2020

Some Short-run Macroeconomic Considerations as Society Deals with a Once-in-Generations Pandemic

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May 7, 2020

Abstract

COVID-19 constitutes a health crisis which has rapidly turned into a social and economic crisis. This paper briefly explores some of the issues raised by the combination of a massive supply-side shock with a massive demand-side shock, and the interaction of these with the exponential dynamics of a viral infection.

The analysis suggests that, during the recovery, the state of infection among the existing workforce relative to that of the incoming one will play an important role in determining the dynamic interactions between economics and epidemiology. Perhaps counterintuitively, the logic of the basic epidemiological SI model suggests that, under plausible assumptions about consumer behavior, steady recovery is helped if the re-hired workers are *more* heavily infected than the existing workforce. This has implications for the fiscal strategies that are likely to be pursued in the coming months. In particular, fiscal instruments should simultaneously target aggregate demand and disease transmissibility in relatively small steps.

There is no restoring economic health without stabilizing economic sentiments, the path to which goes through communicating a reasonable degree of control over pathogen spread.

JEL classifications: E62, H51, E60.
Key words: Epidemiological models, COVID-19, aggregate demand, aggregate supply, fiscal policy.

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1 Motivation

The shock represented by COVID-19 appears to have been unexpected, not in a black swan sense – something like this was likely to happen sooner or later if books by leading epidemiologists and Hollywood blockbusters are to be believed – but rather in the sense that it has forced multitudes to rapidly upgrade their understanding of counter-intuitive concepts such as exponential growth and externalities. Perhaps we may even need to refashion Dornbusch and recognize that, sometimes in economics, things emerge quicker than one thinks they will, and then they evolve even faster than one thought they could.

This paper extends a simple existing epidemiological model of infectious diseases to incorporate economic interactions in a way that I think helps shed light on some ongoing concerns. Consider some salient aspects that make this public health crises unique from an economic perspective:

1. The economic shocks are simultaneously both supply-side and demand-side in nature. Government-mandated isolation and fear have forced large-scale layoffs while at the same time scaring the public into spending less, especially on services.

2. The supply side constraint is likely to relax faster, as long as the supply infrastructure such as employee skills, employment networks, physical capital continue to exist, so that parts of these can be re-activated in line with relaxed public health regulations. Private demand, however, will probably recover more gradually, as a nervous public slowly begins to gain confidence.

3. We are likely to experience the pandemic in waves without the protection of a vaccine over the coming months. It is hard to mandate strict social isolation, especially in a democracy that banks heavily on social trust. When and where mandates are prematurely relaxed, the problem is likely to re-emerge. An ongoing game of whack-a-mole is unfortunately not hard to foresee across states, regions, and countries.

4. As in a broaching sailboat, expectations are likely to be unhinged from fundamentals in the short term. This means that goods and asset prices are not particularly good signals to follow in the near future. A further implication is that rather than assuming backward-looking adaptive behavior or forward-looking rational behavior, it may make sense to expect "animal spirits" and the current state of disease spread to play a major role in guiding actions of economic agents.

5. With the economy already flirting with the zero lower bound at the beginning of the pandemic, monetary policy is largely restricted to lowering the perception of risk, easing liquidity, and attempting to provide a reassuring floor under asset prices.

6. Inflation is likely to appear in some sectors as bottlenecks emerge.[1] However, despite the supply-side shock, economy-wide inflation does not appear to pose a threat in the near future.

7. A policy of rapidly getting people back to work, even if successful on its own terms, could end up creating bigger problems. Increased interactions between healthy and (often asymptomatic or presymptomatic) infected people is a recipe for endogenously generating viral and economic waves.

Taken together, the first 6 features create a formidably strong case for unprecedented fiscal policy action. Such policy must not only seek to provide a floor to incomes but also try to maintain employment infrastructure for the near future. Feature (7) points to a different kind of challenge. As long as we lack a vaccine and/or other effective antiviral interventions, successful fiscal policy may sow the seeds for further waves. The oft-repeated mantra of testing, tracing, and isolating is, therefore, as important from a public health perspective as it is for the success of policy action in the economic domain. Not much less important may be the composition of the workforce that gets re-hired as the economy recovers *relative* to that of the part of the workforce that remained undisturbed by the crisis. This is the message that the remainder of this paper underlines.

The analysis here has some interesting implications. In the simplest set-up that ignores the endogeneity of private spending sentiment, fiscal policy is effective over time in achieving any employment target it sets for itself without increasing the prevalence of the infection as a proportion of the workforce in the steady state. This changes once consumer sentiment is plausibly assumed to vary with the state of the infection among the worker force. The introduction of such variation introduces volatility and cycles of infection and employment, and make it harder, and even impossible, for policy makers to ensure a smooth transition to higher employment. Perhaps counter-intuitively, this result only holds when the prevalence of infection is lower among the incoming workers compared to the existing workforce. Put simply, this is because new employment in this case generates disproportionately more targets for each infected person. The underlying message is reminiscent of the Tinbergen rule. To highlight this aspect, and better match the policy experiment to currently ongoing events, I consider the case where policy makers have an explicit employment ceiling that they set to avoid re-emergence of a viral wave. Policy makers, therefore, have two targets: (1) stabilizing the state of infection spread, and (2) the level of employment. Achievement of the two targets will in general require another

[1] This may be one historical instance where the Fed printing lots of (toilet) paper as legal tender may actually help prevent inflation.

policy instrument in addition to government spending. An expanded regime of testing and contact tracing that lowers the transmissibility of the infection at work could constitute the second instrument.

The analysis proceeds, roughly in increasing level of complexity, as follows. Section 2 develops the basic model where employment is purely demand-led, policy places no upper constraints on how many sectors can re-open starting with a post-initial shock equilibrium, and consumer spending sentiment is not affected by the state of the infection. Section 3 extends the basic model to include endogenous consumer sentiments or animal spirits. Section 4 then incorporates an important aspect of the current situation by allowing policy to set constraints on employment by deciding which sectors can re-open. Thought experiments are developed along the way to explore the effects of various policy-directed and non-policy developments. Section 5 revisits the highlights with concluding thoughts.

2 Incorporating Macroeconomic Considerations in Simple Epidemiological Models of Infection

There are several things to keep in mind as the economy recovers from the first wave of the pandemic: (1) policy help will be required on the demand side to restore normal patterns of employment and spending, and (2) in the absence of a vaccine or effective antiviral treatments, the chance of a second wave will increase as these normal patterns are restored.

