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Consumption-contagion dynamics during epidemic with voluntary social distancing

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Abstract

This paper discusses causal dynamics between epidemic and consumption by incorporating different consumption behavior among those susceptible, infected and recovered from the disease. This paper finds that endogenous voluntary social distancing induces recession in the short-term, but limits the permanent output loss in the medium-term. It slows contagion, lowers the peak of active cases, reduces the total infections and deaths.

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1. Introduction

COVID-19 pandemic has created huge economic downturns in global scale. The main effort of limiting disease transmission is conducted by lockdowns (i.e. mobility restrictions), which reduce economic activities dramatically (see for instance, Baker et al, 2020). Later, several countries ease the restrictions, however the activities are not returning back to normal. This suggest that the disease transmission itself affects consumption or social distancing (Cook, Newberger and Smalling, 2020) and that the voluntary social distancing is significant (Maloney and Taskin, 2020).

Epidemic dynamics are often predicted with Susceptible, Infected, Recovered (SIR) models, which is introduced by Kermack and McKendrick (1927). In the light of COVID-19 pandemic and its large adverse impact to global economy, recent papers extends the discussion to macroeconomic dynamics in epidemic, for example Eichenbaum, Rebelo and Trabandt (2020) and Krueger, Uhlig and Xie (2020).

This paper attempt to explain causal dynamics of epidemic and the economy. Particularly, this paper begins with extending SIR model to imply consumption dynamics by assuming different consumption behavior of susceptible, infected, and recovered person. Further, this paper modifies contagion term in SIR model with consumption of susceptible and infected person. Thus, it allows causal interaction between disease progression and consumption.

This paper is arguably a simpler execution of several ideas on Eichenbaum, Rebelo and Trabandt (2020). Rather than deriving in general equilibrium framework, this paper focuses on the departure of consumption from the pre-pandemic level. In particular, the consumption dynamics relies on the different consumption behavior between the susceptibles, infected, and those who have recovered from the disease. Further, another distinction is that this paper assumes that the original SIR model implies interaction of consumption at pre-pandemic steady state level. Therefore, the deviation of consumption from the steady state changes route of the epidemic.

This paper contributes to the literature related to the relationship between epidemic and the economy. Some findings in this paper include: (1) even without lockdowns, consumption does decline as a result of voluntary social distancing and as infected population consume less; (2) those consumption adjustments lower the peak of active cases, lessen the total infections and deaths; (3) without lockdowns, the economic downturn reaches their bottom approximately during the peak of active cases; (4) consumption adjustments cause recession, but reduce the permanent output loss; (5) compared to one way effect of epidemic to consumption, the causality of consumption and contagion implies slower disease transmissions and lighter but longer recessions.

The paper is structured as follows. Section 2 presents the model. Section 3 reports numerical solutions of the model. Section 4 concludes.

2. The Model

As in Pindyck (2020), the basic SIR framework that is augmented to include deaths is as follows

$$S_{t+1} = -\beta X_t + S_t \tag{1}$$

$$I_{t+1} = \beta X_t - (\gamma_R + \gamma_D) I_t + I_t \tag{2}$$

$$R_{t+1} = \gamma_R I_t + R_t \tag{3}$$

$$D_{t+1} = \gamma_D I_t + D_t \tag{4}$$

Where $X_t = S_t I_t$. Here S_t is a fraction of population that is susceptible to the disease, I_t is a fraction of population that is currently infected. R_t and D_t is a fraction of population that is recovered and died from the disease, respectively. Note that $S_t + I_t + R_t + D_t = 1$. β is contact rate, the key for contagion dynamics. γ_R and γ_D are recovery rate and mortality rate from the disease, respectively. The key assumption on this model is that a recovered person is immune from the disease.

