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Epidemiology's Time of Need: COVID-19 Calls for Epidemic-Related Economics

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The COVID-19 pandemic is a global and systemic human catastrophe on a scale that hasn't been seen for infectious disease since the 1918 Spanish Flu. The rapid spread of this pandemic has upended daily life more quickly and more widely than any other large modern pandemic, including HIV/AIDS, and has propelled the relatively unknown field of epidemiology into the public spotlight. Prior to 2020, it was a long-standing joke that upon telling someone you were an epidemiologist, you would immediately be asked to provide advice on a mole or skin lesion ("epidem-" being mistakenly associated with "epidermis"). This has shifted dramatically in 2020 with epidemiologists now being asked, "when will COVID end?" But this question also misunderstands the nature of epidemiology.

Epidemiology as a field of scientific inquiry largely began in the 19th century—although some examples of statistical analyses of public health data exist from before this time, including the work of John Graunt (1662). The first epidemiologic society, the *London Epidemiologic Society*, formed in 1850 (Morabia 2004), and John Snow published his foundational epidemiologic study, *On the Mode of Communication of Cholera,* in 1855 (Snow 1855). Since then, the field of epidemiology has rapidly expanded, both in size and scope. Today, epidemiology encompasses the study of all factors that influence the health of human populations (Porta 2014). While this includes the study of infectious diseases, many epidemiologists now study non-communicable diseases, environmental exposures, or social structures that lead to or increase disease and inequities. Some epidemiologists even study the impacts

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of economic policies, but the common focus of epidemiologists is on the goal of understanding and improving people's health (Krieger 2011).

Although epidemiology has evolved away from its roots in infectious diseases, epidemic response remains a core feature of epidemiologic expertise. However, in a changing and increasingly connected world, a successful response to COVID-19 is not entirely within the reach of even the best epidemiologic advice. As the pandemic continues to spread, the far-reaching consequences of COVID-19 are no longer just (nor perhaps even primarily) epidemiologic problems. After all, COVID-19 has impacted every sphere of life and aspect of society, and in many countries, decisions about how to mitigate the spread of COVID-19 have become highly politicized. Economists and others skilled in data analysis have recognized this and are anxious to put their skills to use, and those skills are desperately needed as the pandemic evolves.

As an epidemiologist, I ask economists interested in COVID-19 to build on their expertise and ours. Indeed, the efforts of economists in tackling the *economic* sequelae of this pandemic are vitally needed, as are the development of tools for tracking, predicting, and preventing future pandemics based on understanding the flow of people, goods, and other economic activity around the globe. But I also add that applying economics skills to evaluating epidemiology methods, as some more vocal economists have been doing, is not likely the best use of economic expertise nor will it be the most helpful for bringing COVID-19 under control. Despite having first encountered the concepts of infectious disease in January and February 2020, often through trial and error, many economists and other quantitative analysts have offered either prediction models of SARS-CoV-2 transmission or proposed strategies for reducing transmission. Many of these models failed to recognize the ways in which infectious diseases are very different from other types of quantitative data, and further, to recognize that expertise in modeling other datasets does not automatically translate to expertise in infectious disease modeling. As a result, many of the predictions or strategy proposals offered up by non-epidemiologists contain fundamental errors or oversights that greatly limit their value.

In this essay, I attempt to provide an epidemiologist's perspective on how economists can help improve our COVID-19 response. I begin with a discussion of how the goals of infectious disease modeling differ between applied and academic research settings and how some criticisms of epidemiology models are based on confusing these categories. I next discuss the tradeoff between data and assumptions in epidemiology. Early in a pandemic, an applied model must rely on a combination of limited data and assumptions. But as the pandemic evolves, it (perhaps counterintuitively) turns out that the quality of the data does not always improve and that key parameters may shift in unpredictable ways. The following section turns to some implications for epidemiology modeling and explains both what the public got wrong in interpreting these models and what epidemiologists got wrong in explaining them. I then identify some areas where work by economists could be especially helpful in the COVID-19 response.

