive fiscal response provides a disincentive to work. This result helps to underpin the worldwide economic relief policies against the COVID-19 pandemic: social protection can be used as an alternative instrument to restrict mobility and contain the infectious disease. To the extent that the government relieves public concerns about livelihood during the epidemic, individuals are inclined to reduce their production activities and stay longer at home.

Proposition 1 also shows that the post-epidemic labor supply increases with the level of government borrowing under some configurations. Since generous fiscal supports ensure more individuals to survive the epidemic, the future tax burden is spread thinly, which in turn stimulates future labor supply. Nevertheless, an opposite force arises as that the increased government debt today pushes up total income taxes tomorrow, thereby discouraging work effort. The positive effect dominates the negative effect under condition (Equation 11), that is, when the wage rate is high (large \( \omega \)), the virus is not very deadly (small \( \xi \)), and leisure is highly valued (large \( \varphi \)). An empirical study by Dixon et al. (2010) discovers a 0.3% positive deviation for the U.S. total employment in 2011 after the H1N1 epidemic.

In sum, the introduction of government borrowing \( B > 0 \) further encourages the substitution of future work for current work \( (L_0^F < L_0^N < L_1^N < L_1^F) \). Government borrowing and transfers today make workers less necessary to work, which reinforces their adaptive behaviors during the epidemic yet offsets the desire for intertemporal smoothing of leisure (Bigoni et al., 2021). Yet paying off the public debt through income taxation tomorrow prompts them to work harder. Some new classical macro models, such as real business theory, predict that a productivity shock may affect time sequences of allocation for labor (Barro & King, 1984; Kydland & Prescott, 1982). Proposition 1 takes a complementary perspective that a health crisis and the induced fiscal relief affect the intertemporal substitution of labor supply and leisure.

We proceed to analyze the intertemporal substitution of consumption under the fiscal policy in the following proposition:

**Proposition 2** The introduction of government borrowing \( B > 0 \)

(i) lowers the post-epidemic consumption level (i.e., \( C_1^F < C_1^N \));

(ii) facilitates consumption smoothing if and only if

\[
\frac{1 + \varphi}{\varphi} \left( 1 - L_1^F \right) < \frac{\omega L_0^F + B}{\omega L_0^N}.
\]

(12)

Proof See Appendix. ■

Proposition 2(ii) suggests that activating fiscal relief to fight the epidemic will exert a negative impact on future consumption. Given \( B > 0 \), while all living individuals work harder at \( t = 0 \) and hence earn a higher level of income, they also bear a heavier tax burden to pay off the public debt owed by themselves and the dead. The net effect results in a lower level of disposable income and thus consumption in the post-epidemic period.

Proposition 2(ii) shows that the government borrowing/transfer may increase the ratio of \( C_0 \) to \( C_1 \). It demonstrates another salient role of fiscal stimulus in a dynamic framework—a catalyst of a more stable path of private consumption. This is based on the essential idea of the mainstream consumption theory (e.g., life cycle hypothesis and permanent income hypothesis), which posits that rational and forward-looking individuals tend to even out their consumption in the best possible manner over time. Since the health risk at \( t = 0 \) undermines livelihoods (Lemma 1), discretionary fiscal relief intends to play a cushioning role, reducing the size of income loss and counterbalancing the intertemporal consumption asymmetry. In other words, government
transfers enable people to allocate income from the period of affluence toward the period of hardship. The gap between \( C_0 \) and \( C_t \) will be narrower under the fiscal policy than under laissez-faire when condition (Equation 12) holds, and in particular, when \( B \) is large. Intuitively, a sufficiently generous subsidy to households during the epidemic facilitates consumption smoothing. We proceed to discuss the optimal fiscal policy. Define social welfare as a representative individual’s intertemporal utility. Given \( (L_0^F, L_1^F) \), we use Equations (6) and (9) to write the social welfare as

\[
U = \ln \left( \omega L_0^F + B \right) + \varphi \ln \left( 1 - L_0^F \right) + \delta \left[ 1 - \xi \left( L_0^F \right)^{1+\delta} \right] \left[ (1 + \varphi)\ln \left( 1 - L_1^F \right) + \ln \frac{\omega}{\varphi} \right].
\] (13)

Maximizing \( U \) in Equation (13) subject to the two constraints Equations (9) and (10) derives the optimal government borrowing \( B^* \). The next proposition demonstrates that the government finds it desirable to borrow against the future under certain conditions:

**Proposition 3** \( B^* > 0 \) if \( \delta(1+r)(1+\varphi) < 1 \).

**Proof** See Appendix. ■

Proposition 3 characterizes a sufficient condition under which the government chooses to offer fiscal stimulus. This condition is more likely to hold when \( \delta, r, \) and \( \varphi \) are small. Time preference is a crucial determinant in intertemporal problems (e.g., Barro & King, 1984; Dragone & Vanin, forthcoming). The government tends to borrow against the future when individuals prefer material benefits sooner than later (small \( \delta \)). Moreover, a lower interest rate (smaller \( r \)) decreases the cost of borrowing facing the government. Finally, the government should borrow and provide transfers if individuals are impatient for staying at home (small \( \varphi \)).

Before closing this section, let us discuss about the robustness of our results under a couple of alternative assumptions. First of all, earlier theoretical studies assume that purchasing consumption goods brings people into contact with each other and hence the chance of being infected depends on consumption activities (e.g., Eichenbaum et al., forthcoming). Under this assumption, government transfers, which tend to boost consumption through the income effect, will cause more infections and impair the health of workforce. If we take this consumption-related externality into account, our main results will hold qualitatively, although the optimal borrowing level is expected to adjust downward compared with \( B^* \). Besides, thanks to the development of E-commerce, many people choose to substitute physical store shopping with on-line shopping to avoid interpersonal contacts and minimize the infection caused by consumption activities. Second, our model assumes that fiscal policy implementation involves giving a transfer on an equal basis and taxing only the survivors and may not emphasize the government’s incentive to control of the post-epidemic tax base and income tax per capita. If the government instead offers a transfer ex-post to the survivors to encourage individuals to save lives, then individuals will be better motivated to stay at home amid the epidemic (lower \( L_0^F \)). This “bonus” scheme addresses the intertemporal externality that an individual’s saving of epidemic-era work effort benefits the whole economy. In the next section, we will explore a similar idea, which we call “dynamic pecuniary externality” associated with an individual’s ignorance of the contribution of her survival to the post-epidemic labor productivity.