This paper extends the basic framework with simple consumption dynamics. The consumption dynamics is defined as a deviation from pre-pandemic steady state level. Susceptible population reduce their consumption, $C_{S,t}$, as a consequence of voluntary social distancing that is dependent to the number of active cases, so $C_{S,t} = \bar{C}(1 - \theta I_t)S_t$, where $\theta > 0$ and $\bar{C}$ is pre-pandemic steady state aggregate consumption. This is rational as the probability of getting infected or dying is higher as the number of active cases rises. Consumption of infected population, $C_{I,t}$, is less relative to pre-pandemic, $C_{I,t} = \bar{C}\rho I_t$, where $0 < \rho < 1$. This may be due to reduction of activities as they are feeling unwell or in isolation. Consumption of population that have recovered, $C_{R,t}$, is at normal level as they are immune, so $C_{R,t} = \bar{C}R_t$. Therefore, the current aggregate consumption, C_t, is as follows

$$C_t = C_{S,t} + C_{I,t} + C_{R,t} = \bar{C}[(1 - \theta I_t)S_t + \rho I_t + R_t] \tag{5}$$

Just before the outbreak, $S_0 = 1$, $I_0 = 0$, $R_0 = 0$, therefore $C_0 = \bar{C}$. After epidemic ends or risk of contracting the disease disappear completely, $I_E = 0$, therefore $C_E = \bar{C}(S_E + R_E) = \bar{C}(1 - D_E)$. This indicates that minimizing the death rate or minimizing the infections altogether are crucial to prevent permanent output loss. For analytical simplicity, the term (5) can also be interpreted as a fraction of consumption to the steady state pre-pandemic consumption level, as follows:

$$\hat{c}_t = \hat{c}_{S,t} + \hat{c}_{I,t} + \hat{c}_{R,t} = (1 - \theta I_t)S_t + \rho I_t + R_t \tag{6}$$

Where $\hat{c}_t = \frac{C_t}{\bar{C}}$, $\hat{c}_{S,t} = \frac{C_{S,t}}{\bar{C}} = (1 - \theta I_t)S_t$, $\hat{c}_{I,t} = \frac{C_{I,t}}{\bar{C}} = \rho I_t$, and $\hat{c}_{R,t} = \frac{C_{R,t}}{\bar{C}} = R_t$. $\hat{c}_{S,t}$, $\hat{c}_{I,t}$, and $\hat{c}_{R,t}$ are the consumption ratio to pre-pandemic level of susceptible, infected, and recovered population, respectively.

One obvious disadvantage of the above-mentioned model, i.e. Equation (1) to (4) and (6), is that the disease progression affects the consumption dynamics, but not vice versa. As argued by Eichenbaum, Rebelo, and Trabandt (2020), chances to get infected increases as people consume and work. To adapt this idea and maintain the simplicity, the population interaction term $X_t = S_t I_t$ from equation (1) and (2) is replaced by the interaction of consumption of susceptible and infected person, $X_{mod,t} = \hat{c}_{S,t}\hat{c}_{I,t}$. Equation (1) and (2) are modified as follows:

$$S_{t+1} = -\beta \hat{c}_{S,t}\hat{c}_{I,t} + S_t \tag{7}$$

$$I_{t+1} = \beta \hat{c}_{S,t}\hat{c}_{I,t} - (\gamma_R + \gamma_D)I_t + I_t \tag{8}$$

Eichenbaum, Rebelo, and Trabandt (2020) separate consumption interaction, work interaction and population interaction into different terms, sets weights on each term, then defines SIR model as a model with full weight on population interaction. Instead, we assume that the population interaction term on the original SIR model implies consumption at the pre-pandemic steady state level, and therefore the modification is done by replacing the population interaction term with the interaction of current consumption ratio to the pre-pandemic level. Substituting equation (6) to (7) and (8) yields the modified path of susceptible and currently infected population as follows:

$$S_{t+1} = -\beta\rho S_t I_t\,(1-\theta I_t) + S_t \tag{9}$$

$$I_{t+1} = \beta\rho S_t I_t (1-\theta I_t) - (\gamma_R + \gamma_D) I_t + I_t \tag{10}$$

If consumption is uniform, i.e. $\theta = 0$ and $\rho = 1$, equation (9) and (10) are equal to (1) and (2), respectively.

3. Numerical Solutions

For numerical exercise, this paper follows Pindyck (2020) to assume $\gamma_R = 0.0686$ and $\gamma_D = 0.0014$ for $dt = 1$ day. We set $\beta = 0.14$, which implies basic reproduction number of 2, i.e. $\frac{\beta}{\gamma_R+\gamma_D} = 2$, between range 1.5 – 3 that is chosen by Pindyck (2020). Further, we set $\rho = 0.8$, consistent with the assumption of relative productivity of infected person in Eichenbaum, Rebelo, and Trabandt (2020). Pindyck (2020) and Eichenbaum, Rebelo and Trabandt (2020) set initial infections of 6×10^{-6} and 0.001, respectively. This paper sets value between them, i.e. $I_1 = 0.0001$, hence $S_1 = 1 - I_1 = 0.9999$. In addition, we assume $\theta = 0.1$ arbitrarily.