Two years ago, this journal published, "An Economist's Guide to Climate Change Science," which offered a basic overview of the science written for economists (Hsiang and Kopp 2018). That article offers useful context and background for economists working on the benefits and costs of policies that seek to reduce greenhouse gas emissions, or seeking to estimate the economic consequences of rising temperatures and other climate effects. However, it would be a long road from that overview article to the frontier of atmospheric science models. Similarly, the companion paper by Avery et al. in this issue offers a clear and easy-to-follow basic introduction to the concepts of infectious disease epidemiology modeling for economists, but readers should not fall into the trap of assuming this gentle introduction, covering material that would be expected in the first few lectures of an introductory course on this topic, provides an exhaustive catalog of the methodological and substantive expertise required to conduct infectious disease modeling. Infectious disease epidemiology is not a new field. The principles of epidemic dynamics, prevention, and elimination are well-established and have been tested in disease outbreaks, large and small, as well as in computational models and laboratory experiments. There is no more reason for economists to jump into the production of epidemiology models than there is for them to become atmospheric scientists: after all, a central tenet of economics is the benefits that flow from specialization and exchange. I hope this discussion will provide a clearer understanding of the strengths and weaknesses of (infectious disease) epidemiology and spur more productive and impactful collaboration between our two disciplines.

Infectious Disease Epidemiology: Applied versus Academic

Should the public wear face masks? This question has been debated vigorously throughout the COVID-19 pandemic and has become increasingly politically charged. The answer to this question has also evolved over the course of the pandemic, with most public health officials now recommending face mask use for all individuals when outside the home. This changing and debated guidance has led to confusion among the general public and even to accusations that public health agencies and epidemiologists were concealing the benefits of face masks—although to what end they would do so remains unclear. The truth is that this question does not have a single answer, and the confusion arises from the distinction between two key facets of epidemiology.

Economics is often separated into theoretical and empirical work. In epidemiology, the concept of theory is used to discuss larger ideas of the interactions amongst the individual, environment, society, and biology of health and illness. What economists call "theory" would usually be referred to, instead, as "epidemiologic methods." Empirical epidemiology is thus intertwined in methods, based on the idea that we cannot understand why or how to conceptualize a model without understanding how the parameters arise. Rather than the theory/empirical distinction common in economics, a more natural distinction in epidemiology, especially for infectious disease epidemiology, is between applied (or field) epidemiology and academic (or research) epidemiology.

Applied epidemiology focuses on providing rapid understanding to guide decision-making based on imperfect data, existing knowledge, and more than a little expert intuition (Rasmussen and Goodman 2019). Applied epidemiology is not restricted to infectious diseases, but infectious diseases often comprise a larger portion of the work of applied epidemiologists relative to the entire field of academic epidemiology. Even in academic epidemiology, epidemiologists recognize the trade-off between available data and required assumptions in disease modeling (Hernán 2015); this trade-off is even more apparent in applied epidemiology. During an outbreak, the limited available data must be offset with strong assumptions; the challenge is in understanding which assumptions are the most appropriate and which have the largest impact on model results and subsequent recommendations. The goal of applied epidemiology is to identify rapidly and under time pressure the category of infectious disease, to determine the key parameters specific to this infection, and to obtain data to update models based on those key parameters, while relying on prior experience, expertise, and intuition for selecting necessary assumptions. The bulk of COVID-19 models are applied epidemiology models. These models generally seek to estimate particular components of the prediction space, such as best- or worst-case scenarios.

Academic epidemiology, on the other hand, seeks to refine and hone a more detailed understanding of disease processes through extensive data collection, careful estimation of input parameters, and wide assessment of uncertainty (Murray et al. 2017; Eddy et al. 2012; Abuelezam, Rough, and Seage 2013). This process can take years and significant investment of human and financial resources. The goal of academic infectious disease modelers is to arrive at a more complete understanding of disease outbreaks that rely as much as possible on empirically obtained parameters rather than assumptions based on expert knowledge—although many disease models will require at least some input parameters that cannot ever be obtained directly from empirical data (Murray et al. 2020).