### 3 AN INFINITE-HORIZON MODEL WITH SCALE ECONOMIES

In this section, we extend our basic model into an infinite-horizon model in which production exhibits scale economies. Our infinite-horizon framework aims to capture the idea that the adverse macroeconomic impacts of an epidemic spread out over time and into the longer term (see Bloom et al., 2022). Consider that an epidemic hits the economy in the initial period (\( t = 0 \)) and will be eradicated in the subsequent periods (\( t \geq 1 \)). For simplicity, we assume that individuals neither borrow nor save, which can be justified when the discount rate is less than the lending rate and higher than the deposit rate. Individuals face the time constraint (1) for all \( t \) and the mortality probability (2) at the end of the first period. A representative individual’s intertemporal utility can be written as

\[
U = V_0 + (1 - z) \sum_{t=1}^{\infty} \frac{1}{(1 + \rho)^t} V_t,
\] (14)

where \( \rho > 0 \) is the discount rate, and \( z \) and \( V_t \) are expressed in Equations (2) and (4), respectively.
To formalize the production side, we draw on the Dixit-Stiglitz-Krugman model of monopolistic competition (Dixit and Stiglitz, 1976; Krugman, 1980) for three reasons. First of all, real-world manufacturing processes are featured by producers that supply different intermediate goods under increasing returns technologies and enjoy some market power with unrestricted entry. Compared with perfect competition, monopolistic competition gives a more accurate measure of an economy’s response to demand movements (Blanchard & Kiyotaki, 1987; Heijdra and van der Ploeg, 1996). Second, scale economies point to productivity gains associated with increased labor supply, which tend to offset the external health costs as in Equation (2). Finally, the interactions between infection risks and economies of scale implicate a dynamic externality: the epidemic-era labor supply causes mortality, thereby reducing the size of the post-epidemic workforce and impairing its productivity.

Final goods are produced under perfect competition in each period \( t \) by combining \( n_t \) varieties of differentiated intermediate inputs indexed by \( i \in \{1, 2, \ldots, n_t\} \), where \( n_t \) is assumed to be large. The production function exhibits constant returns to scale and constant elasticity of substitution between different inputs:

\[
Q_t = \left( \sum_{i=1}^{n_t} q_{it}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \quad \sigma > 1,
\]

where \( Q_t \) and \( q_{it} \) represent quantities of final goods and the \( i \)th input.

Intermediate inputs are supplied by a number \( n_t \) of monopolistically competitive firms in period \( t \), with each firm producing a different variety. The production of variety \( i \) at firm \( i \) involves a fixed cost and a constant marginal cost, giving rise to scale economies:

\[
l_{it} = \alpha + \beta q_{it},
\]

where \( l_{it} \) represents the units of labor hired by firm \( i \) in period \( t \). Full employment requires that the total labor force must be exhausted by labor used in production:

\[
M_tL_t = \sum_{i=1}^{n_t} l_{it}.
\]

With \( P_t \) and \( p_{it} \) being the prices of final goods and the \( i \)th input in period \( t \), the profit earned from the production of final goods is \( P_tQ_t - \sum_{i=1}^{n_t} p_{it}q_{it} \). The profit maximization problem implies that the demand schedule of the \( i \)th input satisfies

\[
q_{it} = \left( \frac{p_{it}}{P_t} \right)^{-\sigma} Q_t.
\]

Perfect competition in final goods market leads to zero profit in equilibrium, that is, \( P_tQ_t = \sum_{i=1}^{n_t} p_{it}q_{it} \). Inserting the zero-profit condition into Equation (18) yields the price of final goods as a composite index, into which the price of each input enters symmetrically:

\[
P_t = \left( \sum_{i=1}^{n_t} p_{it}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}.
\]

In period \( t \), firm \( i \) earns a profit at the level of

\[
\pi_{it} = p_{it}q_{it} - w_i l_{it} = P_t^{\frac{1}{\sigma}} q_{it}^{\frac{\sigma-1}{\sigma}} - \beta w_i q_{it} - \alpha w_i,
\]

where \( w_i \) denotes the nominal wage rate in period \( t \). Given \( P_t \) and \( Q_t \), maximizing \( \pi_{it} \) with respect to \( q_{it} \) and then using Equation (18) derives the optimal markup ratio (i.e., the ratio of price to marginal cost) of the \( i \)th input, which is symmetric across varieties and decreases with \( \sigma \):

\[
\frac{p_{it}}{\beta w_i} = \frac{\sigma}{\sigma - 1}.
\]

Free entry condition under monopolistic competition drives the profit down to zero in equilibrium. Plugging Equations (18) and (20) into \( \pi_{it} = 0 \) solves the optimal quantity of each input as a constant:

\[
q_{it} = q_i = \frac{\alpha (\sigma - 1)}{\beta} > 0.
\]
Since firms are symmetric, we obtain the equilibrium number of firms by Equations (16), (17) and (21):

\[ n_t = \frac{M_t L_t}{a \sigma}. \] (22)

Combining Equations (19), (20) and (22) yields the real wage rate (in terms of final goods):

\[ \frac{w_t}{P_t} = \frac{Q_t}{M_t L_t} = \begin{cases} \frac{1}{\kappa L_0^{\sigma-1}} & \text{if } t = 0, \\ \kappa \left[ (1-z)L_t \right]^{\frac{1}{\sigma-1}} & \text{if } t \geq 1 \end{cases}, \quad \kappa \equiv \frac{\sigma - 1}{\beta \alpha^{1+1/\sigma}} > 0, \] (23)

where \( \frac{Q_t}{M_t L_t} \) denotes output per unit of labor, and \( \kappa \) is a constant that decreases with \((\alpha, \beta)\). Equation (23) suggests that the larger the workforce, the higher the contemporary wage rate, which reflects a positive static externality. Also, there is a negative dynamic externality: workers spending more time in the workplace amid the epidemic are less likely to survive, which in turn hurts the economy-wide productivity and earnings in the future under scale economies.

### 3.1 Laissez-faire

In a laissez-faire economy, each living individual takes the real wage rate \( w_t/P_t \) as given and chooses her optimal labor supply as denoted by \( \tilde{L}^N \) for \( t \geq 1 \). It is easy to show that in equilibrium she spends a fraction \( \tilde{L}^N = \frac{1}{1+\varphi} \) of time in the workplace (just as \( L_1^N \) in Section 2) and obtains a utility at the level of \( \tilde{V}^N = V \left( \tilde{L}^N \right) \) for \( t \geq 1 \). Her intertemporal utility can be written as

\[ U = \ln \left( \frac{w_0}{P_0} L_0 \right) + \varphi \ln (1 - L_0) + \frac{\tilde{V}^N}{\rho} \left( 1 - \xi L_0 \tilde{L}_0 \right). \] (24)

Given \( w_t/P_t, L_0, \) and \( \tilde{V}^N \), the optimal labor supply in equilibrium, \( L_0^N \), satisfies

\[ \frac{\xi \tilde{V}^N}{\rho} \left( L_0^N \right)^{1+\varphi} \left( 1 - L_0^N \right) + (1 + \varphi)L_0^N = 1. \] (25)

This equilibrium outcome is similar to that in Lemma 1, namely \( L_0^N < \frac{1}{1+\varphi} = \tilde{L}^N \). Nevertheless, our interpretation becomes richer under economies of scale: a representative individual’s decision to stay longer at home at \( t = 0 \) not only reflects her self-protection in response to an exogenous health crisis but also exhibits pro-cyclical nature of her labor supply. Epidemic-induced decline in the employment and wage rates induce workers to substitute current work with future work, which echoes the prediction of the real business cycle theory.