Figure 1 presents rough illustrations of disease progression and consumption on daily basis. Solid line "SIR to consumption" shows disease progression of the original SIR model together with consumption that follows behavior as specified, i.e. equation (1) to (4), and (6). Dashed line "simultaneous" represents simultaneous model, i.e. by replacing equation (1) and (2) with (9) and (10). The third is "uniform" which assumes uniform consumption between susceptible, infected, and recovered population, thus $\theta = 0$ and $\rho = 1$. The path of susceptible, infected and recovered population of the "uniform" is the same to those of "SIR to consumption", hence it is also on the solid line. For consumption, "uniform" is on the dotted line. Note that "uniform" results the exact same path using either "SIR to consumption" or "simultaneous" model.

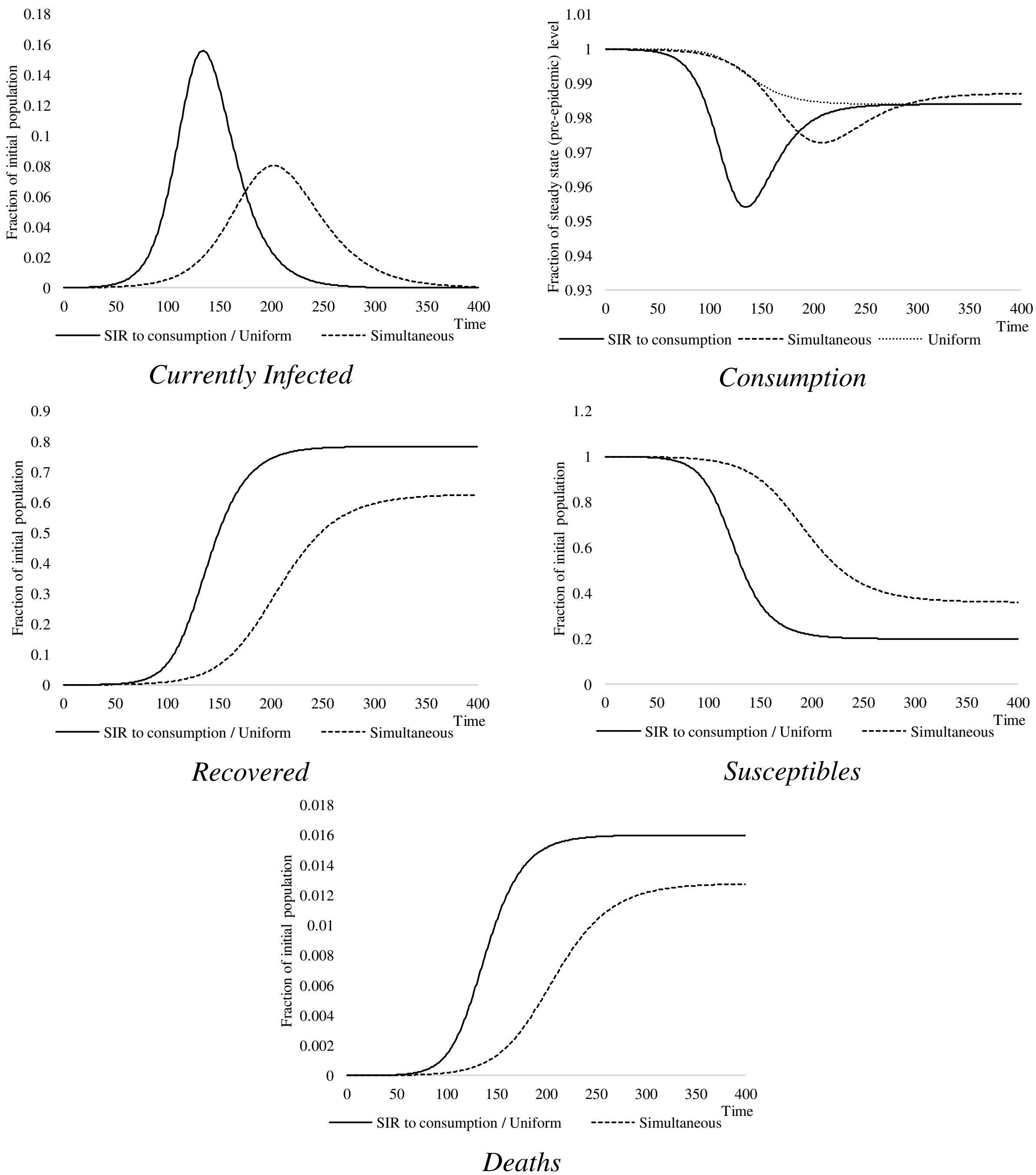

Figure 1. Daily path of susceptibles, infected, recovered, deaths and consumption

On “SIR to consumption” or “Uniform”, the infected population increases rapidly, resulting high peak of active cases. As a large fraction of population had been infected in a short time, the epidemic ends relatively fast. However, this mechanism infects almost 80% of initial population, with 1,6% of initial population died by the end of epidemic. With uniform consumption, the economy gradually shrinks proportional to deaths, but there is no short-term recession.

Consumption adjustment induces recession. By differentiating consumption behavior as in equation (6), a rapid increase of infections on “SIR to consumption” results in an immediate and large drop of aggregate consumption as the infected population consumes less and as susceptible population reduce their consumption. The path of infections decreases quickly, hence consumption recovers relatively fast. The economy converges at the same level as in the “Uniform” at medium term.

Simultaneous relationship between consumption and contagion slows the epidemic and recession. The peak of infected population is reached in a longer time. This results in a slower recession with shallower through, suggesting a lighter, but longer recession compared to “SIR to consumption”. At the end of epidemic, this results in less total infections and deaths, i.e. about 60% and 1,3% of initial population, respectively. Consequently, it results in a higher consumption after epidemic ends, compared to “SIR to consumption” and “Uniform”.

