Modeling to Inform Economy-Wide Pandemic Policy: Bringing Epidemiologists and Economists Together

Michael Darden,[1] David Dowdy,[2] Lauren Gardner,[3] Barton H. Hamilton,[4] Karen Kopecky,[5] Melissa Marx,[2] Nicholas W. Papageorge,[6] Daniel Polsky,[1] Kimberly Powers,[7] Elizabeth Stuart,[2] Matthew Zahn[6*]

1. Johns Hopkins University, Carey School of Business
2. Johns Hopkins University, Bloomberg School of Public Health
3. Johns Hopkins University, Department of Civil and Systems Engineering
4. Washington University in St. Louis, Olin Business School
5. Federal Reserve Bank of Atlanta
6. Johns Hopkins University, Department of Economics
7. University of North Carolina, Gillings School of Global Public Health

Abstract: Facing unprecedented uncertainty and drastic trade-offs between public health and other forms of human well-being, policy makers during the Covid-19 pandemic have sought the guidance of epidemiologists and economists. Unfortunately, while both groups of scientists use many of the same basic mathematical tools, the models they develop to inform policy tend to rely on different sets of assumptions and, thus, often lead to different policy conclusions. This divergence in policy recommendations can lead to uncertainty and confusion, opening the door to disinformation, distrust of institutions, and politicization of scientific facts. Unfortunately, to date, there have not been widespread efforts to build bridges and find consensus or even to clarify sources of differences across these fields, members of whom often continue to work within their traditional academic silos. In response to this "crisis of communication," we convened a group of scholars from epidemiology, economics, and related fields (e.g., statistics, engineering, and health policy) to discuss approaches to modeling economy-wide pandemics. We summarize these conversations by providing a consensus view of disciplinary differences (including critiques) and working through a specific policy example. Thereafter, we chart a path forward for more effective synergy between disciplines, which we hope will lead to better policies as the current pandemic evolves and future pandemics emerge.

Section 1. Introduction

Throughout the COVID-19 pandemic, policymakers have been tasked with designing and implementing policies in the face of extraordinary uncertainty (Manski, 1999) and stark trade-offs between public health and other measures of human well-being. Policies designed to "flatten the curve," "crush the virus" or otherwise reduce transmission (and thus infection-related morbidity and mortality) often have negative economic consequences, such as unemployment, food insecurity, and business and school closures. The downstream consequences can also extend to outcomes more directly related to health, including intimate partner violence, addiction, depression, anxiety, suicide, and delays in medical treatments. Thus, efforts to mitigate the direct public health consequences of COVID-19 (in the form of infection-related illness and death) may not only have negative effects along other (e.g., economic) dimensions, but can have adverse indirect public health consequences as well. By the same token, however, choosing not to aggressively address the immediate public health crisis posed by COVID-19—a choice that has often been justified as a means of avoiding calamitous economic consequences—has driven repeated waves of exponential disease spread. These waves have not only driven morbidity and mortality to numbers in line with some of the direst initial predictions, but also had negative indirect effects on the economy, necessitating prolonged shutdowns, delaying full resumption of economic activity, and disrupting entire industries that cannot survive indefinitely on hiatus. In summary, just as policies designed to promote public health have had unintended adverse health consequences, policies designed to preserve the economy have at times had opposite effects.

Given the complex ways that public policy during a pandemic affects the interplay between health and other measures of well-being (sometimes called "health-wealth tradeoffs," a shorthand

we adopt here), both epidemiologists and economists have been called upon to analyze and forecast the effects of proposed policy solutions. Unfortunately, the perspectives provided from these two fields have often appeared to be in conflict. This need not be the case. Economists and epidemiologists rely on a similar set of basic analytical tools and methods and thus should be able to communicate with one another about their approaches to guiding pandemic policy. For example, both use empirical methods such as multivariable regression to evaluate associations, as well as techniques such as difference-in-differences and instrumental variables to estimate causal policy effects. Even more, subsets of scholars from both fields develop sophisticated mathematical models to evaluate the likely impacts of new policies or behavior patterns on aggregate outcomes.