How does this apply to the changing guidance on community use of face masks? In January 2020, there was strong evidence supporting the use of personal protective equipment, including face masks, in high-risk settings such as health care facilities for the prevention of respiratory infections. However, the existing epidemiologic literature on the use of face masks by the general public for control of respiratory infections was extremely limited and showed mixed results (Brosseau 2020; Brosseau and Sietsema 2020; Chu et al. 2020). For example, one meta-analysis found that mask use in health care approximately halved the risk of influenza infection (Saunders-Hastings et al. 2017), and a randomized trial of non-pharmaceutical interventions in the home found an approximately 20 percent reduction in influenza infection for households using both face masks and hand sanitizer compared to hand sanitizer alone (Larson et al. 2010). In contrast, several randomized trials of households limited to face mask use alone had found no reduction in influenza transmission (Aiello et al. 2010; Canini et al. 2010; Cowling et al. 2008).

Lacking clear information on the benefits of community-level face mask use, epidemiologists in early 2020 engaged in internal discussion about the potential harms and benefits of this intervention, considering aspects such as the limited existing research, the limited supply and interrupted supply chains of masks, what was known at the time about the epidemiology of SARS-CoV-2 transmission, and concerns around the potential for "risk compensation" if people who were wearing masks then engaged in fewer other preventive measures (Bamber and Christmas 2020; Brosseau 2020; Brosseau and Sietsema 2020; Cheng 2020; Javid, Weekes, and Matheson 2020; King 2020). Based on these discussions, many applied epidemiologists, including those at the World Health Organization and Centers for Disease Control, initially advised against the use of face masks by the general public. Instead, they stressed the importance of hygiene and distancing-based interventions, such as hand-washing, social distancing, and quarantine.

Over time, however, new information emerged. First, it became clear that at least some subset of Americans would be amenable to wearing masks. Second, we learned that SARS-CoV-2 could be transmitted by individuals who were not (yet) symptomatic (Gandhi, Yokoe, and Havlir 2020). Finally, as the availability and use of both fabric and surgical masks increased, it became clear that even when individuals wearing masks did increase their risk behaviors (by, for example, joining protests), the evidence did not suggest that transmission in these settings was any higher than if attendees had been unmasked (Dave et al. 2020). Together, these observations have shifted most applied epidemiologists and public health officials towards encouraging the use of face masks by all individuals (Greenhalgh et al. 2020; Roderick et al. 2020).

However, this recommendation does not mean that the *academic epidemiology* of face mask usage by the general public during respiratory outbreaks has necessarily advanced much beyond what we knew in January 2020, and many academic epidemiologists remain agnostic about the value of face masks. In fact, if anything, it may be fair to say that academic epidemiologists have *fewer* answers about the science of face masks than we did 10 months ago—simply because we now have *more* questions. Previous research on face mask usage in respiratory outbreaks focused chiefly on evaluating either N95 masks or surgical masks, both of which are subject to regulatory standards. In contrast, many of the face masks used by the general public during the COVID-19 pandemic are made from fabric, both commercially and homemade, and the filtration efficacy of these masks is both unknown and potentially highly variable (Aydin et al. 2020; Davies et al. 2013; Tcharkhtchi et al. 2020). In addition, previous studies of face mask usage typically assumed individuals had been provided with training and guidance on how to appropriately don, doff, and wear face masks to maximize their benefits. In reality, adherence both in terms of frequency and correctness of face mask use is extremely variable among the general public. Despite this, existing attempts to model the population impacts of community-level face mask use have typically assumed perfect adherence and correct usage (Ferguson et al. 2020). Academic epidemiologists likely will be investigating and debating these topics for many years to come, both to fully characterize the causal effect of community level mask-wearing strategies and to explore the actual risks and benefits that result from these (Bundgaard et al. 2020; Doung-ngern et al. 2020).