Start with a continuous version of the simple SI (susceptible-infected) model from epidemiology.[2] Consider a population of N employed workers, S of whom are currently susceptible to disease, while I are currently infected. There is homogeneous mixing of susceptible and infected individuals in the workforce. Each infected person has χ contacts with other individuals so that $\chi S/N$ of these interactions are with susceptible persons. If the fraction of these contacts resulting in infection is denoted by τ, then each infected person infects $\chi\tau S/N$ susceptible individuals. I will use β $(= \chi\tau)$ to represent the transmissibility of the disease. Of the infected individuals, a proportion γ recover each period and re-enter the pool of susceptible workers. The expression β/γ then defines the widely-used basic reproductive number R_0, which essentially equals the effective reproductive number R_e as long as the share of infected persons is relatively small.[3] Note that, given exponential growth, $1/\beta$ gives the mean duration of the infection.

[2] See, for example, Hethcote (2000).

[3] This number can be interpreted as the tipping point for infection spreading. A value of R_o less (more) than one implies that each person infects fewer (more) than one other individuals. The former implies that the disease is on course to die out. While robust estimates are yet to be established, Anderson et al. (2020) estimated the R_o for SARS-Cov-2 to be 2 – 2.5 in the early phase in China, although other studies have suggested higher numbers. By way of comparison, Biggerstaff et al. (2014) estimated the median R_o for the Spanish influenza pandemic in 1918 to be 1.8.

In each period, as new workers enter the workforce, a fraction α of them are susceptible while the rest are infected (the same is true for workers who leave the workforce). This parameter will play an influential role in driving interactions between the virus and the economy and in highlighting the importance of testing.

Let's employ the boiled down version that incorporates non-linear interactions between S and I without births and deaths.

$$\dot{S} = -\beta \frac{SI}{N} + \gamma I + \alpha \dot{N} \tag{1}$$

$$\dot{I} = \beta \frac{SI}{N} - \gamma I + (1-\alpha)\dot{N} \tag{2}$$

The assumption that workers become susceptible after recovery is important and deserves some attention. One could easily relax this assumption and work with a SIR (Susceptible-Infected-Recovered) model instead. While it is likely, given past experience with SARS-Covid viruses, that recovered people will develop antibodies that give immunity, at least for a few weeks, the weight of the evidence is far from clear at this point.[4] Moreover, given the short-run focus of the analysis here, the proportion of the population that has recovered in these initial stages is likely to be low enough so that this simplification comes at a low cost.

The set-up up until this point is the standard SI one, with the exception of the rightmost terms in eqs. (1) and (2). With society largely socially quarantined, the bulk of the new cases are likely to originate from at-work interactions. This makes policy especially tricky in a rapidly shrinking economy since measures taken to restore employment will also increase the odds of interaction. Let's now introduce macroeconomic considerations by incorporating the goods market.

The focus here is on the short run. The economy retains its capital and infrastructure, capacity utilization is low, and the constraint on output is labor. It makes sense to ignore investment, technological change, and open economy issues for the purpose of the present analysis. With labor productivity normalized to unity, output (Y) at any given instant corresponds with employment (N).

$$Y = N \tag{3}$$

Policy regulates the nature and volume of businesses that can remain open. Later in Section 4, I will model the supply side shock as a variation in the maximum level of employment (and hence output) allowed, $N_{\max}$. The *actual* level of output is demand-determined in a Keynesian sense. One would expect actual output to change gradually in response to changes in regulation as

[4] The epidemiology of other coronaviruses such as SARS-CoV1 and MERS-CoV appear to be substantially different, and are therefore limited in their ability to help establish what to expect from the current pathogen.

consumer sentiment evolves and employment networks are re-established. The adjustment of output is specified here as a partial lag adjustment, with gaps in demand (the sum of the levels of autonomous consumption, $c_0 + c_1 Y$ and government spending g, where $c_1 < 1$ in line with the standard Keynesian setup) and actual output driving the dynamics at a speed denoted by η.

$$\dot{N} = \eta \left[c_0 + g - (1 - c_1)N\right] \tag{4}$$

It would make life easier for later analysis if we normalize S and I by the size of the workforce, $s \equiv S/N$ and $i \equiv I/N$, so that the respective equations of motion become:

$$\dot{s} = (\gamma - \beta s)(1 - s) + \eta(\alpha - s)\left[c_0 + g - (1 - c_1)N\right] \tag{5}$$

$$\dot{i} = -(\gamma - \beta s)i + \eta(1 - \alpha - i)\left[c_0 + g - (1 - c_1)N\right] \tag{6}$$

where I have used the property that $s + i = 1$. Given that the two variables i and s are not independent at any given point in time, either of these two equations along with equation (4) constitutes our dynamic system. I will use equations (4) and (5).

Equations (5) and (6) involve two strong assumptions that are worth some discussion. The fact that α is being assumed constant means that the rate of infection outside the employed workforce has settled at a stable level. As long as society practices social isolation for long enough so that the transmission rate within households is low, this is not a dramatic assumption (think of β being very low within households). A second assumption is that the proportion of the workforce exiting employment is infected to the same extent as the proportion of the individuals re-entering employment. This is a rather strong assumption, especially since the exiting workforce would have been exposed to the virus during employment. The proportion of susceptible workers among the exiting population, in other words, should be a weighted average of α and s. Relaxing this assumption would require a significant increase in the complexity of the specification without much gain in insight, since the results would hold as long as the weighted average is different from s in the same direction as α.[5]

Given our setting, there is one non-trivial steady state, given by:

$$(\bar{s}, \bar{i}, \overline{N}) = \left(\frac{\gamma}{\beta}, \frac{\beta - \gamma}{\beta}, \frac{c_0 + g}{1 - c_1}\right) \tag{7}$$

A non-negative number of infected individuals requires that the rate of recovery γ from infection be less than its transmissibility β. The effective reproduction number, in other words, needs to be greater than 1. This is a well-known result from standard epidemiological models; as mentioned earlier, a value equal to or less than 1 leads to disappearance of the disease.

[5] Put differently, if $\alpha \geqslant s$, then $\delta\alpha + (1 - \delta)s \geqslant s$ holds, where $\delta \in [0, 1]$ and $1 - \delta$ are the respective weights assigned as new workers enter or old workers exit employment.