Differences between these disciplines emerge, however, because epidemiology and economics have traditionally tailored these techniques towards different questions and objectives. Specifically, both epidemiologists and economists have built models to guide public policy during the pandemic—creating frameworks that consider biology, behavior, and the interaction between them. But all modeling of human biology and behavior involves enormous simplification—and the two disciplines tend to emphasize and downplay very different phenomena. These different emphases often translate, in practice, into different modeling assumptions that, in turn, can produce diverging policy prescriptions.

Broadly, epidemiologists tend to center their focus on direct disease-related outcomes (e.g., infection, morbidity, and mortality) and thus prioritize careful modeling of the underlying system of transmission dynamics. In doing so, epidemiologists tend to adopt a biological focus, with emphasis (for example) on incubation periods, infectiousness, and infection-fatality ratios. Meanwhile, economists tend to elevate the importance of health-wealth tradeoffs that individuals face during a pandemic, and thus prioritize modeling the underlying factors that drive how individuals facing such

tradeoffs make decisions. This approach generally adopts a behavioral focus, emphasizing elements such as preferences, utility, and decision rules.

Not surprisingly, models with different emphases and assumptions will often produce different policy recommendations—even if many of the technical underpinnings are similar. In particular, models placing more focus on biological (health) outcomes or health-related capacity constraints might be expected to lead policymakers toward more restrictive policies, while models emphasizing behavioral (economic) outcomes might tend to suggest less restrictive policies.

A lack of consensus across the two disciplines, while an understandable outcome of their different approaches, is costly. It contributes to uncertainty, helps to perpetuate a general lack of trust in science, and undermines the role of science in guiding policy. In today's highly polarized environment, when even scientifically grounded ways out of the crisis (such as scale-up of highly effective vaccines) are called into question, lack of consensus leads to confusion at best and exploitation of scientific findings at worst. Of course, consensus is not always possible. But if epidemiologists and economists jointly tackle pandemic policy analyses, we believe they are likely to come to a more fully informed view, and to arrive at a set of conclusions that both groups can comfortably accept.

Historically, the incentive to find consensus between economists and epidemiologists has been relatively weak. Divergent perspectives between the two disciplines have rarely spilled over into public discord, likely because their respective policy landscapes often do not overlap.[1] The COVID-19 pandemic is different. It has been an economy-wide pandemic, presenting a simultaneous public

---

[1] For example, at the start of the U.S. HIV/AIDS epidemic in the early 1980s or U.S. housing crisis in 2008, it was clear which discipline would be called upon for urgent policy advice even though economists came to examine the first crisis (e.g., the impacts of medical innovation; Lakdawalla *et al.*, 2006) and epidemiologists eventually studied the second (e.g., the health effects of foreclosure; Margerison-Zilko *et al.*, 2016).

health and economic crisis, from day one. A fast-moving pandemic of this magnitude inevitably generates a set of difficult health-wealth tradeoffs (and even tradeoffs between different dimensions of health), thereby thrusting economists and epidemiologists into the same policy arena. Yet, while some interdisciplinary communication has occurred, too few scholars have prioritized the difficult work of earnest collaboration and reconciling divergent results between the two fields—a process that must include an open and civil discussion, mutual attempts to understand and critique the other discipline's approach to modeling pandemics, and openness to receive constructive feedback from colleagues outside one's primary discipline. Instead, researchers from both fields, ostensibly studying the same issues, have tended to stay squarely within the confines of their respective disciplines, claiming to include factors associated with the other discipline, but rarely actually working together to build models. This has not only reinforced existing academic silos but has left policymakers to sift among conflicting pieces of advice.