### 3.2 Optimal labor supply under lockdown policy

Before vaccines or therapies for COVID-19 become available, many countries have reacted by implementing non-medical interventions to contain the spread of the virus. A notable and effective measure is to practice social distancing and to restrict human mobility. It is estimated that 40% of the global workforce lives in countries with mandatory closures in early 2020 (ILO, 2021). In this section, we consider that the government takes emergency containment measures by choosing the length of working time during the epidemic without referring to other policies such as government borrowing and transfer (i.e., \( X_t = 0 \)). In other words, the government serves as a benevolent social planner, who decides on labor supply under utilitarianism until life returns to normal.

Each individual’s labor supply in period \( t \geq 1 \) will be \( \tilde{L}^N = \frac{1}{1+\varphi} \) in equilibrium, which is the same with \( L_1^N \) in Section 2.1. We combine Equations (23) and (24) to write the social welfare as
\[ U = \ln \left( \kappa L_0^{\sigma} \right) + \varphi \ln (1 - L_0) + \frac{1 - \xi L_0^{1+\lambda}}{\rho} \left[ \ln \frac{(1 - \xi L_0^{1+\lambda}) \rho^{\sigma-1}}{(1 + \varphi)^{\sigma-1}} + \varphi \ln \frac{1}{1 + \varphi} \right]. \]

Denote the solution to the welfare maximization problem as \( L_0^S \), where \( S \) represents “social planner”. The social planner’s choice may be different from individually rational choice, as follows:

\[
\frac{1}{L_0^S} - \frac{\varphi}{1 - L_0^S} = \frac{\xi(1 + \lambda)(L_0^S)^\lambda}{\rho(\sigma - 1)} \ln \left( \frac{1 - \xi (L_0^S)^{1+\lambda}}{(1 + \varphi)^{\sigma+\varphi(\sigma-1)}} \right) + \frac{-1}{(\sigma - 1)L_0^S} + \frac{\xi(1 + \lambda)(L_0^S)^\lambda}{\rho(\sigma - 1)}. \tag{26}
\]

Based on Equation (26), we establish the following proposition:

**Proposition 4** The government instructs individuals to work less during the epidemic \( (L_0^S < \tilde{L}^N) \) if and only if

\[
\frac{\kappa^{\sigma-1} \rho^{\varphi(\sigma-1)} \left[ 1 - \xi (L_0^S)^{1+\lambda} \right]}{(1 + \varphi)^{\sigma+\varphi(\sigma-1)}} > \frac{\rho}{\xi(1 + \lambda)(L_0^S)^\lambda} - 1. \tag{27}
\]

**Proof** See Appendix. ■

Proposition 4 demonstrates that \( L_0^S < \tilde{L}^N \) if and only if the right-hand-side of Equation (26) is positive, namely, condition (Equation 27) holds. There are three forces shaping the government’s stay-at-home order to fight the epidemic. The first term is positive, which implies that the government tends to restrict labor supply when an individual’s staying in the workplace increases her chance of getting infected by others and infecting others. Bethune and Korinek (2020) estimate that the social cost including infection externalities is more than three times larger than the cost of an infection perceived by individuals. To internalize the effect of the individual labor supply on public health, the social planner shortens the working time, which echoes Eichenbaum et al. (2021) viewpoint that authorities should carry out large-scale containment measures in the presence of infection externalities. Also, Borri et al. (2021) find that the intensity of lockdown is associated with a significant reduction in mortality by COVID-19 in Italy.

The second term is negative, meaning that the benevolent government needs to encourage labor supply despite the epidemic. Earlier empirical studies have provided some evidence of the strategic complementarity between hours worked and wages in the outset of the COVID-19 pandemic. For example, Cajner et al. (2020) find that U.S. companies have cut wages for about 10% of continuing employees and forgone regularly scheduled pay raises for the others. Grigsby et al. (2021) show that the pandemic recession has led to frequent wages cuts in the U.S., as occurred throughout the Great Recession. Aina et al. (2021) find that the pandemic has negatively affected the wages of the entire Italian workforce by June 2020. As wage rates increase with the total labor supply under scale economies, market failure arises as the laissez-faire labor supply falls below the socially optimal level. The final term captures an intertemporal externality—the greater economic exposure to health risk causes more deaths, which in turn reduces the size of workforce and impairs the average labor productivity after the epidemic. This externality effect has been evidenced in empirical literature on historical pandemics. For example, Guimbeau et al. (2020) find that respiratory deaths caused by the 1918 influenza lead to a fall in Brazil’s agricultural output per worker in 1940. Jinjarak et al. (2022) estimate that the average fatality rate of the 1968 H3N2 influenza is associated with a 1.9% decline in long-term worker productivity across 52 countries. The dynamic pecuniary externality is positive, showing that the government is inclined to choose the labor supply at a level below the laissez-faire level.

Proposition 4 examines the net effect of the external benefit and the two external costs of labor supply amid the epidemic. Equation (27) implies that external costs dominate when \( \rho \) is sufficiently small and \( \kappa \) is sufficiently large. Intuitively, a strong desire to pursue the future well-being (small \( \rho \)) motivates individuals to save themselves by shortening hours worked during the epidemic. All else being equal, a more cost-effective production technology (larger \( \kappa \) due to smaller \( \alpha \) and \( \beta \)) means a higher...
level of income and consumption in every period, which increases the value of life (i.e., the opportunity cost of dying at the end of period 0). Empirically, Brinca et al. (2021) estimate that most sectors in the US were subject to negative labor supply shocks for March and April 2020 that featured the controlled shutdown.

3.3 Fiscal stimulus: Exogenous government borrowing

To overcome the market failure resulting from the three externalities may necessitate government intervention. Autocratic regimes can rely on forceful lockdowns, curfews, and contact tracing to restrict travel and curb virus transmission. However, democratic governments find it difficult to impose mandatory orders, which are often considered to be a violation of freedom of movement (Frey et al., 2020). One of important and common tools that many policymakers have at their disposal is the tax and social security systems. Below, we present a model in which the government uses fiscal incentives to secure the welfare and safety of its people.

