The Urban Mortality Transition and Poor Country Urbanization

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Abstract

Today the world's fastest-growing cities lie in low-income countries, unlike the historical norm. Also unlike the "killer cities" of history, cities in low-income countries grow not just through in-migration but also through their own natural increase. First, we use novel historical data to document that many poor countries urbanized at the same time as the post-war urban mortality transition. Second, we develop a general equilibrium model of location choice with heterogeneity in demographics and congestion costs across locations to account for this. In the model, people prefer to live in low-mortality locations, and the aggregate rate of population growth and the locational choice of individuals interact. Third, we calibrate the model to data from a sample of poor countries, and find that informal urban areas (e.g. slums) grew in large part because they were able to absorb additional population relatively more easily than other locations. We show that between 1950 and 2005 the urban mortality transition by itself could have doubled the urbanization rate as well as the size of informal urban areas in this sample. Of these effects, one-third can be attributed to the direct amenity effect of lower urban mortality rates, while the remainder is due to higher population growth disproportionately pushing people into informal urban areas. Fourth, policy analysis suggests that family planning programs might be as effective as urban infrastructure and institutions at transforming cities in poor countries into "engines of growth".

JEL Codes: R11; R12; R13; J10; J11; O11; O40; O18; N00

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Urbanization has gone hand in hand with economic growth throughout history (Henderson, 2010; Duranton, 2014b). However, the post-war period witnessed "poor country urbanization", i.e. fast urbanization in poor countries (Glaeser, 2014; Glaeser and Henderson, 2017). Dhaka, Karachi, Kinshasa, Lagos, and Manila are some of the largest cities on the planet today. In contrast, only six of the currently largest 30 cities (e.g., London, New York, Paris and Tokyo) are in high income countries. The prevalence of poor mega-cities today runs counter to historical experience. In the past, the world's largest cities were almost all in the most advanced economies.

We first document this puzzling phenomenon by building the largest available historical database on the spatial aspects of the demographic transition from antiquity to modern times, and show that in the post-war era the urban areas of poor countries experienced rates of natural increase - the birth rate minus the death rate - well above levels seen historically. This was due to the drop in urban death rates following the *urban mortality transition* of the mid-20th century. Cities in poor countries grew in absolute terms because of both in-migration *and* natural increase, setting them apart from historical "killer" cities that grew only through in-migration. We further show that cities in poor countries today are very densely populated relative to rich country cities, with much of this density due to a high share of population in slums. They also have low human capital, with high dependent population shares and low education completion rates.

Second, to understand this *poor country urbanization*, we construct a general equilibrium model of population allocation across locations, similar in spirit to work on structural change (Caselli and Coleman II, 2001; Gollin et al., 2002; Duarte and Restuccia, 2010; Michaels et al., 2012; Buera and Kaboski, 2012; Karádi and Koren, 2012; Lagakos and Waugh, 2013). We incorporate locational choice similar to the literature on equilibrium city size (Henderson, 1974; Duranton and Puga, 2004; Desmet and Rossi-Hansberg, 2013, 2014; Duranton, 2014b; Glaeser, Ponzetto and Zou, 2016) and combine that with elements of models of population and growth (Galor and Weil, 1999, 2000; Ashraf and Galor, 2011), as well as incorporating a preference of individuals to live in low mortality locations. Our model allows population to move freely among locations that differ in their demographics, productivity growth, and elasticity of welfare with respect to population. For a stable allocation of population across locations these elasticities are all negative, and their heterogeneity is consistent with locations having production functions that vary in the importance of fixed factors of production and/or in the strength of congestion and agglomeration effects.

A key insight of the model is that the aggregate population growth rate influences the distribution of population across locations. In particular, an increase in the population growth rate (arising in any location) leads to an increase in the population share of the location with the lowest elasticity of welfare with respect to population. Those locations are able to absorb large population increases without lowering the welfare of residents significantly, and thus they disproportionately grow when population growth accelerates. Note that this does not mean these locations are uncrowded. Rather, precisely because of their low elasticity of welfare with respect to population they will absorb more people, and be the densest locations in the economy.

Third, to quantify the effects of the urban mortality transition (UMT), we calibrate the model, matching the average urbanization rate and slum share from 1950 to 2005 for a set of 41 poor and initially unurbanized countries. We use three types of locations so that we can match the model to the available data. In addition to *rural* locations, we specify two types of urban locations: *formal* (e.g. business districts) and *informal* (e.g. slums). A key outcome of the calibration is that informal urban areas display the lowest elasticity of welfare with respect to population of all the locations, and in turn absorbed a large fraction of the additional population growth created by the UMT, contributing to the urbanization of poor countries and the high share of slums in their cities.

We find that the UMT may have accounted for two-fifths (9.7 percentage points of the observed 22.1 point increase) of urbanization, and two-thirds of the growth in the slum share between 1950 and 2005. In addition, the UMT may have increased total urban population size by three-fourths and doubled the total informal urban population. While we want to be careful about making welfare statements involving mortality, our calibrated model indicates that welfare may have been slightly *lower* due to the UMT, as the increased population growth created negative congestion effects that offset the calibrated gain in welfare arising from higher urban life expectancy.

Our calibration indicates that roughly one-third of the effect of the UMT on urbanization acted through the direct urban *amenity* effect of lower urban mortality rates. The remaining two-thirds was due to the relatively low *welfare elasticity* of informal urban areas, which allowed them to absorb a significant fraction of the additional population growth created by the UMT.

Fourth, using our calibration, we forecast urban populations and welfare forward over time. Fifty years after the UMT, poor countries still have high urban birth rates. Without declines in population growth, it appears that poor countries may continue to see rapid urban expansion, and this may occur mostly through the growth of informal locations. These urban areas could thus potentially be in a "poverty trap" of continued expansion, congestion and informality.

Finally, the importance of demographics for the future prospects of urban areas in poor countries is also apparent when we examine the effects of various policies. Family planning policies that reduce birth rates (in any location) appear to be just as effective at increasing welfare and reducing the size of informal urban areas as policies lowering congestion costs in formal urban locations via urban infrastructure investments and/or better urban institutions. In contrast, restricting migration into cities generally, or specifically into informal urban areas (e.g. slum clearance), does little but lower welfare by forcing people to remain in rural areas.

This paper adds to the literature on structural change and urbanization in several ways. First, if knowledge spillovers are the "engines of growth" (Romer, 1986, 1990; Lucas, 1988), and if cities facilitate interactions between people (Jacobs, 1969, 1984), cities should promote growth (Glaeser et al., 1992; Lucas, 2004). However, the rise of over-congested cities in poor countries raises questions about their origin and their contributions to growth. So far, little attention has been given to the growth and characteristics of cities in *low-income* countries (see Duranton, 2014b; Desmet and Henderson, 2014; Brueckner and Lall, 2015; Glaeser and Henderson, 2017, for recent surveys). With the exception of Fay and Opal (2000), Glaeser (2014) and Henderson et al. (2016a,b), the literature has focused on middle-income countries (see Au and Henderson, 2006; Desmet and Rossi-Hansberg, 2013, 2014; Duranton, 2014b; Chauvin et al., 2016; Harari, 2016). Second, with the exception of Jedwab et al. (2015), the literature has ignored the role of population growth in "poor country urbanization".[1] Yet, this explanation appears to be quantitatively important, even if it does not rule out other explanations, such as urban bias (Ades and Glaeser, 1995; Davis and Henderson, 2003), natural disasters (Kocornik-Mina, McDermott, Michaels and Rauch, 2015; Henderson, Storeygard and Deichmann, 2016a), trade (Glaeser, 2014; Gollin et al., 2015; Venables, 2016) and institutions (Glaeser, 2014; Henderson et al., 2016b). Third, locational choices are explained by both local productivities and local quality of life amenities (Rosen, 1979; Roback, 1982; Glaeser et al., 2001; Albouy, 2008, 2016; Albouy and Stuart, 2014). While the literature mostly studies how entertainment-related amenities drive city growth in rich countries, we find that a specific urban amenity – higher urban life expectancy – has directly contributed to urbanization in poor countries. The paper is thus also related to the recent literature on the economic role of urban sanitation, which has become a major topic of interest lately (Beach, Ferrie, Saavedra and Troesken, 2014; Ambrus, Field and Gonzalez, 2015; Ashraf, Glaeser and Ponzetto, 2016; Ashraf, Glaeser, Steinberg and Holland, 2017). Unlike the previous literature, we use our model to discuss the general equilibrium effects of lower urban death rates, and find ambiguous effects on welfare due to congestion. Fourth, the literature has focused on studying agglomeration effects, and says little about urban congestion in developing countries. A few exceptions are Desmet and Rossi-Hansberg (2013, 2014), Duranton (2014a, 2016) and Hanlon and Tian (2015).[2] We also document that cities in poor countries have high child dependency ratios and are low-skilled, in contrast to the literature that emphasizes that cities help disseminate knowledge (Glaeser, Kallal, Scheinkman and Shleifer, 1992; Moretti, 2004; Glaeser, Ponzetto and Tobio, 2014; Roca and Puga, 2017).

Our quantitative analysis is able to deliver clear policy prescriptions, for one of the major problems of the 21st century. Since 2015, the United Nations have adopted as their 11th *Sustainable Development Goals* the need to "make cities and human settlements inclusive, safe, resilient and sustainable." According to their website, "as more people migrate to cities in search of a better life and urban populations grow, housing issues intensify. Already in 2014, 30% of the [world's] urban population lived in slum-like conditions. [...] As population growth outpaces available land, cities expand far beyond their formal administrative boundaries. This urban sprawl can be seen in many cities around the world."[3] While many policies have been tested over the years (United Nations, 2015), our work studies the growth of slums in developing countries and highlight the potential role of family planning policies, which are not typically thought of as urban policies per se.

[1] In a related paper, Jedwab et al. (2015) study the correlations between natural increase and urbanization for a restricted sample of 40 developing countries from 1750 to date. Their work is mostly descriptive, while our theoretical analysis allows us to characterize the trajectory of urban areas in poor countries, quantify the mechanisms by which urban mortality causes urbanization, and identify policies that may alleviate the problem of poor country urbanization.

[2] Our paper connects with the literature on optimal city size (see, for example, Henderson, 1977; Abdel-Rahman and Anas, 2004; Albouy, 2008; Eeckhout and Guner, 2015; Albouy et al., 2015). Only Au and Henderson (2006), Desmet and Rossi-Hansberg (2013, 2014) and Glaeser, Ponzetto and Zou (2016) study developing countries. Moreover, these papers compare cities of different sizes, rather than considering the whole distribution of population, including the rural areas.

[3] Link to url: https://sustainabledevelopment.un.org/sdg11.