In response to this "crisis of communication," we convened a group of scholars from epidemiology, economics, and related fields (e.g., statistics, engineering, and health policy) to discuss modeling economy-wide pandemics, which we define as infectious disease epidemics that are large enough to affect the aggregate economy (e.g., economic growth, GDP, or employment) so that economic and public health impacts must be addressed simultaneously. The goal of these discussions was to chart a path forward for more effective synergy between disciplines. Our current focus is on pandemic planning and response but the basic framework could extend to other arenas where multiple disciplines with diverging methods could have greater policy impact by working together, e.g., climate change, where such integration has already occurred (Moss *et al.* 2010). The spirit of this conversation was to foster communication between economists and epidemiologists— who are methodologically capable of critiquing each other's models but often unaware of the

historical reasons or theoretical grounds for selecting certain approaches. Such communication would enable experts from each field to: (a) better understand the conceptual underpinnings of models from the other discipline; (b) obtain input as to the potential weaknesses of their own models, from the perspective of the other discipline; (c) develop consensus about how to balance results from potentially divergent models from the two fields; (d) agree on the data that might be most important to collect; and (e) discuss which methodological or theoretical aspects of each discipline might be most important to consider incorporating to improve future pandemic models.[2]

In what follows, we report key outputs of our dialogue. In Section 2, we present a consensus view on the respective strengths and weaknesses of epidemiologic and economic models. In Section 3, we illustrate differences in approaches and potential consensus through joint analysis of a concrete example: whether a local authority should institute a 50% capacity restriction at dine-in restaurants. Doing so, we highlight the pitfalls of failing to communicate across fields during a crisis that involves health and other factors interacting dynamically. In Section 4, we discuss why communication and collaboration are critical. Section 5 provides a blueprint for future work in this direction.

Section 2. Epidemiology and Economics: A Consensus View

In the context of infectious disease, economists and epidemiologists each use mathematical models to make *ex ante* policy recommendations. This means that a model of people, a pathogen, and their interaction is built and then used to predict outcomes under different policies *before they are chosen and*

---

[2] Our cross-disciplinary collaboration is similar to the one proposed in Murray (2020). Yet, we likely disagree with the author's conclusion that "we need not choose between a healthy public and a healthy economy," which downplays that a pandemic presents policymakers with difficult tradeoffs between population health and economic well-being. Our discussion centers on the idea that the best path forward is to recognize these tradeoffs exist and to address them as directly as we can through policy built upon collaborative science.

implemented (e.g., how many deaths will occur if a mask mandate is removed or how many restaurants shutter if capacity constraints are imposed).[3]

In this context, epidemiologists and economists often think differently about the role of human behavior during a pandemic. Both groups recognize that there are feedback mechanisms between the pathogen, the population, and individual choices. Models from both disciplines incorporate how behavior may shift during different phases of the epidemic. Thus, for example, it is not controversial in either group that, as a pandemic wave subsides, individuals are more likely to engage in behavior that is conducive to transmission. Key differences lie, however, in how much emphasis is placed on (a) understanding the degree to which behavior shifts occur (and the corresponding impacts), (b) the primary factors considered that might drive that behavior, and (c) balancing health outcomes with non-health outcomes. Epidemiologic models generally emphasize understanding of health outcomes; thus, behavior shifts, and drivers thereof, are considered important largely to the extent that they affect those health outcomes. Economic models, by contrast, generally emphasize health-wealth tradeoffs; thus, understanding economic implications and drivers of behavior change is often seen as a primary goal of the model rather than as a "means to an end" of understanding health outcomes.[4]

These differences in emphasis open both disciplines to critique. A reasonable critique of most economic models is that they impose strong and unrealistic assumptions on disease and transmission dynamics and ignore important heterogeneity in individual disease susceptibility, infectiousness,

---

[3] We distinguish this approach from program evaluation, sometimes called *ex post* policy evaluation, which refers to analyses that examine the impacts of policies that have been implemented in the past.

[4] We recognize the challenge of doing justice to the vast modeling and COVID-19 literatures in epidemiology and economics. James *et al.* (2021), Haber *et al.* (2021), and Lemaitre *et al.* (2021) discuss modeling considerations from epidemiology, while reviews in Brodeur *et al.* (2020) and Papageorge (Forthcoming) highlight economic perspectives to these questions.

and/or severity. A reasonable critique of most epidemiological models is that they fail to explicitly model the preferences and constraints that drive individual decision-making, causing them to poorly predict how individuals respond to evolving disease risk and fundamental health-wealth trade-offs— an effect policymakers should bear in mind.