The distinction between applied and academic epidemiology arises from the different goals and time frames of these groups. Applied epidemiologists must provide the best available advice now and update as soon as new information is available—even if that advice or information arises more from experience and intuition than scientific fact. Academic epidemiologists, on the other hand, can afford to hold off making judgements until the best possible information is available and judgements can be supported by rigorous data collection and analyses. It is thus natural that these two groups will on occasion disagree about the best decision, as was the case with face masks, and such differences should not be misinterpreted as malicious or deceptive on the part of either group.

Data-Assumption Trade-Offs Change over Time as an Outbreak Progresses

Another challenging aspect of outbreaks that is well-known to epidemiologists, but may not be familiar to economists, is the complex and often counterintuitive ways in which data availability and quality can change over the course of an outbreak.

Initially, when a new disease emerges, very few data are available. As an outbreak progresses, the amount of data and the number of recognized cases naturally increase, but the completeness of the data does not necessarily increase in the same way. Many early attempts by non-epidemiologists (or epidemiologists with no experience in infectious diseases) to understand or predict COVID-19 went wrong when analysts either assumed that initial data would continue to describe the changes in disease spread over time, or that initial data could only be biased in one direction. In this section, I briefly describe some of the less intuitive ways in which data quality and biases can change over the course of an outbreak.

For diseases where mild cases or asymptomatic infections are rare, the earliest case reports are likely to be the most complete. This is because, although cases are easy to detect, the capacity for the system to track and record cases may degrade as the number of cases increases. Based on an analogy to the SARS outbreak of 2003, many initially thought this would be the case with COVID-19. This led to errors such as a focus on infection only among the elderly, tracking systems that recorded only death or recovery and failed to follow-up on longer term health outcomes, testing guidelines that restricted eligibility based on known contacts with COVID-19 patients, and diagnostic protocols which included only the symptoms most characteristic of early cases. Failure to update policies and guidance in these areas as the epidemiological and clinical picture of COVID-19 evolved may have contributed to the uncontrolled spread of SARS-CoV-2 in spring 2020.

For diseases with more common mild and asymptomatic cases, on the other hand, the completeness of the data can vary in complex ways over time. Early in an outbreak, mild cases are likely to be missed, as happened with COVID-19, both because individuals are unaware they are ill and because mild cases are rare due to the small overall number of infections. As an outbreak increases, mild cases may continue to be undetected until a robust testing system has been implemented—again, this occurred with COVID-19 in many areas. As testing access increases, it can be challenging to understand how the prevalence of infection has changed since the mix of mild and severe cases detected will change. Without an understanding of the full scope and details of the case finding and reporting systems, infectious disease data can thus be extremely challenging to interpret. Again, this was observed during summer 2020 in the United States, where confirmed COVID cases began increasing post-lockdown due partly to an increase in testing availability detecting asymptomatic or mild cases among younger individuals. Although these outbreaks soon spread to older individuals who were more at risk of severe disease and death, the lag time between increasing test-detected COVID and increasing death rates led to intense speculation by the media that the overall severity of the disease had been misinterpreted, had changed, or had been overblown. Epidemiologists, on the other hand, were clear throughout the summer that the virus had not changed in any fundamental way.

Furthermore, it is not just that data change in their completeness over time—very often data *no longer exist* from which to estimate important epidemiologic parameters. This is particularly true for the basic reproductive number R_0. Early in an outbreak, the cases most likely to be identified are those severe enough to need hospitalization or medical attention, and mild or asymptomatic cases are largely overlooked, as are cases with atypical presentations. The messiness of this data means the R_0 estimate obtained from early data is very likely to be either an under- or overestimate of the true R_0. However, simply waiting until later in the pandemic is not necessarily a solution for obtaining an unbiased estimate of the R_0. In fact, it may not be possible to estimate R_0 from current data the further into a pandemic we get—the basic reproductive number specifically describes the number of new cases resulting from one infectious case introduced into an *entirely susceptible population*. Without a full accounting of asymptomatic, mild, and pre-symptomatic infections, our ability to identify an entirely susceptible population in which to estimate the R_0 can rapidly decay as a pandemic spreads.