With this simple set-up, it is easy to show that the system is locally stable around the non-trivial steady state. Once displaced, the adjustment could be monotonic or in the nature of half cycles.[6] The transitional dynamics, however, depend on whether or not the proportion of new workers that is infected, i.e., $1-\alpha$, is greater than the initial (steady state) proportion of infected workers, i.e., $1-\alpha \lesseqgtr \bar{i}$. The intuition is quite straightforward and is perhaps best illustrated with the help of a few thought experiments. Suffice it to say at this point that, as shown in Figure 1, the $\dot{N}=0$ isocline is horizontal in $s-N$ space since aggregate demand is independent of the proportion of susceptibles in the neighborhood of the steady state, while the slope of the $\dot{s}=0$ depends on whether $1-\alpha \lesseqgtr \bar{i}$. It is upward-sloping when $1-\alpha > \bar{i}$, i.e., when the proportion of incoming workers that is infected is higher than that in the already employed workforce. To understand why, notice that an increase in N creates excess supply in the goods market and leads to declining employment as firms cut output in response. Since the proportion workers leaving is tilted in this case towards infected individuals, lower employment has to be offset by a higher level of susceptible individuals along the $\dot{s}=0$ isocline.

It is also worth noting that the link between the goods market and the state of infection runs through, (i) changes in employment, i.e., $\dot{N} \gtreqless 0$, and (ii) differences in the composition of the existing and entering/exiting work force, i.e., $\alpha \gtreqless s$. Subsequent analysis crucially centers around these links.

Finally, notice that the government has one policy instrument, i.e., fiscal policy (the level of G). Although there is no specific employment target at this point, such an objective will be introduced later.

Fiscal Expansion

Starting with this simple set-up where there are no policy-induced caps on employment, let's consider the effects of an increase in government spending in order to help generate demand and employment. Since firms can hire freely in response to demand, employment picks up through the Keynesian multiplier process. The two isoclines shift up (see the dotted lines in Figure 1). However, the steady state level of per capita infection is unchanged. The transitional dynamics depend on the composition of the incoming workforce. If the incoming proportion of infected individuals is higher, as shown in the left panel of Figure 1, then, not surprisingly, the proportion of infected individuals in the population initially increases. As the infected individuals recover over time, the initial proportions of the two groups in the population are restored. A similar story plays out when the incoming proportion of infected workers is less than that in the existing workforce, although now the transitional dynamics involve an initial decline in the share of the infected population before it rises back to its original value as interactions increase.

In both cases, the steady state level of employment is higher ($N_1 > N_0$), although the steady state proportions of the two populations are unchanged. This result is not surprising in light of equation (7). Given that the proportions

[6] In the latter case, both real roots are negative.

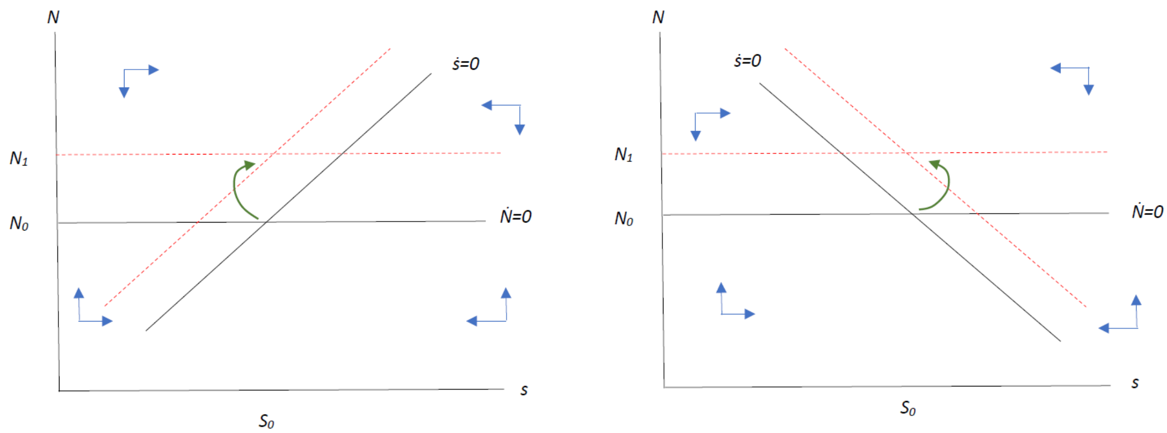

Figure 1: A fiscal expansion when: (i) $1-\alpha > \frac{\gamma}{\beta}$ (left hand panel), (ii) $1-\alpha < \frac{\gamma}{\beta}$ (right hand panel).

haven't changed while employment is higher, the absolute number of both the susceptible and infected individuals must be higher.

Social Quarantining

The aim of public health measures is ultimately to bring the effective reproductive number R_e down to manageable levels. Suppose health officials and politicians have managed to lower β through social isolation. Suppose next that the restoration of some employment networks raises this number again.[7] A quick look at the steady state solutions, as given by equation (7), tells us that the expanded workforce will include a greater proportion of infected individuals. This is true regardless of the existing workforce relative to the outside population! Why? Notice that since demand is unchanged, so is the level of employment. Greater interactions among the workforce mean a greater prevalence of virus hosts, regardless of the level of employment.

The $\dot{s} = 0$ isocline shifts up, as shown in Figure 2, while the other isocline is unmoved. The movement of s is along the horizontal isocline.

Effective Testing to Filter New Workers

Suppose that, with high *specificity* tests,[8] firms are able to lower the proportion of infected workers among those recalled to work (i.e., increase α). Again, since aggregate demand is unchanged, the steady state level of employment is unchanged. It follows trivially from the fact that there are no transitional dynamics – neither of the isoclines shifts – that the steady state composition

[7] Since higher employment would be expected to increase interactions at given levels of s and i, it would be more plausible to endogenize β and make it a function of the level of employment. I address this issue later.

[8] The term *specificity* refers to the percentage of those who do have not been infected and test negative.