The strategic interactions between individuals and the government proceed in two steps. The government moves first to announce the level of borrowing $B$ and faces the following intertemporal budget:

$$B = \sum_{t=1}^{\infty} \frac{(1 - z)T_t}{(1 + r)^t} \quad \Leftrightarrow \quad T = \frac{rB}{1 - \xi L_0 L_0^\xi}, \quad (28)$$

where $r$ is the intertemporal interest rate. Put it another way, everyone receives a transfer payment $B$ during the epidemic, and only the survivors make an installment payment $T$ in future periods. Upon observing the fiscal policy, each individual optimally chooses her labor supply $L_t$ for all $t$. By backward induction, we first examine each individual's optimal choice of the post-epidemic labor supply choices given the fiscal policy. Taking the first order condition of $V_t = \ln \left( \frac{u_t L_t}{P_t} - T \right) + \varphi \ln (1 - L_t)$ with respect to $L_t$, and then using Equations (2) and (23) yields an implicit expression of $\tilde{L}^F$:

$$\tilde{L}^F = \frac{1}{1 + \varphi} + \frac{\varphi rB}{\kappa(1 + \varphi)(1 - \xi L_0 L_0^\xi)} \left( \tilde{L}^F \right)^{\frac{1}{\xi}}. \quad (29)$$

In equilibrium, an individual spends a fraction $H_t = \tilde{H}^F = 1 - \tilde{L}^F$ of time at home and attains a utility at the level of $V_t = \tilde{V}^F = V \left( \tilde{L}^F \right)$ for $t \geq 1$. Given $B > 0$, it is straightforward to infer that $\tilde{L}^F > \tilde{L}^N$: fiscal stimulus induces workers to increase their labor supply after the epidemic.

Next, we discuss the optimal time allocation in period 0. By using Equations (1), (2) and (5), we rewrite the individual intertemporal utility as

$$U = \ln \left( \frac{u_0 L_0}{P_0} + B \right) + \varphi \ln (1 - L_0) + \frac{\tilde{V}^F}{\rho} \left( 1 - \xi L_0 L_0^\xi \right).$$

Given that $B > 0$, an individual’s choice of working time depends on her belief about the aggregate employment level. If the prevailing belief is that other individuals spend the whole crisis period at home, then it will not be attractive for her to go to work by herself. This is because in the economy consisting of a continuum of individuals, when only one worker goes to work during the epidemic, the aggregate employment is zero ($L_0 = 0$), and consequently, the wage rate will be zero (Equation 23). The belief supporting the equilibrium that rational individuals choose not to work during the epidemic is self-fulfilling. We present this Nash equilibrium in the following proposition:

**Proposition 5** For $B > 0$, under the belief that nobody works during the epidemic, individuals choose not to work in equilibrium.

The belief in Proposition 5 is self-fulfilling only if fiscal stimulus package is released ($B > 0$). In this Nash equilibrium, workers choose the corner solution $L_0 = 0$, always stay home during the epidemic ($H_0 = 1$), and live only on transfers ($C_0 = B$), while all factories shut down ($n_0 = 0$). Consequently, everyone survives the epidemic so that the population size remains unaffected ($z = 1$). This situation is presumably a prisoner’s dilemma, particularly when the government transfer is meager (small $B$).
In contrast, the absence of government transfers \((B = 0)\), coupled with strict home isolation \((L_0 = 0)\), causes extreme disutility to everyone, which therefore does not constitute an equilibrium.

One way of eliminating the zero-labor supply equilibrium is to relax the assumption that the government of this small open economy borrows from abroad. Specifically, let’s instead consider a closed economy where the government borrows from its own citizens, and a fraction of citizens get a higher pay than the others and are willing to purchase government bonds during the epidemic. In this case, at least the rich have to work for wages in the epidemic era.

If people believe that others will go to work \((L_0 > 0)\), they expect to earn a positive wage rate. Given the real wage rate, the average labor supply, and the future maximal utility, each individual maximizes her intertemporal utility by choosing her labor supply in period 0, \(L_0^F\), in accordance with the following first order condition:

\[
\frac{\kappa L_0^F \frac{1}{\sigma - 1}}{\kappa L_0^F \frac{1}{\sigma - 1} L_0 + B} - \frac{\varphi}{1 - L_0} = \frac{\xi Y^F \frac{1}{\beta - 1}}{\rho L_0}.
\]

By symmetry, we have \(L_0 = \tilde{L}_0\). Clearly, \(L_0^F\) is influenced by \(\tilde{Y}^F\), which in turn depends on \(\tilde{L}^F\). Combining Equations (29) and (30) solves the labor supply in each period, as summarized below:

**Proposition 6** Given \(B > 0\), \((L_0^F, \tilde{L}^F)\) are determined by

\[
(1 + \varphi)\tilde{L}^F - \frac{\varphi B}{\kappa} \left[1 - \xi (L_0^F)^{1+\lambda}\right]^{\frac{1}{\sigma - 1}} (\tilde{L}^F)^{\frac{1}{\sigma - 1}} = 1,
\]

\[
\frac{\varphi}{1 - L_0^F} + \frac{\xi Y^F}{\rho} \frac{L_0^F}{(L_0^F)^{1+\lambda}} = \frac{\kappa (L_0^F)^{\frac{1}{\sigma - 1}}}{\kappa (L_0^F)^{\frac{1}{\sigma - 1}} + B}.
\]

where \(\tilde{Y}^F\) is a function of \((L_0^F, \tilde{L}^F; B)\):

\[
\tilde{Y}^F = \ln \left[\kappa \left[1 - \xi (L_0^F)^{1+\lambda}\right]^{\frac{1}{\sigma - 1}} (\tilde{L}^F)^{\frac{1}{\sigma - 1}} - \frac{r B}{1 - \xi (L_0^F)^{1+\lambda}}\right] + \varphi \ln \left(1 - \tilde{L}^F\right).
\]

**Proof** See Appendix.

Proposition 6 characterizes the optimal choices of labor supply during and after the epidemic in response to the (exogenous) government borrowing. The nonlinear system of Equations (31) and (32) may have multiple solutions to \((L_0^F, \tilde{L}^F)\), which are associated with different social welfare levels. To the extent that the economy displays several Pareto-ranked Nash equilibria, coordination problems will arise.

To better visualize the equilibrium solutions and their economic impacts, we perform a numerical simulation. Let us first assign values to the three parameters featuring scale economies in the production. Given that the initial population size is normalized to one, we have \(\alpha = 0.0001\) and \(\beta = 0.0003\): these small numbers to the units of labor hired before and during production to ensure a sufficiently large number of monopolistically competitive firms. We also follow Devereux et al. (1996) and Faria-e-Castro (2021) to set the elasticity of substitution as 6, which is equivalent to a markup of 20%. We equate \(\varphi\) to 1 such that a half of time is spent at home under laissez-faire when life returns to normal. The discount rate is set as 5%. As it is lower than the intertemporal interest rate \((r = 10\%)\), individuals choose not to borrow in normal times, which coincides with our model’s assumption. The final two parameters \((\xi, \lambda)\) depict features of the epidemic. In particular, \(\lambda = 1\) means that \(L_0\) and \(L_0^F\) have a symmetric impact on the mortality rate \(z\).