For this very reason, while the reproductive number R_0 is an important tool for modeling outbreaks in an applied epidemiology setting, it is less commonly used to model infectious diseases in *academic* epidemiology research. Instead, given the benefit of time and the challenges of studying endemic diseases for which R_0 cannot be readily observed, academic epidemiologists often prefer to expend resources to measure contact rates and transmissibility per contact as well as how these vary by type of contact and by characteristics of individuals (as described by Avery et al. in their companion paper). The resulting academic models are often more complex in structure, frequently using agent-based or network-based transmission models.

Agent-based and network-based models are able to account for the full heterogeneity in transmission that occurs in the real world as well as the full spectrum of characteristics which impact both exposure to infectious contacts and susceptibility to disease. They highlight areas of additional complexity which have long been recognized in epidemiology: for example, that the basic reproductive number, R_0, can be decomposed into the contact rate, the per-contact transmissibility rate, and duration of infectiousness; that the number of secondary cases per infection follows a distribution for which the mean may not always be the most appropriate summary measure; that heterogeneity in contact patterns, infectiousness, susceptibility, or other parameters may, if substantial, have a large impact on model results; and the need, in many cases, for finely stratified models.

Agent-based, network-based, and other complex system models can be specified in a broad range of ways that allow evaluation of the impacts of specific model components, assessment of interventions, or more realistic prediction of the evolution of an outbreak over time. However, while agent-based models, or other approaches incorporating this complexity, are sometimes used in applied epidemiology settings, the amount of time required to develop and validate these models can be prohibitive in an outbreak setting. Their use is therefore more common in academic epidemiology where these models can be carefully designed to help understand historic outbreaks and make predictions about future outbreak scenarios. Instead, applied epidemiologists often rely on compartmental models, which have limited capacity for incorporation of heterogeneity or endogeneity, but which can be more rapidly designed, tested, and applied to decision-making.

Clarifying the Goals of Early High-Profile Epidemiology Models: What the Public Got Wrong

COVID-19 models of early and mid-2020 are necessarily applied epidemiology models. These models have been rapidly developed based on the data at hand with the goal of providing insight into appropriate response and control activities. Despite this, many criticisms of these models seem to assume a goal closer to that of academic epidemiology—to create a detailed and highly accurate model of the full scope of the pandemic. Indeed, much of the public misunderstanding of epidemiology throughout this pandemic has involved a conflation of methods appropriate for applied epidemiology with those appropriate for academic epidemiology.

When critics argue over what high-profile epidemiology models "got wrong" about the COVID-19 pandemic, their analysis presupposes that the goal of these models was to predict, with both validity and accuracy, the actual total number of cases and deaths expected throughout the course of the pandemic under actual pandemic responses at both the individual and governmental levels. It is absolutely the case that both the high-profile Imperial College (Ferguson et al. 2020) and Institute for Health Metrics and Evaluation (IHME) models (Murray 2020) as well as all other current models, fell well short of this lofty goal; this is to be expected because it was not the intended goal of these models. The limitations of these models are well described in the Avery et al. essay in this issue, including the problems with model structure, parameterization, and uncertainty. However, these criticisms reflect well-recognized limitations of mechanistic and phenomenological models.

But to put these concerns in real-world context, no infectious disease modeler expects to be able to accurately forecast the future based on sparse data from early in a pandemic. Even "nowcasting," the task of modeling the *current* number of true infections, is extremely challenging, especially early in a pandemic. Asking an infectious disease modeler to predict the exact trajectory of an outbreak is akin to asking an economist to select stocks for your portfolio or a climate scientist to predict the best day in 2022 for an outdoor wedding. These tasks, while of interest to many people, are not generally within the purview of scientists. Instead, the goal of both mechanistic and phenomenological models in epidemiology is to forecast a range of possible futures, given a specified set of assumptions.

In an outbreak setting, these early models help applied epidemiologists quickly evaluate the type of outbreak they are dealing with, narrowing the list of potentially appropriate actions to take and guiding the public health response. Academic epidemiologists, on the other hand, will likely spend many years attempting to create realistic models that explain exactly how and why the pandemic evolved the way it did; these models will then, in turn, be useful for future applied epidemiologists dealing with other pandemics.

