The Mortality Transition, Malthusian Dynamics, and the Rise of Poor Mega-Cities*

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Abstract: The largest cities in the world today lie mainly in relatively poor countries, which is a departure from historical experience, when the largest cities were typically found in the richest places. Using new data on the demographic history of the 100 largest mega-cities of today, we establish several new stylized facts distinguishing poor mega-cities from historically rich mega-cities. To account for these facts we develop a model that combines Malthusian models of endogenous population growth with urban models of agglomeration and congestion, and it shows that the absolute growth of the urban population determines whether a city becomes a poor or rich mega-city. We posit that poor mega-cities arose in part because the post-war mortality transition raised their absolute growth above a crucial threshold. Poor mega-cities continue to grow in size but not in living standards because their poverty keeps population growth high. By expanding prior to the mortality transition, historical mega-cities experienced smaller absolute growth that allowed them to sustain wage growth and kept population growth relatively low.

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1. INTRODUCTION

Urbanization has gone hand in hand with economic growth throughout history, and the majority of world population now lives in cities. However, post-war developing countries have urbanized in a fundamentally different manner compared to the historical experience of currently developed countries. Specifically, the post-war period has seen the rise of poor mega-cities in developing nations. Delhi, Dhaka, Karachi, Kinshasa, Lagos, and Manila are some of the very largest urban agglomerations on the planet today, each with over 10 million inhabitants. Only six of the currently largest 30 cities (London, Los Angeles, New York, Osaka, Paris, and Tokyo) today are in high income countries. The prevalence of poor mega-cities today runs counter to historical experience. In the first half of the 20th century, the very largest urban agglomerations in the world were all in the most advanced economies.

The mega-cities of today's developing world are also unlike their historical peers in that their massive size is *not* indicative of rapid economic growth. This "poor country urbanization" (Glaeser, 2013) has generated *poor* mega-cities that do not appear to be able to take advantage of the agglomeration economies of their rich-country peers (World Bank, 2009).

Our aim in this paper is to provide an explanation for the rise of these poor mega-cities, and why they differ from the historical experience of urbanization and rapid economic growth. We propose that these mega-cities grew in poverty - and tend to remain mired in poverty - because of what we characterize as urban Malthusian forces. To describe these forces, we build a model that combines the insights of Malthusian models of endogenous population growth (Ashraf & Galor, 2011; Galor & Weil, 2000) with the urban literature on equilibrium city size (Henderson, 1974; Duranton & Puga, 2004; Duranton, 2013). The Malthusian literature describes how limited resources will tend to reduce living standards as populations grows. The urban literature captures the tension between the positive effects of agglomeration economies and the negative effects of congestion to find that urban wages display an inverted-U shape with respect to city population size. For a given set of urban technologies, in a sufficiently large city the urban congestion effect dominates and generates a Malthusian relationship between city size and city living standards.

In our model the growth rate of wages depends on the urban productivity growth rate relative to the *absolute change* in the city population. A sufficiently large change in city population can produce so much additional congestion that it offsets productivity growth, leaving wages stagnant. Wage growth can be sustained in cities only if the absolute growth in city population remains below a critical level, and this leads to two possible long-run equilibrium outcomes. In the first, the absolute growth of cities is too large, and the economy ends up with poor mega-cities. They end up in a bad cycle where low wages keep city population growth high, and this keeps the absolute growth of the city so large that wages cannot grow. In contrast, the second equilibrium occurs when a city has small absolute increases in population size, what we call a historical mega-city. For these cities, low population growth allows for positive wage growth, and this in turn leads to lower population growth rates, which further accelerates wage growth. Both types of cities grow in population, but poor mega-cities grow because they are poor, and rich mega-cities grow because they are rich.

We posit that a crucial distinction between poor mega-cities and their historical counterparts is in their demographics. We collected historical data for today's largest 100 mega-cities, from antiquity to modern times, to document the differences in demographics between poor and rich mega-cities. In modern developing nations nascent mega-cities experienced extremely large absolute population growth, in large part because of the Mortality Transition of the 1940's and 1950's. The rate of urban natural increase - the urban crude birth rate minus the urban crude death rate - is well above those seen historically, and this is almost exclusively due to the severe drop in urban crude death rates following the Mortality Transition. Cities in these countries grew in absolute terms both because of in-migration from rural areas *and* significant natural increase in the cities themselves. The combination put absolute city growth above the critical threshold, and resulted in poor mega-cities.[1]

In comparison, historical cities grew prior to the Mortality Transition. The rate of urban natural increase was low in historical cities because of high death rates. Even with in-migration, the absolute growth in these city populations was relatively small and fell below the critical threshold. Hence wage growth remained positive even as the cities expanded. When significant declines in urban mortality rates did occur later in these cities, they were already rich enough that population growth rates had slowed down and they were able to sustain wage growth.

The main contribution of our paper is to explain the conditions under which these poor mega-cities will arise, and to describe what their future may look like. In addition to this, our work adds to the literature on the effects of demography on economic growth in general. Population growth promotes economic growth if high population densities encourage human capital accumulation or technological progress (Kremer, 1993; Becker, Glaeser & Murphy, 1999; Lagerlof, 2003). In the urban setting we consider, there are positive impacts of population growth due to agglomeration effects - but only over some range of population size. Population growth also induces congestion effects, which negatively affects living standards, similar to unified growth models that have a fixed resource (i.e. agricultural land) as part of the production process (Galor & Weil, 1999, 2000; Strulik & Weisdorf, 2008; Galor, 2011). Our work shows that the negative Malthusian effects need not arise because of natural resource limits, but rather due to the nature of urbanization. Significantly, this implies that Malthusian forces need not disappear as economies develop. Those forces remain operational even though

[1] Our paper is related to Jedwab, Christiaensen & Gindelsky (2014) who study the effects of urban natural increase on urbanization rates for developing countries from 1960-2010. While they focus their analysis on the growth of the urban population as a whole, we focus on the absolute growth of the largest cities of the world, across space and over time, and study how there are multiple equilibria in city size and city incomes.

agriculture and/or resource extraction cease to be significant sectors of production. The poor mega-city equilibrium is one that arises perversely because of the success of interventions that limited urban mortality rates while urban fertility remained relatively high. In this, our work is similar to others that emphasize the negative effect of mortality interventions and/or the positive impacts of mortality increases (Acemoglu & Johnson, 2007; Young, 2005).

This paper is close in subject matter to Voigtländer & Voth (2013*a*), who study the possibility of multiple equilibria based on the urbanization process in historical Europe and China, but do not consider the modern arrival of poor mega-cities in the developing world. In terms of mechanisms, they introduce a non-linearity in mortality rates tied to a threshold urbanization *rate*, and thus an exogenous shock like the Black Death allows Europe to move to a better equilibrium. In comparison, our model introduces an explicit Malthusian force in city *size*, and the equilibrium that a city ends up is not a result of an exogenous shock to city size, but a change in the growth rate of city population.[2]

While there is some work on urbanization without growth (Fay & Opal, 2000), in general there has been less attention given to poor mega-cities. See Duranton (2008), Henderson (2010), and Duranton (2013) for recent surveys of cities in developing countries that do not address the topic explicitly. In contrast, Glaeser (2013) begins with the same set of motivating facts regarding poor mega-cities, but looks at them in a different light. His paper focuses on the internal institutional structure that prevents mega-cities from reducing the overwhelming congestion effects of their size, examining the trade-off between disorder and dictatorship. His model does not consider the unique demographics leading to the origin of these mega-cities.

The origin of poor mega-cities is certainly not mono-causal, and our explanation involving Malthusian effects should be thought of as a complement to those involving changes in urban transportation and housing technologies (i.e. the ability to build out or build up), changes in preferences towards large cities, urban-biased policies, and others. Other explanations would exacerbate the effects we are discussing here, but do not rule ours out.[3]

In the following section we document more fully the rise of poor mega-cities in the developing world, and the underlying demographic features of these cities. Then, with those stylized facts in place, we present our model of urban Malthusian dynamics, showing how an economy may find itself in an equilibrium with poor mega-cities. We then compare this equilibrium to the

[2]Our work is also linked to studies that consider the effect of lower mortality on population and economic growth (Acemoglu & Johnson, 2007; Bleakley, 2007; Bleakley & Lange, 2009; Bleakley, 2010; Cutler et al., 2010) as well as those examining the effect of unexpected decreases in population on development (Young, 2005; Voigtländer & Voth, 2009; Ashraf, Weil & Wilde, 2011; Voigtländer & Voth, 2013*a*,*b*). Relative to those works we consider the implications of unexpected mortality changes from the perspective of cities and highlights that absolute changes in city populations are a crucial component of development.

[3]Notable alternatives include natural disasters (Barrios, Bertinelli & Strobl, 2006; Henderson, Storeygard & Deichmann, 2013), urban bias (Ades & Glaeser, 1995; Davis & Henderson, 2003; Henderson, 2003), and natural resource exports (Gollin, Jedwab & Vollrath, 2015; Jedwab, 2013)

situation seen in historical European development and discuss the rise of poor mega-cities in the context of our model.