Two recent studies on COVID-19 policy exemplify the respective strengths and weaknesses of each type of model. From an epidemiological perspective, Chang *et al.* (2020) studied the question of mobility restrictions. Data from 98 million individuals included mobility at the census block level to points of interest, such as restaurants, fitness centers, religious organizations, and others. To model the natural history of infectious disease, they used a standard epidemiological framework: the Susceptible, Exposed, Infectious, Recovered (SEIR) model. They estimated health outcomes under a counterfactual scenario in which, rather than the observed mobility, mobility was reduced by 50% or 75%. Unsurprisingly, they found that less mobility would reduce cumulative infections, and they concluded that mobility restrictions enacted by policy would significantly reduce infections and "produce smaller absolute disparities in predicted infections" – beyond the effects of precautions taken by individuals in the absence of policy. This epidemiological model therefore acknowledged—and explicitly included—behavior, but in the absence of a corresponding behavioral model, it is not clear how mobility patterns would change under different policy scenarios. For example, individuals may respond to a policy restricting mobility by spending more time in crowded locations. This analysis also did not address issues such as the cost at which these hypothetical restrictions would come and whether the benefit of these restrictions would be worth the cost.

Benzell *et al.* (2020) studied a similar question with nearly identical mobility data from cellphones, but instead took an economic framing: which types of businesses might be "worth" closing during COVID-19? That is, given the economic importance of different businesses, as

measured by payrolls, receipts and employment, and given the "riskiness" of infection at these establishments, should certain businesses be kept open? This study recognized that business closures also entail costs—it constructed indices of transmission risk and the economic importance associated with each business—while also considering individual heterogeneity (e.g., by age) in transmission risk. However, this analysis did not consider the contribution of each business type to disease transmission over time. For example, keeping a certain type of business open over a longer term might seed ongoing outbreaks in the corresponding community, especially if that business did not enact strict measures to prevent such spillover. Furthermore, this analysis made no attempt to calibrate its transmission risk indices to actual time-varying levels of disease transmission in the community. As such, this static framework cannot be used to link specific policies to numbers of COVID-19 cases and deaths averted.

As a result of these differing approaches, a policymaker attempting to "follow the science" is therefore left with two different sets of modeling results—one from an epidemiological perspective that lacks explicit consideration of economic outcomes or individual health-wealth tradeoffs, and one with an economic framing that omits important features of disease dynamics and linkage of policy to health outcomes. What is missing for decision-makers is a sense of how to compare or trade-off these results.

Our group firmly believes that both types of models offer real value in policymaking and that multidisciplinary modeling, informed with the best available data, is crucial to offer the best policy advice. Thus, a reasonable question is: why can we not simply merge these models into a consensus model—one that adequately captures disease transmission, morbidity, and mortality; individual decision-making; and aggregate economic processes such as unemployment and economic growth? There are two key reasons:

1. A fundamental problem is data availability. Incorporating heterogeneous disease dynamics with individual behavior in the same model requires both detailed data on individuals and a sufficiently large sample to infer population health trends. One needs not only data on geo-coded disease prevalence to calibrate epidemiological models and predict heterogeneous behavior patterns, but also rich information on individual characteristics that can be related to decisions, e.g., the kind of data typically found in large household panel surveys. However, those surveys do not contain data on responses to an emerging pandemic. Nor do they provide data on factors affecting exposure to infection, such as ventilation or ability to work from home. In other words, a more successful approach to pandemic policy would require immediate and flexible data collection efforts that in many cases will be outside our existing capabilities.

2. Conceptually, model tractability depends on critical assumptions regarding the setting, time frame, objectives, mechanistic processes, and outcomes under study. Models of individual behavior that include feedback loops with aggregate processes (such as population health or economic growth) can be difficult to solve even with vast amounts of computing power.[5] Overlaying these models with time-varying disease dynamics at the population level—and thus requiring explicit representation of the interactions between individual behavior and disease dynamics—will in many cases be impossible in the time frames needed for policy decisions.