Based on the above parameter values (as summarized in Table 1), we obtain two interior solutions to \((L_0^F, \tilde{L}^F)\) for any level of \(B \in [4125, 4525]\). For given borrowing \(B\), there coexist two equilibria: a “suppression” equilibrium that involves a very small \(L_0^F\), and a “mitigation” equilibrium that leads to a relatively large \(L_0^F\) (see a further discussion by Piguillem & Shi, 2022). Table 2 reports some selected values of government borrowing and the corresponding outcomes.
We explain our findings taking $B = 4125$, for example. One equilibrium is to allocate 0.61% of time (1 h per week) to outdoor activities amid the epidemic and 51.92% of time (87 h per week) thereafter, which can be viewed as a voluntary lockdown. The recovery sees the number of firms increasing from 10 to 865 and consumption growing from 4151.83 to 5165.35, but two per million of lives are lost. As for the other equilibrium, workers spend 4.81% of time (8 h per week) in the workplace during the epidemic so that each of them consumes 4445.78 units of goods supplied by 80 firms at the cost of 1.39 deaths per ten thousand people. This outcome yields a greater social welfare. Comparing these two solutions suggests the government’s balancing between the fatality cost of the disease and the financial cost of lockdown. As Asukai et al. (2021) note, any policy measure developed amid the epidemic should be evaluated with a view toward the broader benefits of restoring production activities. Despite the stark contrast in economic performance (e.g., labor supply, industrial specialization, and private consumption) during the epidemic, the two equilibria share a similar post-epidemic outlook. Furthermore, with a rise in government borrowing, such a contrast between two solutions will be less marked.

In sum, Table 2 illustrates that a given level of government borrowing generates two equilibria with different welfare levels, and the equilibrium with a larger $L_0$ will be socially preferable. Expectation determines which equilibrium prevails: lockdown seems to be the “bad” equilibrium, and the “good” equilibrium may not emerge without coordination. Improving social welfare requires the government to lead an active role in coordinating way out of bad equilibrium trap through labor market interventions. For example, the government can announce the number of business closures or the length of working time on television and social media platforms. In light of the coordination problem, fiscal stimulus will be more effective if it is carried out jointly with lockdown policies. This policy implication is also provided by Deb et al. (2021), who emphasize the dependence of fiscal policy effectiveness on the intensity of containment measures.

We proceed to examine how the changes in government borrowing influence the economy. To quantify the effects of $B$ on $(L_0, \tilde{L})$, we undertake a simulation based on the previous parameter values and focus on the “good” equilibrium when there exist multiple equilibria. We also simulate the relationship between $B$ and other macro variables such as $(n_0, \tilde{n}, C_0, \tilde{C}, z, U)$.

Figure 1 offers a graphical illustration of our simulation results.
Panel (a) plots the changing length of working time amid the epidemic in response to the changes in government borrowing. If fiscal relief is not put in place, individuals choose to allocate 26.1% of time to working. The length of their working time during the epidemic decreases with the level of borrowing and falls to zero as the borrowing exceeds 4525. Holding other things constant, the mortality rate exhibits a downward trend, as shown in Panel (g). Panel (b) illustrates that the more the government
subsidizes, the longer the individuals stay in the workplace after the epidemic. Overall, our findings from the first two panels echo the insight of the real business-cycle theory, which posits that workers intertemporally substitute their labor supply in response to an employment shock (e.g., Barro & King, 1984; Kydland & Prescott, 1982).

Panels (c) and (d) graph the number of active firms during and after the epidemic at various levels of borrowing. The patterns look alike to those in panels (a) and (b). Under laissez-faire (i.e., $B = 0$), there will be 435 firms during the epidemic and 830 firms thereafter. Yet if the government borrows 4600 units of goods, all firms will be closed during the epidemic and 869 firms reopen thereafter.

Panel (e) plots the relationship between $B$ and $C_p$, which has a positive slope in general. The curve displays an upward trend for $B < 4510$ and reverses for $B \in [4510, 4525]$. In other words, when $L^f_0$ takes the interior solution, an individual's consumption during the epidemic achieves its maximum at $B = 4510$; excessive government borrowing depresses labor supply and earnings as the lost wages are not fully compensated by the received benefits. As the government ramps up borrowing ($B > 4525$), individuals stop working ($L^f_0 = 0$) and live only on borrowing ($C^f_0 = B$). If the fiscal package is very substantial, we may observe a hike in personal disposable income and consumption during the crisis period.

In panel (f), we show an inverse relationship between $B$ and $\tilde{C}^f$ such that rising public debt comes with the cost of future consumption loss. Although the increased borrowing prompts individuals to work harder in the future and creates more job opportunities, it does not mean better prospects for living standards. This is because today's large public debt translates into tomorrow's tax hike and consequently a lower disposable income (e.g., Barro, 1979).

Panel (h) shows that the social welfare curve has a hump shape. Starting from 164.60 at $B = 0$, the social welfare peaks (164.79) at $B = 2211$ (equivalent to a debt-to-GDP ratio of 194.22%) and then falls to 164.56 at $B = 5000$. The key message is that the optimal debt should be moderate. With too small borrowing, individuals have to work during the epidemic for survival, which gives rise to a high mortality rate and consequently undermines long-term earnings. With overly aggressive borrowing, individuals are provided with fiscal relief for the epidemic at the future expense of heavy tax obligations and consumption losses. Finally, we compute that the social planner's solution in Section 3.2 achieves a welfare level of 164.64 based on the same configuration. Comparing this outcome with Panel (h) suggests that $B \in (240, 4410)$ is socially preferable to the lockdown policy. This is largely because fiscal support has an advantage in smoothing consumption.

### 3.4 Optimal government borrowing

We have so far examined individual behaviors and macroeconomic performance during the epidemic given the fiscal policy. In this subsection, we endogenize the policy and explore the design of the optimal government borrowing and financial remedy. In Figure 1(h), we have demonstrated that $B^* = 2211$ under certain configuration. We now extend our quantitative analysis to examine more properties of the optimal borrowing.

Figure 2 plots the numerical comparative statics of $B^*$ with respect to each parameter of our model. Panels (a) and (b) show that the optimal borrowing level decreases with the two measurements of production costs ($\alpha, \beta$). Holding other things unchanged, a more cost-effective production technology (smaller $\alpha$ and $\beta$) means a higher income in every period. The benevolent government that helps individuals to safely secure high levels of future income and consumption tends to provide massive amounts of fiscal support in exchange for people staying at home during the epidemic. This outcome is in line with Benmelech and Tzur-Ilan's (2020) empirical finding that high-income countries implement fiscal policies on a larger scale than the low-income countries.

The negative relationship between $\sigma$ and $B^*$ in Panel (c) can be explained in a similar vein. With $\sigma$ being small, firms yield a large markup of price over marginal cost in a highly specialized market (see Equations 20 and 22). To achieve post-epidemic economic prosperity with large markups and a high degree of specialization requires the preservation of a healthy workforce with the aid of aggressive fiscal relief policy.