4. Conclusion

This paper presents a simple extension of SIR framework to explain consumption-contagion dynamics during epidemic. The model implies that the consumption adjustment, including voluntary social distancing by susceptible population, induces recessions in the short run, but results in a higher output in medium-term. Moreover, it limits disease transmission, lowers the peak of infected population, reduces total infections and total deaths. Lowering the peak of infected population may prevent overcapacity on healthcare system.

There are several caveats or possible extensions of this model. First, progress in contactless technology and behavior change (e.g. wearing masks, maintaining physical distance) may allow consumption to increase with limited acceleration of contagion. Second, if reinfection is possible, the contagion term should be extended by including interaction between the infected and the recovered, adjusted by the probability of reinfection. Third, an effective vaccination may reduce susceptible population and hence limiting the size of infections and recession. Fourth, by incorporating the capacity of healthcare system, voluntary social distancing and consumption adjustment may save more lives as it lowers the peak of infected population.

References

Baker, S. R., R.A. Farrokhnia, S. Meyer, M. Pagel and C. Yannelis. (2020). “How Does Household Spending Respond to an Epidemic? Consumption during the 2020 COVID-19 Pandemic” *The Review of Asset Pricing Studies* **10(4)**, 834-862.

Cook, J., N. Newberger and S. Smalling (2020) “The Spread of Social Distancing” *Economics Letters* **192**.

Eichenbaum, M. S., S. Rebelo, and M. Trabandt (2020) “The Macroeconomics of Epidemics” NBER working paper number 26882.

Kermack, W. O. and A. G. McKendrick (1927) “Contribution to the Mathematical Theory of Epidemics” *Proceedings of the Royal Society of London* A **115**, 700-721.

Krueger, D., H. Uhlig and T. Xie (2020) “Macroeconomic Dynamics and Reallocation in an Epidemic” working paper number No. 27047.

Maloney, W. and T. Taskin (2020) “Determinants of Social Distancing and Economic Activity during COVID-19: A Global View” World Bank Policy Research working paper number 9242.

Pindyck, R. S. (2020) “COVID-19 and the Welfare Effects of Reducing Contagion” NBER working paper number 27121.