Our work also adds to the literature on the economic effects of demography. First, population growth promotes economic growth if high population densities encourage human capital accumulation or technological progress (Becker et al., 1999; Galor and Weil, 2000; Lucas, 2004; Desmet et al., 2015). But the presence of a fixed factor of production (e.g. agricultural land and urban space) implies that living standards are inversely proportional to population size. Due to congestion effects in urban areas, "Malthusian" forces need not disappear just because economies urbanize.[4] Second, the poor country urbanization outcome is one that arises perversely because of the success of interventions that limited urban death rates while urban birth rates remained relatively high. In this, our work is similar to others that emphasize the potentially negative economic effects of mortality interventions and/or the potentially positive economic impacts of mortality increases. Like Young (2005) and Voigtländer and Voth (2013b) we match a model to the data, and quantify the effects of mortality changes on welfare. Unlike Acemoglu and Johnson (2007) and Bloom et al. (2014) we do not pursue reduced form empirics. We do not have sufficient data on wages, prices, amenities, or welfare more generally, across time or locations to run regressions. Nor is there a clear strategy to identify the causal effect of urban mortality relative to overall mortality. In addition, with our analysis, we can quantify the mechanisms through which the urban mortality transition drove urbanization, and examine the impact of policies.[5]

The paper also contributes to the literature documenting demographic patterns over time (see, for example, Jones and Tertilt, 2006; De-Silva and Tenreyro, 2015; Cutler et al., 2016, for studies of aggregate fertility and aggregate mortality). Other studies of urban mortality have focused on England or the U.S. in the 19th century (e.g., Williamson, 1990; Costa and Kahn, 2006; Haines, 2008; Beach et al., 2014; Hanlon and Tian, 2015; Hanlon, 2016), whereas we track the demographic behavior of cities, urban areas, and rural areas, for many countries and over a very long period of time. In this, we contribute to the historiography of both demography and cities.

Lastly, the paper does not assume or imply spatial misallocation, unlike the literature on the urban-rural income gap and the lack of migration (Gollin et al., 2013; Young, 2013; Lagakos et al., 2017) and the broader literature on misallocation and productivity (Hsieh and Klenow, 2009; Restuccia and Rogerson, 2013; Duranton et al., 2015). While we can allow for migration restrictions that generate a suboptimal wedge in wage growth between locations, in our analysis low welfare comes from the fact that individuals do not internalize the negative externalities of their own fertility and location decisions on congestion, aggregate fertility, and living standards.

In the next section we document poor country urbanization, and the underlying demographic and economic features of the urban areas of poor countries. We then present and calibrate our

[4]The literature on the relationship of population and growth is vast (see Jones, Schoonbroodt and Tertilt (2010) and Galor (2012) for recent surveys). Barro and Becker (1989), Becker et al. (1990) and Manuelli and Seshadri (2009) provide models of the negative relationship of income and fertility. Unified growth models depend on a rise in the demand for human capital to induce sustained growth, which is driven by acceleration in technological change (Galor and Weil, 1999, 2000; Ashraf and Galor, 2011; Franck and Galor, 2015). This demand is also driven by the decline in benefits of child labor (Doepke and Zilibotti, 2005), health improvements (Cervellati and Sunde, 2005; Soares, 2005), parental education (Vogl, 2016), parental control (Tertilt and Schoonbroodt, 2016), labor market competition (Doepke et al., 2015), trade (Galor and Mountford, 2006, 2008), culture (Tertilt, 2005), or structural change (Vollrath, 2011).

[5]Other studies that consider the effect of differential mortality on population and growth include: Weil (2007); Bleakley (2007, 2010); Ashraf et al. (2013); Voigtländer and Voth (2013a).

model, and quantify the role of the urban mortality transition in the urbanization process of poor countries. The final section discusses the policy implications of the findings.

1. Stylized Facts on Urban Mortality and Poor Country Urbanization

Using data for both countries and the largest cities in the world, we document the phenomenon of poor country urbanization, the urban mortality transition, and the potential links between the two. While the theoretical analysis of Section 3. will be conducted at the country level, we establish our stylized facts using both country-level data and city-level data, since historical data on urban demography is relatively more available for cities than for countries as a whole.

1.1. Poor Country Urbanization, 1700-2010

Historical Evidence from Countries. The link between urbanization and development has evolved over time. Figure 1 plots the urbanization rate and log per capita GDP (in PPP terms and constant 1990 dollars) for all available countries circa 1700, 1900, 1950, and 2010 (see notes under Figure 1 for details on the sources). The relationship between urbanization and development is estimated and plotted separately for each year. In 1700, development was low and related to urbanization. In 1900, the relationship remained the same. By 1950, this relationship changed, with a higher slope across all countries. However, if we continue the analysis through 2010, we see a significant shift of the relationship. In the period after World War II, poor countries saw urbanization rates increase rapidly. At GDP per capita of $1,100 (7.0 in logs), the urbanization rate was on the order of 40% in 2010, whereas it had been close to 20% in 1950. Likewise, the minimum level of urbanization rose from close to zero in 1950 to 20% in 2010. At the same time, urbanization rates among richer countries has barely changed by 2010. At GDP per capita of $8,100 (9.0 in logs) urbanization rates in 2010 were around 60%, similar to their level in 1950.[6]

Historical Evidence from Cities. Table 1 shows the largest 30 cities in the world in select years from 1700 to 2015. The mega-cities of 1700 were located in the most advanced countries in that period. While London and Amsterdam had wages that were relatively high then, cities such as Beijing and Istanbul had wages equivalent to those found in cities such as Paris and Naples (Özmucur and Pamuk, 2002; Allen et al., 2011b). By 1900, the cities dominating this list were the leading cities from the richest countries, such as London, New York, and Paris. Further down, we see Boston, Liverpool, Manchester, and Philadelphia, all centers of industrialization. There were several large cities in poor countries: Beijing, Kolkata, and Mumbai. But none approached the size of the world leaders. In 1950 the top cities remained those in advanced nations, but we see the beginnings of mega-city growth in poor countries. Kolkata and Shanghai both had more than 4 million inhabitants. Beijing, Cairo, Mexico, and Mumbai were all over 2 million inhabitants. In 2015, the composition of the list is now dominated by developing countries. Only London, Los Angeles, New York, Osaka, Paris, and Tokyo are in rich countries. Poor countries have cities present on this list, such as Dhaka (Bangladesh), Karachi (Pakistan), Kinshasa (D.R.C.), Lagos (Nigeria), and Manila (Philippines). These cities all have at least 11 million people.

[6] These patterns do not appear to be driven by sample selection, mean reversion in urbanization rates, changes in the definition of urban areas, or short-term fluctuations in GDP (see Jedwab and Vollrath, 2015).

Further, city size in the past was a robust indicator of city-level living standards, but that relationship has broken down over time. For the pre-1910 period, we collected data on welfare ratios calculated using wages and price indices for minimal consumption baskets (including food, housing and clothes) in different cities (see notes under Figure 2 for details on the sources). Welfare ratios thus proxy for real wages. The 118 observations are at the city-year level, so that for several cities we have multiple observations over time. We rank all these observations based on their city size, and then we rank all these observations based on their welfare ratio, and plot the rank of welfare ratios against the rank of city size. The left panel of Figure 2 shows there was a positive relationship historically (correlation of 0.60). This is not to say that the cities of industrializing Europe or North America had high *absolute* living standards. But city size indicated something regarding *relative* living standards at the time. For the modern period, we do not have welfare ratios comparable to historical data. However, we do have a city development index for a sample of 118 cities of at least 500,000 inhabitants in 2010 (UN-Habitat, 1998, 2012). The city development index combines information on each city's per capita GDP in purchasing power parity terms, thus accounting for costs of living, and information on infrastructure, waste, health and education (details available in the UN reports). For these observations we plot the rank of living standard against the rank of size, and find a correlation of only 0.31 (Figure 2).[7]

To highlight the differences over time, several cities are shown in the right panel of Figure 2. From 1700 to 1900 both Amsterdam and London shift to the top right, indicating they were growing in relative size as they developed. New York in 1900 was one of the wealthiest and largest cities. From that point forward, however, these cities slipped down the rankings in size while maintaining their position in living standards. In comparison we have plotted a number of poor cities. Delhi in 1875, Jakarta in 1900, Lagos in 1910 and Nairobi in 1930 were all relatively small and poor. Yet they have all moved up to become some of the world's largest cities by 2010. However, this has not been associated, overall, with a move up in the rankings in living standards.

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 in parentheses the projected growth rate from 2015–2030 for each mega-city according to United Nations (2014) (see $\Delta\%2015-2030$). Rich mega-cities such as Tokyo (-0.1%), New York (0.5), Los Angeles (0.5), Paris (0.6) and London (0.7) have growth rates close to zero. In comparison, poor mega-cities similar in size to the rich mega-cities are still growing fast, such as Lagos (4.2%), Kinshasa (3.7), Dhaka (3.0) and Karachi (2.7).

Historical Evidence from Slums. While consistent historical data on slum shares does not exist, due to lack of census data, historical evidence suggests that cities in poor countries were more formal in 1950 than today (e.g. Njoh and Akiwumi, 2011; Njoh, 2013; Fox, 2014; Fox and Goodfellow, 2016; Njoh, 2016). UN-Habitat (2003a) describes how Ahmedabad, Cairo, Ibadan, Karachi, Kolkata, Lima, Mexico, Nairobi, Rio de Janeiro, and São Paulo saw a boom in their slum areas starting in the 1950s, and especially in the 1960s-1970s. For example, "17.1 per cent of Ahmedabad's population lived in slums in 1971. This rose to an estimated 21.4 per cent in 1982.

[7]The city development index is available for 204 cities in 1998 and/or 2012. However, since we have data on welfare ratios for only 118 observations pre-1910, the comparison in Figure 2 is restricted to the 118 largest cities in 2010.

The last estimate, based on a population census for the year 1991, nevertheless indicates that 40 per cent of households lived in slums." Then, the "well-planned town [of Ibadan, the 3rd largest city of Nigeria] turned into a slum. In 1963, half of the city's core area consisted of slum dwellings, growing to 70 per cent of the town's total number of derelict housing in 1985." In Karachi, the share of shacks in makeshift communities increased from 36.8% in 1978 to 51.0% in 2000. Lima's "population growth since the 1960s has been concentrated in barriadas [i.e. squatter settlements]. The barriadas housed 10 per cent of the population of Lima in 1955, 25 per cent in 1970, and probably house 35 per cent of the population today." In Nairobi between 1971 and 1995, "the share of informal-settlement village inhabitants rose from one third to an estimated 60 per cent." Marghany and Genderen (2014, p.3) writes: "25-35% of Cairo's population live in slums [...] Slums in Cairo started to rise in the 1960s with little to no formal attention or control over its crawl, the city's slum has grown to accommodate 3-5 million inhabitants of Greater Cairo today." Perlman (2006, p.156) writes: "Whereas only 7 percent of Rio's population lived in favelas in 1950, five decades later the figure had grown to 19 percent." These case studies rely on different definitions of slums, yet they all paint a similar picture of informalization in the immediate post-WW2 period.

