Number 2020-11
May 28, 2020

ECONOMIC COMMENTARY

Lessons on the Economics of Pandemics from Recent Research

*Sewon Hur and Michael Jenuwine**

The spread of the COVID-19 pandemic has resulted in a dual public health and economic crisis. Many economic studies in the past few months have explored the relationship between the spread of disease and economic activity, the role for government intervention in the crisis, and the effectiveness of testing and containment policies. This *Commentary* summarizes the methods and findings of a number of these studies. The economic research conducted to date shows that adequate testing and selective containment measures can be effective in fighting the COVID-19 pandemic, and in the absence of adequate testing capabilities, optimal interventions involve social distancing and other lockdown measures.

The developing COVID-19 pandemic could be the worst global pandemic since the 1918 influenza pandemic and may have caused the largest economic contraction since the Great Depression. Because of the nature of this situation as both a public health crisis and an economic crisis, topics of paramount interest include understanding the relationship between the spread of disease and economic activity, the role for government intervention in the crisis, and the effectiveness of testing and containment policies. Economists have responded quickly to provide insights into these questions, yielding a rapidly growing body of research literature on the economics of pandemics.

This *Commentary* provides an overview of this research and highlights some of its key lessons. Our starting point is a long-standing model from epidemiology known as the "SIR model." From that building block, we focus on analyses that extend the model to include economic considerations and examine strategies for managing the public health and economic effects of pandemics.

These extended models formalize a tradeoff—associated with shutdowns such as those commonplace in the United States and many other nations—between preventing disease spread and decreasing economic output. According to analyses of such models, in the long term, containment measures such as shutdowns are better than the alternative of taking no action to mitigate the spread of disease, and the addition of testing policies appears more favorable than shutdowns alone. Accordingly, we read the work to date by economists as calling for extensive testing. We also briefly introduce economic models operating outside of the SIR model and present some empirical findings that use prior pandemics to predict the potential impact of COVID-19 and that describe the real-time effects of COVID-19 as it unfolds.

Sewon Hur is a research economist at the Federal Reserve Bank of Cleveland. Michael Jenuwine is a research analyst at the Bank. The views authors express in *Economic Commentary* are theirs and not necessarily those of the Federal Reserve Bank of Cleveland or the Board of Governors of the Federal Reserve System or its staff.

Economic Commentary is published by the Research Department of the Federal Reserve Bank of Cleveland. *Economic Commentary* is also available on the Cleveland Fed's website at www.clevelandfed.org/research. To receive an e-mail when a new *Economic Commentary* is posted, subscribe at www.clevelandfed.org/subscribe-EC.

ISSN 2163-3738 DOI: 10.26509/frbc-ec-202011 FEDERAL RESERVE BANK *of* CLEVELAND

Basic SIR Model from Epidemiology

The SIR model, originally developed by Kermack and McKendrick (1927), is a simple mathematical model of infectious diseases that divides the total population into three groups: *S* for susceptible (at risk of contracting the disease), *I* for infectious, and *R* for recovered, deceased, or otherwise immune. One particular variation of this model, developed by Imperial College London, has had a major impact on the policies of governments worldwide.[1] The model simulates the course of a disease by tracking changes over time in these three populations. The evolution of these populations depends importantly on two parameters. One parameter is the rate at which infected individuals encounter susceptible individuals and successfully transmit the virus (transmission rate). Importantly, recovered people are assumed to be immune from the disease, meaning they cannot be reinfected.[2] The other parameter is the rate at which infected people recover or die (sometimes referred to as the recovery rate, but more accurately as the removal rate, because these individuals are "removed" from the other two populations). (For technical details on the models described in this *Commentary*, see the online appendix.)

In a given week, new infections will be determined by the transmission rate, the number of individuals in the susceptible population, and the fraction of the population that is currently infected. In this formulation, the speed at which the epidemic spreads depends on the number of both susceptible and infected people because susceptible individuals can contract the disease only from infected individuals and infected individuals can transmit the disease only to susceptible individuals. Accordingly, the number of newly sick individuals will be added to the infected count and subtracted from the susceptible count. With the assumption of recovered individuals being immune, every week the number of infected individuals who have recovered or died from the disease is added to the removed count and subtracted from the count of those infected.