The intuition behind the patterns in panels (d) and (e) are straightforward. The government experiences less pressure to borrow if individuals enjoy staying home and if they are patient. In panel (f), a higher interest rate makes it more costly to borrow, which negatively affects the government's ability to pursue expansionary fiscal policies. Benmelech and Tzur-Ilan (2020) show that countries with ultra low interest rates at the beginning of the pandemic deploy larger fiscal spending mainly in the form of government guarantees. Panel (g) shows that the government tends to offer generous transfer payments if the disease is contagious and deadly. Panel (h) demonstrates a negative relationship between $\lambda$ and $B^*$. Given $I_0 \in (0, 1)$, a smaller $\lambda$ indicates a larger infection externality effect. If social interactions at work pose a serious threat to health, it is socially desirable to reduce work activities while maintaining workers' livelihoods through borrowing.
Note that tax revenues can be raised in a lump-sum fashion (as formalized in our model) and by a proportional tax, which is distortionary. If we instead assume a proportional income tax, then we would discuss the substitution effect and the income effect associated with higher taxes. On the one hand, an increase in taxes induce workers to substitute leisure for work after the epidemic. On the other hand, an increase in taxes lowers workers' disposable income, which in turn stimulates them to work.
harder to raise gross earnings. If the substitution effect dominates the income effect, then raising taxes is expected to discourage labor supply. This would limit the extent to which the borrowing and transfers are desirable. Our model setup in Section 3, which allows individuals to repay their epidemic-era debt through installment payment over infinite periods, partly mitigates the distortional effect of high-income taxes on the labor supply in each post-epidemic period. Overall, the consideration of a proportional income tax would not qualitatively changing the main results.

4 | CONCLUSION

The COVID-19 outbreak has severely disrupted the global economy, caused tragic illnesses and deaths, and triggered widespread firm closures and hundreds of millions of layoffs (ILO, 2021). To halt the spread of the virus and limit the economic fallout from the crisis, governments around the world have activated fiscal policy measures on an unprecedented scale. However, massive public support has left them with record debt burdens and fiscal challenges going forward. This paper develops a model to examine the fiscal responses to the pandemic in the form of borrowing against the future and providing transfers equally to workers who suffer economic hardship. We suggest that fiscal relief not only helps to reduce hours worked to prevent infections at the workplace but also facilitates consumption smoothing. We also characterize the condition under which the fiscal intervention can improve social welfare as well as the optimal size of government debt.

We then extend the model to incorporate scale economies in production in an infinite-horizon economy so that there are three externalities associated with the epidemic, namely infection externality, static pecuniary externality, and dynamic pecuniary externality. In our model, individuals rationally react to the health risk by reducing labor supply and increasing home confinement during the epidemic. As they fail to account for the external health benefit and the aggregate demand effect of their self-protection efforts, their choices may be inefficient. If the welfare-maximizing government directly plans hours worked without resorting to fiscal policies, it will constrain working time if and only if the dynamic pecuniary externality, coupled with the infection externality, dominates the static pecuniary externality. Besides, fiscal relief can improve social welfare but may not be a once-and-for-all solution. The rise of multiple Pareto-ranked Nash equilibria implies that the government should coordinate a way out of the low-welfare equilibrium trap by, for example, broadcasting advisories on working hours on television and social media.

We obtain several results through two numerical analyses. The first one examines the effects of an exogenous fiscal policy on labor supply, market specialization, private consumption, and social welfare amid and after the crisis. A rise in government borrowing effectively reduce working time during the epidemic, and accordingly, lowers the wage rate and causes more firms to exit under economies of scale. In particular, a sufficiently high borrowing level leads to a “voluntary” complete lockdown. People’s reduced exposure to the epidemic mitigates the death rate and promotes a healthy labor force, thereby enhancing the long-term productivity. Individuals optimally substitute future labor supply for current labor supply. Yet paying off a large public debt implies a future tax hike, which prompts individuals to cut back private consumption spending after the epidemic. The optimal amount of government borrowing and transfer payments strikes a balance between present and future social welfare. The second exercise explores the optimal fiscal responses to some variations of the benchmark parameter configuration. We show that under some conditions, the optimal borrowing level increases with production markups, the degree of viral transmission, and disease severity, but it decreases with interest rates and production costs.

ACKNOWLEDGMENTS
I am grateful to the two anonymous reviewers and the editor-in-charge, Davide Dragone, for valuable comments and suggestions. I also acknowledge the financial support by Macau University of Science and Technology (FRG-021-009-MSB). The usual disclaimer applies.

CONFLICT OF INTEREST
Author has no conflicts of interest to declare.
DATA AVAILABILITY STATEMENT
Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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ENDNOTES
1 See “What’s in the $2 trillion coronavirus relief package?” by Committee for a Responsible Federal Budget and “Federal debt: Total public debt as percent of gross domestic product” by U.S. Office of Management and Budget and Federal Reserve Bank of St. Louis, January 31, 2022.
2 See “Policy responses to COVID-19” by the International Monetary Fund at https://www.imf.org/en/Topics/imf-and-covid19/Policy-Responses-to-COVID-19.
3 See the discussion of pecuniary externalities in, for instance, Murphy, Shleifer, and Vishny (1989).
4 Empirical studies have found supportive evidence for these two externality effects. See, for example, Aina et al. (2021), Cajner et al. (2020), Jinjarak et al. (2022), Grigsby et al. (2021), Guimbeau et al. (2020).
5 Atalay et al. (2021) present empirical evidence that Australia reported fewer deaths in 2020 when more people are laid off.
6 We focus on the utilitarian optimum for simplicity, although the optimal lockdown strategy may be designed under a different social welfare criterion such as ex post egalitarianism (see Pesteau & Ponthiere, 2022).
7 See the discussion of consumption smoothing in Romer (2012).
8 We follow Boucekkine and Laffargue (2010) to model the epidemic as a one-period adverse shock that generates permanent effects on the population size.
9 For $B < 4125$, there are also two solutions, with one resulting in $n_L^F < 10$. If this solution is ruled out for violation of the assumption in Section 2.3 that $n$ is large under monopolistic competition, the other will be the unique interior solution. Therefore, there will be no coordination problem. For $B > 4525$, there is no interior solution satisfying Equations (31) and (32) simultaneously. Accordingly, the only (corner) solution to $(L_0^F, L^F)$ is $L_0^F = 0$ and $L^F \in (0, 1)$ satisfies $(1 + \varphi) L^F - \frac{\sigma}{\varphi} B (L^F) \frac{1}{1+\varphi} = 1$ by Equation (31).
10 This numerical outcome is in accord with many empirical findings. For instance, Almeida et al. (2021) find that discretionary fiscal policies in the EU member states generate a significant cushioning effect of protecting households against disposable income loss. Garza Casado et al. (2020) estimate the U.S. local spending would decrease if the Federal Pandemic Unemployment Compensation (FPUC) supplement was not carried out.
11 Hall (2018) finds that the typical markup ratio is in the U.S. between 1.12 and 1.38 during the period 1988–2015, which means that $\sigma \in [3.63, 9.33]$ during the past few decades.