Note that slum shares have decreased recently, as exemplified by the rapid economic development of cities in some countries (e.g., China), and as documented by UN-Habitat (2015). Nonetheless, for the poorest countries, those experiencing poor country urbanization, slum shares probably still remain higher today than in 1950. More specifically, we will focus our calibration analysis on 41 "poor" countries in 1950-2005. For these 41 countries, the average slum share actually decreased from 73.1% in 1990 (earliest available year with data) to 64.2% in 2005 according to data from UN-Habitat (2003b, 2012). However, the prior evidence suggests their slum shares increased between 1950 and 1990, and increased overall between 1950 and 2005.

1.2. The Urban Mortality Transition, from Antiquity to the Present

New Data on Urban Demography. Historically, in-migration was the dominant source of new city dwellers as the rates of natural increase were low in urban areas, typically because of high urban death rates. This can be seen in Figure 3, where we compare the crude birth rate (CBR) and crude death rate (CDR) of selected cities across different eras. We used various sources described for each country-period in Table 2 – censuses, demographic surveys, sanitary reports, and historical studies (e.g., books, theses and articles) – to reconstruct demographic data for a sample of the largest cities in the world, from antiquity to date. For most observations, the sources directly report the crude rate of birth and/or death and/or natural increase. For example, for Paris, we obtain the demographic rates: (i) in the 17th century, and the 1700s, 1750s, 1800s and 1820s from Woods (2003) and *Recherches statistiques sur la ville de Paris et le départment de la Seine*. 1826-1829. Bulletin Universel des Sciences et de l'Industrie; (ii) in the 1850s, 1880s and 1900s from *Statistique Annuelle du Mouvement de la Population. France. Statistique Generale.* 1901. Imprimerie Nationale; (iii) in the 1950s from *La Population de la France*. 1974. CICRED Series; and (iv) in the 2000s from *Recensement de la Population*. 2008. Institut National de la Statistique et des Etudes Economiques. For the 392 city-period observations in our sample, we then also obtained when possible the same demographic data for the *urban areas* and the *rural areas* of the same country-period. Note that among the 229 observations available for the pre-WWII period the rates of the corresponding urban areas are missing for 65 observations, hence our focus on the largest cities in this Section.[8]

Historical Era. We first study the 100 largest cities as of 1900, according to Chandler (1987). Panel A of Figure 3 plots the CBRs and CDRs for 38 of these cities in or before 1800 where we have data. The sample includes various pre-industrial cities such as ancient Rome, Teotihuacan, Renaissance Florence, London in the 17th century, and Boston and Philadelphia in 1750. As can be seen, CBRs were high on average (37.3 per 1,000 people), but CDRs were also high (36.9). Mortality was high due to poor water quality, inadequate waste disposal, insalubrious housing conditions, dense areas favoring the spread of contagious diseases, and frequent epidemics (Landers, 1993; Galley, 1998; Woods, 2003; Costa and Kahn, 2006; Haines, 2008; Clark and Cummins, 2009; Voigtländer and Voth, 2013b; Ambrus et al., 2015; Ashraf et al., 2016). As a result, the cities all lie near the 45-degree line, indicating that they experienced no natural increase (0.4, i.e. 0.04% per year).[9]

Panels B-D show that cities remained near the 45-degree line in the first and second half of the 19th century (Panel B: 1820s-1850s; Panel C: 1880s), and at the turn of the 20th century (Panel D: 1900s), using available data from the 100 largest cities in 1900 (33, 69 and 89 observations, respectively). City natural increase was still low on average, at 5.0-6.1 per 1,000 people (0.5-0.6% per year). The samples include various emblematic cities of the Industrial Revolution, such as Boston, Liverpool, Manchester, New York and Philadelphia (see Panel C; 1880s), cities which all had high CDRs due to industrial pollution in addition to the factors listed in the previous paragraph (Williamson, 1990; Steckel and Floud, 1997; Haines, 2004; Hanlon and Tian, 2015; Hanlon, 2016; Beach and Hanlon, 2017).[10] Their growth, which averaged 3% per year in the 19th century, mostly occurred through in-migration (Williamson, 1990; Jedwab et al., 2015). In the developing world during the same period, CBRs and CDRs were also high, and rates of natural increase low, as seen for Beijing, Cairo, Delhi, Kolkata, Mexico and Mumbai in Panel D (1900s).

Modern Era. In the post-war period, there was a distinct change in city demographics. In Panels E and F, we study the 100 largest cities of the future – in 2030 according to projections by the United Nations (2014) –, and show their CBRs and CDRs when available in the 1960s (N = 63) and the 2000s (N = 100) respectively. We choose the largest cities of 2030, and not of 2017, in order to include more mega-cities from poor countries. Indeed, based on the data from United Nations (2014), many African and Asian mega-cities that are not yet in the top 100 will be so in the next decade (e.g. Addis Ababa, Dakar, Faisalabad and Hanoi). Our focus is on poor country urbanization, hence the need for our sample to be representative of poor countries.[11]

Focus first on the relatively rich cities in the lower left of Panel E, in the 1960s (e.g., London,

[8]For the oldest location-periods, we sometimes use the work of anthropometrists who studied graves and skeletons to obtain data on fertility (i.e. crude birth rates) and life expectancy (i.e. crude death rates). The exact source (author-date-title-publication) for each location-period is available from the authors upon request.

[9]All the points in Panel A represent "normal" periods, but each city was at times afflicted by severe shocks to mortality. For example, during the Black Death, cities had death rates of 250-750 (i.e. 25-75%).

[10]We were able to find historical data for many industrializing cities, such as Amsterdam, Antwerp, Baltimore, Berlin, Birmingham, Boston, Brussels, Chicago, Detroit, Glasgow, Hamburg, Leeds, Liverpool, London, Manchester, Milan, Montreal, Munich, Newcastle, New York, Osaka, Paris, Philadelphia, Pittsburgh, St. Louis and Tokyo.

[11]Graphical results are similar if we restrict our sample to the cities that were also among the top 100 cities in 2015.

New York and Paris). Their CBRs fell along with their CDRs, and so their rate of natural increase remained small. Overall, it is apparent from Panels A to E that historically cities were "sliding down" the 45 degree line as they grew. In comparison are the nascent poor mega-cities in the upper left of Panel E, well above the 45 degree line. In the 1960s these cities differed from earlier eras in one distinct way: their CDRs were very low. Dhaka, Karachi, Kinshasa and Lagos, despite being in countries with much lower income levels, all had CDRs that were similar to those seen in London, New York or Paris in the same year. Developing mega-cities in the 1960s were mainly "shifted left". This can also be seen by comparing the respective locations of Cairo, Delhi and Mexico in Panels D (1900s) and E (1960s). This led to large rates of natural increase for emerging mega-cities. For example, in the African cities in the figure, rates of natural increase were roughly 3.5% per year. Even absent migration, these cities would have doubled in size every 20 years.

This difference continued in the 2000s (Panel F). Rich mega-cities remained in the same position as in the 1960s. Poor mega-cities shifted down to lower CBRs. However, the CDRs in poor mega-cities were lower than the historical comparisons, for the most part falling below 10 per thousand. Thus in the 2000s poor mega-cities continued to have rapid rates of natural increase (e.g., Karachi, Kinshasa, Lagos and Manila). A notable exception were Chinese cities (e.g. Beijing), which in the 1960s (Panel E) looked similar to other developing cities, but moved in the 2000s (Panel F) to a pattern of CDRs and CBRs similar to rich mega-cities. One other outlier is Johannesburg, which has a high CDR due to HIV.

Mortality transition. The deviation of developing cities from the historical norms appears due to the *mortality transition*. Following World War II (WW2), there was a sudden improvement in health in poor countries (Stolnitz, 1955; Davis, 1956; Preston, 1975), due to: (i) the discovery of effective techniques for mass production of antibiotics such as penicillin (1942) and streptomycin (1946), which treated diseases such as cholera and dysentery, (ii) the invention of vaccines against the yellow fever (1937), poliomyelitis (1962) and measles (1963), (iii) the creation of the World Health Organization (1948), which disseminated knowledge to poor countries, and (iv) disease eradication campaigns, whether against smallpox or malaria. From the perspective of the poor countries of that period, this *international epidemiological transition* represented an exogenous shock to mortality, as argued by Acemoglu and Johnson (2007). On p.935-936, they write that "until 1940 there were limited improvements in health conditions in most of the Americas, Africa, and Asia" and that the factors listed above "caused a dramatic improvement in life expectancy in much of the world, especially in the lesser-developed parts of the globe, starting in the 1940s."

Urban mortality transition (UMT). The left panel of Figure 4 shows the average crude rates of birth, death and natural increase for the mega-cities, the urban areas and the rural areas in our full sample of 392 observations. The urban areas, which include all cities, have experienced the same patterns as for the mega-cities only, with CBRs being stable until recently and CDRs decreasing over time. Another consequence of the UMT was to raise rates of natural increase in urban areas up to the rates typically seen in rural areas. Rural natural increase was already high before the 20th century (Panel C), due to high rural CBRs (Panel A) and low rural CDRs (Panel B).

In the right panel of Figure 4 we focus on the sample of 167 observations in developing countries – based on their 2015 GDP per capita, i.e. the countries whose income level is below the income of Slovakia, one of the last countries to have become a developed country according to the International Monetary Fund.[12] The urban CBR has remained high at around 40 until the 1960s, after which it decreased to 20 (Panel A). The UMT is clearly apparent now, with urban CDRs falling from 30 in the 1900s to 15 in the 1960s (Panel B). As a result, the urban crude rate of natural increase dramatically increased from 7.5 in the 1900s to 25 in the 1960s (Panel C).

Note that restricting the sample to only observations from developing countries today helps us minimize compositional biases potentially arising from using different lists of cities over time (the top 100 cities in 1900 and 2030 for the pre-1900 and post-1900 periods respectively). We also find similar patterns if we only use observations for cities that will be in the top 100 by 2030 or cities that were in the top 100 in 1900 (not shown, but available upon request).