Much of the research by economists relies on a variation of this framework, known as the SEIR model, which adds a category of exposed (*E*) individuals to account for those who are infected but not yet infectious themselves. In the SEIR model, people have to have been exposed to the virus before they become infected; that is, exposure is a necessary first step for infection. The rate at which exposed individuals start showing symptoms and become infectious is denoted by an additional parameter; medically speaking, this rate is related to the virus's incubation period. The population in the exposed category next week rises by the number of susceptible individuals who encounter the infected and become exposed, as in the SIR model. Also as in the SIR model, the number of new exposures depends on the transmission rate, the number of susceptible individuals, and the fraction of infected individuals in the population. The exposed population falls by the number of exposed individuals who develop symptoms and progress to infection each week. With this exposure category added, the infected count rises with the exposed becoming infected and falls (as in the SIR model) by the number of individuals recovering or dying from infection.

An important number in the SIR class of models is known as the "basic reproduction number" (denoted R_0), which corresponds to how many people the average infected person passes the disease to while infectious and in the absence of mitigation efforts. In these models, R_0 is determined by the ratio of the transmission and removal rates. Most estimates for COVID-19 range between 2.2 and 3.1, meaning that each infected person infects an average of between 2.2 and 3.1 new people before recovering. For comparison, the value of the 1918 influenza is estimated to be between 1.4 and 2.8 and that of seasonal influenza typically ranges between 0.9 and 2.1.[3]

Atkeson (2020) uses an SEIR model with the added wrinkle that the transmission rate can change over time to account for containment measures such as quarantines. Containment measures that alter this transmission rate also change the rate of disease reproduction. The reproduction rate at various points in time is denoted *R* at time *t* or R_t. Atkeson uses this model to simulate the course of the disease under varying paths of the reproduction rate. The first exercise assumes constant reproduction rates ranging from 1.8 to 3.0, all of which lead to infection rates above 1 percent within 150 to 200 days, with peak infection rates well above that. This scenario corresponds to the case in which no mitigation efforts are made. The next exercise examines the speed of mitigation by decreasing reproduction rates from 3.0 down to 1.6 over varying time horizons. This scenario corresponds to the case with mild mitigation efforts. Even the very fastest reductions lead to large infection rates over the course of 18 months. Finally, short-term but severe mitigation efforts, modeled as a rapid reduction of reproduction rates from 3.0 to under 1.0, followed by a gradual increase back to 3.0 as mitigation efforts are relaxed, lead to a temporary reduction in infection initially but still show more than 90 percent of the population's becoming infected over the course of 18 months.

The key takeaway from Atkeson's work is that unless the reproduction rates can be sustained at levels under 1.0 for sufficiently long duration, the disease will eventually affect large segments of the population, leading to a large number of fatalities.

SIR-based Models with Additional Economics

A number of studies have extended the SIR and SEIR models to include various aspects of economics. Some work has brought in macroeconomic modeling, linking infection to economic activity. Other work has focused on the best strategies for limiting or managing the spread of the disease, ranging from complete confinement (quarantines) to working from home when possible, with and without extensive testing. Additional research has addressed some of the complexities that arise when differences across individuals in jobs, income, and wealth levels are taken into account and their resultant implications for COVID-related policies.

Studies of Mitigation Policies

While the Atkeson model makes statements about disease dynamics, it does not account for any relationship between the spread of disease and the economy as a whole. Eichenbaum, Rebelo, and Trabandt (2020) remedy this by tying the likelihood of infection to participation in labor and consumption markets. In addition to the baseline level of transmission, transmission can occur between susceptible and infected individuals while consuming (such as while out shopping) or while working.[4] These modes of transmission, then, depend not just on how many people are susceptible and infected, but also on how much susceptible and infected people choose to consume or work. This calculation directly ties the rate of infection to individuals' economic decisions.