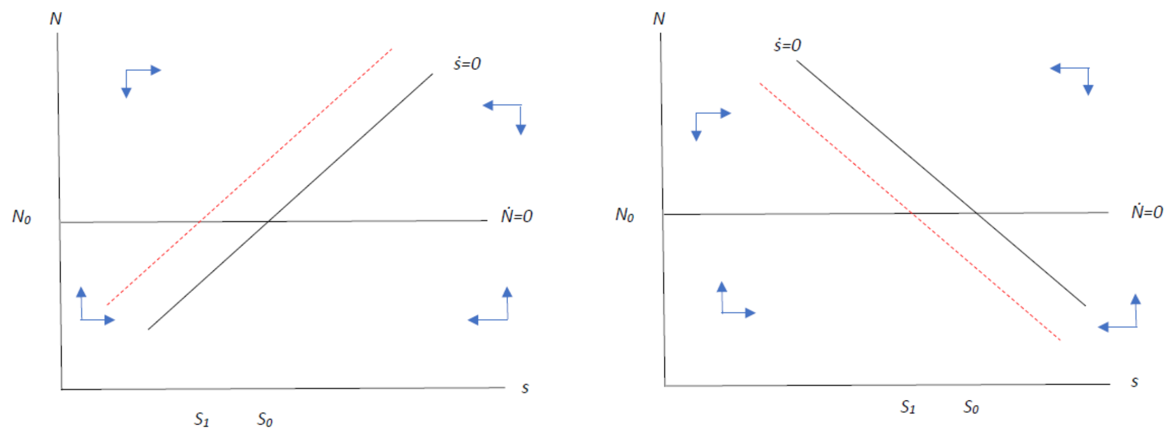

Figure 2: The effects of social quarantining when: (i) $1 - \alpha > \frac{\gamma}{\beta}$ (left hand panel), (ii) $1 - \alpha < \frac{\gamma}{\beta}$ (right hand panel).

of the work force too remains unchanged. Changes in the composition of the incoming work force between the susceptibles and the infected matters only if new employment is generated.

The emphasis in this section so far has been on the role officially-driven demand in determining the level of employment and thus the steady state proportion of susceptible and infected workers in the employed pool. Like Janus, fiscal policy makers manage to transition between lower and higher employment states that coincide with whatever level of infection is acceptable among the work force. The next section will relax this strong assumption. Before we get there, however, let's consider one more thought experiment.

Endogenizing the Basic Reproductive Number

Since higher employment would be expected to increase interactions at *given* levels of s and i, it would be more plausible to endogenize β and make it a function of the level of employment.[9] Such a change will not affect the analysis here in any qualitative sense, although the $\dot{s} = 0$ will then be more likely to have a negative slope. Put differently, this isocline could have a negative slope even if initially $1 - \alpha < \frac{\gamma}{\beta}$. An implication for fiscal policy is that the trade-off between employment and infection control is now less friendly since the resulting steady state level of share of infected workers will be higher per unit of fiscal stimulus. Even an omnipotent fiscal policy maker faces constraints on action in the middle of a virus-induced pandemic!

Things get more complicated once fiscal omniscience is dented by expectations and sentiments. In particular, the ability to reliably achieve any desired

[9]This could be due to, for example, greater use of public transportation, more shared use of office equipment, and more face-to-face meetings that increase the transmissibility of the disease as employment rises.

rate of employment at a given level of infection spread is compromised.

3 The Prevalence of Infection Influences Consumer Sentiment

One would plausibly assume consumer (and investment) sentiment to depend on the state of viral spread. Consumers experiencing infection in their neighborhoods will grow warier about the future and animal spirits will dampen. Let's next incorporate this aspect by making autonomous consumption a function of the proportion of infected individuals in the work force, so that $c_0 = c_0(i)$, where $c_0' < 0$.[10]

Although the solutions for the steady state levels from the previous section are qualitatively unchanged, the system may could now yield instability in a local sense (i.e., the trace of the Jacobian of endogenous variables now has an ambiguous sign). A *sufficient* (but not necessary) condition for stability is that the proportion of incoming workers that is infected be *greater* than the corresponding proportion for the existing work force, i.e., $1 - \alpha > \bar{\imath}$.[11] A *necessary* (but not sufficient) condition for destabilizing dynamics to occur is that the reverse be true, i.e., $1 - \alpha < \bar{\imath}$.[12]

PROOFS IN APPENDIX

Let's start with the major change, as illustrated by Figure 3. The crucial difference from the earlier figures is that the $\dot{N} = 0$ isocline is now upward-sloping. Why? Because consumer sentiment and hence aggregate demand is no longer independent of the prevalence of infection. A higher level of employment, that generates greater interactions and infection spread among the workforce now affects the state of animal spirits. Thus elevated employment is consistent with equilibrium in the goods market only at lower proportions of infection (higher s).

How does this change modify our thinking about fiscal policy? Consider first the stable case. Call this Case 1 which is represented by the top left

[10] One may argue that it is the state of infection in the entire population rather than in the workforce that would affect consumer expectations. While this is a fair comment, the simplification here can be defended on the grounds that it is probably the prevalence of the infection in the working age population – which is normally the most economically active – that is likely to matter the most for expectations about the economic future.

[11] Recall that, in earlier sections, this condition defined the trajectories of transitional dynamics but not the stability properties of the steady state.

[12] More formally, for stable outcomes, the basic reproductive number should be such that,

$$1 - \alpha > \left(1 + \frac{\beta}{\eta c_0'}\right)\bar{\imath} + \frac{1 - c_1}{c_0'}$$

Note that the greater the transmissibility of the disease and the lower the goods market multiplier, the responsiveness of consumer sentiment, or the speed of adjustment in the goods market, the more likely it is for this condition to be satisfied.

hand panel in Figure 3. As in our previous analysis, the steady state level of employment is higher while the steady state proportions of the susceptible and infected proportions are unchanged following a fiscal expansion. A look at the figure should convince the reader that the trajectory will be a clockwise half-cycle with the two variables initially moving in opposite directions and then in the same direction. The semi-cyclical behavior is being directed by volatility in consumer sentiment as the virus expands or contracts among the workforce in waves. Initially, increased government spending creates excess demand in the goods market. As employment expands, the greater proportion of infected among the incoming workforce means that the proportion of susceptibles initially declines. This lowers animal spirits over time and consumption declines. Eventually, the number of targets for the infection are low enough so that the population of susceptibles begins to recover. As this happens employment rises, now aided by consumer sentiment, to the new steady state where the composition of the population is back to its original proportions.

At the end of the day the system approaches the steady state with fiscal policy having achieved the desired aim of higher employment without a change in the infected proportion of the workforce (although the absolute number of infected workers has increased). Higher employment has not come at the expense of compromising on the rate of infection.