The disproportionate mortality changes seen in the urban areas of developing countries post-WW2 are due to the facts that the international epidemiological transition first diffused to their "modern" areas and that colonizers significantly invested in urban public health by building water supply and sewerage systems and managing urban health centers aimed at preventing disease outbreaks (Njoh and Akiwumi, 2011; Njoh, 2013; Fox, 2014; Fox and Goodfellow, 2016; Njoh, 2016). Garenne (2016, p.181-182) writes that "before and in the early stage of the [health] transition [in Europe], urban mortality was higher, sometimes much higher, than rural mortality. This is often called the 'urban penalty', or the 'urban graveyard effect' [...] The situation in developing countries is very different, since they started their health transition much later. Cities could benefit from the start from modern health and medical technology, and as a result, by 1950 urban mortality was lower than rural mortality in most developing countries." Likewise, May (2012, p.4) writes that "Before World War II, colonial powers as well as independent governments in Asia, Africa and Latin America had adopted public health measures, launched disease vector control programs, and improved schooling, nutrition and sanitation (e.g., water purification, drainage, and waste treatment). They had also organized targeted campaigns to bring down high mortality levels, most notably in urban areas. These efforts have undoubtedly accelerated the epidemiological transition". Lastly, Gould (2015, p.100) writes that "before the 1950s and 1960s formal medical care was concentrated in large hospitals, mainly located in urban areas. In Africa this was a legacy of colonial medical systems, directed initially to serve the needs of the colonisers or colonial administrators, and thus was quite the opposite of an urban penalty. Urban population had better access to better services, in addition to better public health measures."

In the model and calibration sections, we will focus on the urban mortality transition, although there was also a slow rural mortality transition, as rural rates of natural increase gradually increased. Based on our data, and the analysis above, we will use as initial pre-UMT conditions in 1950 a CBR of 40 in the urban areas and 43 in the rural areas (1960s in Panel A of the right panel) and a CDR of 40 in the urban areas and 20 in the rural areas (in order to take the rural mortality

[12] Link to url (see April 2009): https://www.imf.org/external/pubs/ft/weo/data/changes.htm.

transition as given). We will then study the effects of a reduction in the urban CDR from 40 to 15. 40 was the urban CDR of the poorest countries in our sample in the 1900s, before the UMT took place circa 1950. 40 was also the urban CDR of developed countries before they started developing with the Industrial Revolution (e.g., England in 1750, and also see Panel A of Figure 3 for selected pre-industrial cities). 15 was the urban CDR of poor countries in the 1960s, after the UMT.

Population Growth. Panel C also shows the mean population growth rate of the entire country (see *Total*). Population growth accelerated between 1900-1960. When crudely decomposing the change in total natural increase for the developing countries of the right panel between the 1900s and the 1960s into its two main sources, urban natural increase and rural natural increase, we find that half of it could be explained by the former (details available upon request). The urban rate of natural increase dramatically increased during the same period. In addition, these countries also slightly urbanized between 1900-1960. Had urban natural increase remained lower than rural natural increase, this increased urbanization would have slowed population growth. But since urban natural increase was high, urbanization increased total population growth.

Demography in Formal vs. Informal Areas. How much of urban natural increase comes from the informal areas versus the formal areas of cities will prove important when quantifying the effects of the UMT in the model section. To answer this question, we used similar sources as for the largest cities to obtain the CBR and CDR of the slum areas of four industrializing cities in the late 19th century: London in 1886, Manchester in 1894, New York in 1890-1895 and Paris in 1864. Knowing the city population share of the slum areas, we reconstruct the demographic rates of the non-slum areas. For London (1886), we use data for the 7 *Sanitary Districts* of the East End from British Medical Journal (1887, p.855). For Manchester (1894), we use data for the *Township* areas from The Lancet (1894, p.824). For New York (1890-1895), we use data for the 8 *Great Tenement House Districts* from New York Department of Health (1897, p.404) and Census Office (1895, p.11). For Paris (1865), we use data for the 7 *Arrondissements pauvres* from Vacher (1866, p.57-59). We then do likewise for seven poor mega-cities today (Cairo, Dhaka, Karachi, Manila, Mexico, Mumbai and Naibori).[13] Note that we could not find data for more cities, or for the slums of *all* urban areas, as such data usually do not exist. For example, the widely used *Demographic and Health Surveys* only report child mortality rates (so not CDRs) for peri-urban areas (so not necessarily slums). The other caveat is that there are different definitions of slums. However, we use data for areas that are widely recognized as slums by local authorities and academic studies. In the following paragraph, we use the average of each set of cities (industrializing cities; poor mega-cities) to discuss the slum share. Since there is not much variation in demographic rates within each sample, removing specific cities should not change the averages in a meaningful way.

In the late 19th century, both slum and non-slum areas had low rates of natural increase, at 0.8-0.9% per year. Slum CBRs were high (at 36.4 per 1,000 people), but slum CDRs were also high

[13] For example, for Nairobi, we obtain birth rate data from *Population and Health Dynamics in Nairobi's Informal Settlements Report of the Nairobi Cross-sectional Slums Survey* of 2012 (p.23) and death rate data from Abdhalah K Ziraba and Ezeh (2013, p.1) who use data from the INDEPTH standard survey (2003-2007). For Karachi, we obtain the CBR and the CDR of Orangi, by far Karachi's largest slum, in 2003 from Hasan (2003, p.25) who use various Health Surveys.

(28.7). In the poor mega-cities of today, the rates of natural increase are higher, at 1.1% per year in the non-slum areas and 2.7% per year in the slum areas. Slum CBRs are similar to our historical cities (at 33.7 per 1,000 people), but slum CDRs are now almost as low in the non-slum areas (6.8). Natural increase is thus disproportionately higher in slums now, which suggests that poor mega-cities are likely to remain informal in the future. Given the fact that natural increase has barely changed in non-slum areas (1.1% today vs. 0.8% in the late 19th century), simple decompositions show that almost 95% of the change in urban natural increase between the late 19th century and today could potentially be explained by the higher rate of natural increase in slums.

1.3. The Urban Mortality Transition, Urban Growth, and Urban Congestion

We now document how measures of urban growth, congestion and poverty relate to urban natural increase in our sample corresponding to the 100 future mega-cities. Please note that the correlations in the figures do not necessarily show causal relationships. Our goal is simply to characterize the conditions for a self-reinforcing trajectory in poor country urbanization.

Urban vs. Rural Natural Increase. Figure 5.A plots the growth rates of the urban population and the rural population between 1950-2015 (source: United Nations (2014)) against their respective rates of natural increase in the 1960s. The relationship is strongly positive for urban areas (slope β of 0.13***; R-squared of 0.62), which indicates that urban natural increase may have been a meaningful driver of urban growth. The correlation is significantly weaker for rural areas (slope β of 0.05**; R-squared of 0.10), which suggests that rural natural increase may not necessarily increase rural population size. One possible interpretation is that when rural areas become "congested" due to rural natural increase, rural residents can move to the urban areas, as if they serve as a "safety valve". The quantitative analysis below will show that when population growth is high the extra population is likely to reallocate itself into the urban areas.

Total Natural Increase. Figure 5.B plots the growth rates of the urban population and the rural population between 1950-2015 (source: United Nations (2014)) against the rate of natural increase for the whole country in the 1960s. As before, the relationship is strongly positive for urban growth (slope β of 0.12***; R-squared of 0.44), and weaker for rural growth (slope β of 0.06***; R-squared of 0.17). When population grows fast, urban areas grow disproportionately faster than rural areas. This suggests that the urban areas may help absorb the extra population growth.[14]

Urban areas that grow through natural increase possibly differ from urban areas that grew through in-migration. Figures 5.C-5.H plot several characteristics of urban areas, or megacities when data is not available for the urban areas, against their rate of natural increase in the 1960s.

Population Density. First, in figure 5.C is log density, which shows a positive relationship (source: Demographia (2014)). Rich mega-cities such as New York (2,000 inh. per sq km), London (6,000) or Paris (4,000) are much less densely populated than poor mega-cities such as Dhaka

[14] Another consequence of the fall in urban mortality was that the absolute growth of cities expanded to previously unseen levels. For each of the 30 largest cities in 2015 (Table 1), we collected information on the largest annual change in population experienced by the city, as well as the decade this occurred. Poor mega-cities such as Delhi (620 thousand; 2000s), Dhaka (440; 2000s), Karachi (410; 2000s) and Lagos (350; 2000s) added population at rates well above those seen in historical mega-cities such as London (90; 1890s), New York (220; 1920s) and Paris (110; 1950s).

(44,000), Karachi (23,000) or Kinshasa (17,000). While density is used as a proxy for economic development when comparing the cities *within* a country, it may measure underdevelopment when comparing the cities *across* countries. Consistent with the literature showing that the income elasticity of housing demand is positive (see Rosenthal and Ross, 2015), people consume more housing space in wealthier cities, which contributes to lower densities in rich countries.[15]

Slums and Infrastructure. This density is potentially indicative of congestion rather than strong agglomeration effects. Figure 5.D shows that national slum shares are much higher in countries with high urban natural increase (sources: UN-Habitat (2003b, 2012); R-squared of 0.40). Roughly two-thirds of the urban residents live in slums in Bangladesh, the D.R.C., Nigeria and Pakistan. Figure 5.E also shows the strong negative correlation between the "city infrastructure index" designed by UN-Habitat (1998, 2012) — which combines information on access to water, sanitation, electricity, roads, and housing (details available in the reports) — and city natural increase (R-squared of 0.63). This is not surprising considering that poor mega-cities with high natural increase had annual growth rates of 3-7% in 1950-2010, thus doubling in population size every 10-25 years (vs. only every 35 years on average for rich mega-cities during the Industrial Revolution, see Jedwab et al. (2015)). If infrastructure and housing investments did not also double every 10-25 years, this could explain why poor mega-cities are so "congested" today.

Dependency Ratios and Human Capital. The high density in urban areas growing through natural increase does not indicate a large supply of productive workers. Figure 5.F shows the urban child dependency ratio (the share of those under 14 to population aged 15-64) across our sample of countries in the 2000s (source: reconstructed for all urban areas using the *Demographic and Health Surveys* (DHS) and census information from IPUMS). In countries with high urban natural increase in the 1960s such as the D.R.C., Nigeria, Pakistan and Tanzania, this ratio reaches more than 50 percent (R-squared of 0.21, but R-squared of 0.74 if we use urban natural increase in the 2000s instead, since the age structure is by construction more strongly determined by current demographic rates). Further, the labor force that does exist in these urban areas is low skilled. In poor countries such as the D.R.C, Nigeria, Pakistan and Tanzania, the urban share of college-educated workers is close to 5-10% (Figure 5.G; sources: DHS and IPUMS). Thus, these urban areas have relatively fewer workers, and the workers they have are relatively less skilled.