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APPENDIX

Mathematical Proofs of Propositions

PROOF OF LEMMA 1 In equilibrium, $L_0^N$ and $L_1^N$ satisfy Equation (7), which can be rearranged as

\[ \frac{1}{L_0^N} - \frac{\varphi}{1 - L_0^N} = \delta (L_0^N) \cdot V_1^N > 0, \quad \frac{1}{L_1^N} - \frac{\varphi}{1 - L_1^N} = 0. \]  

(A1)

In follows that $L_0^N < L_1^N$.

PROOF OF PROPOSITION 1 Rewrite the intertemporal utility in Equation (3) as

\[ U = \ln(\omega L_0 + B) + \varphi \ln(1 - L_0) + \delta \left[ 1 - \xi L_0 \left( \frac{L_0}{L_0^F} \right) \right] \ln \left( \frac{\omega L_1 - \frac{(1 + r) B}{1 - \xi L_0 L_0^F}}{1 - \frac{\varphi}{1 - L_1}} \right) + \varphi \ln(1 - L_1). \]

Taking the first order conditions of $U$ with respect to $L_1$ and $L_0$ and using $L_0 = L_0^F$ obtains

\[ \frac{\partial U}{\partial L_1} = \delta \left[ 1 - \xi L_0 \left( \frac{L_0}{L_0^F} \right) \right] \ln \left( \frac{\omega L_1 - \frac{(1 + r) B}{1 - \xi L_0 L_0^F}}{1 - \frac{\varphi}{1 - L_1}} \right) = 0 \]

\[ \Rightarrow \omega L_1 - \frac{(1 + r) B}{1 - \xi \left( \frac{L_0^F}{L_0} \right)^{1+\lambda}} = \frac{\omega \left( 1 - L_1^F \right)}{\varphi}, \]  

(A2)

\[ \Rightarrow \left[ (1 + \varphi) L_1^F - 1 \right] \left[ 1 - \xi \left( \frac{L_0^F}{L_0} \right)^{1+\lambda} \right] = \frac{(1 + r) \varphi}{\omega} B, \]

\[ \frac{\partial U}{\partial L_0} = \frac{\omega}{\omega L_0 + B} - \frac{\varphi}{1 - L_0} - \delta \xi \left( \frac{L_0}{L_0^F} \right)^{\lambda} \ln \left( \frac{\omega L_1 - \frac{(1 + r) B}{1 - \xi L_0 L_0^F}}{1 - \frac{\varphi}{1 - L_1}} \right) + \varphi \ln(1 - L_1) \]

\[ + \delta \left[ 1 - \xi L_0 \left( \frac{L_0}{L_0^F} \right) \right] \frac{(1 + r) B}{1 - \xi \left( \frac{L_0^F}{L_0} \right)^{2+\lambda}} \xi \left( \frac{L_0}{L_0^F} \right)^{\lambda} = 0 \]

(A3)

\[ \Rightarrow \frac{1}{L_0^F} \left( \frac{\omega}{\omega L_0^F + B} - \frac{\varphi}{1 - L_0^F} \right) - \delta \xi \left[ \frac{\ln(\omega L_1 - \frac{(1 + r) B}{1 - \xi L_0 L_0^F})}{\varphi} + (1 + \varphi) \ln(1 - L_1^F) + \left( \frac{\varphi L_1^F}{1 - L_1^F} - 1 \right) \right], \]

which can be rearranged as Equations (9) and (10).
Totally differentiating Equations (A2) and (10) with respect to \(B, L_0^F,\) and \(L_1^F\) yields

\[
\begin{align*}
\Rightarrow & \left[1 - \xi(L_0^F)^{1+\lambda} \right] (1 + \varphi) dL_1^F + \left[1 + \varphi L_1^F \right] \left[ -\xi(1 + \lambda)(L_0^F)^\lambda \right] dL_0^F = \frac{(1 + r)\varphi}{\omega} dB \\
\Rightarrow & \frac{1 + \varphi}{(1 + \varphi)L_1^F - 1} \frac{dL_1^F}{dB} - \frac{\xi(1 + \lambda)(L_0^F)^\lambda}{1 - \xi(L_0^F)^{1+\lambda}} \frac{dL_0^F}{dB} = \frac{1}{B} \\
\Rightarrow & \frac{1 + \varphi}{(1 + \varphi)L_1^F - 1} \frac{dL_1^F}{dB} = \frac{\xi(1 + \lambda)(L_0^F)^\lambda}{1 - \xi(L_0^F)^{1+\lambda}} \frac{dL_0^F}{dB} = \frac{1}{B}.
\end{align*}
\]  

(A4)

\[
\begin{align*}
\frac{\delta \xi}{1 + \varphi} + \frac{\varphi}{(1 - L_1^F)^2} \left[ \frac{-1 - \xi(L_0^F)^{1+\lambda}}{L_0^F} \right] \frac{dL_1^F}{dB} &= \frac{-\lambda}{\omega \left( L_0^F \right)^{1+\lambda}} \left( \frac{\omega}{\omega L_0^F + B} - \frac{\varphi}{1 - L_0^F} \right) \frac{dL_0^F}{dB} \\
+ & \frac{1}{(1 - L_1^F)^2} \left[ \frac{-\omega \left( \omega d L_0^F + dB \right)}{(L_0^F)^{1+\lambda}} + \frac{-\varphi d L_0^F}{(1 - L_0^F)^2} \right] \\
\Rightarrow & \frac{\delta \xi}{1 - L_1^F} \left[ \frac{-\omega}{\omega L_0^F + B} + \frac{\varphi}{1 - L_0^F} \right] \frac{dL_1^F}{dB} = \lambda \left( \frac{\varphi}{1 - L_0^F} - \frac{\omega}{\omega L_0^F + B} \right) \frac{dL_0^F}{dB} \\
& \frac{-\frac{\omega}{\omega L_0^F + B} + \frac{\varphi}{1 - L_0^F}}{\left( \omega L_0^F + B \right)^2} \frac{dL_0^F}{dB} = \frac{-\frac{\omega}{\omega L_0^F + B} + \frac{\varphi}{1 - L_0^F}}{\left( \omega L_0^F + B \right)^2} \frac{dL_0^F}{dB} \\
\Rightarrow & \frac{\delta \xi}{\omega (1 + \varphi) L_1^F - 1} \frac{dL_1^F}{dB} = \frac{\left( \omega + \lambda \right) L_0^F + \lambda B}{\left( \omega L_0^F + B \right)^2} + \frac{\varphi \left( 1 + \lambda \right) L_0^F - \lambda}{\omega (1 - L_0^F)^2} \frac{dL_0^F}{dB} \\
& \frac{-\frac{\omega}{\omega L_0^F + B} + \frac{\varphi}{1 - L_0^F}}{\left( \omega L_0^F + B \right)^2} \frac{dL_0^F}{dB} = \frac{-\frac{\omega}{\omega L_0^F + B} + \frac{\varphi}{1 - L_0^F}}{\left( \omega L_0^F + B \right)^2} \frac{dL_0^F}{dB} \\
\Rightarrow & \frac{1 + \varphi}{\omega (1 - L_0^F)^2} = \frac{1}{\omega (1 - L_0^F)^2}.
\end{align*}
\]  