Thus, to move forward (especially in the time frames required by policymakers), compromises must be made. That is, epidemiologists and economists would need to not only discuss data

---

[5] For example, absent further assumptions, such models may have many different solutions (multiplicity of equilibria) and so even with massive computing power, the researcher has little guidance as to which solution is the right one. This issue illustrates the type of highly technical issue that economists and epidemiologists should discuss when developing models, preferably before offering advice to policymakers.

priorities, but also modeling priorities, including the factors they could live without and the simplifications they would be willing to make to accommodate the other field in joint modeling efforts. And these discussions would need to begin *before* the next pandemic occurs. The winners of this sort of dialogue are policymakers and the public at large.

Section 3. An Illustrative Example: Restaurant Capacity in the Context of COVID-19

To provide an anchoring example of the differences in approach commonly taken by epidemiological and economic pandemic models, our group of scholars constructed a hypothetical example in which a model might inform policy decisions related to COVID-19. We settled on restaurant capacity restrictions as a tangible scenario in which both epidemiological and economic data and approaches could be brought to bear. To clarify the thought process, we made a series of simplifying assumptions. Specifically, we limited our discussion to: (a) a policy response on the level of a small- to moderate-sized city, assuming typical patterns of movement/immigration/emigration; (b) a decision of whether/when to implement a 50% capacity restriction on restaurants, without explicit consideration of other policy options (e.g., other capacity restrictions, masking mandates, etc.); and (c) a situation in which COVID-19 cases had begun to rise, but not to the level at which restaurant capacity restrictions would yet have been implemented (i.e., we did not consider the question of when to strengthen and/or remove existing restrictions).

Faced with this scenario, epidemiologists responded by suggesting they would build a model of disease spread in the population. The primary outcome would be related to health—cases, deaths, or ICU demand vs. capacity during the current wave—without an attempt to forecast disease burden far into the future. The model would need to be calibrated to the level of disease in the city—thus, a fatally flawed model might be one that could not appropriately replicate current disease incidence in

different population groups (e.g., according to age, race or census tract) that might be relevant to restaurant patronage. Key data to inform the model would likely include population contact patterns across settings and population groups, testing dynamics producing observed case rates, and levels of vaccination/immunity among restaurant-goers and workers (e.g., wait staff, cooks, etc.). The fact that people might change their behavior in a variety of ways, both in response to rising infections and to the policy, was considered something that could be incorporated in a simple manner (e.g., a fraction of people may go to the closest town without constraints), but more detail would be difficult to incorporate in a standard disease transmission framework given existing data. Some epidemiologists highlighted the efficiency and importance of early intervention, that faster implementation of restrictions could prevent future exponential spread.

By contrast, economists responded by suggesting they would build a model of individuals seeking to maximize personal utility. The primary objective of the model would be to identify policy options that would not only consider costs of infections, but also of business closures and unemployment, given people's likely behavior. In other words, an individual's behavior responds both to the policy and to factors influencing their own health-wealth trade-offs. Key to constructing a meaningful utility function would be to estimate the various contributions of different factors (e.g., income, disease risk, ability to eat out) to individual utility—in other words, how individuals would trade-off different choices. The model would need to incorporate rich and varied endogenous behavior change—thus, a fatally flawed model might be one that could not account for activities such as going outside the city limits to eat out or choosing to eat at home in response to perceived risk of disease transmission (not imposed by the policy change itself).[6] Key data to inform the model would include variables describing demand for restaurants and socio-demographic characteristics

---

[6] In Baltimore City, for example, policies such as indoor mask-wearing have been more restrictive than in Baltimore County, which means many people wishing to avoid restrictions can do so after a 15-minute drive.

that affect it, along with indicators of how long restaurants could survive financially under a capacity restriction, the impact of such a restriction on personal incomes, and long-term impacts on the economy of the city (e.g., tax revenues and city services). The fact that restaurants could contribute to city-wide disease transmission was considered important but difficult to incorporate in detail in a standard economic modeling framework. Thus, the plan would be to capture broad contours of disease spread (e.g., relying on a four-compartment SEIR model) but without additional detail. Some economists suggested capacity restrictions may not have meaningful effects on COVID-related health outcomes after accounting for people's endogenous responses to a pandemic wave and the likelihood of circumventing the policy (e.g., going to restaurants in other counties).