Economic Development. Lastly, in Figure 5.H, we show that city natural increase in the 1960s correlates negatively with the "city development index" of UN-Habitat (1998, 2012) for the 2000s (R-squared of 0.44). It could be that urban areas/mega-cities that grow through natural increase are poor because they are highly congested, whether in terms of housing, infrastructure, children or unskilled workers. Or CBRs could remain high in poor urban areas/mega-cities, because their residents do not have the incentives to have and invest in fewer children.[16]

[15]Densities are defined using both the population and the area of the agglomeration. Focusing on the central place or slums should not affect the results. Manhattan's density is 28,000 people per sq km. However, poor mega-cities contain areas with even higher densities. The slums of Mumbai, Nairobi, Dhaka and Cairo have densities of 350,000, 300,000, 200,000 and 110,000 respectively. The Lower East Side in New York was the densest slum of the U.S. (140,000 in 1910). Other slums in rich cities were less dense: Les Halles in Paris (100,000) and the East End in London (90,000).

[16]Results hold if we use data on the housing price-to-income ratio, rent-to-income ratio, floor area per person, persons per room, squatter housing, access to water, waste management, commuting, total dependency ratios (the share of

Urban Areas vs. Rural Areas. Note that one should not necessarily expect to observe the same relationships for the rural areas (or the country as a whole). First, we only find a weak correlation between rural population growth and rural natural increase. Additionally, the relationship between natural increase and child dependency ratios is stronger for the rural areas than for the urban areas (not shown, but available upon request). If rural-to-urban migrants leaving congested rural areas are mostly of working-age, rural areas are disproportionately left with children. Poor megacities today also have higher child dependency ratios than rich megacities in the past. The ratios for Bamako, Karachi and Kinshasa are 72%, 63% and 70% respectively. This is higher than the same ratios for London in 1851 (45%; source: 1851 census), New York in 1870 (50%; source: *1870 census*), and close to ratios for the rural areas of the UK and the U.S. in the same years (65% and 70% respectively). Lastly, the gap between urban and rural tertiary completion rates are smaller for countries with a high rate of natural increase (not shown), thus suggesting that urban areas are not that different from their rural areas. Poor megacities today also have lower literacy rates than rich megacities in the past. When using the DHS and IPUMS, the literacy rates that we obtain for Bamako, Dakar, Dhaka and Karachi are 43%, 48%, 67% and 62% respectively. This is lower than the literacy rate for London in 1851 (80%; source: 1851 census), and New York and the rural areas of the U.S. in 1870 (95% and 80% respectively; source: 1870 census).

Overall, the urban areas growing through natural increase appear to be developing as "giant villages" rather than as high-productivity agglomerations. This seems to hold for mega-cities as well, although they often constitute the most "modern" urban areas of their countries.

2. A Model of Demographics, Locational Choice and Growth

To understand how the urban mortality transition (UMT) could have contributed to poor country urbanization, we build a general equilibrium model of location choice with heterogeneity in demographics and the effect of population growth on welfare. Heterogeneity in the welfare effect of population means that aggregate population growth influences the distribution of population. With people moving between locations, the growth in welfare will be equalized across locations. But because the welfare elasticity with respect to population varies, locations with low elasticities absorb a larger share in population than locations with high elasticities. This interacts with a preference by individuals for locations with low mortality. The UMT, which boosted population growth rates, accelerated the shift of population into low-congestion locations, and also made urban locations more desirable to live in, accelerating the move of population into urban areas.

2.1. Individual Utility

We assume that all individuals in the economy are identical, except that they reside in a specific location j from a given set J. Their utility is determined by

$$V_j = \ln w_j + \ln Q_j + \beta \ln(1/CDR_j). \tag{1}$$

w_j and Q_j refer to the net wage and amenities, respectively, in location j. By net wage, we mean

those under 14 or above 65 to population aged 15-64), primary and secondary completion rates, informal employment, unemployment, and poverty (not shown, but available upon request). The main sources used are the first version (1993) and second version (1998) of the *Global Urban Indicators Database* of UN-Habitat, as well as the DHS and IPUMS.

the wage net of housing and commuting costs. CDR_j is the crude death rate in location j to which an individual is exposed, and hence $1/CDR_j$ can be seen as a measure of life expectancy.[17] The utility function captures the standard Rosen-Roback trade-off of net wages and amenities. β measures the utility weight of life expectancy.[18] Taking as given the sets of (w_j, Q_j, CDR_j) in each location, individuals move between locations until V_j is equalized across locations.

2.2. Agglomeration, Congestion, and the Distribution of Population

Let

$$\begin{aligned} \ln w_j &= \ln a_j^w - \epsilon_j^w \ln N_j \\ \ln Q_j &= \ln a_j^Q - \epsilon_j^Q \ln N_j \end{aligned} \tag{2}$$

where a_j^w and a_j^Q are the exogenous determinant of net wages and amenities in location j, respectively. Both terms may grow over time, and are meant to capture the determinants of wages or amenities that do not depend on population size in location j. ϵ_j^w and ϵ_j^Q are the elasticities of wages and amenities, respectively, with respect to population size in location j, N_j.

Given the specification in (3), we can write the utility function more concisely as

$$V_j = \ln a_j - \epsilon_j \ln N_j - \beta \ln CDR_j, \tag{3}$$

where

$$\begin{aligned} \ln a_j &= \ln a_j^w + \ln a_j^Q \\ \epsilon_j &= \epsilon_j^w + \epsilon_j^Q \end{aligned} \tag{4}$$

are combined terms that capture the location-specific determinants of wages and amenities ($\ln a_j$) and the *location-specific elasticity of welfare with respect to population size* (ϵ_j). The elasticity ϵ_j captures the response of welfare to population size, combining a number of effects. The number of workers will affect nominal wages through the production function for output. Population size will affect housing prices and commuting costs through the production functions for housing and transportation. Finally, the number of people affects the welfare value of amenities, depending on the production function for those amenities. ϵ_j is a reduced form effect of population on welfare, and we are not attempting to derive a micro-founded model of the production of output, housing, transportation, and amenities. Rather, our interest is in examining the implications of population growth on the distribution of population across locations, given those underlying elasticities.

Given the specification in (3) we can now describe the conditions for the equilibrium distribution of individuals across locations.

1. **Labor mobility**. Individuals move costlessly between locations, implying that $V_j = \overline{V}$ for all locations j, where $\overline{V}$ is the equilibrium level of utility.
2. **Stability**. $\epsilon_j > 0$ for all locations j.
3. **Adding up**. $\sum_{j=J} N_j = N$. This closes the model and determines $\overline{V}$.

[17]We do not have the data to do age-specific death rates separately by location, so we proceed as if the death rate is constant at all ages. In this case the mapping from the death rate to life expectancy is exact.

[18]The implied utility weight on wages and amenities is identical, as in Desmet and Rossi-Hansberg (2013). However, the choice of using the same weight for wages and amenities is irrelevant to the results.

The condition regarding stability states that for each location the effect of population on welfare is negative. With this assumption, the equilibrium is stable to any perturbations. If one person were to randomly move away from location j to location k, then welfare would rise in location j and fall in location k. Given labor mobility, this would incent someone to move back from k to j, restoring the original equilibrium. In contrast, if $\epsilon_j < 0$ and hence welfare is *increasing* in population size, then if someone leaves location j for location k, welfare in j actually *falls*, but *rises* in location k. This would incent more migration away from j and into k, meaning the original equilibrium was not stable. With the assumption of free mobility and all $\epsilon_j > 0$, this implies that the economy is at a stable location equilibrium. The exact allocation across locations will change over time due to changes in demographic conditions, changes in the level of wages/amenities, and as we will see below, changes in the aggregate population.

This does not exclude the possibility of, or assume away, agglomeration effects. There may be agglomeration effects at work, but as in standard models of urban areas (Henderson, 1974; Duranton and Puga, 2004) the allocation of population across locations will only be stable if agglomeration effects are more than offset by congestion effects or diminishing marginal returns to labor. One could imagine that agglomeration effects dominate congestion and the impact of fixed fators in some locations within low-population countries (Becker et al., 1999; Desmet et al., 2015). While this hypothesis may apply to prehistorical, antique and medieval societies that were characterized by low population densities, they do not characterize well poor countries in the 20th century, which were already densely populated by the time of the UMT.

Denote the growth rate of any variable X by using a "hat", so that $\hat{X} = \dot{X}/X$. Then we can write the growth rate of welfare in location j as

$$\hat{V}_j = G_j - \epsilon_j \hat{N}_j - \beta C\hat{D}R_j \tag{5}$$

where

$$G_j = \hat{a}^w_j + \hat{a}^Q_j. \tag{6}$$

G_j captures changes in welfare unrelated to the population growth rate of location j. In the calibrations, we will not distinguish wages and amenities due to a lack of data. However, fast population growth crowds out both productive and consumption amenities. Therefore, the effects in terms of amenities should reinforce the effects in terms of wages. Not being able to distinguish wages and amenities is thus not essential here.

2.3. The Dynamics of Location Size and Welfare

At this point, we can establish several results regarding population, location, and welfare, and how they relate to changes in location-specific mortality rates.

The effect of aggregate population growth on welfare. Define the share of population in location j as $s_j = N_j/N$. By definition, the growth rate of aggregate population, N, can be written as the weighted sum

$$\hat{N} = \sum_{j=1}^{J} s_j \hat{N}_j. \tag{7}$$

If we rearrange (5) we have that $\hat{N}_j = (G_j - \beta C\hat{D}R_j - \hat{V}_j)/\epsilon_j$ for each location. Inserting this into (7) yields the following relationship

$$\hat{N} = \sum_{j=1}^{J} s_j \frac{G_j - \beta C\hat{D}R_j - \hat{V}_j}{\epsilon_j}. \tag{8}$$

To proceed further, note that because individuals are fully mobile over locations, it must be the case that $\hat{V}_j = \hat{V}$ for any location. Using that fact, we can solve for

$$\hat{V} = \overline{\epsilon} \left[\sum_{j=1}^{J} \frac{s_j}{\epsilon_j} \left(G_j - \beta C\hat{D}R_j \right) \right] - \overline{\epsilon}\hat{N} \tag{9}$$

where

$$\overline{\epsilon} = \frac{1}{\sum_{j=1}^{J} \frac{s_j}{\epsilon_j}} \tag{10}$$

is the harmonic mean of the elasticities across all locations. Note that by the assumption that $\epsilon_j > 0$ for all locations, it must be that $\overline{\epsilon} > 0$ as well.

Aggregate welfare growth is similar to welfare growth in any given location. It depends on a weighted sum of the location-specific rates G_j and crude death rates $C\hat{D}R_j$, where the weights depend both on their share in population, s_j, and their elasticities, ϵ_j. A higher elasticity ϵ_j mutes the effect of any given G_j, because the high elasticity means that the growth of the population in that location cannot be very large without lowering welfare. On the presumption that $\beta > 0$, declines in the crude death rate in any location, $C\hat{D}R_j < 0$, also contribute positively to welfare.