Is fiscal policy still successful on these terms if $1-\alpha < \bar{\imath}$, that is, the fraction of new workers that is infected is lower than that for the existing workers? Unlike all the analysis leading up to this point, the answer is *no*, if consumer sentiment is adequately sensitive to the state of the infection. To directly analyze the contrast, let's consider Case (3) where the behavior of spending sentiment is sensitive enough as to cause instability. This case is captured by the lower panel of Figure 3. While there is an intermediate case, i.e., Case 2 (represented by the top right panel of Figure 3), I will refer to this case only briefly for comparison purposes.

In formal terms, Case 3 is defined by:

$$\bar{\imath} > \left(1 + \frac{\beta}{\eta c_0'}\right)\bar{\imath} + \frac{1-c_1}{c_0'} > 1-\alpha \tag{8}$$

In words, the proportion of new workers that is infected coming in should be lower than the same proportion of the existing work force by an amount defined by term in between the two inequality signs. Notice that this term depends, among other factors, on the responsiveness of consumer sentiment. In terms of Figure 3, the high sensitivity of consumer sentiment to the state of infection makes the $\dot{N} = 0$ isocline steeper. In this case, we get expanding counter-clockwise cycles and instability.

To understand why, let's consider the consequences of fiscal policy, starting with the initial impact which creates excess demand in the goods market. Since the resulting rise in employment involves, unlike the earlier case, an incoming work force that is less heavily infected, s initially rises, generating a counter-clockwise movement involving an increase in both N and s. As output increases,

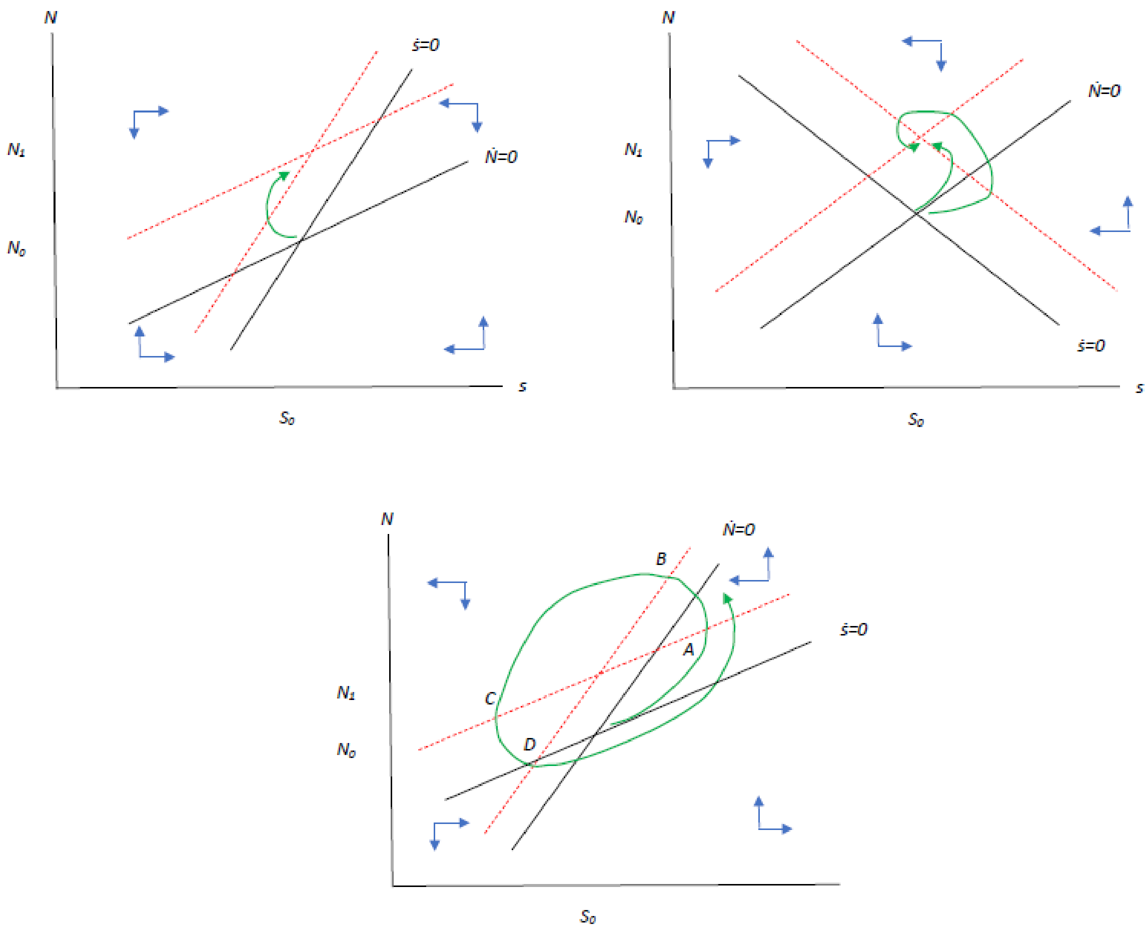

Figure 3: Fiscal policy when: (1) $1-\alpha > \bar{\imath}$ (top left hand panel), (2) $\bar{\imath} > 1-\alpha > \left(1+\frac{\beta}{\eta c_0'}\right)\bar{\imath} + \frac{1-c_1}{c_0'}$ (top right hand panel), (3) $\bar{\imath} > \left(1+\frac{\beta}{\eta c_0'}\right)\bar{\imath} + \frac{1-c_1}{c_0'} > 1-\alpha$ (bottom panel).

it is further bolstered by the fact that the proportion of infected workers is falling, boosting animal spirits. This virtuous process comes to an end at point A, however, when the level of s attains a high enough value that the rate of infection spread due to increased worker interactions significantly exceeds the rate of recovery among the infected. Beyond this point, the number of infections starts rising again, starting a new wave of disease spread even as employment continues to rise. Declining animal spirits and consumer spending now act as a drag on employment generation, until we reach point B, where the initial fiscal stimulus has been neutralized, $\dot{N} = 0$, while the infection is still spreading. Beyond this point, the initial impetus to employment provided by the fiscal stimulus has been more than offset. Now employment is declining while the proportion of infected individuals is increasing (i.e., N and s are moving in the same direction). Once a sufficient number of susceptible individuals have left the work force, we are at a point like C, where $\dot{s} = 0$.[13] Beyond C, the proportion of susceptibles starts recovering due to much fewer interactions, and this eventually restores consumer confidence over time until we reach D, and spending and employment start another upward trajectory along with the number of susceptibles, thanks to the healthier composition of the new workers. In sum, we see counter-clockwise cycles and waves of infection among the work force.