(A5)

By combining Equations (A4) and (A5), we solve

\[
\frac{dL_1^F}{dB} = \frac{\omega}{\left( \omega L_0^F + B \right)^2} \frac{dL_0^F}{dB} = \frac{\left( \omega + \lambda \right) L_0^F + \lambda B}{\left( \omega L_0^F + B \right)^2} + \frac{\varphi \left( 1 + \lambda \right) L_0^F - \lambda}{\omega (1 - L_0^F)^2} \frac{dL_0^F}{dB}.
\]  

(A6)

\[
\frac{dL_1^F}{dB} = \frac{\left( \omega + \lambda \right) L_0^F + \lambda B}{\left( \omega L_0^F + B \right)^2} + \frac{\varphi \left( 1 + \lambda \right) L_0^F - \lambda}{\omega (1 - L_0^F)^2} \frac{dL_0^F}{dB}.
\]  

(A7)

where the Hessian determinant, \(\Delta,\) is positive at the optimum, and the numerator of the right-hand-side of Equation (A7) is positive if and only if

\[
\begin{align*}
\phi & \left( 1 + \lambda \right) L_0^F - \lambda > 0, \\
\phi & \left( 1 + \lambda \right) L_0^F - \lambda \left( \omega + \lambda \right) L_0^F - \lambda > 0, \\
\phi & \left( 1 + \lambda \right) L_0^F - \lambda > 0.
\end{align*}
\]  

(A8)

which can be rearranged as Equation (11).
Proof of Proposition 2

(i) By using Equations (5), (9) and (A2), we write the difference between $C_i^F$ and $C_i^N$ as below:

$$C_i^F - C_i^N = \left[ \omega L_i^F - \frac{(1 + r)B}{1 - \xi(L_0^F)^{1+\lambda}} \right] - \omega L_i^N = -\frac{(1 + r)B}{1 - \xi(L_0^F)^{1+\lambda}} (1 + \varphi) < 0, \quad (A9)$$

(ii) Given $\frac{\partial L_i^F}{\partial B} < 0$ by Proposition 1, combining Equation (5) with Equation (A2) obtains that in equilibrium,

$$\frac{C_0^N}{C_1^N} = \frac{\omega L_0^N}{\omega L_1^N} = (1 + \varphi)L_0^N, \quad \frac{C_0^F}{C_1^F} = \frac{\omega L_0^F + B}{\omega L_1^F - T} = \frac{\varphi (L_0^F + B/\omega)}{1 - L_1^F}. \quad (A10)$$

Therefore, $\frac{C_i^F}{C_i^N} > \frac{C_0^N}{C_1^N}$ if and only if Equation (12) holds.

Proof of Proposition 3 Differentiating Equation (13) with respect to B and then using Equations (10) and (A4) obtains

$$\frac{\partial U}{\partial B} = \frac{1}{\omega L_0^F + B} \left( \frac{\partial L_0^F}{\partial B} + 1 \right) - \frac{\varphi}{1 - L_0^F} \frac{\partial L_0^F}{\partial B} - \delta \left[ (1 + \varphi) \ln (1 - L_1^F) + \ln \frac{\omega}{\varphi} \right] (-\xi)(1 + \lambda)(L_0^F)^\lambda \frac{\partial L_0^F}{\partial B}$$

$$\quad + \delta(1 + \varphi) \left[ 1 - \xi(L_0^F)^{1+\lambda} \right] \frac{\partial L_1^F}{\partial B} + \frac{1}{\omega L_0^F + B} \left( \frac{\varphi}{1 - L_1^F} - \frac{\omega}{\omega L_0^F + B} \right) \frac{\partial L_0^F}{\partial B} \quad (A11)$$

Inserting $B = 0$ into the above expression and then using Equation (7) yields

$$\frac{\partial U}{\partial B} \bigg|_{B=0} = \frac{1}{\omega L_0^N} - \frac{(1 + r)\varphi}{\omega} \frac{\delta}{1 - L_1^N} - \lambda \left( \frac{1}{L_0^N} - \frac{\varphi}{1 - L_0^N} \right) \frac{\partial L_0^F}{\partial B}$$

$$\quad = \frac{1}{\omega} \left[ \frac{1}{L_0^N} - \delta(1 + r)(1 + \varphi) + \delta \xi(L_0^N)^\lambda \frac{\partial L_0^F}{\partial B} \right]. \quad (A12)$$

where the second term is always positive as demonstrated in Equation (A6), while the first term is positive if $\delta(1 + r)(1 + \varphi) < 1 < \frac{1}{\tau_0^N}$. For $\frac{\partial U}{\partial B} \bigg|_{B=0} > 0$, we have $B^* > 0$.

Proof of Proposition 4 By Equation (26) and $\tilde{L}^N = \frac{1}{1 + \varphi}$, we have $L_0^S < \tilde{L}^N$ if and only if

$$\frac{\xi(1 + \lambda)(L_0^S)^\lambda}{\rho(\sigma - 1)} - \frac{\kappa^{\sigma - 1} \phi^{(\sigma - 1)\varphi} (1 - \xi(L_0^S)^{1+\lambda})}{(1 + \varphi)^{\sigma + (\sigma - 1)\varphi}} - \frac{1}{(\sigma - 1)L_0^S} + \frac{\xi(1 + \lambda)(L_0^S)^\lambda}{\rho(\sigma - 1)} > 0, \quad (A13)$$
which can be rearranged as Equation (27).

**Proof of Proposition 6** When \( L_0^F = \bar{L}_0 \) in equilibrium, Equation (32) follows directly from Equation (30), and Equation (31) follows directly from Equation (29). Moreover, by using Equations (1), (23) and (28), we have

\[
\begin{align*}
\bar{V}^F &= \ln \left\{ \kappa \left[ (1 - z) \bar{L}^F \right] \frac{1}{\sigma - 1} \bar{L}^F - T \right\} + \varphi \ln \bar{H}^F \\
&= \ln \left\{ \kappa \left[ 1 - \xi (L_0^F)^{1+\beta} \right] \frac{1}{\sigma - 1} \bar{L}^F \frac{\sigma}{\sigma - 1} - \frac{rB}{1 - \xi (L_0^F)^{1+\beta}} \right\} + \varphi \ln \left( 1 - \bar{L}^F \right).
\end{align*}
\]

(A14)