Finally, *aggregate* population growth, $\hat{N}$, detracts from welfare growth in all locations, with the size of the effect depending on $\overline{\epsilon}$, the aggregate elasticity.

The effect of aggregate population growth on the distribution of population. Using the aggregate welfare growth in (9), we can combine that with (5) to solve for the location-specific growth rate of population in location i as

$$\hat{N}_i = \frac{\overline{\epsilon}}{\epsilon_i} \left(\hat{N} + (G_i - \beta C\hat{D}R_i) - \sum_{j=1}^{J} \frac{s_j}{\epsilon_j} \left(G_j - \beta C\hat{D}R_j \right) \right). \tag{11}$$

Aggregate population growth, $\hat{N}$, is positively related to population growth in location i. Regardless of where new people originate, the additional population is spread across locations to ensure that welfare is equalized. The strength of $\hat{N}$ on $\hat{N}_i$ depends on the ratio $\overline{\epsilon}/\epsilon_i$, the aggregate elasticity relative to the location-specific elasticity. When $\epsilon_i < \overline{\epsilon}$, location i will tend to grow faster than the aggregate population, and hence its share of the population will increase. ϵ_i is the percent loss of welfare for a percent gain in population, so the lower is ϵ_i, the higher the percent gain in population a location can absorb while still maintaining similar welfare growth to other locations. The logic for a location with $\epsilon_i > \overline{\epsilon}$ is just the opposite, and these locations will grow slower.

In both cases, however, these direct effects of population growth are potentially offset or exaggerated by differentials in welfare growth from G_i, and changes in crude death rates $C\hat{D}R_j$. The second two terms in (11) capture the difference between these individual effects and their aggregates across locations. If $(G_i - \beta C\hat{D}R_i) > \sum_j (G_j - \beta C\hat{D}R_j)s_j/\epsilon_j$, then location i will grow relatively quickly as people move there to take advantage of its higher productivity, better amenities, and/or lower mortality.

Regardless, the speed of aggregate population growth will always influence the growth rate of locations. To be more concrete, the share of population in each location, s_i, evolves according to the following simple relationship

$$\hat{s}_i = \hat{N}_i - \hat{N}. \tag{12}$$

The derivative of the growth rate of population share, $\hat{s}_i$, with respect to aggregate population growth, $\hat{N}$, can be found using (11),

$$\frac{\partial \hat{s}_i}{\partial \hat{N}} \begin{cases} > 0, & \text{if } \epsilon_i < \bar{\epsilon} \\ < 0, & \text{if } \epsilon_i > \bar{\epsilon} \\ = 0, & \text{if } \epsilon_i = \bar{\epsilon} \end{cases} \tag{13}$$

Unless all locations have identical values of ϵ, then there must exist at least one location with $\epsilon_i > \bar{\epsilon}$ and one with $\epsilon_i < \bar{\epsilon}$. Heterogeneity in elasticities across locations implies that the aggregate population growth rate influences the distribution of population across locations.

Amenity effects of mortality changes on the distribution of population. As can be seen in (11), if the death rate in location j is falling, $C\hat{D}R_j < 0$, then this will increase the growth rate of population in location j as individuals move there to take advantage of it. The strength of this effect depends on the ratio of $\bar{\epsilon}/\epsilon_j$, not only on the size of β, the utility weight on life expectancy. Hence changes in crude death rates in low elasticity locations will result in bigger shifts of population than will changes in death rates in high elasticity locations.

Effects of population growth on future population growth. The full consequences of population growth depend on how the changing distribution of population influences population growth itself. Each location has an exogenous birth rate, denoted CBR_j. We will explore extensions of this to allow for endogenous changes in birth rates after showing the calibrations. Aggregate population growth is dictated by these birth rates combined with the death rates, CDR_j,

$$\hat{N} = \sum_{j=1}^{J} s_j \left(CBR_j - CDR_j \right). \tag{14}$$

The shares s_j are the way in which aggregate population growth is endogenous in the baseline model. As population shares change, this may lower or raise $\hat{N}$ itself depending on the pattern of child costs or death rates across locations. If higher population growth leads to a shift into locations with lower child costs or death rates, then it will accelerate population growth, which would imply even further shifts of population into that location. The possibility exists that population growth begets more population growth, and leads to a concentration of population in a low-elasticity location.[19]

3. The Role of the Urban Mortality Transition

We now use the model constructed in the prior section, and calibrate it to match the observed experience of poor countries so that we can perform counterfactuals. To begin, we must be more specific about what we mean by locations, so that we can match them up to available data. We will work with three locations: *rural, formal urban, and informal urban*, which we think of as differing along several dimensions: production, housing, transportation, and amenities.[20]

The *rural* location (denoted by subscript r below) involves production of not only agriculture, but also service or manufacturing activities of rural residents. Housing consists mainly of individual houses, with few space constraints. There are few organized transportation networks or amenities. In comparison, the *formal urban* location (denoted by subscript f below) operates a "modern" sector production technology. Manufacturing and professional services would be examples of what we have in mind. Housing involves multi-unit buildings, and faces both physical and institutional (i.e. zoning) constraints. Transportation and amenities are organized centrally to some extent. Finally, the *informal urban* location (denoted by subscript l below) is located in an urban area and involves a production technology that involves low-level personal services. Housing faces some space constraints, but is not subject to strict institutional limits, and consists mainly of individual houses (e.g., shacks). Transportation and amenities are either absent or organized unofficially. Slums are an example of an informal location, although we think the idea of informal locations may encompass more than those places defined as slums.[21]

3.1. Externally Set Parameters

To continue, we need to know the values of the parameters in the model. For many of them, we are able to rely on outside sources, or the data we collected and described in Section 1.. The top panel of Table 3 summarizes the values we describe in this section.

Crude death rates (CDRs). As discussed in Subsection 1.2., the initial CDR in 1950 for both urban locations is set to 40 (per thousand). After the UMT is completed, the CDR for both urban formal and informal locations is set to 15. To capture the onset of the UMT we let the urban CDRs decay exponentially from 1950 forwards, with a half-life of 3 years. This implies that by 1959, urban

[19] Ways to endogenize population growth would work through the parameters related to child costs or the death rate itself. Following Becker (1960) - through income effects - or Galor (2011) - through the value of human capital - we could introduce changes to child costs related to the composition of population across locations. Changes in mortality rates (Kalemli-Ozcan, 2002; Soares, 2005), by changing the expected value of children, would be an alternative way of modeling endogenous population growth changes. We explore some of these possibilities after the baseline calibration.

[20] One could easily allow for a large number of smaller locations that fall under each category; there could be multiple rural locations, for example. We are assuming that all of those smaller locations of a given type have a common growth rate, G_i, and a common elasticity, ϵ_i. With that being the case, examining (9) and (11) it is clear that tracking the individual locations will not offer any additional information beyond that found in tracking the three major categories.

[21] While the characteristics of locations differ, we assume that all individuals are homogenous, and do not have location-specific preferences or skills. For example, we do not assume that people born in informal locations have preferences for or are more capable of working in formal locations than people born in rural areas. We do not have the data to track individuals by their location of origin, or a way of measuring location-specific skills for individuals.

CDRs are only 18.25. For the rural location, we set the CDR to be 20, in line with our data, and that is held constant over the entire period from 1950 to 2005. Our calibration thus takes the *rural* mortality transition as a given, so that we can focus on the effects of the UMT.

Crude birth rates (CBRs). We use information from the demographic data presented earlier, along with the crude rates of natural increase in our sample of 41 poor countries over time, to set the time path of crude birth rates. For 1950, we set the initial rural CBR to 43 (per thousand), the informal CBR to 43, and the formal CBR to 38. These initial CBRs combined with our initial CDRs mean that our model matches the observed crude rate of natural increase in 1950 in our sample.

For the 41 countries, there was a demonstrable rise in the aggregate crude rate of natural increase from 1950 to roughly 1985, and then it began to decline. The crude rate of natural increase was 22.2 in 1960, rose to 28.7 in 1985, and then fell to 25.2 in 2005. This fluctuation was largely due to changes in CBRs. To capture this, we parametrically set the changes in crude birth rates in the model to match the observed behavior in our sample. Specifically, we use the following quadratic

$$\Delta CBR_{t+1} = \phi_1 \times t + \phi_2 \times t^2. \tag{15}$$

Fitting this to the observed sample data, we set $\phi_1 = 0.286$ and $\phi_2 = -0.0041$. We will discuss below the nature of these changes in the birth rate, as they are likely related to the changes in the death rates from the UMT. For the purposes of calibrating the model, however, we require the actual time path of the birth rates to match the data.

Productivity and amenity growth. The exogenous rate G_i in a location includes the growth of net wages and amenities unrelated to population size. Separate data on the growth of net wages and amenities does not exist. For our purposes, assigning the *relative* values of G_i across locations is most important, as these will dictate the movement of people across locations, and allow us to determine the *change* in welfare growth between different counterfactual scenarios. The absolute size of the the G_i terms will dictate the absolute growth in welfare over this period, something we cannot measure and so the choice of the absolute levels of G_i will necessarily be arbitrary.

In relative terms, we assume that G_i in rural and informal locations is identical. Fuglie (2010) shows that agricultural TFP growth was below 1% for nearly all developing regions in the 1960s-1970s. However, since that time TFP growth rates have increased across all regions, reaching 2-3% per year in some cases. Overall, he reports developing countries with agricultural TFP growth of 1.4% from 1961-2007. Block (2010) reports agricultural TFP growth rates for Africa over different time periods as well. Growth rates are negative through much of the 1960s and 1970s, but have been as high as 2.8% in the most recent decade, and were 2% from the 1980s into the 1990s. For informal locations, they are dominated by workers in personal services and small-scale retail trade, so they are likely to have low TFP growth (Duarte and Restuccia, 2010; Karádi and Koren, 2012; McMillan et al., 2014). Duarte and Restuccia indicate that productivity growth in services among the poorest countries in their sample was around 1% per year. We set $G_l = G_r = 0.025$ to account for both productivity growth and any unobserved amenity growth in these locations.