In the case of the Imperial College model, two of the key assumptions which defined their original model were that the government would not respond to the COVID-19 pandemic with any interventions and that the general public would not respond to the pandemic with any changes to their own behavior. These assumptions are clearly unrealistic. However, by making these strong assumptions, the Imperial College model was able to provide epidemiologists and public health practitioners with a rapid estimate of the worst-case scenario: if SARS-CoV-2 was allowed to run unchecked through the population, what is the maximum amount of death that we might expect over the course of the outbreak until it burned out via herd immunity? The answer—510,000 deaths in the United Kingdom and 2,200,000 in the United States (Walker et al. 2020)—rightly spurred both governments and individuals to action.

In contrast, the IHME model used a phenomenological model with a different set of key assumptions to answer an entirely different question. In that model, restrictions on movement imposed by the US government were included so that the model could more accurately reflect the current case count. The goal of this model was to forecast as closely as possible, not *all* future cases, but *tomorrow's* cases—or rather, the expected number of hospital beds needed next week based on the number of cases expected to occur in the current week (Murray 2020). To achieve this goal as rapidly as possible, during the large initial surge in COVID-19 in the United States, the modelers made several simplifying assumptions: that the "lockdown" measures would continue unabated until the outbreak was completely eliminated from the United States and that the basic trajectory of cases over the past week was the best determinant of the trajectory of cases over the coming week. These assumptions are clearly simplistic and resulted in extremely unlikely longer-term forecasts, including a prediction that elimination would happen by June 1, 2020. However, applied epidemiologists could use the short-term model forecasts from the IHME model to obtain a reasonable early warning on areas where hospital capacity was in danger of being overwhelmed, while ignoring the overly optimistic assumption of a June elimination.

The COVID-19 Infodemic: What Epidemiology Got Wrong

The COVID-19 pandemic is uncontained in the United States as of September 2020. As the scientific and applied field expected to protect the public from major health threats, epidemiology clearly has not succeeded in ending the pandemic. From the vantage point of six months since the US lockdowns began, it is clear that this is because many of the major challenges of the COVID-19 response were not, in fact, epidemiological. The science of epidemic response remains largely unchanged by COVID-19 from what it has been over the past century. Interventions such as hygiene, distancing, quarantine/isolation, and testing and contact tracing have worked in countries where they were systematically and rapidly deployed, such as New Zealand, Vietnam, and Mongolia. Instead, the major—and largely unforeseen—challenge for epidemiologists and public health professionals has been navigating the intense public scrutiny of the global scientific conversation about SARS-CoV-2/COVID-19 and the extreme politicization of that conversation.

Consider the conflict between public and scientific messaging about the American lockdowns in March and April. The main evidence-based approach to outbreak response advocated by epidemiologists at the time was, and remains, widespread frequent and rapid testing coupled with rigorous contact tracing, enforced quarantine and isolation, and appropriate personal protective equipment in all high-risk settings. However, delays in the availability of tests in the United States meant that targeted quarantine and isolation was unavailable as a response measure. Instead, the blunter tools of curfews and lockdowns were used to restrict transmission. Lockdowns were explained to the public as a tool for alternately eliminating transmission entirely or delaying transmission, resulting in confusion about the expected duration of both lockdown and the pandemic.

Many epidemiologists were vocal in the media and on social networks that the goal of lockdown should be to delay transmission until the availability of testing, contact tracing, quarantine supports, and personal protective equipment would allow safe reopening (Gottlieb et al. 2020). However, these more targeted approaches are still lacking in many jurisdictions, and the message much of the public seems to have internalized is that intervention to control the pandemic on a community-, state-, or federal-level is largely futile and that individual-level actions such as staying home and wearing a mask are sufficient (Gramlich 2020; Kramer 2020).