The same kind of countercyclical cycle emerges in case 2 (represented by the top right hand panel in Figure 3), which is, however, distinguished from case 3 by the fact that the cycles shrink and lead back to the steady state over time. Why this difference? Recall that in Case 3, the defining feature is the condition $\bar{\imath} > \left(1 + \frac{\beta}{\eta c_0'}\right)\bar{\imath} + \frac{1-c_1}{c_0'} > 1 - \alpha$, while in Case 2, $\bar{\imath} > 1 - \alpha > \left(1 + \frac{\beta}{\eta c_0'}\right)\bar{\imath} + \frac{1-c_1}{c_0'}$. The goods market multiplier $(1/(1 - c_1))$ and sensitivity of spending to the state of the infection turn out to be a crucial factor. The more responsive the sentiment, the greater the likelihood of explosive cycles and repeating waves of infection.

Why does spending sentiment play such a decisive role in the course of the response? Why is high sensitivity such a crucial factor? A fiscal expansion increases employment and interactions. If the incoming workforce is less infected, this creates more targets for the infection just as consumer sentiment is rebounding. If this latter rebound is strong enough, the initial impact of the fiscal action is magnified, which then allows for a bigger resurgence of infections. The lack of consumer sensitivity, or the complete absence of it, on the other hand, dampen these exploding interactions between infection and employment.

How would one want to address the volatility in this situation? Since policy makers do not have an employment ceiling to target, one option for them is to choose the highest point in the first cycle, i.e., the point where employment is at its peak in that cycle, and then freeze aggregate demand at that point using fiscal policy. Point B' in Figure 4, which corresponds to point B in Figure 3 represents

[13] Notice that, at point C, s is still below its initial steady state value β/γ, so that the first term on the RHS of equation (5) is positive but this is exactly offset by the fact that employment is falling, so that the second term on the RHS is negative.

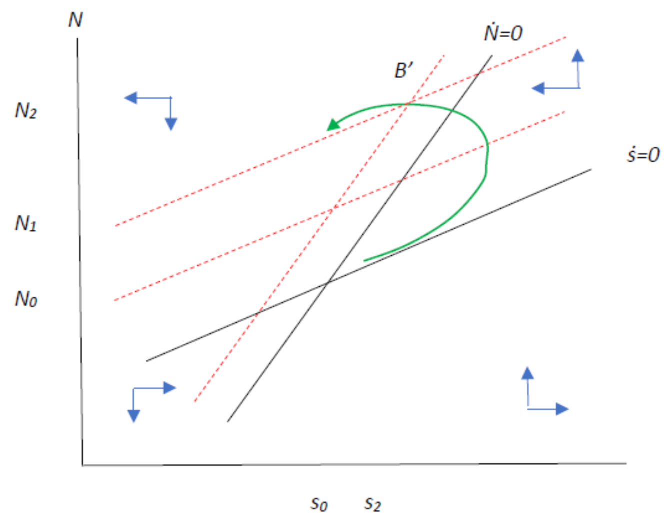

Figure 4: Policy induced control of volatility

such a choice. Even in our simple set-up, this poses a challenge. At B', the prevalence of infection is lower than that in the steady state (which recall is unchanged from its original level). The high number of susceptibles should cause infection spread. With the level of employment frozen, the only way to avoid this would be to take actions that shift the $\dot{s} = 0$ isocline up so that it passes through B'. This, in turn, requires epidemiological interventions that lower the β/γ ratio, i.e., actions such as testing, medical interventions, and re-designing of work spaces that accelerate recovery and reduce the transmissibility and duration of infection. This scenario takes us to a higher employment level with a lower prevalence of infection in the workforce without intermediate volatility. Two goals, as Tinbergen reminds us, require two instruments. The second instrument here has been the use of public health measures to stabilize the reproductive number. The main lesson is that fiscal policy will have to be two-pronged, with spending directed both at demand recovery and at health measures to achieve higher employment at stable levels of infection.

MATH IN APPENDIX

I have assumed here that the fiscal expansion is a one-time level change. Of course, however, the policy makers may in the middle of a pandemic place constraints on how much employment is allowed to open up at a given stage of the recovery, regardless of the level of aggregate demand. Also, they may under the circumstances, respond aggressively to negative consumer sentiment. The next section addresses these issues.

4 The SI Model with Policy-Induced Employment Constraints

As mentioned earlier, the COVID19 pandemic has simultaneously generated supply- and demand-side shocks, and policy must address both. On the supply side, officially sanctioned/enforced/encouraged social quarantining has forced companies to radically cut employment at the same time that dramatically pessimistic animal spirits and imminent job losses have led people to cut expenditures. The analysis in the previous sections has assumed the absence of supply-side constraints on employment. This is unrealistic in the midst of an ongoing response to a pandemic.

To introduce a supply-side constraint, let's assume that the government places a cap on the nature and number of establishments that can be re-opened for business. While in reality the caps may vary by sector, I simplify by supposing an aggregate ceiling on employment, $N_{\max}$. One can think of this as regulations that, for example, limit how many persons can work or be served in a building in order to maintain a safe distance between them. Actual employment would be expected to react gradually to regulations as firms slowly feel their way towards hiring more workers in response to excess demand. In the meantime, fiscal policy responds to any gap between the mandated maximum employment and actual employment. This expanded system can now be captured by three equations of motion.[14]

$$\dot{s} = (\gamma - \beta s)(1 - s) + \eta(\alpha - s)\left[c_0 + g - (1 - c_1)N\right] \tag{9}$$

$$\dot{N} = \eta\left[c_0 + g - (1 - c_1)N\right] \tag{10}$$

$$\dot{g} = \phi\left(N_{\max} - N\right) \tag{11}$$

As before, there is one non-trivial steady state, given by:

$$(\overline{s}, \overline{i}, \overline{N}, \overline{g}) = \left(\frac{\gamma}{\beta}, \frac{\beta - \gamma}{\beta}, \frac{c_0 + g}{1 - c_1}, N_{\max}\right) \tag{12}$$