On the economic side of the model, individuals choose how much to consume and how much to work. In doing so, they want to balance the utility they receive from consumption against the utility they receive from not working. The choices an individual makes change based on whether that person is susceptible, infected, or recovered. In particular, susceptible individuals may choose to consume and work less than others to lower the risk of becoming infected. Hence, even without mitigation measures, changes in individuals' economic behavior reduce the spread of the virus—average consumption is estimated to fall by about 10 percent, just by virtue of people's choosing to stay home more to avoid getting sick. The effect of individuals' decisions also matters for the model's epidemiological implications—compared to the basic SIR model, the infection peak decreases from 7 percent to 5 percent and the death toll decreases from 0.30 percent to 0.26 percent. Meanwhile, infected individuals are assumed not to take into account that their consumption and work habits may infect others, an externality that results in an inefficient outcome in which infected individuals choose to consume and work more than would be socially optimal.

The authors next estimate how the mitigation measures might alter this externality. They solve for optimal containment measures, which are modeled as a consumption tax and lump sum rebate, that maximize the discounted sum of utility from consumption and leisure for all agents in the economy.[5] The consumption tax directly reduces the incentive to participate in consumption activities and indirectly reduces the incentive to participate in the labor market by making consumption less attractive relative to leisure. This leads individuals to change their behavior and reduces their likelihood of becoming infected and infecting others. The tax revenue is then rebated lump-sum to the households so that the net tax is unchanged. This approach to the taxes and lump-sum transfers holds disposable income of households constant, and permits an assessment of the mechanisms at work without income changes muddying the picture. Relative to the laissez-faire economy with no mitigation measures, optimal containment reduces aggregate consumption even more, but it also reduces the peak level of infection and the death toll by changing the behavior of the infected. The authors estimate that the optimal containment measures will reduce peak level of infections from 5 percent to 3 percent of the population and the death toll from 0.26 percent to 0.21 percent of the population at the cost of consumption's dropping an additional 18 percentage points.

Alvarez, Argente, and Lippi (2020) extend the basic SIR model to include lockdown measures and solve for an optimal lockdown policy that minimizes both the economic losses and the lives lost because of the pandemic. The key addition to their model is that a fraction of the population can be placed into lockdown or quarantine. When in lockdown, susceptible people cannot meet or become infected by any contagious people. However, people are less able to work when in lockdown, so there is an economic cost. An optimal lockdown policy over time is chosen to balance the loss of lives from COVID-19 against the loss of economic output because of the lockdown. Changes in the number of infected individuals are determined in the same way as in the basic SIR model except that only the fraction of individuals out of lockdown can pass along the disease to those not in lockdown. A parameter in their model governs the effectiveness of the lockdown. When it is 0, the lockdown is completely ineffective, and the disease dynamics boil down to the basic SIR model. Another small change is that infected individuals die at a rate that is determined as a function that is increasing in the number of infected people. This addition reflects a situation in which as more people are infected, the capacity to treat them is reduced, and the death rate increases.

The authors find that the optimal policy is a rapid and severe lockdown that peaks at 60 percent of the population and then slowly decreases to below 10 percent of the population by 15 weeks after the lockdown starts. These results are most sensitive to the effectiveness of lockdown, the value of statistical life,[6] and the rate at which the death rate increases in the number of infected people. A less effective lockdown makes the optimal lockdown time shorter as the economic costs of lockdown outweigh the benefits faster. For example, if the lockdown is not effective at all in reducing transmission rates, then its only effect would be to harm the economy, and the optimal lockdown would be none at all. Increasing the value of statistical life makes the optimal lockdown time longer as the benefits of lockdown in terms of lives saved are greater. Finally, assuming that the death rate is unaffected by the number of infected makes any lockdown suboptimal. This is because without any congestion in the healthcare system, the model assumes that resources such as hospital beds and ventilators will not need to be rationed in order for everyone in need to be treated, making the speed at which the infection spreads inconsequential to the overall death rate.

Jones, Philippon, and Venkateswaran (2020) also study optimal mitigation policies in an SIR-macro model. As in Eichenbaum, Rebelo, and Trabandt (2020), new infections are a function of the levels of consumption and labor of the susceptible and infected populations, but with an added element that working from home can reduce the rate of infections. Moreover, Jones, Philippon, and Venkateswaran (2020) assume that there is "learning by doing" in terms of a household's ability to work from home, meaning that the more households work from home, the better they become at doing so. The optimal policy involves more drastic and earlier mitigation measures, compared to those in both Eichenbaum, Rebelo, and Trabandt (2020) and Alvarez, Argente, and Lippi (2020). This is because the model not only takes into account the negative effects of hospital congestion and high infection rates, but it also accounts for the time it takes for workers to become productive while working from home, so earlier mitigation measures allow for workers to become productive more quickly.

