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THEMATIC ESSAY

Mobility Restrictions and the Control of COVID-19

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Abstract: A recent study on the impact of mobility controls on the final size of epidemics by Espinoza, Castillo-Chavez, and Perrings (2020) found that mobility restrictions between areas experiencing different levels of disease risk and with different public health infrastructures do not always reduce the final epidemic size. Indeed, restrictions on the mobility of people from high-risk to low-risk areas can increase, not reduce, the total number of infections. Since the first response of many countries to the COVID-19 pandemic was to implement mobility restrictions, it is worth bearing in mind the implications of the Espinoza result when considering the effectiveness of such restrictions.

Keywords: Mobility Restrictions; COVID 19; Diseases Risk; Health Infrastructure.

1. INTRODUCTION

Most governments' first response to the COVID-19 pandemic was to introduce mobility restrictions. These took many forms, spanning selective restrictions on national and international travel and trade; closure of schools, museums, and cultural and social centres; restrictions on non-essential local travel; local stay-at-home orders; and area quarantines. By the end of May 2020, 220 countries had imposed a total of over 62,000 restrictions on international travel (International Organization for Migration 2020). As a result, trade in services involving proximity between suppliers and consumers, especially services involving travel or the temporary movement of people, has since been 'paralyzed' (World Trade Organization

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2020a). Internally, public curfews, domestic travel restrictions, and lockdowns of varying severity have had similar effects.

A recently published paper by Espinoza, Castillo-Chavez, and Perrings (2020) analysed the effectiveness of mobility restrictions in controlling infectious diseases such as COVID-19. The paper particularly considered the impact of mobility restrictions between areas experiencing different levels of infection risk and having different access to healthcare. The main result reported in the paper (hereafter 'the Espinoza result') was that mobility restrictions between low- and high-risk areas do not always reduce the final epidemic size. Indeed, in some cases, restrictions can have the opposite effect. Restricting people in high-risk areas from moving to low-risk areas can increase, not reduce, the total number of infections. In some cases, allowing mobility out of high-risk areas can be sufficient to control an outbreak. In this paper, we discuss the implications of the Espinoza result for the effectiveness of COVID-19 disease control.

The problem modelled by Espinoza, Castillo-Chavez, and Perrings (2020) is one in which mobility restrictions limit movement between areas that differ not just in the level of infection risk but also in their capacity to treat those who are infected. It is assumed that the low- and high-risk areas are distinguished by differences in income, nutrition, health status, and health infrastructure. It follows that they will also differ in terms of outcomes associated with the same number of cases. While theoretical studies on the impact of mobility restrictions on epidemiological dynamics in a multi-patch system suggest little impact on the final epidemic size if restrictions permit some movement between patches (Arino *et al.* 2007), the Espinoza result finds that restrictions on movement between high- and low-risk areas can have a substantial impact on both the area-specific and global final epidemic size.

In all recent epidemics affecting multiple countries—the 2003 SARS epidemic, the 2009 H1N1 influenza pandemic, and the 2014 Ebola epidemic—the speed, direction, and extent of spread of the disease were determined by pre-existing patterns of trade and travel. These patterns determined both the routes along which the disease spread and the frequency with which it was introduced (Sirkeci and Yucesahin 2020). In all cases, the response to the outbreak included travel restrictions, international border closures, and area quarantines (*cordons sanitaires*). Broadly similar measures have been deployed in the management of infectious diseases for hundreds of years (McNeill 1977; McNeill 2003).

The motivation for the study by Espinoza, Castillo-Chavez, and Perrings (2020) was evidence that mobility restrictions have not always succeeded in controlling the size of epidemics. In the 2014 Ebola epidemic, for example, quarantining an area that later contained about 70% of all cases led to a perfect storm within the area. Food supply was disrupted, the healthcare system was overwhelmed, infection risk increased, and both, the number of cases and the case mortality rate, increased over time. The final epidemic size—around 29,000 cases leading to around 11,000 deaths—was larger than it would have been with no quarantine (Towers *et al.* 2014; Castillo-Chavez *et al.* 2015; Espinoza *et al.* 2016). In the following sections, we first summarize the Espinoza result and then consider the implications it has for the spread of COVID-19 and for the wellbeing of people in regions with varying degrees of development.