Adding an extra dimension to a dynamic system, as we have done here, renders the workings of the system harder to explain in intuitive terms. However, the system here is simple enough for us to refer back to the intuition developed earlier. In particular, notice that the steady state expressions for the state variables from the earlier sections are unchanged. That for government spending is the value that matches employment to its mandated level. Notice also that equation (10) is independent of s, as is equation (11), which in addition is also independent of g. The latter equation determines the value of government spending commensurate with the gap between actual employment

[14] Lurking in the background again is a fourth equation, that for the evolution of i, but it is superfluous as before.

and its mandated level at any instant. The first two dynamic equations then determine changes in the level of (demand-led) employment and the fraction of infected individuals. This decoupling of the new equation of motion means that the system has very similar properties to the earlier one. In particular, once fiscal policy has chosen the level of government spending that yields the targeted level of employment, it can be made consistent with any level of s.[15]

Without going into too much detail, the trace and determinant of the Jacobian of endogenous variables are negative, and the Routh-Hurwitz conditions for a 3×3 system are unambiguously satisfied. As long as nothing changes the reproductive number, fiscal policy can reliably achieve any chosen rate of employment at a given rate of infection.

[Proof in the Appendix]

Reintroducing the Volatility of Consumer Sentiment

If, as earlier, we think about how spending sentiment may respond to the state of infection spread, then things become more complicated and policy makers may not be able to achieve their objectives. As it turns out, the stability conditions are exactly the same as under similar conditions without the supply-side constraint (see Section 3). The prevalence of infection in the existing workforce relative to that among entering workers remains the decisive factor along with the responsiveness of consumer sentiment.

As before, an interesting case again is when a greater proportion of incoming workers is infected than the existing work force, and consumer sentiment responds strongly to conditions. Under these conditions, the system could be unstable. Barring good luck or a drop in community transmission, employment and infection interact in waves. Good luck here, perhaps ironically, consists of the incoming work force being more infected than the existing workforce, so that there are fewer targets for infection as employment grows.

Suppose that we are in the unstable case, where the prevalence of infection is lower among incoming workers (see Figure 5), and which coincides with the lower panel in Figure 3. Suppose further that policy makers, in order to avoid volatility, set the ceiling at point $N_{\max}$, which coincides with the level of employment where the two isoclines intersect.[16] Employment runs into this ceiling at a point like A", where $\dot{G} = 0$ but employment and the proportion of susceptibles is still growing. Fiscal policy has attained its target but unless other policy instruments are available, the rate of infection has not stabilized, and excess demand pressures remain in the goods market. The state of supply is not commensurate with the animal spirits that remain positive in light of declining infection prevalence.

Alternatively, to remove these pressures, policy makers could set the ceiling, $N_{\max 2}$, at point B", which coincides with point B in Figure 3 and point B' in Figure 4. At this point, employment and government spending have stabilized

[15] Again, this will change once consumer sentiment is endogenized.

[16] Since we are now discussing a 3×3 system, the isoclines and the ceiling should be interpreted as planes or surfaces rather than lines.

but the level of infection is still in flux. The addition of a policy goal, i.e., controlling volatility, without the addition of a policy instrument has again left policy makers one instrument short. A public health instrument that changes the reproductive number and shifts the $\dot{s} = 0$ isocline up is needed.

What if this ceiling is set too high, say above $N_{\max 2}$? Such an ambitious employment target will set into motion cycles of employment and infection. Contrary to an oft-repeated proverb, it is desirable to cross the chasm between full and current employment in small steps.

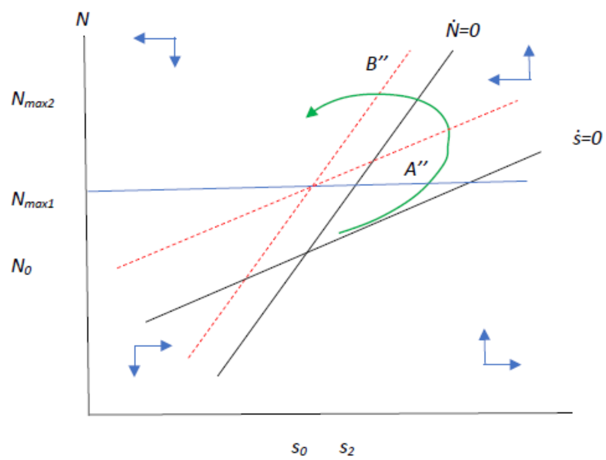

Figure 5: Policy sets a ceiling on employment

5 (Preliminary) Concluding Thoughts

This paper has extended a simple model from epidemiology to analyze the interaction of economic policy, infection spread, and consumer sentiments. In the simplest set-up fiscal action is helpful in boosting employment at a given level of infection spread, and the only constraint is the size of the multiplier. Incorporation of complications such as the endogeneity of the basic reproductive number places limits on success that depend on the composition of the incoming workforce. While this underlines the importance of testing, employment objectives are still achievable. Incorporation of consumer sentiments and animal spirits eliminate guaranteed success, and the magnitude of these factors becomes crucial alongside the state of infection among the existing and entering/exiting workforce in determining the interplay of disease and employment. A corner solution with matters spiraling out of hand becomes a possibility in the case where recovery of employment and a fall in infection rates among the workforce generates excessive consumer optimism. Policy makers may place limits on the level of employment in any given state of recovery from the pandemic, both in order to control spread and to manage volatility. The analysis here indicates that doing this succesfully while stabilizing virus spread will require adding another weapon to the armory. Tinbergen's insight remains relevant: the number of instruments must in general match the number of goals.

A significant amount of recent policy focus has (rightly) been on testing. The analysis here highlights a related but different dimension. As long as infection is prevalent among the work force, there is a case for enlarging the fiscal focus from purely aggregate demand-driven spending towards measures that reduce the transmissibility of the disease in the workplace. The task of policy is near-Sisyphean in an ongoing pandemic, and once the drastic step of society-wide lockdown has been taken, the small steps back to normalcy will have to be simultaneously epidemiological and economic in nature to match the goals.

6 Mathematical Appendix

This appendix presents in more detail the mathematical results derived in the main text.