We assume that $G_f = 0.05$, twice as large as in the other locations. This choice implies that absent any population growth or changes in death rates, workers would be moving from rural to formal urban areas to take advantage of the higher productivity and/or amenities there. Thus we are allowing for a typical process of structural change over time. The justification for assuming that G_f is larger than in informal or rural areas is based, from the productivity perspective, on the types of industries we associate with formal locations. Manufacturing experiences unconditional convergence (Rodrik, 2013), and hence growth rates of productivity are rapid relative to informal locations. Duarte and Restuccia (2010) and McMillan et al. (2014) both find evidence that productivity growth in sectors we associate with formal locations - manufacturing and finance - had faster productivity growth than other sectors. It seems also valid to assert that amenity growth in formal locations was as least as rapid as in other locations over this period.[22]

Preferences. The utility weight on life expectancy (β) will determine how important changes in the CDR's across locations are to changing the distribution of population. We follow Becker et al. (2005) and Weil (2010) who compare the value of changes in life expectancy with changes in income per capita. Specifically, Becker et al. (2005) convert the changes in life expectancy to equivalent changes in annual income. Using this information, we can back out an implied value of β such that the observed growth in life expectancy is equivalent to their equivalent change in annual income. We use their estimates for Africa, as the majority of our sample comes from that region. Becker et al. (2005) calculate that the increase in life expectancy in this region between 1960 and 2000 (a 12% increase from 41 to 46 years) was equivalent to an increase of 72 intl. dollars (a 4.9% increase on a base of 1,470 dollars). This implies a value of β of 0.41.

Rural welfare elasticity. For the rural location elasticity ϵ_r, sources point to a high negative elasticity of output per capita with respect to population size in predominantly rural countries. Lee (1987) finds an elasticity of -1.6 and Weir (1991) finds -1.2, both using an agricultural production function with a low degree of substitutability between land and population, and pre-Industrial Revolution data. Lee (1997) updated his own estimate to -1.0. Acemoglu and Johnson (2007) have work on the effect of the international epidemiological transition that implies an elasticity of -1.2 in a sample of low and middle-income countries in 1940-1980, all of which had very low urbanization rates in 1950.[23] This elasticity is derived from the production technology alone. However, we feel this is a good approximation for rural areas, as housing faces few constraints in terms of space, and due to their low densities, their amenities and transportation networks are less prone to congestion. Hence we use -1.2 as our preferred estimate of ϵ_r.

Note that a value of this rural elasticity of one, or more, is still consistent with a constant returns rural production function in which the elasticity of output with respect to labor is less than one. Adding a new non-working resident to a rural area lowers output *per capita* without raising output, with an elasticity of negative one, close to our preferred value.[24]

[22] Ideally, we would like to separate net wages and amenities, since it is standard in the literature. However, there are no existing estimates of the location-specific availability of consumption amenities for low-income countries between 1950 and 2005, and there are almost no studies of how people value amenities relative to net wages in those contexts.

[23] -1.2 comes from dividing their estimate of the effect of life expectancy on GDP per capita, -2.43, by the effect of life expectancy on population, 2.04 (see column (3) of their Tables 8 and 9).

[24] Further, starting with an assumed value of the $0 > \epsilon_r > -1$, as would be implied by a constant returns production

3.2. Initial Conditions and Calibrated Parameters

Given the externally set parameters, we still require values for the elasticities of welfare with respect to population for the formal urban and informal urban locations. To set these, we match the model to observed data from a set of 41 developing countries that experienced the UMT.

Country data. The set of 41 countries we match to includes 28 countries from Africa, 11 from Asia, 2 from Latin America and 1 from the Middle East (see the notes under Table 3 for the full list of countries). We selected countries with (a) at least 1 million inhabitants in 1950, (b) an urbanization rate below 20% in 1950, so countries that were unurbanized initially, (c) data available on the slum share in 2005, and (d) slum shares of at least 30% in 2005, meaning countries that remained markedly informal. The choice of 2005 was dictated by the availability of widespread slum data in this year (UN-Habitat, 2003b, 2012). UN-Habitat defines slums similarly for all countries. In particular, the slum population is "the urban population living in households with at least one of the following four characteristics. Lack of access to improved drinking water. Lack of access to improved sanitation. Overcrowding. Dwellings made of non-durable material."

Urban and informal shares. We use 1950 as the initial period for our calibration. For our set of countries, the average urbanization rate in 1950 is 8.9%. Explicit information on the informal share of either the housing or labor market in 1950 does not exist. We thus assumed a value of 50%. In 2005, the average slum share for the 41 countries is 64.2%, so 50% implies an increase from 1950 to 2005. We will later show that results are similar if we assume that their urban areas were mostly formal (i.e. a formal share of 60%) or informal (a formal share of 40%) in 1950.

Urban welfare elasticities. To calibrate the model, we use a discrete-time version of the model to solve for values of the formal elasticity ϵ_f and the informal elasticity ϵ_l that make it match the average urbanization rate and informal share of urban areas from our 41 countries in 2005, given the initial conditions of those 41 countries and the external parameters set in the prior section.

In particular, we set the initial shares of population in the three locations (formal share: $s_{f,1950}$; informal share: $s_{l,1950}$; rural share: $s_{r,1950}$) using the average values from our set of 41 countries in 1950. The urbanization rate of 8.9% pins down $s_{f,1950} + s_{l,1950}$, and thus $s_{r,1950}$ is equal to 91.1%. Our assumed informal share of 50% implies that $s_{f,1950} = s_{l,1950} = 4.45\%$ in 1950.

Given those initial conditions, we then proceed with the following algorithm. We use equation (14) to solve for the growth rate of aggregate population ($\hat{N}_{1950}$), and then use equation (11) to solve for the growth rate of population in each location ($\hat{N}_{f,1950}$; $\hat{N}_{l,1950}$; $\hat{N}_{r,1950}$). Using (12) we can get the growth rate of the share of population in each location, and thus obtain the share of population in each location in the following period ($s_{f,1951}$; $s_{l,1951}$; $s_{r,1951}$). We continue this process period-by-period until we reach 2005, and retrieve predicted values of the urbanization rate ($s_{f,2005} + s_{l,2005}$) and the informal share ($s_{l,2005}/(s_{f,2005} + s_{l,2005})$).

We repeat the algorithm using different values of ϵ_f and ϵ_l until we find those values that make the model's predicted values for urbanization and the informal share match the observed averages in 2005 (31.0% and 64.2%, respectively). Practically, this search for the values of ϵ_f and

function, alters the calibrated values of the other elasticities, but changes little the effects of the UMT (not shown).

ϵ_l is not computationally intense, given that the model is effectively a series of static allocation problems. We use a non-linear least squares routine to find the values of ϵ_f and ϵ_l that match the model's predictions to the data moments. Table 3 shows the results of the calibration. We find that $\epsilon_f = 1.32$ and $\epsilon_l = 0.60$. The data suggests that formal locations have elasticities slightly higher than rural ones, while informal locations are implied to have elasticities about half of the rural value. In other words, rural and formal sectors cannot absorb new residents as easily as the informal sector in this specific sample of 41 developing countries that experienced the UMT.

Additional clarifications. First, it may not be immediately clear why welfare in the formal locations would be as sensitive to population size as rural areas, or larger than in informal locations. Formal locations presumably enjoy agglomeration effects, and land would appear to be less important in production. However, poor countries are likely to use backward technologies in production, housing, and transportation that are more susceptible to congestion. The institutional structure may mean that production, housing and transportation cannot expand at a pace equal to that of population. In contrast, informal locations can adapt relatively easily to population inflows because their production (e.g. street vending), housing (e.g. shacks), and transportation (e.g. rickshaws) have low fixed costs and are not subject to the same institutional constraints as in formal areas. The difference in formal and informal elasticities is entirely consistent with the data we presented in Figure 5.C comparing mega-cities at different income levels, as well as Section 1.3. discussing why slums are densely populated despite consisting mostly of low-rise structures. High-elasticity built-up (formal) locations in rich countries have low population densities compared to low-elasticity slum (informal) locations in poor countries, even though formal locations have technologies (e.g. skyscrapers) that relieve space constraints.

Second, the elasticities we calibrate are intrinsically different from the "net agglomeration effects" (i.e. agglomeration benefits net of congestion costs) that have been studied in the literature, where one regresses measures of productivity and pecuniary and non-pecuniary living costs on population for a sample of cities belonging to the same country. Econometrically, the effects that studies estimate are the *relative* effects of moving one person from one city to another larger city within a same country. The effects that we are calibrating are the *absolute* effects of adding an extra person to the whole urban sector of one country. In that case, the entire urban sector may become more congested and urban welfare may decrease. To our knowledge, this parameter has not been estimated in the literature, hence our need to rely on calibration. In addition, with the notable exception of Duranton (2014a), there are almost no studies of the *relative*, or *absolute*, congestion effects in developing countries. Further, there are few studies of the *relative*, or *absolute*, agglomeration effects for most of the 41 poor countries (including 28 non-industrial African countries) in our sample. Duranton (2014a) studies Colombia and Chauvin et al. (2016) focus their analysis on Brazil, China and India, four middle-income countries.

Third, these elasticities are held constant over time and with respect to the absolute size of the urban or informal population. It could be the case that the informal elasticity has risen in the last decades as slums have become so large in absolute terms that living conditions or mortality are more sensitive to further population growth than in the past. However, urban CDRs have, if anything, further decreased for developing countries between the 1960s and the 2000s, as can be observed in Panel B in the right panel of Figure 4. The only exception is South Africa due to HIV, as can be seen for Johannesburg in Panel F of Figure 3. Furthermore, in our sample of 7 "poor" mega-cities for which we have CDR data on slums in the 2000s, the mean slum CDR (6.8) is barely above the mean non-slum CDR (6.1) (see Section 1.2.). While slums might have higher child mortality rates than non-slum areas (Fink et al., 2016), they also tend to have a much younger population (UN-Habitat, 2003a), which must have limited the feedback effects of slum expansion on urban CDRs, since CDRs also depend on non-child mortality as well as age structure. In addition, the epidemiological transition targeted epidemic diseases likely to propagate in dense urban environments, making high densities less consequential from a health perspective.

Finally, we consider two broad urban locations, as opposed to tracking individual cities that could possibly vary in their elasticities or inherent wage/amenity growth rates. If there were substantial variance in the elasticities or wage/amenity growth across cities, then this should also show up as changes in the distribution of city sizes within economies over time.

3.3. Implications of Calibration

Before examining quantitative exercises, we can examine some general implications of our calibrated parameters for the UMT and poor country urbanization. The acceleration of population growth due to the UMT should have had several effects:

1. The economy urbanized faster. The UMT had a direct effect on urbanization by making urban locations more desirable to live in given individual's preference for lower CDRs. In addition, there was an indirect effect of the UMT on urbanization given the differences in elasticities between locations. The values of the elasticities, along with the initial shares of population, indicate that $\epsilon_r > \bar{\epsilon}$. Hence in response to the increase in population growth from the UMT, the growth rate of the rural population share, $\hat{s}_r$, fell, and hence urbanization occurred faster.