For a significant number of epidemiologists, myself included, COVID-19 represented their first experience communicating directly with the media and the public. Public health communications are typically the purview of national and international organizations, such as the Centers for Disease Control and the World Health Organization, but these organizations failed to respond at the speed of the 24-hour news cycle. The infectious disease and applied epidemiology communities were focused on response, but gaps in expert communication remained which were rapidly filled by media personalities, talking heads, and non-epidemiologists.

At least from the perspective of this outsider, public communication appears to be a skill that economists have honed. Although surely many economists do not interface with the media or public regularly, news and public dialogue about economic topics frequently appears to include economists, and the public does appear to be aware of and defer to economic expertise. I suspect epidemiology has much to learn from economics about communicating with a skeptical and sometimes hostile public.

Epidemic-Related Economics, not *Epidemiology*-Related Economics

In the absence of more targeted control of COVID-19, the United States has relied largely on lockdown, resulting in unprecedented unemployment and a pandemic-induced recession. Epidemiologists as a discipline are singularly focused on saving lives but are generally unprepared to provide recommendations on how individuals can best *live* those lives. In particular, the pandemic-induced recession has raised many questions that are outside the scope of epidemiology and instead fall squarely in the domain of economics.

Macroeconomists as a group are already confronting the ways in which their models of fiscal policy, monetary policy, and financial regulation can be applied to a recession with very different underlying causes than, say, the Great Recession of 2007–2009 or the dot-com recession in 2001. The pandemic has reshaped concerns about the design of unemployment insurance, the connection between health insurance and employment, the availability of sick leave for workers, childcare, nursing home care, and many other issues. As an epidemiologist, I have been frustrated during this pandemic by the lack of answers to questions which lie beyond the usual boundary of epidemiology but are nonetheless vital for guiding pandemic response. Here, I highlight some examples of topics to which I believe economists could apply their unique skill sets, resources, and expertise to aiding in our understanding of and response to COVID-19.

1) Envisioning a Vibrant Remote Economy

Although official lockdowns are in the process of being lifted, much of the United States still functions in what might be called the "remote economy," where close proximity to large groups and to strangers are widely viewed as less desirable. Millions of people worldwide found themselves confined at home in March 2020, unable to continue to participate in economies which relied, in large part, on face-to-face contact. Indeed, even with lockdown (perhaps temporarily) eased or lifted in many locations, many people are hesitant to resume pre-lockdown activities, and many businesses are realizing some potential financial benefits of remote workers. The consequences of the remote economy are potentially very widespread: in the workplace, in commuting patterns and the location of housing, in the economic health of cities, in the provision of medical advice and education, in the hospitality and leisure industries, and more. Indeed, the consequences of the remote economy may well outlast the COVID-19 pandemic. A full recovery of employment may require a dramatic shift across jobs and industries. A clear vision of this emerging remote economy is desperately needed.

2) Designing a Capitalism-Compatible Preparedness and Response Structure

Economists have long recognized that a market economy will tend to focus on activities that are likely to generate revenue. But being appropriately prepared to face a pandemic of uncertain form, whenever it arrives, is not this kind of activity. Similarly, responding to a pandemic cannot be sustainably done through market pressures alone. When SARS-CoV-2 began spreading outside Wuhan, China, it was predictable to many epidemiologists that supply chains of vital testing supplies, reagents, medications, and personal protective equipment would be overtaxed. Historically, public health agencies have sought to address this problem via the creation of pre-pandemic stockpiles. However, this system failed during COVID-19 when it was discovered that stockpiles created after the spread of epidemic H1N1 influenza in 2009–2010 had been left to expire or had their stock sold off. The COVID-19 epidemic was dramatically exacerbated by the lack of available testing and protective equipment. Epidemiologists do not, generally, have the skill set to untangle the complexities of so-called "just-in-time" supply chains and how they interact with regulatory imperatives. But economists might fruitfully consider how to build greater quick-response capacity into the economy.