Section 2

The Jacobian of endogenous variables based on eqs. (4) and (5), and evaluated in the neighborhood of the initial steady state is given by:

$$\mathbf{J}_{(\bar{s},\bar{N})} = \begin{bmatrix} \gamma-\beta & -\eta\left(\alpha-\frac{\gamma}{\beta}\right)(1-c_1) \\ 0 & -\eta(1-c_1) \end{bmatrix}$$

From which it follows that the determinant is given by, $|\mathbf{J}| = -\eta(\gamma-\beta)c_0 > 0$, and the trace by $\mathbf{Tr} = \gamma - 2\beta - \eta c_0 < 0$.

The condition for both eigenroots to be negative and real, which can be shown to be:

$$[\gamma - 2\beta + \eta(1-c_1)]^2 > 0$$

is unambiguously satisfied.

The comparative statics for the various thought experiments are as follows (presented n the same sequence as these are discussed in the main text).

$$\frac{ds}{dg} = 0, \ \ \frac{dN}{dg} = \frac{1}{1-c_1} > 0$$

$$\frac{ds}{d\beta} = -\frac{\gamma}{\beta^2}\frac{1-c_1}{c_0} < 0, \ \ \frac{dN}{d\beta} = 0$$

$$\frac{ds}{d\alpha} = 0, \ \ \frac{dN}{d\alpha} = 0$$

Section 3

Endogenizing consumer sentiment changes the endogenous variable Jacobian to:

$$\mathbf{J}_{(\bar{s},\bar{N})} = \begin{bmatrix} \gamma-\beta-\eta\left(\alpha-\frac{\gamma}{\beta}\right)c_0' & -\eta\left(\alpha-\frac{\gamma}{\beta}\right)(1-c_1) \\ -\eta c_0' & -\eta(1-c_1) \end{bmatrix}$$

As a consequence, $|\mathbf{J}| = -\eta(\gamma-\beta)(1-c_1) > 0$, and the trace by $\mathbf{Tr} = (\gamma-\beta) - \eta(1-c_1) - \eta\left(\alpha - \frac{\gamma}{\beta}\right)c_0' \gtrless 0$. The first two terms in the trace expression are negative (recall that $\gamma < \beta$ from the steady state solution), while the final term has a positive effect (recall that $c_0' < 0$) if $\alpha > \gamma/\beta$ and a negative effect otherwise.The 3 different cases considered in the main text canbe derived directly from the expression for the trace.

The discriminant, i.e., $\mathbf{\Delta} = \mathbf{Tr}^2 - 4\,|\mathbf{J}|$ yields the conditions under which the sytem yields real or imaginary roots. Since,

$$\mathbf{\Delta} = [(\gamma-\beta)+\eta(1-c_1)]^2 + \left[\left(\alpha - \frac{\gamma}{\beta}\right)\eta c_0'\right]^2 - 2\,[(\gamma-\beta)-\eta(1-c_1)]\left[\eta\left(\alpha-\frac{\gamma}{\beta}\right)c_0'\right]$$

therefore, a sufficient condition for $\mathbf{\Delta} > 0$ and both eigenvalues to be negative is that $\alpha < \gamma/\beta$. A necessary condition for imaginary roots, and hence cycles is that this inequality be reversed. The necessary and sufficient condition for explosive cycles (expression (8) in the main text), can be derived from here.

The compartative dynamics of a one time increase in fiscal spending are as follows:

$$\frac{ds}{dg} = 0, \;\; \frac{dN}{dg} = \frac{1}{1-c_1} > 0$$

Section 4

Again, first the case with exogenous consumer sentiments.

$$\mathbf{J}_{(\bar{s},\bar{N})} = \begin{bmatrix} \gamma-\beta & -\eta\left(\alpha-\frac{\gamma}{\beta}\right)(1-c_1) & \eta\left(\alpha-\frac{\gamma}{\beta}\right) \\ 0 & -\eta(1-c_1)N_{\max} & \eta N_{\max} \\ 0 & -\phi & 0 \end{bmatrix}$$

so that $|\mathbf{J}| = \eta(\gamma-\beta)\phi N_{\max} < 0$ and $\mathbf{Tr} = (\gamma-\beta) - \eta(1-c_1)N_{\max} < 0$.

The Routh-Hurwitz conditions, given by:

$-\left[(\gamma-\beta)-\eta(1-c_1)N_{\max}\right] > 0$

$\left[1-(\gamma-\beta)(1-c_1)\right]\eta N_{\max} > 0$

$-(\gamma-\beta)\eta\phi N_{\max} > 0$

$\left\{\left[1-(\gamma-\beta)(1-c_1)\right]\eta N_{\max} + (\gamma-\beta)^2\right\}(1-c_1)\eta N_{\max} > 0$

are satisfied unambiguously.

Endogenizing consumer sentiment changes the endogenous variable Jacobian to:

$$\mathbf{J}_{(\bar{s},\bar{N},\bar{g})} = \begin{bmatrix} \gamma-\beta-\eta\left(\alpha-\frac{\gamma}{\beta}\right)c_0' & -\eta\left(\alpha-\frac{\gamma}{\beta}\right)(1-c_1) & \eta\left(\alpha-\frac{\gamma}{\beta}\right) \\ -\eta c_0' & -\eta(1-c_1)N_{\max} & \eta N_{\max} \\ 0 & -\phi & 0 \end{bmatrix}$$

so that $|\mathbf{J}| = \eta(\gamma-\beta)\phi N_{\max} < 0$, and $\mathbf{Tr} = (\gamma-\beta)-\eta(1-c_1)-\eta\left(\alpha-\frac{\gamma}{\beta}\right)c_0' \gtrless 0$.

In this case, the Routh-Hurwitz conditions change to:

$-\left[(\gamma-\beta)-\eta(1-c_1)N_{\max}-\eta\left(\alpha-\frac{\gamma}{\beta}\right)c_0'\right] > 0$

$\left[\phi-(\gamma-\beta)(1-c_1)\right]\eta N_{\max} > 0$

$-(\gamma-\beta)\eta\phi N_{\max} > 0$

$\left\{\left[\eta\left(\alpha-\frac{\gamma}{\beta}\right)c_0'+(1-c_1)\eta N_{\max}\right]\phi+\left[(\gamma-\beta)-\eta\left(\alpha-\frac{\gamma}{\beta}\right)c_0'-\eta(1-c_1)N_{\max}\right]\right\}(1-$
$c_1)(\gamma-\beta)\eta N_{\max}>0$
which yields 3 cases, as captured by expression (8) of the main text.

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