2. A MODEL OF MOBILITY RESTRICTIONS AND DISEASE DYNAMICS

The model developed by Espinoza, Castillo-Chavez, and Perrings (2020) describes infectious disease transmission between two communities connected through the movement of people. Specifically, it models the time spent by individuals in each community using a residency time matrix. In a two-community world, time not spent in one community is assumed to be spent in the other community. Individuals either spend all of their time in a single community or they divide their time between two communities. Their location is tracked over time, making it possible to understand the impact of mobility and mobility restrictions on disease dynamics in each community and on a global scale (Bichara *et al.* 2015). The risk of infection in a given community is assumed to be proportional to the time spent there, weighted by a community-specific infection likelihood. This makes it possible to model the impact of mobility restrictions on disease dynamics in communities. The model is parameterized for COVID-19.

Intuitively, one would expect people's mobility away from the outbreak location to increase both the rate at which the disease is spread and the final epidemic size. What the Espinoza result shows, however, is that if the two communities differ in population density, disease risk, and standards of healthcare, outcomes may be quite different. Specifically, if infected individuals in a high disease risk community move to a less densely populated region with better sanitary conditions, then the increase in the number of secondary infections in that region may be offset by the reduction in the number of secondary infections in the high-risk community.

The dynamics of COVID-19 in two communities with distinct infection risks is described by the following system of differential equations:

$$\dot{S}_i = -(1-t_i)\beta_i S_i\left(\frac{(1-t_i)(I_i+qE_i)+t_j(I_j+qE_j)}{(1-t_i)N_i+t_jN_j}+\frac{lJ_i}{N_i}\right)-t_i\beta_j S_i\left(\frac{t_i(I_i+qE_i)+t_j(I_j+qE_j)}{t_iN_i+(1-t_j)N_j}\right)$$

$$\dot{E}_i = -(1-t_i)\beta_i S_i\left(\frac{(1-t_i)(I_i+qE_i)+t_j(I_j+qE_j)}{(1-t_i)N_i+t_jN_j}+\frac{lJ_i}{N_i}\right)-t_i\beta_j S_i\left(\frac{t_i(I_i+qE_i)+t_j(I_j+qE_j)}{t_iN_i+(1-t_j)N_j}\right)-\kappa E_i$$

$$\dot{I}_i = \kappa E_i - (\alpha+\gamma_1+\delta)I_i$$

$$\dot{J}_i = \alpha I_i - (\gamma_2+\delta)J_i$$

$$\dot{R}_i = \gamma_1 I_i + \gamma_2 J_i$$

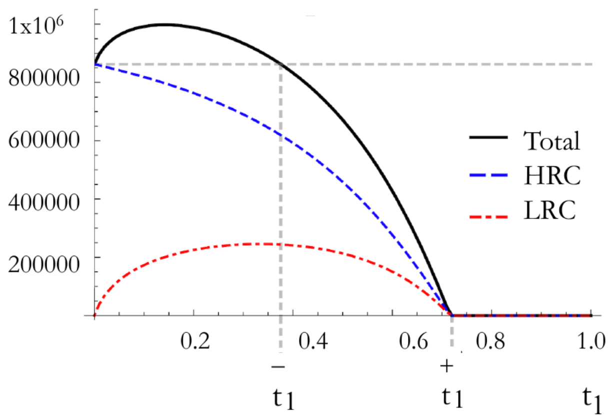
$$i, j \in \{1,2\}, i \neq j$$

For the i^{th} community, the compartments comprise susceptible, S_i, exposed and potentially infectious, E_i, symptomatic infectious and undiagnosed individuals, I_i; diagnosed cases, J_i; and recovered individuals, R_i. Individuals move between compartments, depending upon: β_i, the community-specific transmission rate per day; κ, the progression rate to symptomatic infectious; α, the progression rate from infectious to quarantine; γ_1, the infectious individuals' recovery rate; γ_2, the diagnosed individuals' recovery rate; q, the reduced infectiousness of the exposed class; l, the reduced infectiousness of diagnosed cases; and, δ, the COVID-19-induced mortality rate per day. Transmission rates in the i^{th} community are weighted by the average proportion of time spent in that community, and t_i refers to residency time in the community.

It is assumed that different conditions in the two communities drive differences in the community-specific values of the basic reproduction number, R_0. For the case where the disease dies out in the low-risk community (when the R_0 for that community is less than one), the Espinoza result shows that strong mobility restrictions can increase the final global epidemic size while weak restrictions can reduce it.

To illustrate this result, Figure 1 shows the community-specific and global final epidemic sizes, measured on the y axis, as functions of the average proportion of time that people from the high-risk community spend in the low-risk community, denoted by t_1 and measured on the x axis. The first threshold, $\overset{-}{t}_1$, reflects the trade-off involved in mobility from the high-risk to the low-risk community—the reduction in the number of secondary infections in the high-risk community against the increase in the number of secondary infections in the low-risk community. The second threshold, $\overset{+}{t}_1$, gives the level of mobility between the high-risk and low-risk communities required for the global basic reproduction number to fall below 1. Espinoza, Castillo-Chavez, and Perrings (2020) then test the sensitivity of this result to variations in population density ratios and community-specific risks of infection.

Figure 1: Patch-specific, global final size in the presence of mobility



Source: Espinoza, Castillo-Chavez, and Perrings (2020)

Figure 1 shows the community-specific and total final epidemic size with unidirectional mobility from the high-risk community, t_1 (t_2 = 0). The thresholds $\overset{-}{t}_1$ and $\overset{+}{t}_1$ denote the level of mobility required to reduce the total final epidemic size below that reached by applying the most extreme mobility restrictions (area quarantine), and the level of mobility needed to control a disease outbreak in the whole system, respectively.

3. COVID-19 AND THE 2020 RECESSION

Estimating the cost of disease control measures is complicated by the fact that the pandemic coincided with an expected downturn in the economy. COVID-19 proved to be the trigger for a widely anticipated recession, making it hard to identify the excess costs due to disease control measures.

In mid-April 2020, the International Monetary Fund (IMF) estimated that government measures to sustain economic activity amounted to USD 3.3 trillion and that loans, equity injections, and guarantees totalled an additional USD 4.5 trillion—most of which were at least formally tied to COVID-19. They projected the increase in public-sector borrowing to finance this to be equal to 6.2% of the global gross domestic product (GDP). In the US, the IMF expects the fiscal balance to GDP ratio to rise from 5.8% in 2019 to 15.7% in 2020. France, Germany, Italy, Japan, and the United Kingdom all have public sector support measures exceeding 10% of their GDPs (International Monetary Fund 2020). In terms of GDP growth, the IMF's April 2020 estimate was that the global economy would decline by 3.0% in 2020 but that the impact would be significantly different for developed (-6.1%) and developing economies (-1.0%) (Table 1).

Table 1: Projected Change in World GDP

	2019	2020 (Projected)
World	2.9	–3.0
Advanced economies	1.7	–6.1
United States	2.3	–5.9
Euro Area	1.2	–7.5
Japan	0.7	–5.2
Other advanced economies	1.6	–5.2
Emerging market and developing economies	3.7	–1.0
Regional groups		
Emerging and developing Asia	5.5	1.0
Emerging and developing Europe	2.1	–5.2
Latin America and the Caribbean	0.1	–5.2
Middle East and Central Asia	1.2	–2.8
Sub-Saharan Africa	3.1	–1.6

Source: International Monetary Fund (2020)

In terms of trade, a similarly timed estimate by the World Trade Organization (WTO) was that the decline in world merchandise trade would be between 12.9% and 31.9% in 2020 (Table 2).

In these projections, the differences between developed and developing economies are less pronounced. World trade was already declining in 2019, and this was expected to become worse in 2020. Detecting the impact of the COVID-19 response in the data is hard. Mobility restrictions primarily affect trade in services, which are not included in merchandise trade. However, the WTO makes the point that there are tight connections between trade in goods and trade in services (since transport is a service). They also note that there are no inventories of services. It is not possible to draw down on a service in one year and restock it in another. The implication is that any decline in services in 2020 cannot be recouped later (World Trade Organization 2020b).

Table 2: Projected Change in World Merchandise Trade

		Optimistic Scenario	Pessimistic Scenario
	2019	2020	2020
Volume of world merchandise trade	-0.01	-12.9	-31.9
Exports			
North America	1	-17.1	-40.9
South and Central America	-2.2	-12.9	-31.3
Europe	0.1	-12.2	-32.8
Asia	0.9	-13.5	-36.2
Other regions	-2.9	-8.0	-8.0
Imports			
North America	-0.4	-14.5	-33.8
South and Central America	-2.1	-22.2	-43.8
Europe	0.5	-10.3	-28.9
Asia	-0.6	-11.8	-31.5
Other regions	1.5	-10.0	-22.6

Source: World Trade Organization (2020b)

Note: Other regions comprise Africa, Middle East, and Commonwealth of Independent States (CIS) including associate and former member states.

In the case of COVID-19, the social cost of the disease includes the cost of the morbidity and mortality it induces along with the cost of treatment. The social cost of disease control includes all direct and indirect consequences of disruptions to trade and travel, social distancing, industry closures, domestic market restrictions, and financial measures to compensate firms and households for the effect of such restrictions. Backward and forward supply chain linkages mean that disease control measures in one location have consequences for employment and output elsewhere. Just as private contact decisions may generate external effects, so also disease control measures may have external consequences for both disease transmission and economic disruption elsewhere in the trade network.

4. IMPLICATIONS FOR EFFICIENCY

While the result reported in Espinoza is strictly epidemiological, in that it concerns the impact of mobility restrictions on the final size of the epidemic only, it does have implications for the efficiency of mobility restrictions as a disease control measure. First, trade and travel decisions both affect disease transmission through their effects on contact between infectious and susceptible individuals (Jones *et al.* 2008; Daszak 2012). For private individuals, the potential disease risks of contact are included in the costs of both trade and travel decisions and are weighed against the benefits of those decisions. Disease dynamics are thus sensitive both to the cost of disease and the cost of disease avoidance (the forgone benefits of contact). If the cost of disease is low, there is little incentive to avoid it. If the cost of disease is high, people will do more to avoid it. Understanding the trade-offs involved can therefore strengthen our capacity to predict disease dynamics (Fenichel *et al.* 2011).

At the same time, unless private individuals confront the full social cost of their actions, the level of disease avoidance may be less than socially optimal. This is the motivation for interventions designed to limit contact—for example, mobility restrictions and social distancing measures. The test for whether such interventions are socially efficient is whether they minimize the social cost of disease and disease control. If the health authorities implementing disease control measures neglect the cost of those measures for people elsewhere, their actions are unlikely to be cost-minimizing (Perrings *et al.* 2014).

The Espinoza result assumes that the public health authority responsible for imposing mobility restrictions weighs disease prevalence in each community equally. If we do not consider the economic costs of disease control, it then follows that mobility restrictions should be increased up to the point that the global final epidemic size is minimized. The reason that mobility restrictions fail to minimize the global epidemic size is that individual communities generally place a greater weight on containing their own risk than on reducing risk overall. They focus on community-specific epidemic size rather than the global epidemic size. Multiple public health authorities, each representing a different community or a different jurisdiction, have little incentive to coordinate their responses to the pandemic to assure the lowest global epidemic size (Espinoza *et al.* 2020).

Including the economic cost of disease control complicates the calculus. In the current COVID-19 pandemic, most disease control interventions are made at the national level. Indeed, efforts to coordinate control interventions across nation states have been frustrated by efforts to weaken the World Health Organization. In several countries, control has devolved to even lower levels. In the US, for example, most disease control measures have devolved to individual states, while some measures have devolved to individual counties or cities. While it may be motivated by the subsidiarity principle, the devolution of disease control to local authorities is problematic when the consequences of control are realized over a much wider area. For the individual authority, the incentive is to increase disease control up to the point where only the local costs of disease and disease control are minimized irrespective of global costs. If this results in higher overall costs than could be achieved through a cooperative approach, the outcome is socially inefficient.

For any given public health authority, their actions involve two possible sources of inefficiency. First, the adoption of specific disease control measures in one location may have a direct impact on both morbidity and mortality in other locations, but this impact may be ignored. The Espinoza result described above indicates why. Second, disease control measures that affect either labour or transport potentially have effects either up or down the supply chain, and these effects may occur at a distance from the place where the measures are enforced. A recent study on the short-term economic impacts of sector-specific transport and labour supply constraints imposed in response to the COVID-19 pandemic found that even countries that are not directly affected by the virus would face large losses (greater than 20% of their GDP) due to the disruption of supply chains. They also found that low- and middle-income countries are more vulnerable to supply chain-mediated effects than high-income countries (Guan *et al.* 2020).

5. IMPLICATIONS FOR EQUITY

An additional issue with a public health control strategy that privileges individual communities is that the outcome may not only be inefficient from a social perspective, it may also be inequitable. In the long history of area quarantines, the question of whether quarantining people is ethical and/or equitable has seldom been raised. In the COVID-19 pandemic, however, the question is being discussed in ways not been seen before. Countries have different approaches to it. In China, the imposition of a cordon sanitaire around Wuhan, the epicentre of the pandemic, was not questioned. In the US, by contrast, much milder social distancing measures that limit the behaviour of individuals have been challenged as a violation of individual rights.

Because mobility restrictions differentially affect the health and welfare of those who are restricted and those who are not, they have distributional implications. The Espinoza result implies that the people who are constrained to remain in high-risk areas face an increased risk to their health. If they also face increased losses due to the disruption of supply chains, lost access to product or labour markets, the collapse of public services, and so on, they are twice harmed. The evidence currently suggests that low-income countries, and low-income communities within developed countries, are most affected by the disease. This is in part due to the state of their public health infrastructures. Limited healthcare personnel (especially anaesthesiologists), hospital beds, intensive care units, oxygen, ventilators, infusion pumps, and even water and power supply mean that low-income countries have a more limited capacity to handle a large number of cases compared to high-income countries (see, for example, Sonenthal *et al.* 2020). This is partially because most surgeries are urgent and non-elective (such as caesarean deliveries). They cannot be postponed (Bong *et al.* 2020). But it is also because people with low incomes have fewer options to avoid infection, whether by changing work habits, social distancing, or moving to safer environments.

In New York, the city most affected by the pandemic in the US, evidence indicates (a) that residents from high-income neighbourhoods were more likely to move away from the city than residents from low-income neighbourhoods, (b) that residents in low-income Black and Hispanic neighbourhoods exhibit the most high-risk work activity during working hours, and (c) these residents are least likely to 'shelter in place' outside of working hours (Coven and Gupta 2020). The evidence also indicates that COVID controls affect women more than men. The closure of schools and day-care centres has impacted child care and hence working mothers (Alon *et al.* 2020). In East and South East Asia, travel restrictions have restricted the availability of employment for female foreign domestic workers traveling between the Philippines, Indonesia, Hong Kong, and Singapore (Wenham, Smith, and Morgan 2020).

The central point here is that mobility restrictions evidently limit the capacity of those in less safe environments to move to more safe environments, whether within a country or between countries. This raises the cost of disease in less safe environments and lowers it in more safe environments. Just as this has implications for epidemiology, so does it have implications for equity.

6. CONCLUDING REMARKS

The emergence of COVID-19 shares many similarities with the emergence of other novel zoonotic diseases over the last 50 years. The first appearance of the disease in the wet markets of Wuhan mirrors the first appearance of many other emerging zoonoses. An interface between humans and wildlife at forest margins is the likely origin of the disease, and local markets for wildlife products are the likely mechanisms for transmission from the forest margin to the urban centre. As with other emerging zoonoses, its transmission from one country to another was due to patterns of travel and trade. Where it differs from other recently emerged zoonoses is in the characteristics that make it especially difficult to contain—the high proportion of people infected who are asymptomatic but infectious. In these circumstances, mobility restrictions appear to be an effective means of slowing spread between communities, although a recent study concluded that airline travel restrictions would not have been sufficient to prevent the spread of the virus (Shi *et al.* 2020).

What makes the Espinoza result interesting is that the same mobility restrictions can, conversely, increase transmission within restricted communities. When communities are differentiated in terms of population density, health infrastructure, and the resources that susceptible individuals have to avoid infection, restrictions that limit the capacity of people in high-risk areas to leave can lead to higher rates of infection in those areas. Not only does this increase the number of cases in high-risk communities, but it also increases the probability that health infrastructures will fail, that case mortality rates will rise, and that the disease will not be contained. Aside from the ethical issues this raises, it also risks prolonging the pandemic. Despite the lack of a coordinated response to COVID-19, it is still an infectious disease and its control is still a public good of a very particular kind. As with other infectious diseases, control of COVID-19 is a weakest link public good (Sandler 2004). The benefits of disease control to all are, ultimately, only as effective as the benefits of disease control offered by the least effective provider. As long as there are any countries where public health authorities are unable to contain the disease, no country is safe.

An immediate implication of this is that the interests of all are best served by strengthening the capacity of the weakest links in the chain. As it happens, we have seen resources being diverted away both from health-oriented development assistance and from intergovernmental organizations set up to protect global interests. Indeed, the US has announced its intention to withdraw from the World Health Organization at the very moment it is most needed. We have also seen the use of mobility restrictions that are certain to increase the stress on already stretched health infrastructures in low-income countries. There is certainly scope for collaborative action within the Global South to fill the void, but there is also little clear indication that this will happen.

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