In summary, in suggesting models to evaluate restaurant capacity constraints during a pandemic, experts in each discipline considered (at least to some extent) both individual behavior and the spread of illness, but neglected elements that the other discipline would consider to be essential. Members of both disciplines agreed, at least in principle, on the importance of: (a) considering health and economic outcomes together; (b) using data to inform differential disease transmission (i.e., mixing patterns, infection progression) and endogenous behavioral responses; and (c) making the model realistic in terms of disease burden and human behavior. However, the relative prioritization of these different elements differed dramatically. Epidemiologists were willing to accept strong simplifying assumptions in the realm of economic outcomes, data on endogenous behavior, and the mechanisms by which individual people might respond to policies; whereas economists were willing to accept equally strong assumptions regarding outcomes of disease spread, data on heterogeneous mixing patterns, and realism in terms of calibrating the model to population-level disease burden.

Thus, even though the methods proposed relied on somewhat similar mathematical tools (and could be understood at a basic level by both groups on purely technical grounds), discussants realized that differences in our respective disciplinary foci could quite plausibly lead to different policy recommendations even though both groups openly recognize both the seriousness of the health crisis and the health-wealth tradeoffs society faces during such a crisis. For example, the group predicted that a model focused on health outcomes could provide support for decisive action to constrain restaurant capacity. Conversely, a model emphasizing that individuals may stay home regardless of the policy (or would substitute equally or more hazardous behaviors in response to a capacity constraint) would likely provide support for the idea that the policy would be minimally productive or perhaps even counterproductive, while also threatening the local economy.

Encouragingly, through this discussion, both groups recognized that the epidemiologic model failed to account for important health-wealth tradeoffs and potentially ruinous economic consequences of restrictive health policies. Both groups also recognized that the economic model failed to account for potentially catastrophic impacts of transmission hotspots on infection rates and mortality of less restrictive health policies. A combined approach taking these various factors into account could lead to a consensus view about the policy.

Section 4. Benefits to a Combined Approach

The example above illustrates the potential benefits of closer collaboration between economists and epidemiologists in economy-wide pandemic modeling (and, indeed, other economy-wide public health crises). First, experts in both fields have the capacity to improve models from the other discipline, not least by simply identifying critical omissions and explaining their importance. For example, as economists were describing their proposed modeling approach, epidemiologists in our

group could quickly describe how such models could do a better job of incorporating key features of the underlying transmission dynamics and calibrating to population-level epidemiological indicators. Similarly, when epidemiologists described their model, economists rapidly weighed in as to how richer heterogeneity in endogenous behavioral responses could be included. Thus, it is not that either discipline's modeling approach was incapable of accounting for the priorities of the other; rather, the "fatal flaws" identified in each discipline's model largely reflected a failure to prioritize elements that experts from the other discipline considered crucial. Second, through closer communication, the intrinsic biases of each field may be partially mitigated. Epidemiological models could, for example, be constructed that place more emphasis on individual behavior and preferences—while economic models could similarly be developed that incorporate greater consideration not only of disease spread itself, but also of specific health-related constraints (e.g., ICU beds, medical personnel, and ventilators). Third, bringing epidemiologists and economists together could result in recommendations that might be better trusted by decision-makers—and by extension, the general public. Rather than having to decide between models with disjointed (or even competing) results, policymakers could instead be presented with a more holistic and balanced picture, with both disciplines (and their potential disagreements) represented in the same set of results, recommendations, and considerations.

Section 5. A Path Forward

In a setting of unconstrained time, resources, and data, the ideal model for informing economy-wide pandemic policy would likely be a highly detailed framework including multiple representative populations, one built by a multidisciplinary team including epidemiologists and economists and incorporating granular detail on biology, disease transmission, and individual behavior. The model would also incorporate specific health-related resources and constraints (e.g., ICU beds and

personnel) along with economic considerations (e.g., unemployment and business closure). More elaborate models could emerge that incorporated even more features (e.g., misinformation, medical personnel fatigue, shifting norms surrounding infection-avoidant behavior, or the long-term consequences of educational attainment gaps). The model would also need to be built to incorporate new scientific results as we begin to resolve some of the uncertainty surrounding a novel pathogen. This is a lofty goal, a project that we believe should be pursued eventually. It would likely take years to develop and require unprecedented resources and collaboration but could improve policy during future crises. However, this longer-term work requires a foundation of mutual trust and understanding, which must first be built.

During a rapidly evolving pandemic, quick decisions are necessary, modeling resources are limited, data sources are never complete, uncertainty abounds, unexpected circumstances arise, new information emerges, and the ideal infrastructure cannot be built overnight. It is therefore unlikely that the full modeling infrastructure necessary to plan for any given pandemic can be fully anticipated in advance. A pragmatic path forward, therefore, might address the question, "How can epidemiologists, economists, and other experts start working together to produce a coherent evidence base for pandemic policymaking in the context of known constraints?" We propose a six-step approach in response.

Figure 1. Six Steps Toward Bringing Epidemiologists and Economists Together for Evidence-Based Pandemic Decision-Making.

	Build Relationships		Improve Assumptions and Data		Combine Efforts	
	Learn Each Other's Language and Priorities	Build Trust and Respect	Recognize and Justify Assumptions	Advocate for Better Data	Attempt Combined Model-Building	Communicate Results Together
Major Challenge:	• Developing deep expertise in multiple fields is difficult.	• Building new expert teams takes time and resources.	• Different fields may prioritize different assumptions in models.	• The ability of models to inform policy is limited by data availability.	• Models that incorporate disease dynamics and behavior are complex.	• Staying in silos makes it easier to ignore elements critical to counterparts.
Response:	• Recognize the basic vocabulary and fatal flaws of other fields.	• Promote dialogue and collaboration now, before the next pandemic.	• Understand other disciplines' assumptions and why they are made.	• Advocate for higher quality data to reliably inform policy.	• Seek to fill the biggest gaps to enable integrated decision-making.	• Present results in mutual, balanced fashion—to deliver a comprehensive, consistent message.

An initial step toward bringing epidemiologists and economists together is to learn each other's language and priorities. If economists learn why epidemiologists value model components such as unbiased population-level data, calibration to time-dependent disease burden, and secondary transmission, and epidemiologists begin to understand why economists use utility functions, tradeoffs, and endogenous behavior, then experts from both fields can be more careful in constructing their own models. After developing something of a shared vocabulary, economists and epidemiologists could begin to form teams (before the next pandemic occurs) where they could not only continue to learn each other's language but also observe how those priorities play out in practice. Such collaboration need not (at this stage) involve developing a suite of consensus models to be fruitful. Rather, experts from both disciplines might still work in their own domains, but by observing how members of the other discipline think and act, mutual trust and respect would likely emerge.

Beyond the experience of language-learning and trust-building, epidemiologists and economists can also work together to achieve common goals. In a third step, for example, experts from each discipline tasked with guiding specific policy could come together with their potentially competing models to explicitly discuss their assumptions, thus subjecting them to challenge from experts in the other field. It is likely that such an exercise would expose assumptions not thought in one discipline

to be particularly strong or limiting—but perceived by the other discipline to be fatal. With sufficient dialogue, experts in both fields could potentially agree on the model modifications and data collection priorities that would be most critical to further modeling efforts.

Once a rough consensus is developed between economists and epidemiologists with respect to critical assumptions and data gaps, a sufficient foundation should exist for useful combined model-building exercises between the disciplines. In building a consensus model, experts from both fields would be explicitly forced to make compromises and thus come to terms with their own underlying disciplinary philosophical biases—and potentially overcome them. Finally, whether or not epidemiologists and economists can succeed in building combined models, we must learn to provide consistent and harmonious messaging (or clearly articulated reasons for discrepancies) to decision-makers. Only in this fashion can decision-makers receive expert advice as to how they can appropriately balance the priorities of epidemiology and economics—rather than simply receiving siloed advice from each side and being forced to make decisions between the two on their own.

In summary, while economists and epidemiologists often construct models that provide different—even competing—results, this apparent conflict reflects more the philosophical and theoretical underpinnings of each discipline, rather than a lack of methodological depth on either side. Both fields struggle tremendously with data limitations, but in the face of limited data, they often make different types of assumptions that reflect different priorities. These differences can be overcome, however, through a structured process that involves first learning each other's language/priorities and building mutual respect, next recognizing assumptions and data limitations on both sides, and finally working together in cross-disciplinary teams to build models that incorporate each group's most essential priorities and communicate results to decision-makers in a consistent fashion. This process will take years to complete. As such, starting this dialogue while the

lessons of COVID-19 are still fresh, and before the next pandemic hits, could not be a more urgent

priority.

References

Benzell, Seth G., Avinash Collisa, and Christos Nicolaide. 2020. "Rationing Social Contact During the COVID-19 Pandemic: Transmission Risk and Social Benefits of U.S. Locations." *Proceedings of the National Academy of Sciences of the United States of America* 117(26): 14642–14644.

Brodeur, Abel, David Gray, Anik Islam, and Suraiya Bhuiyan. 2020. "A Literature Review of the Economics of COVID-19." *Journal of Economic Surveys.* 35(4): 1007–1044.

Chang, Serina, Emma Pierson, Pang Wei Koh, Jaline Gerardin, Beth Redbird, David Grusky, and Jure Leskovec. 2020. "Mobility Network Models of COVID-19 Explain Inequities and Inform Reopening." *Nature* 589: 82–87.

Haber, Noah A., Emma Clarke-Deelder, Joshua A. Salomon, Avi Feller, and Elizabeth A. Stuart. 2021. "Impact Evaluation of Coronavirus Disease 2019 Policy: A Guide to Common Design Issues." *American Journal of Epidemiology.*

James, Lyndon P., Joshua A. Salomon, Caroline O. Buckee, and Nicolas A. Menzies. 2021. "The Use and Misuse of Mathematical Modeling for Infectious Disease Policymaking: Lessons for the COVID-19 Pandemic." *Medical Decision Making* 41(4): 379–385.

Lakdawalla, Darius, Neeraj Sood, and Dana Goldman. 2006. "HIV Breakthroughs and Risky Sexual Behavior." *The Quarterly Journal of Economics* 121.3 1063–1102.

Lemaitre, Joseph C., Kyra H. Grantz, Joshua Kaminsky, Hanna R. Meredith, Shuan A. Truelove, Stephen A. Lauer, Lindsay T. Keegan, Sam Shah, Josh Wills, Kathryn Kaminsky, Javier Perez-Saez. 2021. "A Scenario Modeling Pipeline for COVID-19 Emergency Planning." *Scientific Reports* 11(1): 1-3.

Manski, Charles F. (1999). *Identification Problems in the Social Sciences.* Harvard University Press.

Margerison-Zilko, Claire, Sindra Goldman-Mellor, April Falconi, and Janelle Downing. 2016. "Health Impacts of the Great Recess: A Critical Review." *Current Epidemiology Reports* 3: 81–91.

Moss, Richard H., Jae A. Edmonds, Kathy A. Hibbard, Martin R. Manning, Steven K. Rose, Detlef P. van Vuuren, Timothy R. Carter, Seita Emori, Mikiko Kainuma, Tom Kram, Gerald A. Meehl, John F. B. Mitchell, Nebojsa Nakicenovic, Keywan Riahi, Steven J. Smith, Ronald J. Stouffer, Allison M. Thomson, John P. Weyant, and Thomas J. Wilbanks. 2010. "The Next Generation of Scenarios for Climate Change Research and Assessment." *Nature* 463: 747–756.

Murray, Eleanor J. 2020. "Epidemiology's Time of Need: COVID-19 Calls for Epidemic-Related Economics." *Journal of Economic Perspectives* 34(4): 105–20.

Papageorge, Nicholas W. Forthcoming. "Modeling Behavior During a Pandemic Using HIV as an Historical Analogy." Econometric Society World Congress Manuscript.