Studies of Testing Policies

We now turn to recent research that considers testing policies in addition to containment policies. Both Piguillem and Shi (2020) and Berger, Herkenhoff, and Mongey (2020) use an SEIR model as in Atkeson (2020) and assume that exposed asymptomatic individuals can also spread the disease. The Piguillem and Shi (2020) study is similar to Alvarez Argente, and Lippi (2020) in that the government can institute a lockdown or quarantine for a fraction of the population. However, Piguillem and Shi assume that all infected people who are showing symptoms (I) are placed into quarantine as a matter of course, so the lockdown affects people who are exposed but without symptoms (E) and those who are susceptible (S). In the absence of testing, exposed asymptomatic individuals cannot be identified as exposed but are still contagious, so a lockdown policy must be set as a fraction of both susceptible and exposed individuals. Testing allows the government to distinguish between susceptible and exposed individuals and thus to quarantine or enact lockdown policies more selectively.

The model shows that mass lockdown is optimal if there are no means of widespread testing, but increasing testing of subjects is superior to mass lockdown. However, these results are dependent on the economic cost of testing, which is unknown. These findings are consistent with Berger, Herkenhoff, and Mongey (2020), who demonstrate that the government can simultaneously ease lockdown and quarantine measures and increase testing while keeping the overall mortality rate constant. For example, targeted lockdown and quarantine with testing reduces the economic output loss by 5 percentage points relative to a common lockdown and quarantine without testing.

Distributional Consequences

The SIR models described above do not feature the heterogeneous effects of COVID-19 and various mitigation efforts across income, wealth, age, or occupation. Kaplan, Moll, and Violante (2020) document that workers employed in sectors that are more contact intensive and offer less job flexibility (to work remotely), such as the leisure and hospitality sector, have lower income and wealth relative to workers employed in sectors that are less contact intensive and offer more flexibility, such as the information sector. This is important since the workers who are more likely to be adversely impacted by lockdown policies—those that work in contact-intensive and low-flexibility sectors—also tend to be the ones who have less savings to rely on for smoothing consumption.[7] Kaplan, Moll, and Violante add these dimensions to an SIR model within an otherwise standard Heterogeneous Agent New Keynesian (HANK) model—a model developed by Kaplan, Moll, and Violante (2018) that is often used to study the distributional effects of monetary policy—to find that in the absence of any public interventions, aggregate consumption falls by more than 4 percent, and more than 1.5 percent of the initial population dies as a result of the pandemic.

Another paper that studies the distributional consequences of the pandemic is that of Glover et al. (2020), who extend the SEIR model by allowing for transmission rates to interact with the levels of consumption and labor supplied (as in Eichenbaum, Rebelo, and Trabandt, 2020) and by embedding these features into a macroeconomic model in which individuals differ by age and the sector in which they work. Adding the age dimension is especially relevant since the case fatality rates for COVID-19 vary dramatically for different age groups. In particular, older individuals have the most to gain from mitigation policies, while younger workers in sectors that are forced to shut down have the most to lose. The optimal mitigation policy is sensitive to how much weight each type of agent receives. A planner that puts more weight on older agents would choose extensive and prolonged mitigation measures (shutting down 35 percent of the nonessential sector until June 2020 and fully opening by November 2020), while one that puts more weight on the nonessential sector workers would choose much weaker mitigation measures (shutting down 15 percent of the nonessential sector initially and fully opening by June 2020).

Model Limitations

While the SIR model is a powerful tool to measure disease dynamics, its implications depend heavily on the chosen values of the parameters that determine how quickly the disease spreads and how quickly people recover (or die) from it. Modelers choose these values to make their model best match observed, real-world data. Korolev (2020) raises the concern that SIR models cannot be accurately estimated using only the readily available data of confirmed cases and deaths. In particular, estimates of the case-to-fatality ratio, which drives the long-run number of deaths, may be inaccurate, and estimates of the basic reproduction number (R_0) are dependent on characteristics of the virus, such as its incubation period or duration of illness, for which there are no consensus values. Variation in these estimates can cause massive fluctuations in long-run forecasts of deaths and cases while still matching the short-run observed data.

Korolev simulates the model with various parameter values, resulting in possible paths of confirmed cases and deaths that all match the current short-run data but diverge widely in the long run. For example, estimates of the number of currently infected people (including unconfirmed cases) vary from 6 million to 140 million, and estimates of total deaths range from 33,000 to 1.1 million, depending on how these values are set. As a longer sample of data becomes available and testing increases, these estimates can be made more accurate. However, Korolev's work illustrates the importance of carefully looking at how models choose their parameters and how those parameters can affect the models' results.

Other Economic Approaches to COVID-19

This *Commentary* thus far has focused on literature using the SIR model or some variation of it. However, it is far from the only quantitative modeling framework by which economists are examining the effects of COVID-19. For example, Faria-e Castro (2020) studies the effects of the US COVID-19 outbreak and subsequent fiscal stimulus using a dynamic stochastic general equilibrium model—a model often used to study fiscal policy—and finds that the pandemic causes a 40 percent drop in employment in the services sector and a 15 percent contraction in GDP during the first three months of the pandemic, followed by a slow recovery. Guerrieri et al. (2020) develop a theory for how negative supply shocks, such as the COVID-19 pandemic and social distancing policies, can lead to drops in aggregate demand that are even larger than the initial supply shock and a reduction in the natural interest rate. Finally, Hall, Jones, and Klenow (2020) develop a simple framework to compute the fraction of annual consumption a society would be willing to give up to avoid the risk of death associated with COVID-19. In the most basic setup, the authors find that a society would be willing to give up 26 percent of its total annual consumption in order to avoid the aggregate increase in mortality caused by COVID-19.

Outside of the modeling literature, there are also many empirical studies seeking to determine the real-time effects of the COVID-19 pandemic. The research of Barro, Ursúa, and Weng (2020) and Correia, Luck, and Verner (2020) use data from the 1918 influenza pandemic as a basis for comparison to the COVID-19 pandemic. These studies measure the macroeconomic impacts of the 1918 influenza outbreak, along with the impacts of local government interventions in response to it. They find that the 1918 influenza pandemic significantly decreased economic output at the time and that quickly enacted and long-lasting containment measures improved long-run output and employment. Moving to contemporary effects, Fang, Wang, and Yang (2020) and Greenstone and Nigam (2020) seek to understand the efficacy of social distancing measures using data from the United States and China and conclude that social distancing and mobility restrictions significantly reduce the spread of the virus. Mongey and Weinberg (2020) and Bick and Blandin (2020) both examine the heterogeneous effects of social distancing measures on workers. They find that less educated and less wealthy workers are more likely to hold jobs that do not allow for remote work or that involve high levels of person-to-person contact and thus are most likely to face unemployment because of social distancing measures. Alon et al. (2020) discuss the potential long-run effects of the pandemic on gender equality, pointing out that the economic downturn caused by the pandemic more negatively impacts sectors with higher female employment compared to economic downturns in "regular" recessions. Finally, Baker et al. (2020) use real-time household financial data to examine how the spread of COVID-19 and implementation of social distancing measures have affected Americans' consumption patterns, finding patterns consistent with a period of rapid stockpiling following by greatly depressed spending as social distancing measures are enacted.

Conclusion

The spread of the COVID-19 pandemic has resulted in a dual public health and economic crisis. This has led to a quickly emerging body of literature on the economics of pandemics, some parts of which were covered in this *Commentary*. This literature has demonstrated that it is important for models of the pandemic to incorporate changes in individuals' economic behavior; failing to do so can result in overestimates of infection rates by ignoring how rates of transmission change as people behave differently in response to the pandemic and their perceived risk. Furthermore, because of the externality that infected and asymptomatic individuals do not fully take into account the effect of their actions on aggregate infection and hospitalization rates, there is a role for government intervention in fighting the pandemic.

As governments choose policies to follow in response to the pandemic, it is imperative that we understand precisely how both the pandemic and potential government interventions will impact us. The SIR-macro literature provides a useful framework within which to predict the effects of policies. The research conducted to date shows that adequate testing and selective containment measures can be effective in fighting the pandemic, and in the absence of adequate testing capabilities, optimal interventions involve social distancing and other lockdown measures. However, the research landscape continues to evolve quickly, and more research is needed to guide monetary policy, especially taking into account that most central banks in severely affected nations are already at or near the effective lower bounds of their policy interest rates.

Footnotes

1. See Ferguson et al. (2020) for a description of the model and this *Washington Post* article for a discussion of the model's importance: https://www.washingtonpost.com/outlook/2020/04/14/coronavirus-models-ihme-ic/.

2. It is not yet clear whether this assumption is correct for COVID-19.

3. https://www.infectioncontroltoday.com/public-health/100-years-after-spanish-flu-lessons-learned-and-challenges-future.

4. In this model, no distinction is made between those who work at home and those who work under other conditions, though another model discussed below does.

5. As in most economic models, agents derive utility—think units of happiness—from consumption and leisure. Because this is a multiperiod model, agents discount future utility relative to current utility, and optimal policies are those that maximize the discounted sum of these utilities.

6. The value of statistical life is a measure used by policymakers in cost–benefit analysis. For example, in the United States, these estimates ranged from $8.9 million (Department of Agriculture) to $10 million (FDA) per life in 2016. https://www.bloomberg.com/graphics/2017-value-of-life/.

7. For example, a report from the Board of Governors (2020) finds that 39 percent of people working in February 2020 with a household income of less than $40,000 reported a job loss in March of that year.

References

Alon, Titan M, Matthias Doepke, Jane Olmstead-Rumsey, and Michèle Tertilt. 2020. "The Impact of COVID-19 on Gender Inequality." National Bureau of Economic Research Working Paper No. 26947. https://doi.org/10.3386/w26947.

Alvarez, Fernando, David Argente, and Francesco Lippi. 2020. "A Simple Planning Problem for COVID-19 Lockdown." University of Chicago, Becker Friedman Institute for Economics, Working Paper (April 6). https://bfi.uchicago.edu/working-paper/a-simple-planning-problem-for-covid-19-lockdown/.

Atkeson, Andrew. 2020. "What Will Be the Economic Impact of COVID-19 in the US? Rough Estimates of Disease Scenarios." National Bureau of Economic Research, Working Paper No. 26867. https://doi.org/10.3386/w26867.

Baker, Scott R, R.A Farrokhnia, Steffen Meyer, Michaela Pagel, and Constantine Yannelis. 2020. "How Does Household Spending Respond to an Epidemic? Consumption during the COVID-19 Pandemic." University of Chicago, Becker Friedman Institute for Economics, Working Paper (March 31). https://bfi.uchicago.edu/working-paper/how-does-household-spending-respond-to-an-epidemic-consumption-during-the-2020-covid-19-pandemic/.

Barro, Robert J., José F. Ursúa, and Joanna Weng. 2020. "The Coronavirus and the Great Influenza Pandemic: Lessons from the "Spanish Flu" for the Coronavirus's Potential Effects on Mortality and Economic Activity." National Bureau of Economic Research, Working Paper No. 26866. https://doi.org/10.3386/w26866.

Berger, David W, Kyle F Herkenhoff, and Simon Mongey. 2020. "An SEIR Infectious Disease Model with Testing and Conditional Quarantine." National Bureau of Economic Research, Working Paper No. 26901. https://doi.org/10.3386/w26901.

Bick, Alexander, and Adam Blandin. 2020. "Real Time Labor Market Estimates During the 2020 Coronavirus Outbreak." Arizona State University, unpublished manuscript. https://alexbick.weebly.com/uploads/1/0/1/3/101306056/bb_covid.pdf.

Board of Governors. 2020. "Report on the Economic Well-Being of US Households in 2019, Featuring Supplemental Data from April 2020." https://www.federalreserve.gov/publications/files/2019-report-economic-well-being-us-households-202005.pdf.

Correia, Sergio, Stephan Luck, and Emil Verner. 2020. "Fight the Pandemic, Save the Economy: Lessons from the 1918 Flu." Federal Reserve Bank of New York, *Liberty Street Economics* (March 27). https://libertystreeteconomics.newyorkfed.org/2020/03/fight-the-pandemic-save-the-economy-lessons-from-the-1918-flu.html.

Eichenbaum, Martin S., Sergio Rebelo, and Mathias Trabandt. 2020. "The Macroeconomics of Epidemics." National Bureau of Economic Research, Working Paper No. 26882. https://doi.org/10.3386/w26882.

Fang, Hanming, Long Wang, and Yang Yang, 2020. "Human Mobility Restrictions and the Spread of the Novel Coronavirus (2019-nCoV) in China." National Bureau of Economic Research, Working Paper No. 26906. https://doi.org/10.3386/w26906.

Faria-e Castro, Miguel. 2020. "Fiscal Policy during a Pandemic." Federal Reserve Bank of St. Louis, Working Paper No. 2020-006E. https://doi.org/10.20955/wp.2020.006.

Ferguson, Neil, Daniel Laydon, Gemma Nedjati Gilani, Natsuko Imai, Kylie Ainslie, et al. 2020. "Report 9: Impact of Non-pharmaceutical Interventions (NPIs) to Reduce COVID19 Mortality and Healthcare Demand." Imperial College of London, Technical Report No. 16-03-2020. https://www.imperial.ac.uk/media/imperial-college/medicine/sph/ide/gida-fellowships/Imperial-College-COVID19-NPI-modelling-16-03-2020.pdf.

Glover, Andrew, Jonathan Heathcote, Dirk Krueger, and José-Víctor Ríos-Rull. 2020. "Health versus Wealth: On the Distributional Effects of Controlling a Pandemic." Centre for Economic Policy Research, Discussion Paper No. 14606. https://cepr.org/active/publications/discussion_papers/dp.php?dpno=14606.

Greenstone, Michael, and Vishan Nigam. 2020. "Does Social Distancing Matter?" University of Chicago, Becker Friedman Institute for Economics, Working Paper (March 25). https://bfi.uchicago.edu/working-paper/2020-26/.

Guerrieri, Veronica, Guido Lorenzoni, Ludwig Straub, and Iván Werning. 2020. "Macroeconomic Implications of COVID-19: Can Negative Supply Shocks Cause Demand Shortages?" National Bureau of Economic Research, Working Paper No. 26918. https://doi.org/10.3386/w26918.

Hall, Robert E., Charles I. Jones, and Peter J. Klenow. 2020. "Trading Off Consumption and COVID-19 Deaths." Stanford University, unpublished manuscript. https://web.stanford.edu/~chadj/Consumption_v_Covid.pdf.

Jones, Callum J., Thomas Philippon, and Venky Venkateswaran. 2020. "Optimal Mitigation Policies in a Pandemic: Social Distancing and Working from Home." National Bureau of Economic Research, Working Paper No. 26984. https://doi.org/10.3386/w26984.

Kaplan, Greg, Benjamin Moll, and Giovanni L. Violante. 2018. "Monetary Policy According to HANK." *American Economic Review*, 108(3): 697–743. https://doi.org/10.1257/aer.20160042.

Kaplan, Greg, Benjamin Moll, and Giovanni L. Violante. 2020. "Pandemics According to HANK." Virtual Presentation, March 31. https://www.youtube.com/watch?v=WYisQeoha7U.

Kermack, William Ogilvy, and Anderson G. McKendrick. 1927. "A Contribution to the Mathematical Theory of Epidemics." *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character,* 115 (772): 700–721.

Korolev, Ivan. 2020. "Identification and Estimation of the SEIRD Epidemic Model for COVID-19." Binghamton University. http://dx.doi.org/10.2139/ssrn.3569367.

Mongey, Simon, and Alex Weinberg. 2020. "Characteristics of Workers in Low Work-from-Home and High Personal-Proximity Occupations." University of Chicago, Becker Friedman Institute for Economics, White Paper. https://bfi.uchicago.edu/working-paper/characteristics-of-workers-in-low-work-from-home-and-high-personal-proximity-occupations/.

Piguillem, Facundo, and Liyan Shi. 2020. "The Optimal COVID-19 Quarantine and Testing Policies." Einaudi Institute for Economics and Finance, Working Papers No. 2004. https://EconPapers.repec.org/RePEc:eie:wpaper:2004.