2. Urbanization occurred through informalization. With $\epsilon_l < \bar{\epsilon}$ the growth rate of the informal share, $\hat{s}_l$, rose in response to the UMT. At the same time, with $\epsilon_f > \bar{\epsilon}$, the growth rate of the formal share was pulled down by faster population growth. The UMT not only urbanized the economy, but did so by pushing people into the location with the lowest welfare elasticity - informal areas.

3. Population growth sped up. The immediate effect of the UMT is to raise $\hat{N}$ directly. But in addition, by urbanizing the economy through informalization, the UMT led to higher aggregate $CRNI$ as population moved into high-population-growth informal locations. The UMT thus eliminated the natural limitation on population growth that historical economies experienced as they urbanized.

4. Ambiguous welfare effects. By raising $\hat{N}$, welfare growth was pushed down due to negative effects of population growth. But in addition, because informal locations have low exogenous welfare growth, the increased share of population in informal locations meant that aggregate welfare growth became slower. On the other hand, because the CDR fell, there was an increase in welfare given that people value lower mortality. On net, there is no conclusion to draw analytically, and this remains a quantitative question. It is important to note with respect to welfare that the shift into informal locations is the welfare-maximizing response to the UMT, and there is no spatial misallocation. There is a negative externality, as individuals do not internalize their effect on congestion, but individuals are not constrained from moving between locations.

3.4. Effects of the UMT, 1950-2005

Observed data. In Table 4 we work through several scenarios to quantify the role of the UMT. Row 1 shows the average urbanization rate, both in 1950 (8.9%) and 2005 (31.0%), for our set of 41 poor countries. In addition, it shows the relative size of urban populations in 2005, and urban populations grew by a factor of 15.2 from 1950 to 2005 in our sample. We do not have data on slum shares in 1950, which we use to measure the informal share. But in 2005, this share was 64.2%. The relative size of informal locations was 18.6 in 2005 compared to 1950.[25]

Calibrated model. Row 2 presents outcomes from our calibrated model. We take the initial urbanization and informal shares as given, and target the final urbanization and informal shares of 31.0% and 64.2%. Those are thus matched exactly. We did not match either the absolute size of the entire urban population, nor the informal population, but the calibration does a good job in capturing their growth from 1950 to 2005 nonetheless. For urban size, the calibration finds that urban areas are larger by a factor 14.8, compared to the average value of 15.2 from our set of 41 countries. For the relative size of informal areas, the calibration delivers a value of 19.0, compared to the actual value of 18.6 in the data. This assures us that the calibrated model is capable of capturing the gross demographic patterns found in the data over this period of time.

Removing the UMT. In row 3, we rerun the model from 1950 to 2005, but this time we remove the UMT. The formal and informal CDRs stay at 40 throughout. In this case, the urbanization rate would only have been 21.3% in 2005. Compared to the observed data, this indicates that the UMT accounted for 9.7 percentage points of urbanization between 1950 and 2005 (31.0 minus 21.3), or roughly 45% of the increase in the urbanization rate in this period. Urban areas in 2005 were roughly 75% larger (14.8 versus 8.4) because of the UMT. The informal share without the UMT would have been 54.8%, compared to 64.2% in the observed data, and thus 9.4 percentage points of the informal rate in 2005 can be attributed to the UMT. This is roughly 70% of the increase in the informal rate from 1950 to 2005. Without the UMT informal areas in 2005 would have been 9.2 times larger than in 1950, compared with the actual ratio of 18.6. Hence informal areas are twice as large today due to the UMT. From a welfare perspective, there are two conflicting effects at work. First, without the UMT mortality is higher and hence welfare is lower. Second, slower population growth reduces the drag on welfare due to crowding effects. In our calibration, the net result is that welfare in 2005 could have been 8% *higher* without the UMT, suggesting that the latter effect of less crowding might have outweighed the former effect of higher mortality.

We now attempt to separately quantify these the amenity effect of lower urban death rates and the effect of differential elasticities.

[25]The size of the population in 2005 was roughly 5 times that of 1950. Productivity growth (or lower international transport costs for food as in Glaeser (2014)) must have been sufficient to either produce, or import, enough food to support this increase in population while allowing for higher urbanization rates. Our wage/amenity growth rates implicitly take this into account, and this is why we have not explicitly accounted for food demand in the model.

Direct congestion effects. In row 4, we rerun the model with the UMT occurring, but set the preference parameter on life expectancy, β, to zero. Thus the UMT does not provide any direct incentive to move to urban areas. Urbanization in this case is driven only by differentials in the underlying wage/amenity growth rates, G_i, and differentials in elasticities, ϵ_i. Here, the results show that urbanization in 2005 would have been 22.7%, or 1.4 percentage points higher than without the UMT. Similarly, an informal share of 59.1, compared to 54.8 without the UMT, indicates that these effects added 4.3 percentage points to the informal share of urban areas. Welfare in this scenario is reported as 88% of the baseline welfare *with* the UMT, but this is attributable to removing the benefits of lower urban death rates from the welfare calculation.

Life expectancy effects. Row 5 looks at the effects of the UMT arising purely from preferences for lower CDRs. We rerun the model including the UMT, but we set the values of the elasticities, ϵ_i, in all locations to be equal.[26] The urbanization rate is 25.0, which is 3.7 percentage points higher than without the UMT. For the informal share, the implied size is only 21.2%, meaning that informal areas would have shrunk as a share of urban areas. With the informal location elasticity equal to the other locations, the advantages of this location dissipate.

Life expectancy vs. direct and indirect congestion effects. Roughly one-third (3.7/9.7) of the urbanization due to the UMT remained when we removed the differential congestion elasticities (row 5). The remaining two-thirds is due both to the direct effect of differential elasticities (row 4), as well as the interaction of the mortality preference with these differential elasticities. The low elasticity in informal areas means that when individuals move to these locations out of a desire for lower mortality, the wages/amenities in informal areas do not fall much, and hence even more individuals can move into the urban areas in search of lower mortality rates. The two effects reinforce each other. Without the lower informal elasticity, urbanization would have been much lower following the UMT. The role of differential elasticities is also present in the rise of informal shares. Preferences for lower mortality (row 5) alone would have *shrunk* the informal sector as a share of urban population, as people would have moved almost exclusively to formal locations if the elasticities are equal across locations. But absent the amenity effect of lower mortality (row 4), we see that informal areas still would have grown to 59.1% of urban population due solely to the lower elasticities in informal areas. The combination of the two, with the low elasticity amplifying the effect of mortality preferences, is necessary to account for the 9.4 percentage point effect of the UMT on the informal share (64.2% versus 54.8%). The lower elasticity in informal areas accounts for more than 100% of the growth in the informal share from the UMT. While one cannot take a percentage greater than 100% too seriously, it indicates how important the differential elasticity effects were.[27]

[26] We use $\epsilon_i = 1.014$, the harmonic mean of the three sectoral elasticities from the baseline model.

[27] The overall analysis and decomposition could be different if we were able to account separately for child and adult mortality changes from the UMT. Drops in urban child mortality may create a stronger amenity effect drawing people to cities, which may imply an even bigger role for the UMT. Drops in urban adult mortality may have less of an amenity effect, but could lead to bigger congestion effects if adults take more "space" than children. Using national-level data, we find that adult and child mortality each account for about half of the overall decline in crude death rates during the UMT, so our decomposition is not necessarily over- or under-estimating the amenity versus congestion effects.

3.5. Endogenous Fertility and Effects of the UMT, 1950-2005

So far, we held the fertility behavior equal to that observed in the data. Here, we show this implied impact of the UMT on urbanization and informalization may be *understated*.

Fertility bulge. Under almost any reasonable setting, endogenous responses of fertility to the UMT will make CBRs *higher*, at least temporarily. This occurs through several channels. First, the drop in CDRs contributes to higher CBRs by ensuring cohorts survive longer through child-bearing ages. This demographic momentum effect is larger, the faster is the decline in CDRs (Heuveline, 1999; Guillot, 2005). Second, while total fertility rates may fall after declines in mortality due to risk-aversion or the value of human capital (Kalemli-Ozcan, 2002; Soares, 2005), the CBR will not necessarily fall, and will likely increase (Doepke, 2005). Last, if fertility is linked to the opportunity cost of parents time (Becker, 1960), then lower wages induced by congestion following the UMT would raise fertility rates. These mechanisms all indicate that in the *absence* of the UMT, the CBR would have been *lower*. That is, our counter-factual simulation in row 3 of Table 4 understates the effects of the UMT on urbanization because it holds constant the observed time path of CBRs, which includes their rise from 1950 to 1985. If we incorporate endogenous fertility, this will result in lower CBRs, and result in less urbanization and informality, and higher welfare.

Constant fertility. As a crude means of establishing the possible consequences of endogenous fertility, we first show in row 6 of Table 4 a counter-factual in which we remove the UMT, and also hold CBRs constant at their 1950 level. The results show that urbanization and informal shares would have been lower, and welfare higher, than in our first counter-factual (row 3).

Endogenous fertility. To be more sophisticated we introduce endogenous fertility into the model. We cannot incorporate age-specific effects related to population momentum due to the lack of location-specific data on age distributions and demographic behavior in this time period. We can, however, build in responses based on wages and CDRs (details available in the Web Appendix). The crucial elements are as follows. First, the fertility decision is assumed to depend on both the wage, w_j, and death rate, CDR_j, in location j. Second, in line with literature, CBRs are negatively related to wages and CDRs (note that this does not imply that total fertility rates are necessarily negatively related to CDRs). Specifically, the elasticity of fertility with respect to wages is set to -0.30, and the elasticity of fertility with respect to the CDR is set to -0.30, based on outside sources (see Web Appendix). The utility weight on fertility is set to be equal to that on life expectancy, also consistent with outside evidence.[28] As can be seen in row 7, the results with endogenous fertility are similar to those where we hold CBRs at their pre-UMT levels in 1950. The higher wages induced by lower population growth in turn push down CBRs, which in turn helps keep wages high. Overall welfare is higher due to smaller population size.

3.6. Sensitivity Checks for the Effects of the UMT, 1950-2005

Table 5 shows the effects of changing the assumptions regarding the externally set parameters, and in the choice of data to match the model to. Row 1 reproduces our baseline results (see Rows

[28]The elasticities have the same value (-0.30), but this was a coincidence. We examined outcomes with values ranging between -0.05 and -0.75 for the elasticity of fertility with respect to the CDR and wages, and the results hold (not shown).

2-3 of Table 4). Columns (2) and (3) show how much lower the urbanization and informal shares would have been in 2005 without the UMT, whereas column (4) shows how much higher welfare would have been. Columns (5) and (6) display the calibrated values of the formal and informal elasticities, ϵ_f and ