SHOCKS AND THE SPATIAL DISTRIBUTION OF ECONOMIC ACTIVITY: THE ROLE OF INSTITUTIONS

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Abstract

Why do some historical shocks permanently impact local development, while others do not? This paper examines how institutions influence local recovery to population shocks, using a model with multiple regions and increasing returns to economic activity within regions. Extractive institutions crowd out productive activity, making its spatial coordination more difficult in the aftermath of large, negative shocks. Hence, when one region experiences such a shock, extractive institutions can hinder recovery, ensuring a redistribution of productive activity away from that region over the long-run. Using a dataset of major earthquakes and 1860 world cities from 1973 to 2018, I find sustained negative effects of earthquakes on city population growth, with effects being driven by cities located outside of stable democracies, consistent with the theory.

JEL codes: B52, C72, J24, P48, R12
Key words: History dependence; multiple equilibria; institutions; increasing returns; earthquakes

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1 Introduction

In 2010, a 7.0 magnitude earthquake struck just outside of Port-au-Prince, Haiti. In the years following, the city witnessed a nearly 50% decline in annual population growth, a trend which has persisted ever since.[1] A year later and across the world, an even larger earthquake struck off the coast of Sendai, Japan, fueling massive tsunamis. Today, that city is enjoying its highest levels of population growth in over a decade.[2]

Why do some historical shocks permanently impact local development, while others do not? And what factors determine the distribution of economic activity across space more generally? These questions are of central importance in urban and development economics for understanding differences in economic performance within countries, as well as the potential role of policy. Despite this, their answers remain subject to active debate.

One theory is that there exists the potential for multiple equilibria in spatial development but conditions set by both nature and history select among them. In this view, the location of economic activity is driven in part by incentives for humans to locate near each other, such as in production (i.e. agglomeration spillovers). Such increasing returns can generate path dependence, while also implying a potential for policy to induce or transplant economic activity in self-reinforcing ways (Kline and Moretti, 2014; Jedwab and Moradi, 2016). However, some empirical research has cast doubt upon the empirical relevance of multiple equilibria. Davis and Weinstein (2002, 2008) and Miguel and Roland (2011), among others, have shown how even massive shocks may only temporarily redistribute economic activity across space. This literature supports a more deterministic view, in which individuals co-gravitate toward strong fundamentals over the long-run, while returns to scale matter more for determining spatial dispersion (e.g. of cities). Efforts to reconcile these findings have varied considerably, with selection in shock exposure, focal points, and heterogeneity in physical geography all being proposed as potential sources of differential effects (Redding, 2010; Acemoglu, Hassan, and Robinson, 2011; Bleakley and Lin, 2012; Nunn, 2009, 2014; Schumann, 2014; Jedwab, Johnson, and Koyama, 2019).[3]

This paper provides an alternative approach to understanding this empirical puzzle, by considering the interaction of increasing returns with another important force for long-run development: formal institutions (Acemoglu, Johnson, and Robinson, 2001; Dell, 2010; Acemoglu and Dell, 2010). Using a two-region model with migration between regions, I explore

[1] In 2009, Port-au-Prince added approximately 126,712 to its population; in 2018, it added only 67,782.

[2] Between 2017 and 2018, Sendai grew by approximately 18,131, its largest increase since 2005 saw 20,960.

[3] In addition, an alternative theory for the persistence of shocks posits that growth follows a random walk (Simon, 1955; Gabaix, 1999). While I do not focus on this mechanism in this paper, I do discuss and provide some evidence against it in the context of the empirical exercise in Section 3.

the role of institutions in explaining the differential impact of temporary shocks on the long-run spatial distribution of economic activity. In the model, more extractive institutions decrease the return on production relative to "unproductive" activities that do not contribute to the productive process, thus utilizing resources at the expense of it (Nunn, 2007). In the presence of increasing returns to productive activity within regions, a large negative shock to a region's population can temporarily reduce productive spillovers. When institutions are sufficiently extractive, this can induce substitution among workers from productive into unproductive activities. Now absent productive spillovers, relatively fewer workers will prefer to live in the affected region, while those who do migrate there will also prefer to engage in unproductive activities, locking in asymmetries in both population and production between regions.

Hence, the model exhibits multiple equilibria: one with two similarly productive and populated regions, and one with a single highly populated, productive region neighboring a less populated and relatively unproductive region. Moreover, these asymmetries can arise even when there are no differences in natural advantages, local institutions, or endowments *ex ante* between regions. Then, as institutions become stronger and less extractive, spatial equilibria become more robust to large shocks. This illustrates how relatively lowered levels of economic activity may persist in a region following a negative population shock, causing population and productive inputs such as human capital to become concentrated in select regions over the long-run – even if formal institutions eventually improve.

The notion that institutions can have long-lasting effects on economic development is not new. A large theoretical and empirical literature exists documenting numerous cases throughout history in which extraction negatively impacted long-run development. Human capital (Acemoglu, Gallego, and Robinson, 2014), culture (Tabellini, 2010), and public goods provision (Dell, 2010) have all been cited as important channels through which historical institutions continue to matter. Most similar to this paper is Nunn (2007), who models a similar tradeoff between productive and unproductive activities in explaining the importance of historical extraction. This paper goes a step further, exploring how national institutions influence the persistence of shocks, and therefore the distribution of economic activity, *within* countries. In particular, it argues that in places that feature less economic activity, extractive institutions promote comparative advantages in unproductive activities that, as such, do not attract productive workers. In the context of a large shock, such as a natural disaster, this means that activities such as corruption and property theft made more attractive by weak institutions are present to reinforce the effects of the initial shock. It also means that, by weakening incentives underlying urban recovery in the short-run, weak central institutions may produce greater variation in development within countries.

Nevertheless, a link between the institutional environment experienced by a country or region and the persistence of population shocks therein has often been alluded to in existing empirical research on war, expulsion, and natural disaster. Mirroring Davis and Weinstein's (2002, 2008) finding that Japanese city size and composition were robust to the bombings of WWII, returning to their prewar distributions within decades, Miguel and Roland (2011) observe similar convergence in Vietnam. At the same time, they argue that differential convergence would be unsurprising in a larger sample of studies. In particular, the authors note that while postwar Japan was a market democracy and Vietnam a socialist regime, both had relatively strong institutions, which would have aided in catch-up in both places. Similar points about the importance of preexisting institutions are made by Brakman, Garretsen, and Schramm (2004), who find swift convergence after WWII in West but not East Germany, as well as in surveys of the empirical literature by Redding (2010) and Nunn (2014).

Given this, it is perhaps unsurprising that much of the work on forced migration has shown, in contrast, strong persistence in the origin economy. For instance, Chaney and Hornbeck (2016) find delayed convergence following the expulsion of Moriscos from Spain in 1609, citing preexisting extractive institutions in Morisco areas as a potential source. Testa (2020) similarly finds Czech municipalities affected by expulsions of Germans after WWII to be worse off today relative to unaffected areas nearby, attributing these differences in part to the widespread property exploitation that took place of affected areas by settlers and local officials. Meanwhile, Nunn (2008) finds a negative relationship between exports of slaves and future economic performance in African countries, characterizing the slave trade as an extractive regime that gave rise to raiding and internal warfare in origin economies.

Such can also be found in the relatively smaller literature on non-political population shocks, such as natural disaster. In the case of earthquakes, Barone and Mocetti (2014) cite preexisting institutions as a source of differential effects, with corruption and declining social capital impeding recovery in poorly institutionalized places, while Anbarci, Escaleras, and Register (2005) similarly show poor collective action to exacerbate earthquake fatalities in places with greater inequality, and Belloc, Drago, and Galbiati (2016) observe local institutional stagnation following earthquakes in medieval Italy in places where separation of relevant powers had previously been weak. Meanwhile, Acemoglu, de Feo, and de Luca (2019) find that severe droughts paved the way for the Sicilian Mafia where institutions were weak, at the expense of subsequent local development.[4]

[4] Also see Maloney and Caicedo (2015) and Jedwab, Johnson, and Koyama (2019) for more on institutions as a source of heterogeneous effects in the persistence of pre-colonial American agglomerations and the Black Death, respectively, as well as Dell and Olken (2019) for evidence that within the extractive colonial Dutch regime in Java, agglomeration economies from sugar factories gave rise to countervailing long-run effects locally.

The remainder of the paper adds to this empirical literature by testing the predictions of the model. To do this, I consider the effects of large earthquakes on city population growth over time, using a dataset of all major earthquakes (i.e. 5 or greater magnitude on the Richter scale) and population size for 1860 world cities from 1973 to 2018. I first show that earthquakes tend to have a negative impact on city population growth, with this effect becoming large and growing over time when I account for a city's time-invariant earthquake risk. When I examine heterogeneous effects on the basis of political institutions, I find this effect to be driven by cities located outside of stable democracies, in line with the predictions of the model. These findings complement an existing literature on the economic effects of earthquakes and other national disasters, to which they contribute an examination into the city-level population effects of earthquakes at a global level (Ahlerup, 2013; Cavallo et al, 2013; Hsiang and Jina, 2014; Boustan et al, 2017; Kirchberger, 2017).[5]

2 The model

The economy in the model is composed of a share of non-atomic workers M_r in each region $r \in \{1, 2\}$. Workers are long-lived but myopic, and I focus for now on a single time period. Each worker begins a period with some endowment, which she may choose to transform into a *labor input*, h (e.g. human capital). If she does, then her labor input is combined with a firm's resources to produce goods, and she is compensated at the regional market wage rate w_r. In this scenario, she is said to be *engaged in production*. At any given time, the share of all workers living in region r *and* engaged in production is $m_r \leq M_r$.[6] Each region also has a fixed stock of *resources*, K, which are divided amongst $\lambda * m_r$ identically-producing firms indexed by ω.[7] In a given period, each region r firm has some amount $k_r \leq K/\lambda m_r$ of resources for use in production, to be defined shortly.

However, a worker may also choose to forgo engagement in production. In this scenario, she simply consumes resources directly – resources which might otherwise be used by firms as inputs in production. I refer to such behavior as *unproductive*, to the extent that it does not contribute to the local production process and as such comes at its expense. The relative payoffs from unproductive activities as compared to productive ones crucially depend on the formal institutional environment. The assumption that extractive or weak institutions decrease the relative payoffs from productive activities and give rise to unproductive behavior is long-standing in the political economy literature (Skaperdas, 1992; Nunn, 2007). In this

[5] A more similar empirical study is Kocornik-Mina (2019), who find persistent urban effects of floods.

[6] Thus the share of the world's workforce that is engaged in production is $m_r + m_{-r} \leq 1$, where the prevalence of productive worker activity in region r does not necessarily scale with but is constrained by M_r.

[7] For simplicity, K is immobile and regenerates each period.

model, the *quality of institutions* is exogenous to local economic activity and represented simply by the parameter β.[8]

The productive environment

Production is subject to constant returns to scale within firms in resources and labor inputs. However, the model allows for *external* increasing returns (i.e. within regions) in regional labor inputs $H_r \equiv m_r h$. In this case, as relatively more productive activity locates in region r, region r firms can produce relatively more given the same labor inputs. This *agglomeration spillover* is represented by H_r^γ, where $\gamma \geq 0$ gives its magnitude.[9]

Besides agglomeration, heterogeneity across regions in firm-level productivity can also be attributed to differences in *natural advantages*. These locational benefits are given by the parameter a_r. Thus the overall productivity level for region r is given by:

$$A_r = a_r H_r^\gamma.$$

Altogether, this yields a firm-level CRS production function of:

$$f_r(\omega) = A_r k_r h_r(\omega),$$

where $h_r(\omega)$ gives a region r firm's demand for labor inputs. Hence, a firm's profit maximization problem can be given by:

$$\max_{h_r(\omega)} pa_r H_r^\gamma k_r h_r(\omega) - w_r h_r(\omega), \tag{1}$$

where prices p are set collectively by all regions with workers engaged in production.[10] Assuming zero profit, this implies a real income and thus consumption payoffs for productive

[8]This assumption implies that, as a measure of central institutions, β is invariant to the local economic conditions within individual regions. As the model shows, however, the implications of poor central institutions may nonetheless vary by region, with some regions being *as if* they are in a country with good institutions, making the effective institutional environment endogenous within regions. Complicating the model so β is instead modeled as endogenous to local economic activity simply magnifies existing strategic complementaries in local worker behavior, as shown in Theory Discussion 1 in the Supplemental Material.

[9]This term is common in the economic geography literature (Allen and Donaldson, 2018). For microfoundations, see Marshall (1920) and Duranton and Puga (2004). For empirical estimation, see Rosenthal and Strange (2004), Moretti (2004), Greenstone, Hornbeck, and Moretti (2010), and Ellison, Glaeser, and Kerr (2010).

[10]As regions are in close proximity, I assume no trade costs or differences in market access.

workers in region r of:

$$V_r(h) = a_r H_r^\gamma k_r * h \\ = a_r k_r h^{1+\gamma} m_r^\gamma. \tag{2}$$

How does the institutional environment matter?

Unlike typical two-region models of economic geography, this framework incorporates a strategic component in which workers may prefer to engage in unproductive activities. In contrast with production, which involves combining worker endowments with resources to create value for consumers, unproductive activities involve acquiring and consuming resources directly (i.e. every man for himself), which does not entail external economies of scale, while coming at the expense of the local productive sector, which does. This distinction between productive and unproductive activities is common in the literature on institutions and conflict (Acemoglu, 1995; Nunn, 2007). Real-world examples of unproductive activities include corruption and rent-seeking, as well as looting and other property crime. Institutional qualities that might drive relatively high payoffs from such activities, e.g. following a negative shock such as a bombing or natural disaster, include poor property rights protection and weak rule of law in the enforcement of building codes and aid dispersal.

I model such resource acquisition using a variant of the contest success function (Skaperdas, 1996). Unproductive workers consume resources that would otherwise be used in production, where the total amount of resources acquired by unproductive workers in region r is proportional to the relative prevalence of unproductive behavior in the regional economy:

$$\frac{M_r - m_r}{M_r} K,$$

where $M_r - m_r$ equals the share of all workers living in region r and engaged in unproductive activities. This leaves each region r firm with a final resource endowment of:

$$k_r^* = \left(1 - \frac{M_r - m_r}{M_r}\right) \frac{K}{\lambda m_r} \\ = \frac{K}{\lambda M_r}. \tag{3}$$

Unproductive payoffs follow from this. Adopting the assumption that relative value from unproductive activities is derived inversely from the quality of institutions, consider the following payoffs from engaging in unproductive activities in region r:

$$\begin{aligned} V_r(u) &= \frac{1}{\beta}\frac{1}{M_r - m_r}\left(\frac{M_r - m_r}{M_r}\right)K \\ &= \frac{K}{\beta M_r}. \end{aligned} \tag{4}$$

Recall that β describes the quality of institutions, which I consider to be a deep parameter that is the same in both regions. In spite of this, unproductive behaviors may become widespread in one region and not the other, as one will see shortly. At the same time, because resources are fixed in each region and of use in both production and unproductive activities, they will serve as a relative congestion force in each region that prevents "black hole" equilibria, in which all workers locate in one region, from arising in the long-run.

2.1 Short-run equilibria

I assume that in the short-run, workers cannot move between regions (i.e. M_r is fixed) but can move between productive and unproductive activities. For analytical simplicity, this choice is modeled as a binary decision. That is, an agent prefers to transform her endowment into a productive labor input if and only if

$$a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma} \geq \frac{K}{\beta M_r}. \tag{5}$$

For now, let $\gamma > 0$. Since agents are non-atomic, each takes m_r as given when deciding whether to deviate. Hence, worker behavior exhibits strategic complementaries around some critical threshold, $\widehat{m_r}$, above which the optimal $m_r^* = M_r$, the total share of workers in r.

Definition 1. A *high production short-run equilibrium* [HPSE] consists of all workers in a region r specializing in production ($m_r^* = M_r$).

Definition 2. A *low production short-run equilibrium* [LPSE] consists of all workers in a region r specializing in unproductive activities ($m_r^* = 0$).

Now consider the first result:

Proposition 1. *There exists a high production short-run equilibrium [HPSE] for each region r. In every HPSE:*

(i) There is a threshold prevalence of productive activity $\widehat{m_r}$ when $\gamma > 0$, above which the total share of workers in region r, M_r, prefer to specialize in production, $m_r^* = M_r$.

(ii) The share of the worker population located in r must be sufficiently large, $M_r \geq \widehat{m_r}$, where this equilibrium is locally stable in M_r whenever this inequality is strict.

(iii) $\widehat{m_r}$ is decreasing in a_r, h, and β and increasing in λ.

The remaining space below $\widehat{m_r}$ is characterized by a LPSE, in which all agents in region r forgo production and instead simply acquire and consume local resources (i.e. $m_r^* = 0$). Importantly, because productive activity entails within-region externalities, and because the relative prevalence of productive activity in one region is constrained by its relative population size, a temporary decrease (i.e. shock) in the share of the population located in that region has the potential to permanently shift it from a HPSE to a LPSE (i.e. $M_r < \widehat{m_r}$ implies $m_r < \widehat{m_r}$). However, this depends on the quality of formal institutions. When the quality of institutions β is sufficiently high, even large shocks will not generate incentives for workers to substitute toward unproductive activities in the affected region. This is important, as a population shock which cannot induce a shift from one short-run equilibrium to another within a region will also have no effect on the long-run equilibrium population distribution *across* regions, as we will see shortly.

Now let $\gamma = 0$, such that there are no agglomeration spillovers. This is relevant for understanding how sectors such as agriculture respond to population shocks in the short-run. As it turns out, population shocks cannot shift a region from one short-run equilibrium to another in the absence of agglomeration spillovers:

Remark 1. *In the absence of agglomeration spillovers, $\gamma = 0$, if a HPSE exists in region r for some M_r, then it exists for all M_r'.*

Hence, the propensity for a population shock to shift a regional economy from a HPSE to a LPSE depends not only on the quality of formal institutions but also on the presence of external increasing returns (i.e. $\gamma > 0$), which generate strategic complementarities in production choices within regions. In fact, absent agglomeration spillovers, economic activity will always tend toward its initial distribution as determined by fundamentals *regardless of institutions*. To show this, however, I must first introduce population dynamics, in the form of migration between regions over time.

2.2 Long-run equilibria

In the long-run, agents can move between productive and unproductive activities within regions as well as migrate between regions. Population dynamics are modeled as in the economic geography literature,[11] using a standard replicator dynamic:

$$\dot{M}_r = M_r(V_r - \overline{V}), \tag{6}$$

where $\dot{M}_r$ gives the change over time in the share of the population in region r, which depends on the relative size of the short-run payoffs in region r, and where $\overline{V} \equiv M_1V_1 + M_2V_2$ gives the national average payoffs. There is no cost to migration. However, since agents are non-atomic, short- and long-run incentives can interact to generate coordination problems which in turn constrain migration.

Suppose, for instance, that $m_r \geq \widehat{m_r}$ initially in each region r, such that both regions specialize in production (i.e. $m_r^* = M_r$ for all r). Then there exists some steady state $M_r \equiv M_r^*$ at which $\dot{M}_r = 0$ as long as $M_r^* \geq \widehat{m_r}$ for each region r. That is, when enough agents are coordinating on productive behavior in each region, $m_r \geq \widehat{m_r}$, there is some population distribution M_r at which both regions have high levels of production and no worker prefers to deviate from one region to other. From (2) and (6), this is the solution to:

$$\frac{a_1Kh^{1+\gamma}}{\lambda}M_1^{\gamma-1} = \frac{a_2Kh^{1+\gamma}}{\lambda}M_2^{\gamma-1}, \tag{7}$$

which implies for each region r:

$$M_r^* = \frac{a_r^{\frac{1}{1-\gamma}}}{a_r^{\frac{1}{1-\gamma}} + a_{-r}^{\frac{1}{1-\gamma}}}.$$

However, the local stability of this as a long-run equilibrium depends on γ.

Assume for now that $\gamma \in (0,1)$. When $\gamma \in (0,1)$, the lefthand side of (7) is strictly decreasing in M_r while the righthand side is strictly increasing. Then small changes in M_r will have only temporary effects, holding short-run equilibria fixed. However, by Proposition 1, the stability of this state also depends on the size of M_r relative to the threshold $\widehat{m_r}$ for each region, i.e. local stability in the short-run. I thus define the following:

Definition 3. A *symmetric high production long-run equilibrium* [HPLE] consists of (i) each region being in a HPSE ($m_r^* = M_r$ for all r), with (ii) a steady state share of workers located

[11] In this tradition, population dynamics are often framed in relative terms (i.e. regional shares), such that the total population does not matter for the long-run analysis (Krugman, 1991; Davis and Weinstein, 2008; Allen and Donaldson, 2018). This allows for overall population to grow due to births, immigration, etc., letting the model abstract from such factors. As such, the model does not consider migration from outside the country in driving post-shock dynamics. That being said, such might occur (absent significant migratory frictions) if post-shock payoffs in region r grow enough to induce it. This might be the case in an LPSE or an HPSE with relatively small agglomeration economies, in which decreases in population reduce resource-related congestion forces, making migration to that region relatively more appealing.

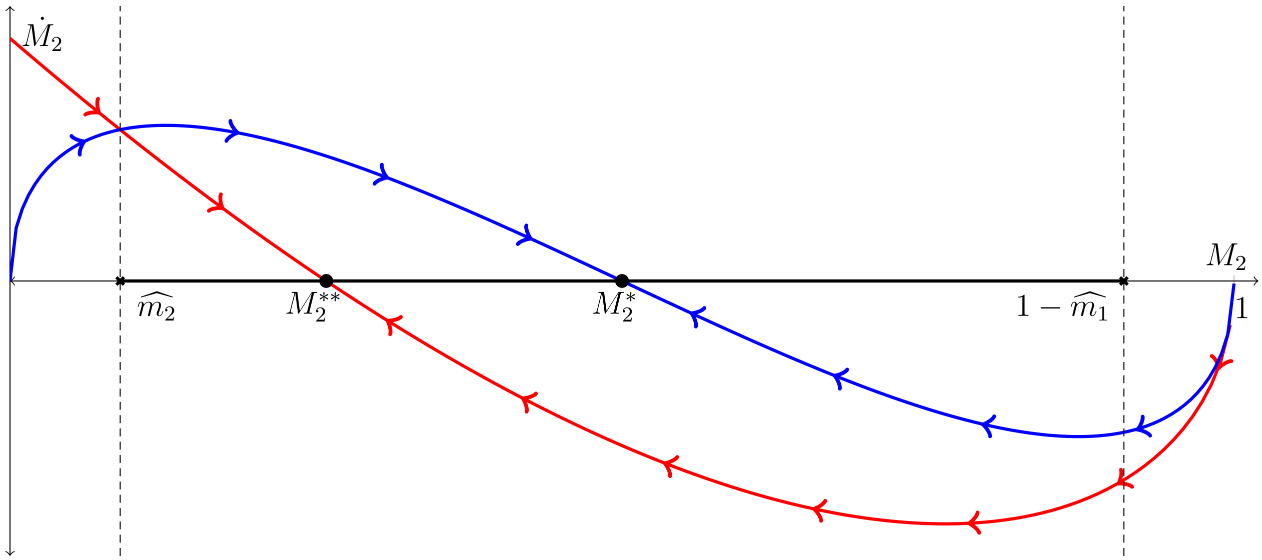


Figure 1: Symmetric high production (in blue) versus asymmetric (in red) long-run equilibria for $\gamma = 1/2$, $\beta = 10/3$, $a_1 = a_2 = K = h = \lambda = 1$

in each region, M_r^*, which is said to be *locally stable* in M_r if short-run equilibria are locally stable in M_r ($M_r^* > \widehat{m_r}$) and small changes in M_r are temporary ($\frac{\partial \dot{M}_r}{\partial M_r}|_{M_r = M_r^*} < 0$).

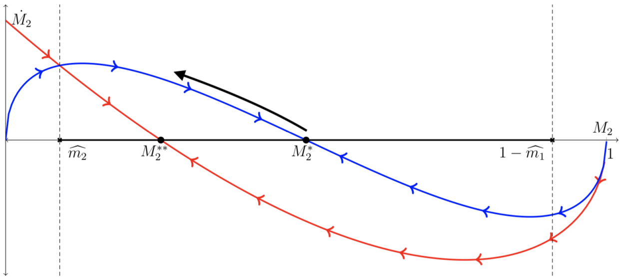
Now suppose that M_r and $\widehat{m_r}$ are sufficiently close. Then a large, negative shock to M_r in the short-run (e.g. from death or displacement) may result in a shift to a LPSE in region r, such that the steady state population distribution is no longer determined by (7).

This brings me to a second case, in which a large, negative shock to e.g. M_2 occurs, shifting region 2 from a HPSE to a LPSE. In other words, in depleting region 2 of its productive workforce relative to region 1, a large negative population shock reduces its productive spillovers, thus making it relatively more appealing for those living in region 2 to engage in unproductive behavior, so long as institutions are sufficiently extractive. Furthermore, conditional upon engaging in unproductive activities, it also increases the consumable amount of resources *per capita* in region 2. In the long-run, this will trigger migration into region 2 by those who see opportunity in unproductive activities, but *not productive ones*. Assuming that such a shock did not also occur in region 1, the new steady states M_r will be the solution to:

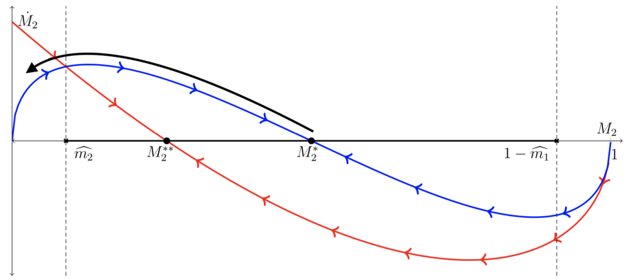
$$\frac{a_1 K h^{1+\gamma}}{\lambda} M_1^{\gamma-1} = \frac{K}{\beta M_2}. \tag{8}$$

It can be shown that such a shock should leave region 2 at a permanently lower relative population level when $\gamma \in (0,1)$, as in Figure 2. To do this, I first define the following:

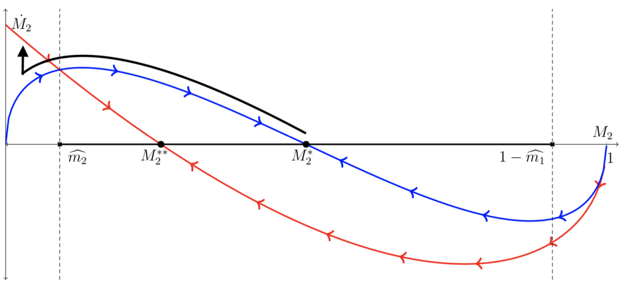
Definition 4. An *asymmetric long-run equilibrium* [ALE] consists of (i) one region r being



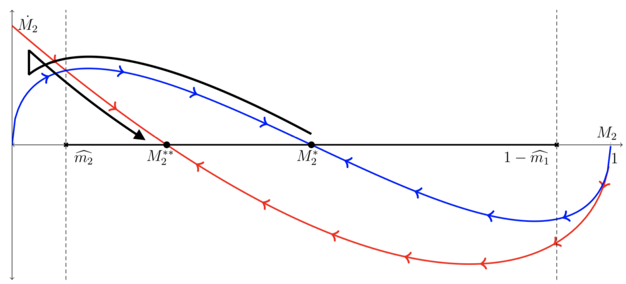
(a) Small negative shock



(b) Large negative shock



(c) Transition to new short-run equilibrium in $r = 2$



(d) Transition to new long-run steady state

Figure 2: Transition from HPLE to ALE following a negative shock to M_2

in a HPSE ($m_r^* = M_r$) and (ii) the other region $-r$ being in a LPSE ($m_{-r}^* = 0$), with (iii) a steady state share of workers located in each region, M_r^{**}, which is said to be *locally stable* in M_r if short-run equilibria are locally stable in M_r for region r ($M_r^{**} > \widehat{m_r}$) and small changes in M_r are temporary ($\frac{\partial \dot{M}_r}{\partial M_r}|_{M_r = M_r^{**}} < 0$).

Altogether, these results can now be summarized by the following proposition:

Proposition 2. *(i) There exists a locally stable symmetric high production long-run equilibrium [HPLE], with a unique interior steady state population $M_r^* \in (0,1)$ when agglomeration spillovers are moderately strong, specifically $\gamma \in (0,1)$, where $M_r^* = \frac{1}{2}$ if and only if $a_2 = a_1$, and where M_r^* increasing in a_r and decreasing in a_{-r}.*

(ii) There also exists a locally stable asymmetric long-run equilibrium [ALE], with a steady state population share in the productive (unproductive) region of $M_r^{**} > M_r^*$ ($M_{-r}^{**} < M_{-r}^*$), with M_r^{**} increasing in a_r, h, and β and decreasing in λ.

Thus, a sufficiently large, negative population shock in one region (i.e. such that $M_r < \widehat{m_r}$) can permanently (i) shift its local economy from production to unproductive activity, (ii) lowering its relative population due to the now relatively larger productive spillovers in the other region, (iii) leaving a population that is nonetheless positive to the extent that its resources may still be utilized in relatively unproductive ways, with such payoffs being determined by the quality of institutions (i.e. $\frac{\partial \widehat{m_r}}{\partial \beta} < 0$).[12]

In other words, given more extractive institutions, large-scale population loss tends to induce a shift toward unproductive activities in the affected region by those remaining as well as incoming migrants (e.g. property exploitation, corruption),[13] rendering it less productive and populated over the long-run. Stronger institutions, meanwhile, limit the extent to which being production becomes relatively unappealing following large shocks, such that agents are more likely to coordinate back to pre-shock patterns.

Lastly, let $\gamma \notin (0,1)$. We know that when $\gamma = 0$, short-run shocks of any size should have no bearing on short-run equilibria. Hence, sectors lacking agglomeration spillovers should see their workers return to their pre-shock distribution, as determined by either (7) or (8).[14]

Remark 2. *In the absence of agglomeration spillovers, $\gamma = 0$, population shocks have no long-run effect on the spatial distribution of productive activity.*

In other words, in sectors like agriculture which lack external economies of scale, shocks have no permanent effects, regardless of institutions. Rather, the distribution of productive activity is determined solely by the fundamentals. If fundamentals vary across space, then activity will tend to locate more where they are stronger. If they are symmetric across regions (i.e. $a_2 = a_1$), then so will be the distribution of e.g. farmers, both before and after population shocks, assuming a HPLE to begin with.

What about when agglomeration spillovers are very strong, i.e. $\gamma > 1$?[15] As it turns out, when productive spillovers are sufficiently great, HPLE are *always* unstable:

Proposition 3. *When agglomeration spillovers are sufficiently strong, specifically $\gamma > 1$, then:*

(i) There exists a symmetric high production long-run equilibrium [HPLE].

(ii) It is always unstable in M_r.

Hence, the existence of a locally stable HPLE is sufficient but not necessary for uneven patterns of development to arise. Reminiscent of the new economic geography, when ag-

[12] Thus if a shock also negatively affects K over the long-run in that region, even fewer would reside there.

[13] Alternatively, this could be thought of as corresponding to changes in local institutions or social norms.

[14] As a corollary to Propositions 1 and 2, note that if institutions become too extractive, then unproductive activities will become too appealing relative to productive ones, such that no HPLE or ALE can survive and both regions will be in LPSE as part of a globally stable symmetric low production long-run equilibrium [LPLE]. To see this, note that the derivative on $\widehat{m_r}$ and those on both steady states M_r^* and M_r^{**} are opposing in β. For sufficiently low β, $M_r \geq \widehat{m_r}$ can never occur, regardless of shocks.

[15] I opt to ignore the trivial case where $\gamma = 1$, in which M_r is not well defined under equation (7).

glomeration spillovers are sufficiently strong, more interior equilibria tend toward instability, in favor of unevenness over the long-run.[16]

The role of local development policy

Finally, note that in contrast with negative shocks, the model implies that the effects of temporary local development policies and positive population shocks associated with them (assuming an unproductive equilibrium to begin with) may actually be *more* likely to persist in the long-run in places with strong institutions. This is because while it takes a negative shock to m_r larger than $M_r - \widehat{m_r}$ to move a region from a productive equilibrium to an unproductive one, it takes a positive policy shock larger than $\widehat{m_r}$ to do the opposite. Hence, when β is large, only a small-scale coordinated effort (e.g. by some "city corporation") is needed to move a region from an unproductive equilibrium to a productive one: an investment need only attract a few to the region simultaneously before complementarities take over.

3 Empirical evidence

There exists a growing empirical literature exploring the short- and long-run impacts of shocks on the location of economic activity, with war, expulsion, disease, and natural disaster all serving as temporary shocks to relative city or region size (Davis and Weinstein, 2002; Jedwab, Johnson, and Koyama, 2019; Kocornik-Mina et al, 2019; Testa, 2020). To the extent that relative population levels and growth trends do not return to pre-shock levels, as compared to places not exposed to the shock, it is taken as evidence in favor of multiple spatial equilibria and the importance of increasing returns for determining differences in development across space. At the same time, a sizable literature finds no such persistence in the aftermath of even very large shocks, supporting a more deterministic view of spatial development.

This paper proposes an interaction between increasing returns and a place's underlying formal[17] institutions in determining its short- and long-run response to population shocks. In the model, pre-shock equilibria are robust to even large shocks when institutions are strong. To the extent that extractive institutions crowd out productive activities that generate increasing returns, however, the model sees multiple equilibria emerge, with shocked places experiencing a persistent relative decline in economic activity thereafter.

[16] For more on alternative equilibria when $\gamma > 1$, see Theory Discussion 2 in the Supplemental Material.

[17] Although I focus on formal institutions, it is important to note that more informal institutions with which they are correlated may also affect payoffs in the model and earthquake effects in this section.

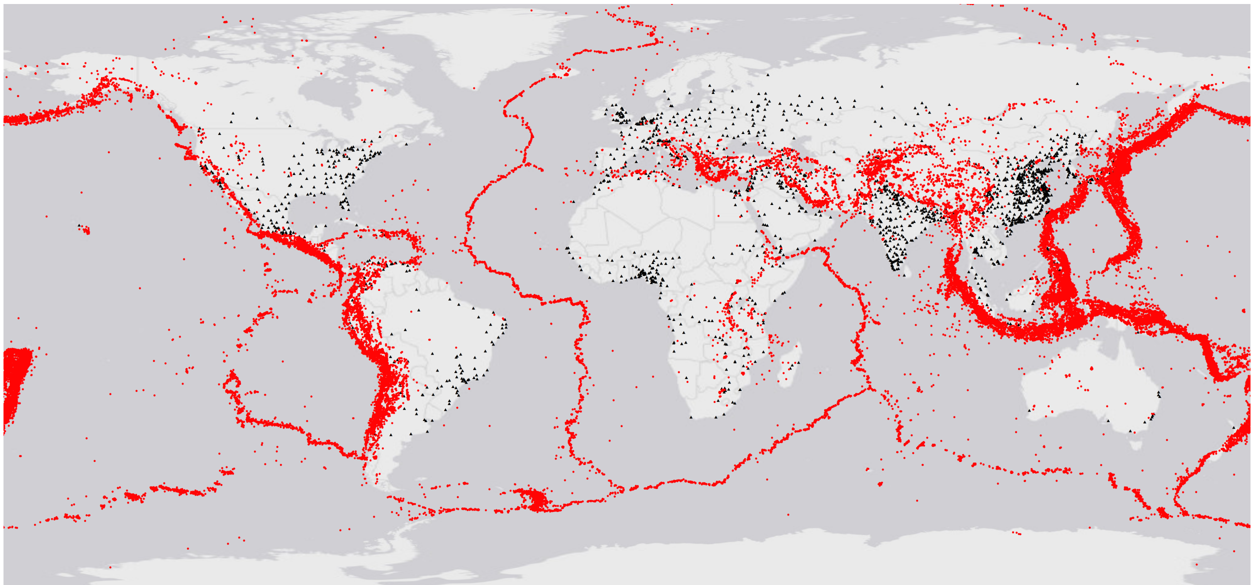


Figure 3: Earthquakes of Richter magnitude 5+ (in red) and major cities (in black), 1973-2017

In this section, I test and find evidence consistent with this prediction, using a new dataset of large earthquakes and 1860 world cities spanning nearly half a century to explore how large, temporary shocks to relative city size affect city growth in the short- and long-run, both overall and across different institutional settings. I will begin by describing these data, before discussing estimation and results.

3.1 Data

To study the relationship between earthquakes and subsequent city growth, I use data on the locations and annual populations of major world cities from the World Urbanization Prospects (WUP) by the UN's DESA/Population Division (2018). Based on census and other data, WUP reports approximate population counts since 1950 for all urban agglomerations with 300,000 residents or more as of 2018 – a total of 1860 cities in 153 countries.

Data on major earthquake events from 1973 to 2017, including data on earthquake characteristics, come from the U.S. Geological Survey.[18] Prior to 1973, earthquake detection technology precluded reliable estimates of earthquake magnitude, and such is still the case for weaker earthquakes (Bentzen, 2019). The final sample has almost 8000 5+ magnitude earthquakes occurring within 100 km of major city centers and 700 striking within 25 km. The full sample is plotted against the sample of cities in Figure 3.

Data on earthquake risk come from UNEP/GRID-Geneva (2015), which maps all parts of the world with at least a 10% probability of experiencing an earthquake with a Modified

[18]This database can be accessed at https://earthquake.usgs.gov/earthquakes/search.

Mercalli intensity (MMI) greater than V (i.e. moderate strength) within the next 50 years, where MMI measures the effect of an earthquake at the surface.[19] I consider a city as being located in an earthquake risk area if such areas are within 50 km of its centroid. Under this definition, 895 or about half of cities in the sample are assigned to earthquake risk areas.

To measure formal institutions, I use Polity IV's (2019) POLITY index, which ranges from -10 to 10. By their definition, a democracy is a country with a score of 6 or greater. The advantage to using the POLITY index is that it consists of a long panel covering many years and countries. Only three cities in the full sample are not covered by POLITY. One concern, however, is that it provides a poor measure of institutions, in part because it reflects contemporaneous political outcomes in addition to relatively "deep" institutional attributes (Glaeser et al, 2004). To deal with this concern, I develop a time-invariant indicator of institutions, in which a city is considered to be in a "stable democracy" if it has consistently been in a democracy under POLITY's definition for the entire sample period. To the extent that stable democracies tend to have stronger institutions than autocracies as well as relatively unstable regimes (e.g. new or backsliding democracies), this should proxy for the deeper institutional qualities with which the theory concerns itself.[20]

In secondary specifications, I also interact the treatment with a time-invariant indicator of a city's income level: its country's income classification in 1990, midway through the sample, as determined by the World Bank in their World Development Indicators (2019) catalog.[21] Countries with gross national income per capita below $2465 USD in 1990 are considered low or lower-middle income, with the remainder of countries being upper-middle or high income. I refer to cities in these two groups as low and high income, respectively.

3.2 Estimation

To estimate the immediate (i.e. following year) and longer-run impact of strong earthquakes on city population growth, I adopt a distributed-lag approach that controls for a finite number of lags on the explanatory variable (Dell, Jones, and Olken, 2012), using panel

[19] The four levels are >V, >VII, >VIII, and >IX. See Figure A.2 in the Supplemental Material for a heatmap of these areas, with darker orange corresponding to higher MMI scores with at least a 10% probability of being exceeded, recreated using raster data available at https://preview.grid.unep.ch.

[20] A few countries in the sample were colonial territories (Angola, Djibouti, Guinea-Bissau, Mozambique, and Papua New Guinea) in the first few years of the sample and lack POLITY scores in those years. Similarly, since Berlin was divided until the end of the Cold War, it only enters the POLITY sample upon German reunification. I consider all of such cases as having experienced democracy and nondemocracy at various times and code them as zeroes. I also derive alternative institutional measures using both POLITY and the World Governance Indicators (2020) rule of law and control of corruption indices, which I discuss below.

[21] See http://databank.worldbank.org/data/download/site-content/oghist.xls for these data.

Table 1: Summary Statistics, Subgroups

Subsample	% City growth	Earthquake_{t-1}	Earthquake risk area	Stable democracy
Full sample	3.418	0.008	0.481	0.291
N= 83700	(3.265)	(0.091)	(0.500)	(0.454)
$\text{Earthquake}_{t-1} = 1$	2.867	–	0.969	0.283
N= 700	(2.287)		(0.175)	(0.451)
$\text{Earthquake}_{t-1} = 0$	3.423	–	0.477	0.291
N= 83000	(3.271)		(0.499)	(0.454)
Earthquake risk area = 1	3.403	0.017	–	0.287
N= 40275	(2.965)	(0.129)		(0.453)
Earthquake risk area = 0	3.432	0.001	–	0.295
N= 43425	(3.520)	(0.023)		(0.456)
Stable democracy	2.156	0.008	0.475	–
N= 24345	(2.391)	(0.090)	(0.499)	
Not stable democracy	3.939	0.008	0.484	–
N= 59220	(3.432)	(0.092)	(0.500)	

Notes: Standard deviations in parentheses. For a complete list of summary statistics, see Table A.1 in the Supplemental Material. For map representations, see Figure A.3.

regressions of the following form:

$$\Delta Pop_{it} = \sum_{s=1}^{L} \gamma_s Quake_{i,t-s} + \theta_i + \mathbb{Y}_t + \varepsilon_{it}, \tag{9}$$

where ΔPop_{it} is a city's rate of population growth between year $t-1$ and year t; $Quake_{i,t-s}$ is a dummy equal to one if an earthquake of 5+ magnitude on the Richter scale struck within 25 km of a city centroid in year $t-s$ for $s = 1, 2, ...$ up to some fixed number of lags L; θ_i are city fixed effects; and $\mathbb{Y}_t$ are year fixed effects, interacted separately with a national income level dummy and a time-invariant earthquake risk dummy in main specifications.[22] Regressions are robust to including various controls and interactions, as discussed below. Errors ε_{it} are assumed to be spatially correlated beyond the city level (Conley, 2004; Hsiang, 2010). For main specifications, I use a distance cutoff of 300 km.[23] Results are robust to using alternative cutoffs as well as to clustering at the city or country level.

Spatial correlations in the frequency of earthquake activity may also give rise to heterogeneous effects.[24] In particular, cities in areas regularly at risk of experiencing earthquakes

[22]Following comments received on previous drafts, all main specifications are now pooled and feature year fixed effects with these interactions. Alternative specifications using institutions, region, and other interactions continue to be featured in the Supplemental Material, in Table A.5, as discussed below.

[23]This is based on the fact that contemporaneous treatment assignment may span such a radius, e.g. following tectonic structures spanning multiple cities (Tosi et al, 2008; Abadie et al, 2017).

[24]Of the 153 countries in the sample, only 64 (and only 13.7% of cities) experienced any major earthquake at all, yet among those 64, 40 saw more than one strike within 25 km of a major city between 1973 and 2017. Meanwhile, all years experienced such earthquakes, with a median of 15 per year, a mean of 15.6, and a standard deviation of 4.6 across years. This is consistent with Tosi et al (2008), who show that while the distribution of seismicity across time is random at a global level, some areas are more prone to activity than

are likely to be different in relevant ways from those that do not. For instance, they may be more prepared to deal with an earthquake, with better infrastructure or more funds allocated toward post-earthquake recovery, which could attenuate effects (Neumayer, Plumper, and Barthel, 2014). Since I am interested in the effects of exogenous and unexpected shocks to city size, I also estimate regressions with a time-invariant earthquake risk dummy, which I interact with $Quake_{i,t-s}$ for all s. This estimates separately the effects of an earthquake on relative city growth in high-risk areas and in cities where it constitutes a relatively truer shock.

3.3 Results

Table 2 examines the effect of earthquakes on city population growth, first without interactions or lags. Columns (1) show that a one-off earthquake of 5+ magnitude is associated with about a 0.1 percentage point decrease in a city's rate of population growth the following year. While this estimate is statistically significant, it lacks economic significance. Introducing lags in columns (2) sees this immediate effect estimated to be smaller still, reflecting autocorrelation among lags.[25] Then, in the years following an earthquake, dynamic effects trend toward zero. Hence, when one utilizes the full sample of cities without differentiating among them, the effect of a large, one-time earthquake shock on relative city growth appears to be temporary and small at best.

The remainder of Table 2 accounts for a city's time-invariant earthquake risk, estimating the effects of earthquakes in high- and low-risk cities separately. Evaluating effects in cities that historically experience few earthquakes, in which they are arguably more likely to serve as an exogenous shock to city size, columns (3) reveal effects to be driven by these, with this coefficient being much larger at about -1.1 (.37) pp. Moreover, when I introduce lags here, a different trend emerges from before: the years following a one-off earthquake see persistent if not increasing population growth decline, suggestive of a circular feedback process ongoing in these cities as their relative sizes move to new equilibria.[26] This trend persists if I add additional lags, as shown in Table A.2 in the Supplemental Material.[27] In contrast, summing baseline and interaction coefficients reveals high-risk cities hardly respond at all, exhibiting swift convergence back to pre-earthquake population levels with little cumulative effect,

others over the long-run (i.e. those near tectonic structures).

[25] Hsiang and Jina (2014) discuss tradeoffs when choosing lags. Too few will bias estimates if omitted lags are correlated with included ones, while adding lags will reduce bias but increase standard errors.

[26] Another reason for relatively small instantaneous effects is that any interpolation used to derive population counts between official reports would have averaged pre- and post-earthquake counts. Hence, measured effects may be largely capturing cases in which there *was* persistence (enough to be measurable years later).

[27] This finding mirrors Ager et al (2019), who find persistent changes to the spatial distribution of economic activity in the American West following the 1906 San Francisco Earthquake.

Table 2: Effects of earthquakes on relative city growth

	Annual city population growth$_t$ (%)			
	No lags		3 lags	
	(1a)	(1b)	(2a)	(2b)
Earthquake$_{t-1}$	-.124 (.070)*	-.124 (.070)*	-.099 (.071)	-.099 (.071)
Earthquake$_{t-2}$	–	–	-.072 (.066)	-.072 (.068)
Earthquake$_{t-3}$	–	–	-.051 (.070)	-.051 (.071)
Earthquake$_{t-4}$	–	–	-.029 (.071)	-.029 (.072)
Cumulative effect	–	–	-.251 (.139)*	-.251 (.144)*
Adj. R^2	.134	.134	.146	.146
	With earthquake risk area dummy interaction			
	(3a)	(3b)	(4a)	(4b)
Earthquake$_{t-1}$	-1.147 (.371)***	-1.147 (.370)***	-.521 (.166)***	-.521 (.168)***
Earthquake$_{t-2}$	–	–	-.579 (.145)***	-.579 (.149)***
Earthquake$_{t-3}$	–	–	-.885 (.267)***	-.885 (.267)***
Earthquake$_{t-4}$	–	–	-1.075 (.365)***	-1.075 (.364)***
Cumulative effect	–	–	-3.060 (.608)***	-3.060 (.606)***
Earthquake$_{t-1}$×Earthquake risk	1.060 (.377)***	1.060 (.377)***	.434 (.181)**	.434 (.183)**
Earthquake$_{t-2}$×Earthquake risk	–	–	.519 (.160)***	.519 (.164)***
Earthquake$_{t-3}$×Earthquake risk	–	–	.864 (.276)***	.864 (.277)***
Earthquake$_{t-4}$×Earthquake risk	–	–	1.084 (.372)***	1.084 (.371)***
Cum. interaction×Earthquake risk	–	–	2.900 (.624)***	2.900 (.624)***
Adj. R^2	.134	.134	.146	.146
Observations	83700	83700	78120	78120
Conley S.E. cutoff	100 km	300 km	100 km	300 km

Notes: Standard errors are robust to spatial correlation up to the distance specified, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. Baseline effects in the second set of results represent effects in low-risk cities. Interaction estimates represent the *difference* between effects in low- and high-risk cities.

Table 3: Short-run effects of earthquakes by institutions

	(1)	(2)	(3)	(4)
Earthquake$_{t-1}$	-1.147 (.370)***	-1.484 (.468)***	-1.356 (.432)***	-.870 (.285)***
Earthquake$_{t-1}$×Stable democracy	–	1.096 (.511)**	1.160 (.492)**	1.403 (.548)***
Earthquake$_{t-1}$×Earthquake risk	1.060 (.377)***	1.396 (.475)***	1.301 (.439)***	.807 (.297)***
Earthquake$_{t-1}$×Stable democracy×Risk	–	-1.093 (.535)**	-1.010 (.501)**	-1.288 (.571)**
Earthquake$_{t-1}$×Income level	–	–	-.275 (.169)	-1.326 (.572)**
Earthquake$_{t-1}$×Income×Risk	–	–	–	1.116 (.598)*
Adj. R^2	.134	.134	.134	.134
Observations	83700	83565	83565	83565
Income level interaction?	No	No	Yes	Yes
Income×risk interaction?	No	No	No	Yes

Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. "Income level" is a dummy that equals 1 if the country in which a city resides was classified as high or upper-middle income in 1990. Baseline effects represent effects with dummies set to 0.

suggesting greater preparedness in such places re-coordinating activity post-quake.

The second exercise I perform with the data seeks to test the model's key prediction: that the relative amount of economic activity will be less robust to shocks in places with weaker or more extractive institutions. If the logic of the model is correct, one would expect the effects of earthquakes on relative city size to be driven disproportionately by the cities located outside of stable democracies, in autocracies as well as relatively unstable regimes.

The estimates in Tables 3 and 4 suggest this to be the case. Looking first at short-run effects, columns (2-4) in Table 3 show negative and statistically significant effects for such cities after accounting for earthquake risk. In particular, estimates show an initial decrease in annual city population growth of about 0.9-1.5 pp associated with a nearby earthquake for low-risk cities outside of stable democracies, with positive and statistically significant interaction coefficients for cities in stable democracies, suggesting overall effects are being driven by the former.

Similar patterns are observed upon the inclusion of lags, as shown in Table 4. After accounting for earthquake risk, long-run effects mirror those in Table 2 for cities not located in stable democracies, with negative and increasing effects over time for a four-year cumulative effect of -2.5 to -3.7 pp, mirroring the findings in Barone and Mocetti (2014) on a global scale. In contrast, interaction coefficients again cancel out after a few years for cities in

Table 4: Dynamic effects of earthquakes by institutions

	(1)	(2)	(3)	(4)
Earthquake$_{t-1}$	-.521	-.569	-.517	-.547
	(.168)***	(.224)**	(.232)**	(.234)**
Earthquake$_{t-2}$	-.579	-.599	-.562	-.562
	(.149)***	(.199)***	(.205)***	(.212)***
Earthquake$_{t-3}$	-.885	-1.007	-.901	-.624
	(.267)***	(.316)***	(.273)***	(.210)***
Earthquake$_{t-4}$	-1.075	-1.492	-1.365	-.720
	(.364)***	(.438)***	(.404)***	(.220)***
Cumulative effect	-3.060	-3.667	-3.345	-2.453
	(.606)***	(.678)***	(.634)***	(.572)***
Earthquake$_{t-1}$×Stable democracy	–	.113	.219	.114
		(.308)	(.324)	(.383)
Earthquake$_{t-2}$×Stable democracy	–	.172	.313	.174
		(.289)	(.306)	(.351)
Earthquake$_{t-3}$×Stable democracy	–	.564	.619	.643
		(.383)	(.356)*	(.348)*
Earthquake$_{t-4}$×Stable democracy	–	1.324	1.340	1.602
		(.486)***	(.459)***	(.414)***
Cum. interaction×Stable democracy	–	2.172	2.491	2.533
		(.837)***	(.802)***	(.773)***
Earthquake$_{t-1}$×Earthquake risk	.434	.508	.482	.514
	(.183)**	(.239)**	(.245)**	(.250)**
Earthquake$_{t-2}$×Earthquake risk	.519	.558	.556	.557
	(.164)***	(.215)***	(.219)**	(.228)**
Earthquake$_{t-3}$×Earthquake risk	.864	.994	.919	.638
	(.277)***	(.327)***	(.283)***	(.227)***
Earthquake$_{t-4}$×Earthquake risk	1.084	1.528	1.426	.771
	(.371)***	(.446)***	(.412)***	(.236)***
Cum. interaction×Earthquake risk	2.900	3.588	3.383	2.479
	(.624)***	(.698)***	(.651)***	(.597)***
Adj. R^2	.146	.146	.146	.146
Observations	78120	77994	77994	77994
Income level interaction?	No	No	Yes	Yes
Income×risk interaction?	No	No	No	Yes

Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. "Income level" is a dummy that equals 1 if the country in which a city resides was classified as high or upper-middle income in 1990. Regressions in columns (2-4) also include three-way interactions of the treatment, "stable democracy," and "earthquake risk" for each lag s. Baseline effects thus represent effects with dummies set to 0.

stable democracies. Both annual and cumulative baseline effects for cities in and outside of stable democracies can be seen visually in Figure A.4 in the Supplemental Material.

One concern is that stable democracy is positively associated with wealth. Since reactions to earthquakes likely vary in rich versus poor countries, it is possible that controlling for national income level could account for differences associated with formal institutions above. Columns (3) and (4) in Tables 3 and 4 include this interaction alongside the institutions one. Significant interaction effects from institutions persist in all cases. Interestingly, cities in higher income countries tend to exhibit *more* negative effects, as shown in Table 3. This potentially reflects the economic ease of migration in response to negative shocks in such places, relative to cities in lower income countries.

Results are also robust to including other city-year controls. Potentially important interactions include earthquake depth and Richter magnitude as well as a city's distance from the nearest other major city. For instance, Richter magnitude and quake depth tend to increase and decrease the surface effects of earthquakes, respectively, while Bosker et al (2017) show that spatial interdependencies between cities can impact the effects of shocks. Effects with these interactions included can be found in Table A.4 in the Supplemental Material.

Another important assumption is the choice of year fixed effects. The preferred specification lets time effects vary by both national income level and earthquake risk, on the basis that such factors are likely to impact a city's population growth over time. In the Supplemental Material, I explore several alternative fixed effects assumptions, including different combinations of (i) year×income level, (ii) year×earthquake risk, (iii)year×institutions, and (iv) year×region dummies.[28] Point estimates are substantively similar across specifications while precision varies, with those that control for heterogeneity across institutions and/or income groups yielding more precise estimates. In contrast, estimates lose precision when I do not interact fixed effects or interact them only with region dummies, with little earthquake variation existing within regions, particularly outside of Asia and the Americas, and much important variation in income, institutions, and other relevant unobservables existing within each region. These estimates can be found in Table A.5.

Alternative institutions measures

Thus far, the paper has used Polity IV's (2019) POLITY index to measure institutions. Instead of using a city's country's POLITY score, however, I develop a time-invariant indicator which considers a city's entire history over the 1973-2017 period, in order to capture relatively "deep" institutional attributes rather than contemporaneous political outcomes. The POLITY index is thus ideal on the basis that it spans this entire period.

[28] Regions used are Africa, Asia, Oceania, Europe, and the Americas.

Results are robust, however, to using alternative measures of institutions. First, I use the POLITY index to construct two alternative measures of institutions. The first instead uses a cutoff POLITY score of zero to define "stable democracy," while the second allows institutions to vary over time if the state in which the city resided changed in the POLITY index (e.g. Prague resided in Czechoslovakia, a communist autocracy, through 1992, after which it resided in the Czech Republic, a parliamentary republic).[29] These results can be found in columns (1a-2b) of Table A.6 in the Supplemental Material.

The second set of alternative measures uses indices from the World Governance Indicators (2020) report, which only covers 1996 to the present. I examine two measures of institutions relevant to the model: (i) rule of law and (ii) control of corruption.[30] For each of these, I construct a measure analogous to the paper's main measure, in which a city is given a value of 1 if it is in a country that has consistently had a positive standardized score in that index through 2017. Encouragingly, the interaction effects here bear the same signs as those of the POLITY measure, though estimates tend to be smaller, with effects becoming statistically significant after 3 years. These results can be found in columns (3a-4b) of Table A.6.

Event-study specification and pre-trends

Although a distributed-lag model is commonly used to study the effects of phenomena with multiple or repeated events as in this paper (Hsiang and Jina, 2014; Dell, Jones, and Olken, 2012; Cerra and Saxena, 2008), an alternative approach would be to adopt an event-study difference-in-differences design, in which event time is defined around earthquake years. This would enable estimation of pre-trends leading up earthquake shocks as further evidence of their exogeneity. Yet it may also produce biased estimates if cities have multiple earthquakes in close proximity, each with its own effect and with pre- and post-treatment effects overlapping.

I mitigate this latter concern by estimating the dynamic treatment effects of the *first* earthquake in each treated city's *observation window* spanning 1973 to 2017. To further reduce bias from earthquakes immediately preceding the observation window, which could generate the appearance of pre-trends, I limit the *effect window* to three relatively balanced

[29] Relatedly, when I split the sample of cities not in stable democracies into those in stable nondemocracies (POLITY<6 for all years) and those in neither stable democracies nor stable nondemocracies (i.e. unstable polities), the same patterns persist in both samples, as shown in Tables A.7. To the extent that effects reflect the importance of formal institutions, this affirms the presumption that transitioning and young democracies do not necessarily have strong underlying deep institutional qualities. However, due to limited observations as subgroups increase, I do not emphasize these estimates.

[30] While rule of law pertains to important dimensions such as the protection of property rights, corruption is a key "unproductive" activity that comes up repeatedly not only in the earthquake case studies below but in prior research on earthquake effects (Ambraseys and Bilham, 2011; Barone and Mocetti, 2014).

pre-periods (including the omitted period), before which $< 80\%$ of treated cities have observable pre-periods. Similarly, as post-earthquake periods are increasingly likely to estimate the effects of subsequent earthquakes, I limit post-periods to four, as in the distributed-lag model. Lastly, such factors are less likely to be problematic upon considering cities outside of earthquake risk areas. The event-study framework thus estimates the following:

$$\Delta Pop_{it} = \sum_{s=-2}^{-1} \gamma_s FirstQuake_{i,t-s} + \sum_{s=1}^{4} \gamma_s FirstQuake_{i,t-s} + \theta_i + \mathbb{Y}_t + \varepsilon_{it},$$

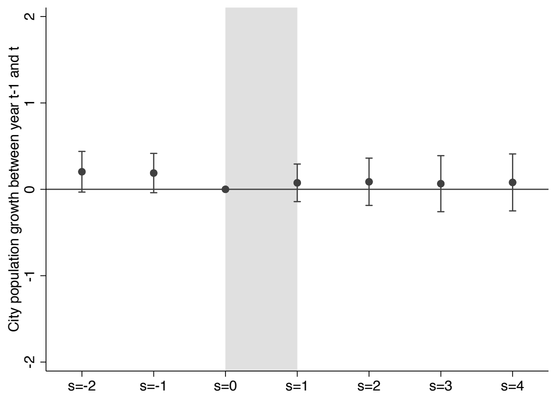
where $s = 0$, the year in which the earthquake occurred, is the omitted period (i.e. $\gamma_0 = 0$ imposed), to which effects for all fully post-treatment years $\gamma_{s>0}$ as well as pre-trends $\gamma_{s<0}$ are relative. Remaining observations outside the effect window are binned, serving as additional controls in the estimation of dynamic effects alongside never-treated observations. As in the distributed-lag model, I let time effects vary by national income level and earthquake risk.

I plot event-study estimates from three variants of this model. The first analyzes overall effects (Figure 4, top left); a second accounts for earthquake risk (Figure 4, top right); and a third lets effects vary by institutions (Figure 4, bottom row). Estimated pre-trends lack statistical significance in all cases, though one might argue subtle trends exist between $s = -1$ and $s = 0$. This likely reflects the fact that population effects may occasionally occur in the omitted year, i.e. if the earthquake happened quite early in the year. Post-treatment effects are similar to distributed-lag estimates using the full set of quakes, with only cities outside stable democracies exhibiting persistent negative effects.

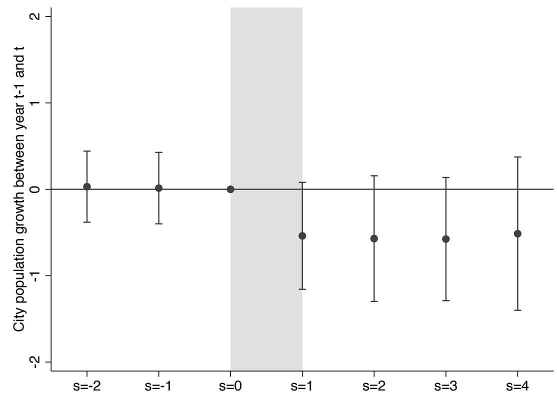
Agglomeration economies

A secondary prediction of the model is that agglomeration spillovers remain a necessary condition for a population shock to have persistent effects, regardless of institutions (see Remark 2). This has implications for local economies dominated by sectors such as agriculture that are not generally associated with external economies of scale – that is, one would not expect effects to persist in such economies. Although this section examines cities, on the basis that their existence is generated associated with agglomeration economies (Glaeser and Gottlieb, 2009; Bleakley and Lin, 2012), the extent to which such spillovers matter for effects has thus far been taken for granted in the empirical analysis. Unfortunately, there are no measures of agglomeration economies across cities with which to match the dataset. Data do exist, however, which can roughly capture the extent to which such incentives to agglomerate are present *in the country* in which each city is located. I derive two such measures.

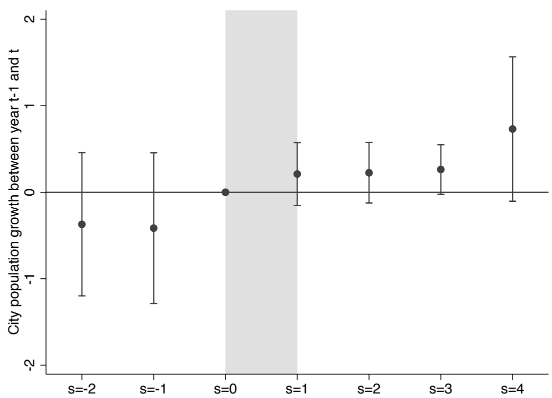
The first is an indicator of whether a country is relatively agricultural (i.e. above the



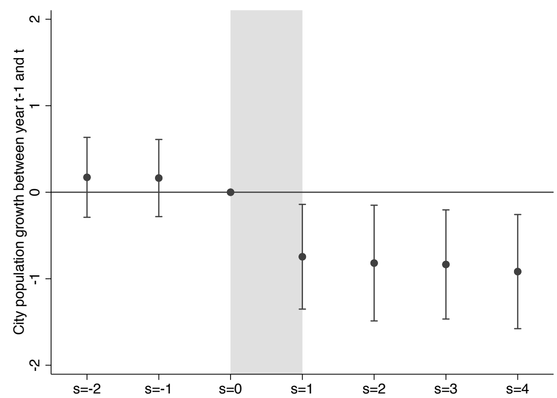
(a) Overall effects



(b) Effects in low-risk areas



(c) Low-risk, stable democracies



(d) Low-risk, outside stable democracies

Figure 4: Event-study plots for treated cities' first-observed major earthquake

Notes: Coefficient plots from event-study difference-in-differences regressions of annual city population growth on an indicator of the first-observable major earthquake in a city (interacted with event time fixed effects) as well as city, year×income level, and year×earthquake risk fixed effects. The gray shaded area roughly indicates the time frame within which earthquakes occur. Bands represent 95% confidence intervals.

sample average) in its workforce. If an economy is highly agricultural, incentives to agglomerate will be relatively small, as there are arguably few benefits to scale when it comes to agricultural production relative to the costs of congestion. Indeed, the spatial distribution of agricultural activity tends to be dispersed. Hence, if externalities from agglomeration matter, one would expect this indicator to decrease the effects of a negative shock over time. The second is an indicator of whether a country is relatively urban in where its population lives. Whereas a highly urban country is likely to have most of its economic activity concentrated, a totally rural country has all of its activity spread out across space, consistent with a lack of agglomeration economies. Hence, one would expect this indicator to have the opposite sign as the first one, increasing the effects of a negative shock over time. The results, in Table A.9 in the Supplemental Material, are consistent with these predictions, with effects disappearing after three periods for cities in agricultural and rural countries and otherwise continuing to grow. This suggests the persistence of effects here are indeed rooted in the presence of externalities from the agglomeration of activity, as opposed to simply following a random walk a la Gabaix (1999).

3.4 Discussion

Though interaction effects from measures of institutions corroborate the theory presented above, it remains to be seen whether the effects observed here are indeed rooted in shifts toward unproductive behavior in the aftermath of earthquakes – such as corruption in the local public sector or property crime in the absence of strong enforcement, which in turn prolong the effects of the initial shock – or other unobservable factors associated with institutions.

Some qualitative support for this mechanism can be found by examining notable major earthquakes in recent history. In this section, I analyze four such events: (i) the January 2010 earthquake near Port-au-Prince, Haiti; (ii) the May 2008 earthquake in Sichuan, China, outside of Chengdu; (iii) the February 2010 earthquake north of Concepción, Chile; and (iv) the March 2011 earthquake off the coast of Sendai, Japan. I choose to focus on these earthquakes as each generated significant (negative or positive) analysis among the press, highlighting the different local political and economic responses that followed them. Underlying these differences, I will argue, is significant variation in the institutional qualities of the countries in which each took place (e.g. in the rule of law, control of corruption, etc.), while the importance of such differences is evident in the economic dynamics that followed.

2010 Haiti earthquake

On January 12, 2010, a magnitude 7.0 earthquake struck about 25 km outside of Port-au-Prince, Haiti. Though the island has a history of destructive earthquakes, this earthquake was particularly shallow and, given its close proximity to a major urban area of nearly 3 million people, severe damage was unavoidable (Hou and Shi, 2011).

Aftermath. At the time of the earthquake, Haiti was one of the poorest and least developed countries in the world, leaving it vulnerable to higher death tolls and destruction. In the end, upwards of 316,000 died in the quake, alongside 300,000 injured and 1.5 million displaced, with somewhere between 1.5 and 4.5 million affected in total. Estimates of direct economic loss range from 7.8-13.9 billion USD (Hou and Shi, 2011; Assessing Progress in Haiti Act, 2014). Given this, the Haitian government relied heavily on international support for relief and reconstruction, with about $13.5 billion donated or pledged from foreign governments and private charities in total (Assessing Progress in Haiti Act, 2014).

Beyond poverty, however, the depth of the crisis can also be attributed to a "lack of social structures [and] weak political system that lacks both efficiency and legitimacy" (Hou and Shi, 2011, 28), with weak institutions giving rise to corrupt and unproductive uses of resources and recovery funds. Government teams were mobilized slowly and in low numbers, with bodies and debris remaining in the streets for days after the quake. Police responses were also limited; of the 6000 police directed to Port-au-Prince after the quake, just over half actually arrived. Nor were police efficacious in bringing calm; days after the earthquake, police opened fire on rioters and looters who had emerged in the quake's aftermath (Hou and Shi, 2011). And in the years since, large amounts of aid have gone unallocated to affected communities. Beyond corrupt uses of funds by local officials, an NPR (2015) report documents how a lack of trust in the local use of funds led to a reliance on outside contractors, slowing dispersal and inflating costs.

Effects. Haiti continues to experience direct and indirect effects of the earthquake today. Thousands remained displaced, living in "makeshift camps, with no power or running water," according to one Al Jazeera report (2020). Haitian refugees also continue to flow into nearby countries, such as Brazil as well as Ecuador and Peru (Miura, 2014; Fagen, 2013). And population growth in Port-au-Prince seems to have slowed indefinitely. In the WUP data, Port-au-Prince enjoyed population growth of just over 5% annually in the decade leading up to the earthquake. After 2010, which saw the city lose 19% of its population, its growth rate has remained around 2.6% – a nearly 50% decline from pre-quake trends.

2008 Sichuan earthquake

In May of 2008, an earthquake of Richter magnitude 8.0 hit the Wenchuan area of Sichuan, China (Zifa, 2008). Its epicenter was about 80 km from Sichuan's largest city and provincial capital of Chengdu, which had a population of about 14 million in 2010, with the next largest cities in the province located further away. Importantly, an earthquake of this size was unexpected and buildings in the area generally had relatively low seismic resistance.

Aftermath. The impact of the quake was immediately felt. Though estimates suggest 68-88,000 died in the earthquake, hundreds of millions were affected in the form of displacements, property damage, etc. (Yang et al, 2014). In terms of economic losses, initial estimates of direct property losses ranged from 98-500 billion RMB (the equivalent of 14-70 billion 2020 USD), making it one of the more destructive earthquakes in modern history (Zifa, 2008).

Other consequences were less direct. Several scandals unfolded in the wake of the quake, most notably in the construction and public sectors. Although 3800 new schools and housing for 1.9 million households were constructed in the aftermath, an NPR (2013) investigation found that many of the new builds did not meet the new earthquake standards required by law, with "cracks [appearing] before any major tremors." Other corners were cut as well, in the form of unpaid worker salaries and projects finished months ahead of schedule. Coinciding with this was the illegal use of at least $228 million in reconstruction funds, with one low-level official being charged with $1.7 million in bribery. A report by the South China Morning Post (2018) documents how reconstruction budgets were inflated, costs over-reported, and billions of yuan embezzled via repeated filings for relief aid by local bureaus.

Effects. The effects of the Sichuan earthquake were highly regional, with changes in the distribution of economic activity occurring within the province of Sichuan thereafter. Although the earthquake's epicenter was about 80 km northwest of Chengdu, affected populations resided disproportionately around Chengdu and in areas to its east (Jia et al, 2018). The same areas saw significant population decline between 2005 and 2012, as high as 5% in some counties, with less affected counties continuing to see significant population growth over the same period (Yang, Han, and Song, 2014). In Chengdu itself, population growth in the WUP data sees slowdown beginning in 2010, with more in the following years. Whereas population growth in Chengdu had been just over 5% prior to the earthquake, by 2012 it was about 1.8%, around which it has remained since, a trend I do not observe in other Sichuan cities.

2010 Chile earthquake

Not all major earthquakes are associated with criminal or corrupt activity in their aftermaths. One such counterexample is the 2010 Chile earthquake, which was felt most strongly in the city of Concepción, about 100 km to the south of the quake's epicenter. Occurring just one month after the Port-au-Prince earthquake, Chile's quake was 8.8 in magnitude and felt throughout the country (Hombrados, 2020).

Aftermath. Despite destructive beginnings, with economic damages of about 15-30 billion USD, Chile's government was praised in the press for its disaster response, and only 547 fatalities were reported (Hombrados, 2020). News coverage in TIME (2010) and Brookings (2010) compared the conditions that followed favorably to those in Port-au-Prince, noting the swift allocation of government resources and an absence of corruption in the country's construction and public sectors, as evidenced by strong enforcement of building codes. Another article by Warren (2010) likewise lauded Chile's aid response but criticized its ability to protect property rights and restore public order in face of post-quake vandalism and looting. However, this narrative is empirically questioned by Hombrados (2020), who finds that the incidence of property crime actually *decreased* in areas exposed to more intense tremors, driven by strong community-based crime-prevention mechanisms.

Effects. Although Chile frequently experiences earthquakes and is infrastructurally prepared for such disasters, the effects of this particular earthquake – which at a magnitude of 8.8 was about 500 times more powerful than the one in Port-au-Prince – are not *a priori* clear. As it turns out, population growth in Concepción as well as all other major Chilean agglomerations is remarkably stable in the WUP data in the years following the earthquake, relative to pre-quake trends.

2011 Sendai earthquake

The 9.0 magnitude earthquake that struck off the coast of Sendai, Japan in March 2011 generated similar commentary in the press. That earthquake, which also produced extensive tsunamis, was declared the "toughest and the most difficult crisis for Japan" since WWII by the prime minister and, like the Port-au-Prince quake, affected the entire main island (Clark and Heath, 2014).

Aftermath. Though much of Japan is earthquake prone, the earthquake's magnitude and subsequent tsunamis made it highly destructive, killing over 15,000 across 20 prefectures and damaging over a million buildings,[31] with economic damages of up to $235 billion (Kim, 2011). Despite such initial destruction, however, press reports mirrored the positive response that had followed the Chile earthquake the previous year. One Brookings (2011) report argued that Japan's strict enforcement of building codes, its strong control of corruption, and low property crime in the aftermath of the disaster favored a quick local recovery, while criticizing the government's response to the nuclear accidents that followed the disaster. An NPR (2011) report similarly pointed to strong enforcement of building codes by officials and a corresponding lack of corruption and bribery in the construction sector as being key to Japan's recovery relative to Haiti's and Sichuan's, with Japan and Chile both emerging with far fewer deaths despite suffering far more severe quakes.

Effects. As with Chile's earthquake a year prior, the effects of the Sendai disaster appear to have had little impact on the spatial distribution of economic activity within Japan or population growth in affected areas. In Sendai, the largest major city in close proximity to

[31] Statistics are made available by the National Police Agency of Japan at https://www.npa.go.jp/news/other/earthquake2011/pdf/higaijokyo e.pdf.

the quake, the WUP data actually sees population growth go from about -1.1% annually in the years leading up to the quake, to about 0.8% annually afterward.

4 Conclusion

Why do some shocks to local development permanently impact the spatial distribution of economic activity, while others do not? This paper considers the role of formal institutions in explaining these differential effects. In the model, extractive institutions decrease the return on productive relative to unproductive activities. In the presence of increasing returns to productive activity within regions, a sufficiently large, negative shock to one region's labor force can serve as a tipping point, inducing its workers to substitute into unproductive activities. Thereafter, new migrants will also prefer to engage in unproductive activities, resulting in regional asymmetries in population and production levels over the long-run. This suggests that extractive institutions may magnify the importance of increasing returns for long-run local development, while long-run equilibria may be more robust to large negative shocks where there are strong institutions to help coordinate the reemergence of production. An empirical examination into the effects of large earthquakes on population growth in major world cities finds suggestive evidence for these predictions.

I conclude with a few remarks. First, it is important to note that the choice between productive and unproductive activity is, in reality, not binary. Rather, the prevalence of the latter will depend on its relative return as determined by the institutional environment (i.e. β). As institutions improve, it seems likely that even unproductive regions would become more developed. Nor is this stylized model sufficient to explain all differences in development observed within countries. A richer model is needed to capture the nuanced interactions between institutions, agglomeration spillovers, natural geography, infrastructure, etc. That being said, this model illustrates in simple terms how formal institutions can influence the importance of increasing returns in the face of large shocks. In particular, it suggests that spatial equilibria may be more subject to influence by negative shocks in places and times in which institutions are weak, becoming more robust as they improve.

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Proof of Proposition 1

Proof. Suppose

$$V_r(h) = V_r(u) \Leftrightarrow a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma} = \frac{K}{\beta M_r}, \tag{10}$$

where $m_r \leq M_r$ gives the prevalence of productive worker activity in region r. Hence, any arbitrarily small positive perturbation to m_r will induce

$$a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma} > \frac{K}{\beta M_r}, \tag{11}$$

such that the remainder of workers in region r also shift to production iteratively until the total share of workers in r are all engaged in production and $m_r = M_r \equiv m_r^*$. I define the m_r that solves (10) to be:

$$\widehat{m_r} \equiv \left(\frac{\lambda}{\beta a_r h^{1+\gamma}} \right)^{\frac{1}{\gamma}},$$

above which all workers in region r prefer to specialize in production over unproductive activities.

Because $M_r \geq m_r$ by definition, it follows that $M_r \geq \widehat{m_r}$ must hold for this equilibrium to be feasible. If instead $\widehat{m_r} > M_r$, then $\widehat{m_r} > m_r$ always. □

Proof of Remark 1

Proof. In a HPSE, $m_r^* = M_r$, and

$$a_r \frac{K}{\lambda M_r} h^{1+\gamma} M_r^{\gamma} \geq \frac{K}{\beta M_r}.$$

Suppose $\gamma = 0$. Then this condition becomes $\beta a_r h \geq \lambda$, which is invariant to M_r. Hence, when $\gamma = 0$, if a HPSE exists in region r for some population share M_r, then it also exists for all M_r'. □

Proof of Proposition 2

Proof. Let $\gamma \in (0, 1)$. Suppose $M_r > \widehat{m_r}$ and $m_r^* = M_r$ in each region r, such that there is a locally stable HPSE in each region. Then

$$\begin{aligned} \dot{M_r} &= M_r(V_r(h) - \overline{V}(h)) = M_r(1 - M_r)(V_r(h) - V_{-r}(h)) \\ &= M_r(1 - M_r)(a_r \frac{K}{\lambda} h^{1+\gamma} M_r^{\gamma-1} - a_{-r} \frac{K}{\lambda} h^{1+\gamma} M_{-r}^{\gamma-1}), \end{aligned} \tag{12}$$

where $M_{-r} = 1 - M_r$. By inspection, $V_r(h)$ is strictly decreasing in M_r for all M_r, while $V_{-r}(h)$ is strictly increasing in M_r for all M_r. Furthermore, $\lim_{M_r \to 0} V_r(h) = \infty$ and $\lim_{M_r \to 0} V_{-r}(h) = a_{-r}\frac{K}{\lambda}h^{1+\gamma}$, while $\lim_{M_r \to 1} V_r(h) = a_r\frac{K}{\lambda}h^{1+\gamma}$ and $\lim_{M_r \to 1} V_{-r}(h) = \infty$. Hence, $\dot{M}_r = 0$ if $V_r(h) = V_{-r}(h)$, where $V_r(h) = V_{-r}(h)$ if and only if

$$M_r = \frac{a_r^{\frac{1}{1-\gamma}}}{a_r^{\frac{1}{1-\gamma}} + a_{-r}^{\frac{1}{1-\gamma}}} \equiv M_r^* \in (0,1)$$

for regions r and $-r \neq r$, and $\frac{\partial \dot{M}_r}{\partial M_r}|_{M_r = M_r^*} < 0$. Hence, if $m_r^* = M_r$ and $M_r^* > \widehat{m_r}$ in each region r, then there is a locally stable HPLE, with a unique interior steady state population $M_r^* \in (0,1)$ when $\gamma \in (0,1)$.

(ii) Suppose there is a sufficiently large negative population shock in one region, say 2 (without loss of generality), such that (11) no longer holds and $m_2^* = 0$. However, suppose $M_1 > \widehat{m_1}$ and $m_1^* = M_1$ still. Then

$$\dot{M}_1 = M_1(1 - M_1)(V_1(h) - V_2(u)) = M_1(1 - M_1)\left(a_1\frac{K}{\lambda}h^{1+\gamma}M_1^{\gamma-1} - \frac{K}{\beta(1 - M_1)}\right). \quad (13)$$

By inspection, $V_1(h)$ is strictly decreasing in M_1 for all M_1, while $V_2(u)$ is strictly increasing in M_2 for all M_2. Furthermore, $\lim_{M_1 \to 0} V_1(h) = \infty$ and $\lim_{M_1 \to 0} V_2(u) = K/\beta$, while $\lim_{M_1 \to 1} V_1(h) = a_1\frac{K}{\lambda}h^{1+\gamma}$ and $\lim_{M_1 \to 1} V_2(u) = \infty$. Hence, $\dot{M}_1 = 0$ if $V_1(h) = V_2(u)$; $V_1(h) = V_2(u)$ for a unique $M_1 \equiv M_1^{**} \in (0,1)$; and $\frac{\partial \dot{M}_r}{\partial M_1}|_{M_r = M_1^{**}} < 0$. Hence, if $m_1^* = M_1$, $m_2^* = 0$, and $M_1^{**} > \widehat{m_1}$, then there is a locally stable ALE, with a unique interior steady state $M_1^{**} \in (0,1)$ when $\gamma \in (0,1)$.[32]

Next, it is straightforward to show that the steady state population share in a productive (unproductive) region will be greater (lower) in a ALE than in a HPLE: $M_1^{**} > M_1^*$ and $M_2^{**} < M_2^*$.

Suppose to the contrary that $M_1^{**} \leq M_1^*$. When $M_1 = M_1^*$,

$$a_1\frac{K}{\lambda}h^{1+\gamma}M_1^{*\gamma-1} = a_2\frac{K}{\lambda}h^{1+\gamma}(1 - M_1^*)^{\gamma-1}. \quad (14)$$

If $M_1^{**} \leq M_1^*$, then when $M_1 = M_1^*$ holding all else fixed,

$$a_1\frac{K}{\lambda}h^{1+\gamma}M_1^{*\gamma-1} \leq \frac{K}{\beta(1 - M_1^*)} \Leftrightarrow \dot{M}_1 < 0. \quad (15)$$

[32]Note that a black hole equilibrium in which M_1 goes to 1 does not exist here, since the limit of $\dot{M}_1$ as M_1 goes to 1 is $-K/\beta$.

Together (14) and (15) imply that when $M_1 = M_1^*$, if $M_1^{**} \leq M_1^*$ then

$$a_2 \frac{K}{\lambda} h^{1+\gamma}(1 - M_1^*)^{\gamma-1} \leq \frac{K}{\beta(1 - M_1^*)} \Leftrightarrow M_2^* \leq \widehat{m_2}.$$

However, by Definition 3, $M_r^* > \widehat{m_r}$ for all r in any locally stable HPLE. Hence, $M_1^{**} > M_1^*$ by contradiction, and $M_2^{**} = 1 - M_1^{**} < 1 - M_1^* = M_2^*$ by symmetry.

To check comparative statics for M_1^{**}, implicitly differentiate $V_1(h) - V_2(u) = 0$ with respect to each variable of interest. Doing so yields:

$$a_1 : \frac{1}{\lambda} h^{1+\gamma} M_1^{**\gamma-1} + (\gamma - 1)\frac{\partial M_1^{**}}{\partial a_1} a_1 \frac{1}{\lambda} h^{1+\gamma} M_1^{**\gamma-2} = \frac{\partial M_1^{**}}{\partial a_1} \frac{1}{\beta(1 - M_1^{**})^2},$$

$$h : (1+\gamma) a_1 \frac{1}{\lambda} h^{\gamma} M_1^{**\gamma-1} + (\gamma - 1)\frac{\partial M_1^{**}}{\partial h} a_1 \frac{1}{\lambda} h^{1+\gamma} M_1^{**\gamma-2} = \frac{\partial M_1^{**}}{\partial h} \frac{1}{\beta(1 - M_1^{**})^2},$$

$$\lambda : -a_1 \frac{1}{\lambda^2} h^{1+\gamma} M_1^{**\gamma-1} + (\gamma - 1)\frac{\partial M_1^{**}}{\partial \lambda} a_1 \frac{1}{\lambda} h^{1+\gamma} M_1^{**\gamma-2} = \frac{\partial M_1^{**}}{\partial \lambda} \frac{1}{\beta(1 - M_1^{**})^2},$$

$$\beta : (\gamma - 1)\frac{\partial M_1^{**}}{\partial \beta} a_1 \frac{1}{\lambda} h^{1+\gamma} M_1^{**\gamma-2} = -\frac{1}{\beta^2(1 - M_1^{**})} + \frac{\partial M_1^{**}}{\partial \beta} \frac{1}{\beta(1 - M_1^{**})^2},$$

which imply $\frac{\partial M_1^{**}}{\partial a_1}, \frac{\partial M_1^{**}}{\partial h}, \frac{\partial M_1^{**}}{\partial \beta} > 0$ and $\frac{\partial M_1^{**}}{\partial \lambda} < 0$ when $\gamma \in (0, 1)$. □

Proof of Remark 2

Proof. By Remark 1, population shocks cannot shift a region from one short-run equilibrium to another when $\gamma = 0$. Hence, if the steady state population distribution M_r^* is determined by (12) or (13) prior to a population shock, then all else fixed, it will also be determined by (12) or (13) after a shock, respectively, when $\gamma = 0$. □

Proof of Proposition 3

Proof. (i) Let $\gamma > 1$. Suppose $M_r > \widehat{m_r}$ and $m_r^* = M_r$ in each region r, such that there is a locally stable HPSE in each region. Then

$$\begin{aligned}\dot{M}_r = M_r(V_r(h) - \overline{V}(h)) &= M_r(1 - M_r)(V_r(h) - V_{-r}(h)) \\ &= M_r(1 - M_r)(a_r \frac{K}{\lambda} h^{1+\gamma} M_r^{\gamma-1} - a_{-r} \frac{K}{\lambda} h^{1+\gamma}(1 - M_r)^{\gamma-1}), \quad (16)\end{aligned}$$

By inspection, $\dot{M}_r = 0$ if $V_r(h) = V_{-r}(h)$, where $V_r(h) = V_{-r}(h)$ if and only if

$$M_r = \frac{a_r^{\frac{1}{1-\gamma}}}{a_r^{\frac{1}{1-\gamma}} + a_{-r}^{\frac{1}{1-\gamma}}} \equiv M_r^* \in (0,1)$$

for regions r and $-r \neq r$ for all $\gamma > 1$. Hence if $M_r > \widehat{m_r}$ and $m_r^* = M_r$ in each region r, then there is an HPLE with a unique interior steady state population $M_r^* \in (0,1)$ when $\gamma > 1$.

(ii) However, note that for $\gamma > 1$, $V_r(h)$ is strictly increasing in M_r for all M_r and $V_{-r}(h)$ is strictly decreasing in M_r for all M_r. Furthermore, $\lim_{M_r \to 0} V_r(h) = 0$ and $\lim_{M_r \to 0} V_{-r}(h) = a_{-r}\frac{K}{\lambda}h^{1+\gamma}$, while $\lim_{M_r \to 1} V_r(h) = a_r \frac{K}{\lambda} h^{1+\gamma}$ and $\lim_{M_r \to 1} V_{-r}(h) = 0$. Hence, $\frac{\partial \dot{M}_r}{\partial M_r}|_{M_r = M_r^*} > 0$, such that any HPLE is unstable when $\gamma > 1$. □