2. RICH AND POOR MEGA-CITIES IN HISTORY

Table 1 shows the largest 30 cities in select years from 1700 to 2015 (Chandler, 1987; United Nations, 2014). In 1700, the largest cities were all under 1 million persons in size, with Istanbul, Tokyo, and Beijing all at around 700,000 inhabitants. While small in absolute size, the largest cities in 1700 were generally located in the most economically advanced areas of the world in that period. While London and Amsterdam had wages that were high relative to the rest of the world, cities such as Istanbul, Tokyo, and Beijing all had wages equivalent to those found in cities such as Paris and Naples (Allen, 2001; Allen et al., 2011; Özmucur & Pamuk, 2002).

By 1900, the nature of the list of largest cities changed along several dimensions. First, the absolute sizes were roughly ten times larger than in 1700. The largest city was London, with 6.5 million inhabitants, and there were 17 cities with over one million residents. Second, the cities that dominate this list were the leading cities from the richest countries. London, New York, Paris, Berlin, Chicago, Vienna, and Tokyo are all found on the list. Further down, we see Birmingham, Boston, Hamburg, Liverpool, Manchester, and Philadelphia, all centers of industrialization.

There were several large agglomerations of around 1 million in relatively poor places in 1900: Beijing, Kolkata, Mumbai, and Rio de Janeiro. But none approached the absolute size of the leaders like London or New York. Comparing 1900 to 1700, one can also see that their growth in this period was not on the same scale as the richer cities. Beijing increased only from 700,000 to 1.1 million in the same 200 years that London went from 600,000 to 6.5 million. Istanbul had 900,000 residents in 1900, up from 700,000 in 1700.

In 1950 the top cities remained those in relatively advanced nations but we see the very beginnings of mega-city growth in relatively poor countries. Kolkata and Shanghai both had more than four million inhabitants in 1950, putting them in the top 10 cities in the world in 1950. Beijing, Cairo, Mexico City, Mumbai, and Rio de Janeiro were all over 2 million inhabitants, reflecting rapid growth for most of them from earlier periods.

By 2015, the nature of the largest cities has changed dramatically. First, the absolute scale of cities is 3-5 times larger than in 1950. Second, the composition of the list is now dominated by cities in poor countries. Only Tokyo, Osaka, New York, Los Angeles, Paris, and London are in what we would term rich countries. Instead we see cities such as Delhi, Mexico City, Mumbai, and Sao Paulo. Countries that rank at the bottom in development levels have cities present on this list, such as Dhaka (Bangladesh), Manila (Philippines), Karachi (Pakistan), Lagos (Nigeria), and Kinshasa (DRC). Each of those poor cities have at least 11 million people, making them larger in absolute size than nearly every city in the world in 1950.

The shift of the largest cities in the world from rich countries to poor countries can be more easily seen in Figure 1. This plots the number of cities with more than one million inhabitants for two groups, developed countries (based on their 2013 GDP per capita) and developing countries. As can be seen, in 1700 there were no cities in either set of countries with one million inhabitants. In 1900 and 1950 nearly all of the million-plus sized cities were in currently developed nations. This switches dramatically between 1950 and 2015, however, and this reversal is projected to increase well into this century. By 2030, the UN expects there to be close to 400 one-million-resident cities in developing countries, versus only 250 in developed nations.[4]

This change in the composition of the largest cities is only going to be exacerbated in the future. The final column of Table 1 shows the projected growth rate from 2015–2030 for each mega-city. The largest values are all for poor mega-cities such as Lagos (Nigeria), Kinshasa (DRC), and Dhaka (Bangladesh). In comparison, rich mega-cities have growth rates that are close to zero (New York, Paris, London) or are negative (Osaka and Tokyo). The list of largest cities in the world will continue to be dominated by poor mega-cities in the future.[5]

3. THE CHARACTERISTICS OF POOR MEGA-CITIES

The rapid population growth of poor mega-cities is different from that experienced during earlier urbanization episodes. The poor mega-cities of today grow in large part through natural increase, in addition to in-migration. Historically, in-migration tended to be the dominant source of new city dwellers as the rates of natural increase were quite low in urban areas, typically because of very high mortality rates (Jedwab, Christiaensen & Gindelsky, 2014).

This can be seen clearly in Figure 2 where we compare the crude birth rate (CBR) and crude death rate (CDR) of cities across different historical eras. Panel A plots these rates for a collection of 14 pre-Industrial Revolution cities, such as ancient Rome, Renaissance Florence, London in the 17th century, and Delhi in the 19th century. As can be seen, the cities all lie on or below the 45-degree line, indicating that the cities experienced negative rates of natural increase. Their growth could occur only through in-migration. Those that do lie above the

[4]We find a similar pattern if we only consider agglomerations over 5 million people, or the absolute population living in mega-cities (defined either as greater than 1 million or greater than 5 million), or the proportion of population living in mega-cities (again, for either more than 1 million or more than 5 million). The patterns also hold if we exclude India and China. Please see the Web Appendix for details.

[5]Of all cities over 5 million inhabitants in 2015, the fastest projected growth rates over 2015–2030 are in Dar es Salaam (5.1%), Luanda (4.4%), and Abidjan (3.2%), which will take them into the top 30 in that time period. Please see the Web Appendix for rankings of cities by projected growth rates among the top 30 cities of 2015 or the top 100 cities of 2015.

line (Berlin in the 1810s, Beijing in the 19th century, Moscow in the 19th century) are barely above the line, and the crude rate of natural increase is very low.[6]

These data do not give a full account of the effects of major disease outbreaks. During the Black Death crude death rates of 400 were seen across European cities (Christakos et al., 2005). All the points in Panel A thus represent "normal" periods, but each city was at times afflicted by severe shocks to mortality, so that the average CDR over long periods of time was likely higher than indicated. Overall, pre-industrial cities tended to experience rates of natural increase of about zero, and grew only through in-migration.

Panel B of Figure 2 shows similar data for cities during the Industrial Revolution. Here we can see that while crude birth rates are roughly on the same level with the pre-industrial era, the crude death rate has declined slightly. There remain several cities below the 45-degree line (e.g. London in the 1750s, Amsterdam in the 1850s) but most cities now experienced some small positive rate of natural increase. These cities grew not only through in-migration, but in part through a modest increase in their own population. Note, though, that crude death rates remain high, in the range of roughly 15-40 for these cities.

If we now turn to the post-war period, and the 1960s in particular, we can see in Panel C a distinct change in city demographics. Focus first on the collection of relatively rich cities in the lower left, such as London, New York, and Paris. These cities are already very large. But their crude birth rates have fallen along with their crude death rates, and so their rate of natural increase (CBR minus CDR) remains relatively muted, similar in size to that seen during the Industrial Revolution. Overall, it is apparent from Panels A to C that historically cities were moving "down" the 45 degree line as they grew. Natural increase in these cities was never particularly large. As these places developed, the CDR and CBR drop in tandem, keeping the rate of natural increase small.

In comparison are the nascent poor mega-cities of the developing world in the upper left of Panel C, well above the 45 degree line. In the immediate post-war era these cities differed from earlier eras in one very distinct way: their crude death rates are very low. Lagos, Karachi, and Jakarta, despite having much lower levels of income per capita, all have crude death rates in the 1960s that are roughly similar to those seen in London, New York, or Paris in the same year. The crude birth rates in these cities are large, but not substantially larger than those seen in pre-industrial or industrial revolution era cities. Developing cities in the 1960s were "shifted left" in Panel C compared to their historical peers. This led to very large rates of natural increase for emerging mega-cities. For example, in the African mega-cities in the figure, crude rates of natural increase are roughly 30, or 3% per year. Absent migration, this implies that these cities double in size roughly every 20 years.

This difference continues into the more contemporary period of the 2000s, which is plotted in

[6] Data descriptions of the sources for the city-level data in this section are available in the Web Appendix.

Panel D of Figure 2. Rich mega-cities such as London, New York, and Paris remain in roughly the same position as in the 1960s, with low crude death and crude birth rates. The poor mega-cities of the developing world have also shifted down to lower crude birth rates. However, the crude death rates in these poor mega-cities are much lower than the historical comparisons, for the most part falling below 10 per thousand. Thus in the 2000s poor mega-cities continued to have extremely rapid rates of natural increase. A notable exception are Chinese cities, which in the 1960s (Panel C) looked quite similar to other developing mega-cities, but after the introduction of the one-child policy moved in the 2000s (Panel D) to a pattern of crude death and crude birth rates very similar to rich mega-cities.

The deviation of the developing countries in Panels C and D from the historical norms appears due, in large part, to what Acemoglu & Johnson (2007) refer to as the *international epidemiological transition*. Following 1940, there was a rapid improvement in health (particularly in infant mortality) in many developing countries. This was due to the availability of vaccines and new treatments (e.g. antibiotics), a world-wide effort by the World Health Organization and others to provide access to those vaccines and new treatments, and a focus on rapid dissemination of public health innovations to developing countries (Stolnitz, 1955; Davis, 1956; Preston, 1975).[7]

Population growth in poor mega-cities is driven in part by natural increase, and not simply in-migration. Figure 3, in Panel A, plots the projected growth rate from 2015-2030 of the 100 projected largest cities in 2030 against their crude rates of natural increase. The projected growth rates are based on non-linear extrapolation given the rates of growth pre-2010, estimated independently of the rates of natural increase. The relationship is clearly positive, which indicates that crude rate of natural increase is a significant driver of overall city population growth. The Chinese cities are the main outliers to this relationship, with relatively low rates of natural increase, but relatively high expected growth rates due to in-migration. Cities that are expected to stagnate in size (Tokyo) all have crude rates of natural increase of roughly zero.

Poor mega-cities are quite different from rich mega-cities on several dimensions. Panels B through E of Figure 3 plot several characteristics of cities against their crude rate of natural increase. The Web Appendix contains full information on sources for this data. First, in panel B is log density (persons per square kilometer), which shows a positive relationship. Perhaps surprisingly, rich mega-cities such as New York or Paris are far less densely populated than poor mega-cities such as Dhaka or Lagos. Poor mega-cities have both high rates of natural increase *and* are already highly dense, meaning they are likely to become even more dense in

[7] An additional consequence of the epidemiological transition was to raised crude rates of natural increase in cities up to the rates typically seen in rural areas, another anomaly compared to historical experience. During the Industrial Revolution the CRNI was only 3.4 per thousand, while the rural CRNI average 15.4 (see Web Appendix for sources). By the 1960's the CRNI in the largest cities was 22.6, on average, while in rural areas of the same countries CRNI was 22.3. Poor mega-cities tend to have urban rates of natural increase similar to rural areas, while historically mega-cities had much lower rates of natural increase than their associated rural areas.

the future.

This density is indicative of congestion rather than positive agglomeration effects. Panel C shows that slum shares (measured at the national level) are much higher in poor mega-cities than in rich ones. Roughly two-thirds of the residents of Dhaka, Lagos, and Kinshasa live in slums, which is measured based on lack of access to services like running water or sewage. Density and slum shares are not the only means of measuring congestion. The Web Appendix contains supplemental plots using a variety of alternative measures of congestion. Poor mega-cities with rapid population growth perform worse on each metric.

The high rates of natural increase and density of poor mega-cities do not necessarily indicate a large supply of skilled workers, which may generate positive agglomeration effects. Panel D shows the dependency ratio (the share of those under 14 and 65-plus to population aged 15-64) across our sample of cities. In poor mega-cities with high crude rates of natural increase, this dependency ratio reaches more than 60 percent. While there are several richer cities with relatively high values (Tokyo or Osaka) due to large elderly populations, in general the dependency ratio is lower the smaller the crude rate of natural increase. Poor mega-cities grow quickly through natural increase, but this does not necessarily lead to rapid growth in the effective labor force.[8]

Further, the labor force that does exist in poor mega-cities tends to be low skilled. Panel E plots the tertiary school completion rate against the crude rate of natural increase. In poor mega-cities, the share of college-educated workers is close to zero, as compared to rich mega-cities like London, New York, or Paris where it is one-third or more. Poor mega-cities have large populations, but due to age structure and lack of education, this does not translate to a large effective workforce.

This is consistent with the final Panel F of figure 3, where we show that city crude rates of natural increase correlate negatively with income levels in 2000. As we do not have individual city-level data, we plot city crude rates of natural increase against country-level GDP per capita. Natural increase is extremely high in the African and Asian mega-cities located in the poorest countries (e.g. Dhaka, Kinshasa, and others). Natural increase falls regularly as countries get richer, consistent with their rising education levels seen in panel E.[9]

Overall, it is the distinct characteristics of developing countries seen in both figures 2 and 3, in our model, the source of their move into a poor mega-city equilibrium. The rapid rate of natural increase in these cities has two effects. First, it implies that they very quickly hit the Malthusian congestion effects in urban areas: high density, a large prevalence of slums, low education, and high dependency ratios. Second, the high rate of natural increase lowers living

[8]The Web Appendix contains alternative plots using child dependency and old-age dependency, each showing higher dependency ratios in poor mega-cities with only a few exceptions.

[9]The Web Appendix contains further plots of city labor force characteristics on education, employment, productivity, and poverty that are consistent with the relationships in panels E and F.

standards due to that congestion. Rapid natural increase thus keeps wages low, which in turn implies that natural increase remains high, and the poor mega-cities remain stuck in a low-wage equilibrium where they grow without bound. The demographic shock of low mortality rates in the post-war era seen in figure 2, by increasing the rate of natural increase, contributed to the arrival and persistence of the poor mega-city equilibrium.

4. A MODEL OF RICH AND POOR MEGA-CITIES

The facts presented above established that poor mega-cities have distinctly different demographic patterns than mega-cities of the past. One reaction is that these demographic patterns, while deviating from past experience, are just part of a transitory phase of growth in these cities, and that they will become rich mega-cities given sufficient time. What we will show in the model that follows is that this is likely too optimistic an outlook. Under reasonable assumptions that match the facts we outlined in the prior sections, we show that a *poor mega-city equilibrium* exists. In particular, cities that experience extremely rapid absolute gains in population can find themselves stuck in an equilibrium with low wages and high population growth. As we discuss after the model is presented, the Mortality Transition after World War II may have pushed cities into the poor mega-city equilibrium.

Our model is based on two strands of literature. First, we adopt explicit micro-foundations for city production that display both agglomeration and congestion, as emphasized in the urban economics literature. Second, we combine that with endogenous population growth as in a typical quantity/quality trade-off model. The combination shows that it is the *absolute* growth in city population, not the growth *rate*, that is crucial in determining whether a city ends up a poor or a rich mega-city.

We derive the model for a mega-city that has an associated rural area which provides a possible pool of migrants. The absolute growth of the city population will depend on the natural increase in both the urban and rural sectors, as well as on the urbanization rate, which we will initially take as exogenously given. We show in the Web Appendix how to adapt the model to allow for a distribution of cities and/or an endogenous determination of the urbanization rate. The basic logic of the single city model will not be altered by the introduction of either element. For clarity we therefore continue to work with the single city model.

4.1 The City Sector

The city in our model will benefit from agglomeration effects in the sense that output has increasing returns to scale with respect to city population. This arises in a model of differentiated inputs to city production combined with firm fixed costs. As the scale of the city increases, more firms find they can make enough profits to offset the fixed cost, the number of intermediate goods in production rises, and this increases output.[10]

4.1.1 Production and Agglomeration

Urban final goods are produced using a series of intermediate inputs,

$$Y_u = \left(\sum_{i=0}^{M} x_i^{\frac{1}{1+\sigma}} \right)^{1+\sigma} \tag{1}$$

where x_i is the amount of intermediate good i used and M is the number of intermediate goods used in equilibrium. The elasticity of substitution between intermediate goods is $(1+\sigma)/\sigma$, with $\sigma > 0$. Letting p_i represent the price of intermediate good i, the inverse demand function for good i is

$$p_i = x_i^{-\frac{\sigma}{1+\sigma}} Y_r. \tag{2}$$

Each intermediate good is produced by a monopolistically competitive firm using the production function

$$x_i = BL_i - F \tag{3}$$

where B is the productivity of the firm (assumed to be identical across all firms), L_i is the labor used by firm i, and F is a fixed cost for a firm to operate. The fixed costs imply that there are increasing returns to scale in the production of each intermediate good. These increasing returns will ultimately capture the agglomeration effects at work in urban areas.

The intermediate good firms maximize their profits,

$$\pi_i = p_i x_i - w_u L_i, \tag{4}$$

taking the wage w_u as given, and knowing the inverse demand curve for their good given in (2). This leads to the typical markup over marginal cost, with

$$p_i = (1+\sigma)\frac{w_u}{B}. \tag{5}$$

We further assume that intermediate goods firms can enter and exit freely in the urban area, so that profits for any individual intermediate goods firm are driven to zero. Using the production function for firms in (3) and the price given in (5) the only possible level of output consistent with zero profits is

$$x_i = \frac{F}{\sigma}. \tag{6}$$

[10]The structure for production and agglomeration effects matches that in Duranton & Puga (2004). The departure of our model from theirs takes place in congestion and population growth.

Given this level of output, each firm hires

$$L_i = \frac{1+\sigma}{\sigma}\frac{F}{B}. \tag{7}$$

As each intermediate good provider is identical, their total demand for labor must equal the total supply of labor in the urban area, L_u

$$\sum_{i=0}^{M} L_i = L_u, \tag{8}$$

which can be solved for the equilibrium number of firms,

$$M = \frac{L_u}{L_i} = \frac{\sigma}{1+\sigma}\frac{B}{F}L_u. \tag{9}$$

Finally, using (6) and (9) in the production function (1) yields

$$Y_u = A_u L_u^{1+\sigma} \tag{10}$$

where

$$A_u = \frac{\sigma^\sigma}{(1+\sigma)^{1+\sigma}}\frac{B^{1+\sigma}}{F^\sigma}. \tag{11}$$

A_u is the aggregate productivity term for the urban sector. Note that output in the city sector has increasing returns to scale with respect to labor, as $\sigma > 0$. Each intermediate good firm operates with a number of workers proportional to the fixed cost. If there are more workers in the city, then this allows more firms to operate. More intermediate goods firms increases productivity in the final goods sector by allowing them to access a wider variety of inputs. This captures the agglomeration effects at work in cities in our model - a larger city workforce allows greater specialization and therefore higher productivity.

A last assumption is that A_u grows at some exogenous rate, g. We do not attempt to explicitly model this process.

4.1.2 Congestion Effects

To model the congestion associated with higher city populations, we adopt a simple structure. All production takes place at a central point in the city, a central business district (CBD), so to speak. Residents of the city live along a line extending both directions from the central business district. There is a time cost to commuting to the CBD, equal to 2τ times the distance from the CBD. As each worker needs to go back and forth each day, the total time cost for a worker at distance j from the city center is $4\tau j$, leaving them with only $1-4\tau j$ units of time left to provide to the labor market.

The distance that each worker has to travel is a function of the number of workers in the city, N_u. Each worker uses up one unit along the line, so that the maximum distance a worker is from the center is $N_u/2$, as workers can live in either direction. Integrating over all the workers we can find the total labor supply

$$L_u = 2\int_0^{N_u/2} (1-4\tau j)\,dj = N_u\left[1-\tau N_u\right]. \qquad (12)$$

Here we can see the impact of congestion. Labor supply, L_u is increasing in the number of city workers, N_u, but only up to a point. Eventually increased city population becomes so burdensome that the actual labor supplied by workers falls.

The effective labor force in (12) has a strict upper limit of $N_u = 1/\tau$. Above that limit the labor provided is zero, and this would put a firm cap on city size. To avoid this limit, we make a functional modification to this standard model of city congestion. We let τ be a function of city size itself, specifically setting $\tau = (1-exp(-\lambda N_u))/N_u$. λ captures the speed at which congestion costs adjust to population size. Using this expression for τ in (12) yields the following expression for effective labor

$$L_u = N_u e^{-\lambda N_u}. \qquad (13)$$

As can be seen, this formulation of congestion preserves the idea that N_u has conflicting effects on effective labor. More workers raises the available labor, but also creates congestion which lowers each worker's effective time. This form of the congestion function allows us to work with unbounded city sizes while preserving the notion of congestion effects. While our non-standard assumption regarding congestion makes the subsequent analysis tractable, it does not sacrifice any of the implications or logic associated with typical models of congestion.[11]

4.1.3 Urban Wage Determination and Growth

To see the city wage at any given moment in time, combine the expression for output from (10) with the labor supply equation from (13) to find

$$Y_u = A_u N_u^{1+\sigma} e^{-\lambda(1+\sigma)N_u} \qquad (14)$$

and income per worker is

$$w_u = A_u N_u^{\sigma} e^{-\lambda(1+\sigma)N_u}. \qquad (15)$$

[11]As in typical urban models we presume that there is a competitive rental market that ensures each work in the city earns, on net, an identical amount. Those workers living closer to the CBD will supply more labor and have higher gross earnings, but this will be offset by higher rents. Total rents are distributed equally across workers. Similarly, we abstract from the question of competition for land between rural and city sectors, assuming that city area can expand costlessly.

What can be seen here is that the number of city workers, N_u, influences earnings in the city, and that these earnings form an inverted U-shape. That is, for low levels of N_u earnings are increasing in city workers as the agglomeration effects outweigh the congestion effect. Eventually, though, when N_u is large enough the congestion effects dominate and more city workers will lower earnings. Differentiating (15) with respect to N_u shows the wage-maximizing number of workers is $N^* = \sigma/[(1+\sigma)\lambda]$. Above that level, wages fall as more residents arrive in the city.

$$\frac{\dot{w}_u}{w_u} = g + \frac{\dot{N}_u}{N_u}[\sigma - \lambda(1+\sigma)N_u] \tag{16}$$

so that we have the growth rate of population times this term in the brackets. The term in brackets captures agglomeration (σ) and congestion ($\lambda(1+\sigma)N_u$). As the absolute size of N_u goes up, congestion gets worse.

Given this determination of the wage, we can turn to how this wage will grow (or stagnate). Taking logs and time derivatives, we have that

$$\frac{\dot{w}_u}{w_u} = g + \sigma\frac{\dot{N}_u}{N_u} - \lambda(1+\sigma)\dot{N}_u \tag{17}$$

where recall that g is the exogenous growth rate of A_u. City wage growth depends positively on productivity growth, and on the agglomeration effects coming from the *growth rate* of the city population.[12]

But there are congestion effects, and the last term in (17) captures this drag on wages. Notice that the congestion term depends on the *absolute* change in city population, not its growth rate. Larger absolute increases in city population push up congestion costs for all existing residents, no matter how many there are, and this lowers the wage.

From equation (17) we can already develop the basic intuition behind poor mega-cities, and the relevance of the Mortality Transition coming before widespread urbanization. In poor countries, the Mortality Transition raised the rate of urban natural increase, so that even without any in-migration from rural areas, cities experienced very large absolute gains in population. Urbanization then pushes even more workers into cities from rural areas, and together this leads to very large absolute gains in city population, $\dot{N}_u$. If this absolute gain is too large, then wage growth can actually become negative, leading to a poor mega-city. This poverty, as we will discuss in more detail below, keeps population growth rates high, and thus the poor mega-city becomes self-perpetuating.

[12]The dependence of wage growth on the absolute growth in urban population is not an artifact of our particular assumption regarding congestion. This would appear in any model where the absolute number of residents was associated with higher congestion costs. It implies that a city doubling in size from 50 thousand to 100 thousand residents will be able to sustain higher wage growth than one doubling from 500 thousand to 1 million, ceteris paribus.

Urbanizing before the Mortality Transition, as in currently rich mega-cities, avoided this problem. With high mortality, and particularly with high mortality in urban areas, the absolute increase in city populations was very small over time. Even with in-migration from rural areas, $\dot{N}_u$ was small, and this ensured that wage growth could remain positive. As wages rose, this induced lower population growth rates, which reinforces the outcome of positive wage growth in cities.

A simple example of the difference is between New York and Dhaka. Both have roughly 18 million inhabitants today, but the absolute growth in city population was much slower in New York. In the 19th century New York grew by about 67,000 residents per year, and at its peak from 1900 to 1940 grew at roughly 155,000 per year. In contrast between 1960–2010 Dhaka grew by about 284,000 per year, reaching 445,000 per year in the 2000's. The absolute growth of modern developing cities is on a different scale than that experienced historically.

4.2 City Population Growth

Wage growth in the city sector depends on both the growth rate of the city population as well as its absolute change. By modeling the population growth process more formally, we can better understand the conditions under which poor mega-cities will develop. City population growth depends on both the urban rate of natural increase and on in-migration from rural areas, so we will need models of population processes in both sectors.

In each sector, there is natural increase in population. We model this natural increase as depending on the wage rate, $w(t)$, as well as a sector-specific mortality shifter, m. Specifically, we have

$$\begin{aligned} \dot{N}_u^{NI} &= \phi(w(t), m_u) \\ \dot{N}_r^{NI} &= \phi(w(t), m_r), \end{aligned} \tag{18}$$

where $\phi(w(t), m_i)$ is the function describing the relationship of natural increase to wages and the shifter, with $i \in (u, r)$. The $\phi()$ function captures demographic behavior related to income, including both fertility and mortality responses, and the shifter m_i is intended to capture exogenous changes in the underlying mortality regime.

We do not specify precise micro-foundations for the $\phi()$ function, as those are readily available from the literature.[13] The specific properties that we assume are as follows,

$$\phi_w(w(t),m_i) < 0 \tag{19}$$

$$\phi_m(w(t),m_i) < 0 \tag{20}$$

$$\lim_{w\to\infty} \phi(w(t),m_i) = \phi_{min}. \tag{21}$$

The first property simply states that natural increase in either sector is decreasing with income, matching the empirical evidence.[14] The second property states that natural increase is negatively related to exogenous mortality, m_i. We think of m_i as representing level effects on population growth. In particular, the mortality transition will be captured by a decrease in m_i. The final property says that regardless of sector, as wages get arbitrary high, the rate of natural increase reaches a minimum. This minimum need not be zero.

With total population equalling the sum of urban and rural population, $N(t) = N_u(t) + N_r(t)$, the absolute change in total population is the sum of natural increase in the two sectors,

$$\dot{N} = N_u(t)\dot{N}_u^{NI} + N_r(t)\dot{N}_r^{NI}. \tag{22}$$

Plugging in (19) for the natural increase terms, dividing by N, and suppressing the time notation we have

$$\frac{\dot{N}}{N} = \frac{N_u}{N}\phi(w,m_u) + \frac{N_r}{N}\phi(w,m_r), \tag{23}$$

as the expression for total population growth.

Define the urbanization rate (again suppressing time notation) as

$$u = \frac{N_u}{N}. \tag{24}$$

It follows that the growth rate of the urban population is simply

$$\frac{\dot{N}_u}{N_u} = \frac{\dot{u}}{u} + \frac{\dot{N}}{N}. \tag{25}$$

Use expression (23) to plug in for the growth rate of total population and after a small amount of manipulation we have that the growth rate of city population can be written as

$$\frac{\dot{N}_u}{N_u} = \phi(w,m_u) + \frac{\dot{u}}{u} + (1-u)\left[\phi(w,m_r) - \phi(w,m_u)\right]. \tag{26}$$

[13] Jones, Schoonbroodt & Tertilt (2010) and Galor (2011) provide reviews of common explanations for the relationship between wages, fertility, and mortality.

[14] Becker (1960) observed the negative relationship of incomes and fertility, and see Jones, Schoonbroodt & Tertilt (2010) for a more recent summary of the available evidence. Allowing for a positive effect of income on population growth at very low income levels, as in unified growth models (Galor, 2011), complicates the analysis but does not change the ultimate implications of the model.

The first term on the right is urban natural increase, i.e. the growth in city population arising solely from the growth of urban families, and ignoring in-migration. The last two terms on the right capture net migration. If $\dot{u}/u > 0$, and the urbanization rate is rising, then this implies a net movement of population from rural areas to the city. Additionally, if there is some difference in natural increase between rural and urban areas ($\phi(w, m_r) - \phi(w, m_u)$), then there will be additional net migration between the two. Historically economies had $\phi(w, m_r) > \phi(w, m_u)$ because of high city mortality (i.e. a high value of m_u), and even with a fixed urbanization rate this led to a constant flow of workers from rural areas to the city.[15]

From equation (26) we can identify several of the important forces that will determine whether an economy ends up with poor mega-cities or rich ones. First, note that the growth rate of city population, and by extension the absolute change in city population, depends on the rate of natural increase in cities. The mortality transition, by raising $\phi(w, m_u)$, raises absolute city population growth, and hence lowers the growth rate of wages. Lower wages implies that natural increase remains high, and hence city population growth remains high.

For clarity, we will continue by analyzing an economy where the urbanization *rate*, u, is constant, and hence $\dot{u}/u = 0$. Available in the appendix is a discussion of the model with the urbanization rate allowed to change over time. With $\dot{u} = 0$, we then define the following function,

$$n(w, c_u) \equiv \phi(w, m_u) + (1 - u)[\phi(w, m_r) - \phi(w, m_u)] \tag{27}$$

as the instantaneous growth rate of city population. It is straightforward to see that $n(w, m_u)$ inherits the properties of the $\phi(w, m_u)$ function and therefore

$$\begin{aligned} n_w(w, m_u) &< 0 & (28) \\ n_m(w, m_u) &< 0 & (29) \\ \lim_{w \to \infty} n(w, c_u) &= n_{min}. & (30) \end{aligned}$$

The growth rate of city population is negatively related to wages, as this lowers population growth in both rural and urban sectors. City population growth is also negatively related to the value of m_u. As wages rise, the growth rate falls towards a minimum, and again this minimum need not equal zero.

4.3 Equilibrium Outcomes

We can now characterize the dynamics of wages with respect to city population size. From equation (17) we know that growth in wages is positive if productivity growth and the

[15] An additional consideration is that in many developing countries after the mortality transition, cities became less deadly than rural areas, and $\phi(w, m_r) < \phi(w, m_u)$. This would, by itself, limit city population growth. But then any increase in urbanization, u, actually *increased* city population growth as more people moved into a low-mortality area, further raising population growth.

agglomeration effects are large relative to the congestion effect driven by the absolute change in city population. Given that city population growth itself depends on the wage we will be able to define a relationship between the wage rate and city population size that determines whether wages grow or not. Following that we will provide the conditions under which a city will be able to sustain positive wage growth over time.

In words, a city will be able to sustain wage growth indefinitely if their rate of absolute population growth is sufficiently small. This will occur if either their initial wage is high, and so natural increase is low, or if their initial size is small, and hence the absolute growth in city size is also small. Rich mega-cities will arise because their wages grow fast enough to lower population growth rates, which in turn reinforces wage growth. Poor mega-cities will arise because their population growth makes wages growth slow enough (or shrink) to keep population growth high, which in turn reinforces the slow or falling wage growth. We then show that a sufficiently large boost to population growth, such as occurred following the mortality transition, could push a city into the poor mega-city equilibrium regardless of initial conditions. Conversely, a sufficiently large drop in population growth, such as with China's single-child policy, could push a city into the rich mega-city equilibrium.

More formally, we begin by establishing the conditions under which wage growth in urban areas will be positive.

Lemma 1. *There is a function*

$$\overline{N}(w, m_u) \equiv \frac{g}{\lambda(1+\sigma)n(w, m_u)} + \frac{\sigma}{\lambda(1+\sigma)} \tag{31}$$

such that

- *For* $N_u < \overline{N}(w, m_u)$*, wage growth is positive,* $\dot{w}/w > 0$
- *For* $N_u > \overline{N}(w, m_u)$*, wage growth is negative,* $\dot{w}/w < 0$.

and with the properties

- $\partial \overline{N}(w, m_u)/\partial w > 0$
- $\partial \overline{N}(w, m_u)/\partial m_u > 0$.

Proof. Please see appendix. □

If the city population is sufficiently small, then the absolute growth in city population is also small enough that congestion effects do not overwhelm the positive effects of agglomeration and productivity growth, and wages grow. $\overline{N}(w, m_u)$ defines the cutoff level for city population to achieve this wage growth.

The cutoff is increasing with the wage. This occurs because at higher wages, the city population growth *rate* is smaller, given the properties of $n(w, m_u)$. With a smaller growth rate, the absolute change in city population is small even in a large city, and the congestion effects do not offset productivity growth. Hence, at higher wages the absolute size of the city can be larger and yet still have positive wage growth. Whether cities can maintain positive wage growth over time is the subject of the following lemma.

Lemma 2. *There is a function*

$$\underline{N}(w,m_u) \equiv \overline{N}(w,m_u)\frac{1}{1+\Omega}, \tag{32}$$

where $\Omega = -n(w,m_u)^2/n_w(w,m_u)wg > 0$ *such that*

- *If* $N_u < \underline{N}(w,m_u)$*, then* $\dot{N}_u < \dot{\overline{N}}(w,m_u)$
- *If* $N_u > \underline{N}(w,m_u)$*, then* $\dot{N}_u > \dot{\overline{N}}(w,m_u)$

and with the properties that

- $\underline{N}(w,m_u) < \overline{N}(w,m_u)$
- $\underline{N}(w,m_u) \to 0$ *as* $w \to 0$
- $\underline{N}(w,m_u) \to \overline{N}(w,m_u)$ *as* $w \to \infty$

Proof. Please see appendix. □

Lemma 2 shows that for cities below a lower threshold, $\underline{N}(w,m_u)$, wage growth will be positive *and* their population growth is low enough to continue to stay below $\overline{N}(w,m_u)$. But can those cities indefinitely maintain wage growth as their populations grow? Or will they eventually become so big that congestion effects overwhelm the growth in productivity? What the following Proposition establishes is that if city size is smaller than $\underline{N}(w,m_u)$ to begin with, then in fact it will *always* remain below that threshold and wage growth will be positive forever. These cities become rich mega-cities. Conversely, cities with populations above the threshold $\underline{N}(w,m_u)$ will grow in size too quickly and eventually reach a point where congestion overtakes them. These become poor mega-cities.

Proposition 1. *Given initial conditions* $w(0)$ *and* $N_u(0)$ *there are two possible equilibrium outcomes*

(a) ***Poor Mega-City:*** *If* $N_u(0) \geq \underline{N}(w(0),m_u)$ *then wages will approach zero,* $\lim_{t\to\infty} w(t) = 0$*, and population growth will remain strictly above* n_{min}*.*

(b) ***Rich Mega-City:*** *If* $N_u(0) < \underline{N}(w(0),m_u)$ *then wage growth is always positive,* $\dot{w}/w > 0 \forall t$*, and population growth approaches the minimum* $n_m in$*.*

Proof. Please see appendix. □

The intuition for rich mega-cities in Proposition 1 is that for a sufficiently small city wage growth is rapid enough that the city population growth rate shrinks relatively quickly. As the population growth rate falls, the absolute change in city size is never sufficient to have congestion effects overwhelm productivity growth, and hence wages continue to rise. As population growth is decreasing in wages, once started, this process reinforces itself as time goes on. Note that population growth goes to n_{min}, which can be non-zero, meaning that both wages and city size can continue to grow indefinitely in rich mega-cities.

In poor mega-cities, with initial city population sizes above $\underline{N}(w(0), m_u)$, wage growth is not very rapid (or is negative), and hence the population growth rate does not decline by much (or rises). This leads to larger absolute gains in city population size, which create congestion effects that overwhelm productivity growth. Eventually city wages fall, and this drives population growth higher, exacerbating the congestion effects, which further lowers wages. Poor mega-cities grow in size because they are poor.

Note that having positive wage growth initially, $N_u < \overline{N}(w(0), m_u)$, is not sufficient to ensure a city becomes a rich mega-city. A city may begin with positive wage growth, but still acquire a population so large that congestion effects begin to offset productivity growth and agglomeration.

The dynamics can be most easily seen in a diagram. Figure 4 plots city population, N_u, against wages, w. In the figure, the curves defined by $\overline{N}(w, m_u)$ and $\underline{N}(w, m_u)$ are plotted, and note that at every wage $\underline{N}(w, m_u) < \overline{N}(w, m_u)$, as noted in Lemma 2. Three initial points are plotted with equal wages, but with varying initial city sizes.

Below $\underline{N}(w, m_u)$, the city starts small enough that wage growth is positive and sufficient to lower population growth fast enough to sustain wage growth indefinitely. This city becomes a rich mega-city. Between $\underline{N}(w, m_u)$ and $\overline{N}(w, m_u)$, in the shaded area, wage growth is positive at first but is *not* sufficient to lower the absolute population growth far enough to overcome the effects of congestion. Eventually this city transitions into the third zone on the figure, where $N_u > \overline{N}(w, m_u)$, and wage growth becomes negative. This city becomes a poor mega-city eventually.

Finally, the city starting with $N_u > \overline{N}(w, m_u)$ is already so large that congestion effects are sufficient to overwhelm productivity growth and the wage shrinks as the city grows. This city is a poor mega-city as well.

The figure shows that the initial position of the city relative to the $\underline{N}(w, m_u)$ curve is crucial for determining the long-run outcome. Only cities that have a combination of high wages and/or low population are able to experience fast enough wage growth to overcome the drag of congestion effects.

The model indicates the poor mega-cities have wages that collapse to zero in the long-run. We can easily allow for non-zero long-run wages in poor mega-cities by allowing for a minimum level of earnings in the urban technology. We show in the appendix how to incorporate an informal urban sector into the analysis that provides just such a minimum level of earnings. Productivity growth in this informal technology would allow for wage growth in poor mega-cities over time, but this wage growth would fall below rich mega-cities under most reasonable assumptions.

4.4 The Rise of Poor Mega-Cities

Given our model, how do we explain the divergence of poor mega-cities from the historical norms? As noted in the introduction, we focus on the distinct change in demographics following the mortality transition that occurred after World War II. Recall from Figure 2 that crude death rates in developing cities fell dramatically relative to their crude birth rates, and thus the crude rate of natural increase in developing cities became very large. We propose that in developing countries after the mortality transition, m_u fell below a critical threshold that pushed these cities into the poor mega-city equilibrium. Formally, in our model the following proposition holds.

Proposition 2. *For any given initial conditions $w(0)$ and $N_u(0)$ there is a threshold level $\overline{m}_u$ such that*

- *if $m_u \leq \overline{m}_u$ the city becomes a Poor Mega-City*
- *if $m_u > \overline{m}_u$ the city becomes a Rich Mega-City*

Proof. Please see appendix. □

Low mortality cities become poor mega-cities because their population growth proceeds too quickly. But note that the proposition implies that there is a non-linear effect of m_u on city development. Cities with mortality rates just above and just below the threshold $\overline{m}_u$ can look very similar at first, but the slightly faster natural increase in a city with a low mortality rate will eventually create congestion effects that cannot be overcome. Differences in mortality rates need not be large to generate significant long-run differences between poor and rich mega-cities.

The difference between these poor mega-cities and their historical peers can be seen most easily in Figure 5. Think of the pre-mortality transition demographics as being measured by $m_u^{Pre} > \overline{m}_u$, implying a low growth rate of urban population due to the high mortality rates in urban areas. In comparison, developing countries after the mortality transition faced a much higher level of population growth, because $m_u^{Post} < \overline{m}_u$.

In Figure 5 we have plotted both $\underline{N}(w, m_u^{Pre})$, the pre-mortality transition curve, and $\underline{N}(w, m_u^{Post})$, the post-mortality transition curve. We have also noted initial conditions of $w(0)$ and $N_u(0)$. Given these initial conditions, after the mortality transition $N_u(0) > \underline{N}(w(0), m_u^{Post})$ and wage growth was negative as city size grew so fast it overwhelmed productivity growth. This kept wages low, and because wages were low population growth continued at a rapid rate, which in turn kept wages low. Poor mega-cities became stuck in the bad equilibrium.

Compare this to a historical city with identical initial conditions, but prior to the mortality transition. In this case $N_u(0) < \underline{N}(w(0), m_u^{Pre})$, and city growth was slow enough that wages were able to grow. This city was able to become a rich mega-city. Its wage growth was sufficiently high to reduce population growth, and that in turn ensured that wage growth remained high. They found themselves in the good equilibrium. The mortality transition came to the historically rich mega-cities as well, later in their development. By beginning to grow prior to the mortality transition, though, they would have been able to reach a high enough wage that once the mortality transition did hit, they still had $N_u < \underline{N}(w, m_u^{Post})$, and thus were able to continue having growth in wages.

Note in the Figure that cities developed into poor mega-cities even though they may have shared the same initial conditions and productivity growth as historical cities. Developing country cities did not necessarily have to start out poorer or larger than their historical counterparts in order to become poor mega-cities. The mortality transition was sufficient to push them into that outcome. Of course, technology levels ($A_u(0)$), productivity growth (g), the strength of congestion effects (λ), and the exact relationship of population growth to income ($n(w, m_u)$) could all be different between historical cities and those in developing countries. Those factors would alter the position or shape of the $\underline{N}(w, m_u)$ curve, generating differences in the long-run outcomes for cities. Those other factors are not irrelevant to the growth of poor mega-cities, but the shift in mortality rates seen after World War II deserves particular attention given the departure from historical norms.

5. DISCUSSION AND CONCLUSION

The model we developed relates city population growth to agglomeration and congestion in those cities. It shows that wages in a city are not simply a function of productivity levels or growth rates, but depend also on demographic behaviors. It is a general framework that can be used to understand the dynamics of both city size and wage levels over time.

The model shows that small differences in population growth rates in emerging mega-cities can result in very different long-run outcomes. We used this to explain the rise of poor mega-cities after World War II, attributing it in part to the severe decline in death rates that occurred because of the mortality transition. These lower death rates led these mega-cities to grow so fast in absolute terms that the congestion effects overwhelmed productivity growth and led to lower wages, which in turn perpetuated high population growth rates. This spiral led to the poor mega-cities of today.

A critical implication of the model is that the poor mega-city equilibrium is stable. Once upon that path a city will remain a poor mega-city indefinitely, even if it shares the same underlying rate of productivity growth as rich mega-cities. The poor mega-cities of today are not simply in a transitional state towards becoming the next New York or Tokyo, but rather have grown so fast they are actively working against their own prosperity.

As in standard Malthusian models, our model implies that it takes a significant shift in demographic behavior to break out of a poor equilibrium. Examples of these shifts and the possibility of breaking out of the poor mega-city equilibrium exist. China's one-child policy was a severe brake on population growth, bringing crude rates of natural increase in major cities close to zero. Now mega-cities like Beijing, Chongqing, Guangzhou, and Shanghai look similar to historical mega-cities, growing only through in-migration from rural areas and generating sustained growth in living standards.

At the other end of the scale we have the currently rich mega-cities that grew slowly over time, which allowed productivity growth to stay ahead of congestion. One question is how these cities have become so large (e.g. Tokyo with 38 million residents) while avoiding the issues of poor mega-cities. As our model indicates, it is the relative growth rate of productivity and absolute growth of population that determine wage growth. The *level* of population does not necessarily dictate outcomes. There is nothing in our model dictating that rich mega-cities must stay below a certain absolute cap in size. Aside from the theoretical considerations, these rich mega-cities obviously invested in alleviating congestion as they grew. While we did not discuss this explicitly, one could easily imagine that the effect of congestion (our parameter λ) as an endogenous decision. At some threshold of total city revenues, for example, it is possible to invest in congestion-alleviating technologies like sewage systems and subways. Rich mega-cities were able to hit that threshold because their wages and population size grew, while poor mega-cities are unable to hit the threshold because wages remain low even while population grows.

Other explanations for the nature of poor mega-cities certainly exist. Urban bias, changing preferences, and rural over-crowding are just some of the possibilities. While we focused on mortality changes, our model is flexible enough to incorporate those alternatives easily. It provides a way of understanding how these other factors may change cities dynamically, and highlights that the effect of these factors on demographics are likely just as important as their effects on city productivity or congestion.

The rise of poor mega-cities is a distinct shift from the historical experience. Given the sheer numbers of people involved, understanding these cities is an important part of understanding growth and development in general. Urbanization is often presumed to be synonymous with economic growth, but the evidence on these poor mega-cities and the implications of our model suggest that this is too broad a generalization. It is entirely possible for poor mega-cities to appear and persist in poverty given their rapid growth in population. We cannot presume that these poor mega-cities represent the initial stages of rapid economic development. Rather, they may indicate traps that cannot be escaped from.

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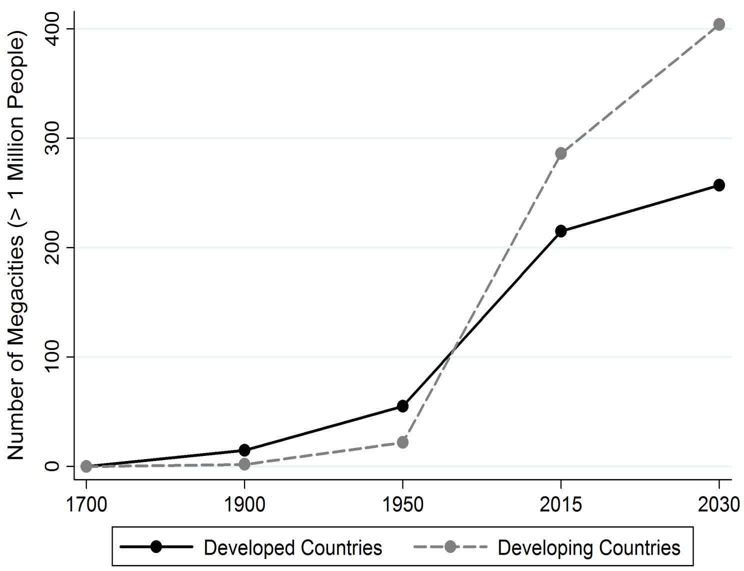
TABLE 1: WORLD'S LARGEST MEGACITIES (MILLIONS), 1700-2015

Rank	1700		1900		1950		2015 (△% 2015-30)		
1	Istanbul	0.7	London	6.5	New York	12.3	Tokyo	38.0	(-0.1)
2	Tokyo	0.7	New York	4.2	Tokyo	11.3	Delhi	25.7	(2.3)
3	Beijing	0.7	Paris	3.3	London	8.4	Shanghai	23.7	(1.8)
4	London	0.6	Berlin	2.7	Paris	6.3	Sao Paulo	21.1	(0.7)
5	Paris	0.5	Chicago	1.7	Moscow	5.4	Mumbay	21.0	(1.9)
6	Ahmedabad	0.4	Vienna	1.7	Buenos Aires	5.1	Mexico	21.0	(0.9)
7	Osaka	0.4	Tokyo	1.5	Chicago	5.0	Beijing	20.4	(-0.1)
8	Isfahan	0.4	St. Petersburg	1.4	Kolkata	4.5	Osaka	20.2	(-0.1)
9	Kyoto	0.4	Manchester	1.4	Shanghai	4.3	Cairo	18.8	(1.8)
10	Hangzhou	0.3	Philadelphia	1.4	Osaka	4.1	New York	18.6	(0.5)
11	Amsterdam	0.2	Birmingham	1.2	Los Angeles	4.0	Dhaka	17.6	(3.0)
12	Naples	0.2	Moscow	1.1	Berlin	3.3	Karachi	16.6	(2.7)
13	Guangzhou	0.2	Beijing	1.1	Philadelphia	3.1	Buenos Aires	15.2	(0.7)
14	Aurangabad	0.2	Kolkata	1.1	Rio de Janeiro	3.0	Kolkata	14.9	(1.7)
15	Lisbon	0.2	Boston	1.1	St. Petersburg	2.9	Istanbul	14.2	(1.1)
16	Cairo	0.2	Glasgow	1.0	Mexico	2.9	Chongqing	13.3	(1.8)
17	Xian	0.2	Osaka	1.0	Mumbai	2.9	Lagos	13.1	(4.2)
18	Seoul	0.2	Liverpool	0.9	Detroit	2.8	Manila	12.9	(1.8)
19	Dacca	0.2	Istanbul	0.9	Boston	2.6	Rio de Janeiro	12.9	(0.6)
20	Ayutthaya	0.2	Hamburg	0.9	Cairo	2.5	Guangzhou	12.5	(2.3)
21	Venice	0.1	Buenos Aires	0.8	Tianjin	2.5	Los Angeles	12.3	(0.5)
22	Suzhou	0.1	Budapest	0.8	Manchester	2.4	Moscow	12.2	(0.0)
23	Nanking	0.1	Mumbay	0.8	Sao Paulo	2.3	Kinshasa	11.6	(3.7)
24	Rome	0.1	Ruhr	0.8	Birmingham	2.2	Tianjin	11.2	(1.8)
25	Smyrna	0.1	Rio de Janeiro	0.7	Shenyang	2.1	Paris	10.8	(0.6)
26	Srinagar	0.1	Warsaw	0.7	Roma	1.9	Shenzhen	10.7	(1.1)
27	Palermo	0.1	Tientsin	0.7	Milano	1.9	Jakarta	10.3	(2.0)
28	Moscow	0.1	Shanghai	0.6	San Francisco	1.9	London	10.3	(0.7)
29	Milan	0.1	Newcastle	0.6	Barcelona	1.8	Bangalore	10.1	(2.6)
30	Madrid	0.1	St. Louis	0.6	Glasgow	1.8	Lima	9.9	(1.4)

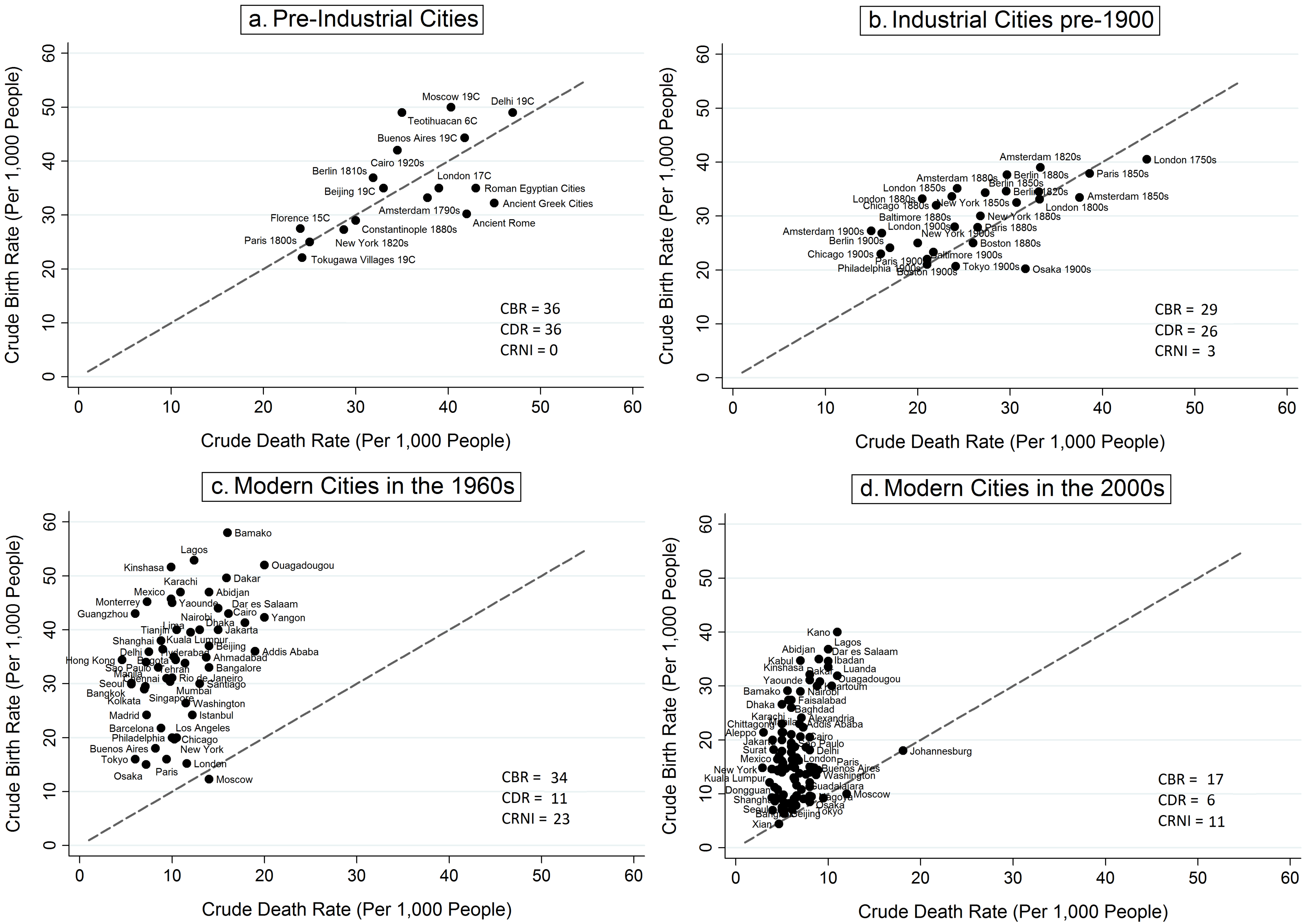
Notes: The main sources of the data are Chandler (1987) and United Nations (2014). △% 2015-30 is the projected annual growth rate of the city between 2015 and 2030 according to United Nations (2014). These growth rates are based on non-linear extrapolation given the rates of growth pre-2015.

FIGURE 1: NUMBER OF MEGACITIES (ABOVE 1 MILLION PEOPLE), 1700-2030



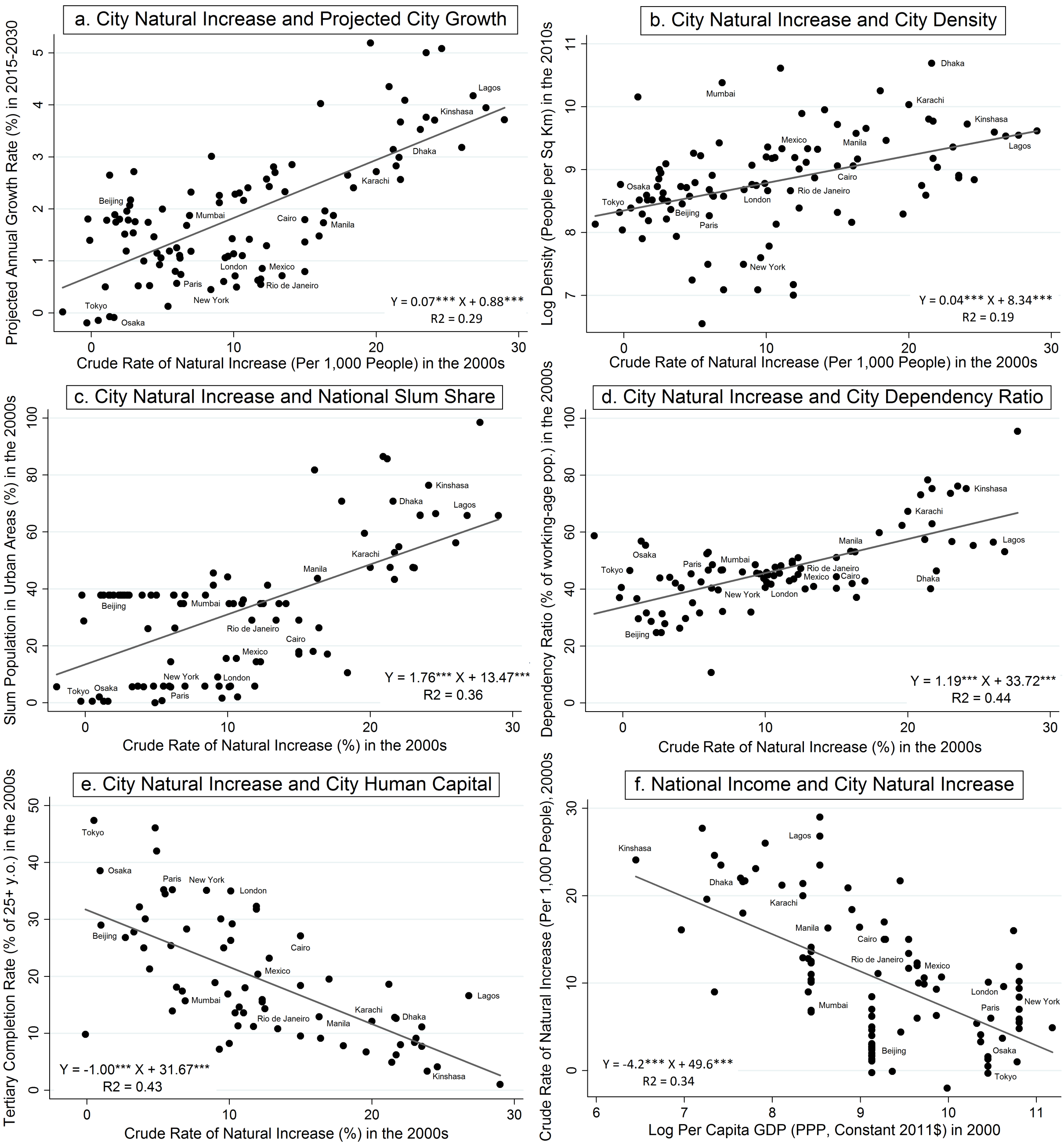
Notes: This figure shows the number of urban agglomerations of at least 1 million inhabitants in developed countries and developing countries in 1700, 1900, 1950, 2015 and 2030. Developed (developing) countries are countries whose GDP per capita (PPP, constant 2011 international $) is above (below) $12,476 in 2013. Sources: Maddison (2008), World Bank (2013) and United Nations (2014).

FIGURE 2: CITY CRUDE BIRTH AND DEATH RATES, FROM ANTIQUITY TO DATE



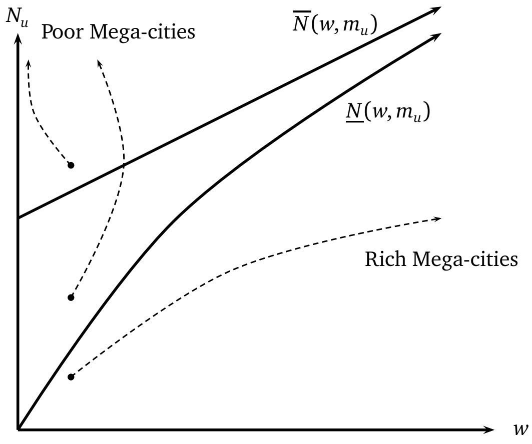
Notes: This figure shows the crude birth and death rates (per 1,000 people) for 17 pre-Industrial Revolution cities, 28 city-decade observations for the Industrial Revolution, 54 cities in the 1960s, and 100 cities in the 2000s (these cities were selected because they will be the 100 largest cities in 2030 according to United Nations (2014)). It also shows the mean crude birth rates (CBR), death rates (CDR) and rates of natural increase (CRNI). See Web Appendix for data sources.

FIGURE 3: CHARACTERISTICS OF THE 100 LARGEST MEGA-CITIES IN 2030



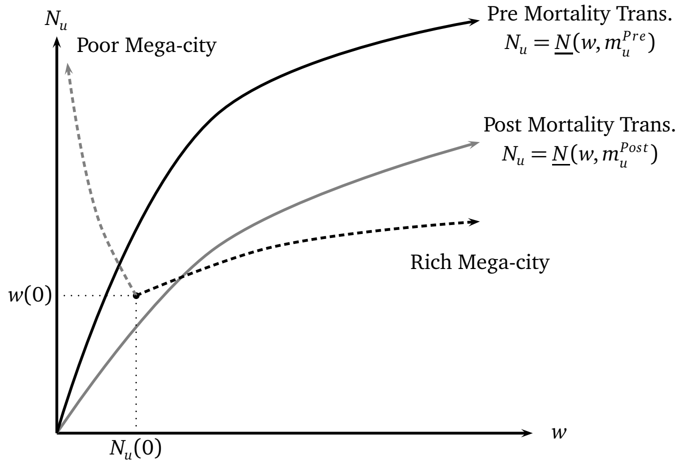
Notes: This figure shows various characteristics of the 100 largest cities in 2030 according to United Nations (2014). Subfigure a shows the relationship between the city projected annual growth rate (%) in 2015-2030 and the city crude rate of natural increase (per 1,000 people) in the 2000s. We use United Nations (2014) to obtain the projected growth rate of each city. These rates are based on non-linear extrapolation given the rates of growth pre-2010, and are thus estimated independently of the rates of natural increase. Subfigures b, c, d and e show the relationships between four measures of city congestion and the city crude rate of natural increase in the 2000s: the city density (b), the national slum share (c), the city total dependency ratio (d), and the city literacy rate (e). Subfigure f shows the relationship between the city crude rate of natural increase in the 2000s and the national income level in 2010. See Web Appendix for data sources.

FIGURE 4: URBAN WAGE DYNAMICS AT DIFFERENT INITIAL CONDITIONS



Notes: This figure shows how the dynamics of wages and population depend on the initial position of the economy relative to the two curves, $\overline{N}(w, m_u)$ and $\underline{N}(w, m_u)$. With $N_u < \underline{N}$, the absolute city growth is small enough to maintain sustained wage growth. For $\overline{N} > N_u > \underline{N}$, wage growth is positive initially but not sufficient to overcome absolute city growth creating congestion effects, and eventually wage growth becomes negative. For $N_u > \overline{N}$, absolute population growth is so large that wages fall immediately, and continue falling as city population expands.

FIGURE 5: URBAN WAGE DYNAMICS PRE- AND POST- MORTALITY TRANSITION



Notes: This figure shows that for a given set of initial conditions on wages, $w(0)$, and city population, $N_u(0)$, the dynamics depend on the value of m_u. Prior to the mortality transition, with m_u^{Pre}, low population growth rates mean that the city is able to sustain wage growth high enough to overcome any congestion effects, and it becomes a rich mega-city. After the mortality transition, with m_u^{Post}, the same initial conditions lead to rapid population growth that creates congestion effects that drive down wages, which increase population growth, and this creates a poor mega-city.