3) Detecting Early Warning Signals of Pandemic Spread in Economic Networks

Epidemiologists interested in predicting pandemics have for many years tracked economic activity, especially trade in animals and animal products (Cunningham, Daszak, and Wood 2017). However, COVID-19 highlights that the costs and benefits of long-range international economic connections should come under greater scrutiny. For example, the Lombardy region of Italy includes one of the major world suppliers of nasopharyngeal swabs, Copan Diagnostics. In retrospect, it seems reasonable to expect that an outbreak of respiratory disease anywhere in the world might be accompanied by increased trade between Lombardy and the outbreak hotspots—and that even though this trade would be in the form of exports from Lombardy, it would involve increased contacts between individuals involved in the movement of supplies. Thus, it seems plausible that the Lombardy region of Italy could have been predicted as a location likely to be hit early and hard in any respiratory pandemic. Unfortunately, this is not the type of contact which epidemiologists are used to evaluating when predicting outbreak spread. Might economists be able to follow or even predict disease outbreaks by looking at flows of trade in a way that would have allowed us to detect and intervene earlier to contain COVID-19 in Italy?

4) Collaborating to Evaluate Policy Impacts

While some epidemiologists are interested in the impacts of policy decisions on health, the bulk of epidemiology focuses on understanding the impacts of individual-level interventions. Economists, on the other hand, are much more experienced at understanding the impacts of group-level policy interventions. Economic methods for evaluating group-level interventions, such as difference-in-difference, interrupted time series, or instrumental variables, are less familiar to many epidemiologists. Economists could likely add much value through building partnerships and collaborations with epidemiologists who have subject-matter expertise that is vital to understanding potential endogenous variables and identifying key research questions. Such collaboration may not be easy—economists and epidemiologists have fundamental differences in language which can create confusion when trying to engage in cross-disciplinary collaborations. For example, epidemiologists rarely use the term "endogeneity," but understanding, assessing, and controlling for endogenous variation is at the heart of nearly all epidemiologic investigations—often under terms like "confounding" and "selection bias."

5) Rapidly Deploying Research Resources

Finally, economists have access to research resources which could be rapidly deployed to answer important questions about how, where, and when people are experiencing effects of a pandemic, beyond case counts and deaths. For example, economic research can be useful in tracking the different ways in which people react to the pandemic, thus helping policymakers to identify groups where the burden of the pandemic may be especially large.

As one example, Alsan et al. (2020) surveyed US adults to understand how knowledge, behaviors, and incidence of COVID-19 were distributed, with particular attention to the ways in which existing social, economic, and health disparities might be exacerbated during the pandemic. Their results, although perhaps unsurprising to many in public health, provided important quantitative evidence of COVID-19 related disparities that can help guide targeted messaging, outreach, and intervention. As another example, the United States has relied on so-called "essential workers" during the pandemic, which puts such workers at higher risk for contracting SARS-CoV-2. In addition, many of the occupations deemed essential are blue collar occupations. McCormack et al. (2020) confirmed the suspicion of many epidemiologists and public health practitioners that essential workers were often economically vulnerable, lived in smaller and more crowded living conditions, and belonged to minority groups. This research will serve an important role in helping guide public health actions to protect the economic health of these vulnerable populations. Of course, a number of economists are already working in these areas, and I look forward to seeing more of this work in the future.

Conclusion

Epidemiology is a sister discipline of economics; both fields combine the study of observational and experimental data on human populations with a goal of understanding and supporting human flourishing. Both our fields are forced to grapple with observational data in ways that other scientific fields can more easily sidestep by experimentation, and both our fields have developed robust approaches to combining this data with subject-matter expertise to make causal inferences. Both our fields require a deep understanding of sociological processes and quantitative methods. Both fields can even trace the origin of key methods to John Snow—the originator of the difference-in-difference approach and a founder of epidemiology.

Despite this, economics and epidemiology have largely operated in isolation. We have developed our own, often mutually unintelligible, languages and practices, and we have allowed the public to create a narrative of conflict between us (Escandón et al. 2020). But we need not choose between a healthy public and a healthy economy! In the face of a systemic catastrophe like COVID-19, we can no longer afford to work alone. We need to join forces to recognize and apply our discipline-specific strengths to the problem at hand.

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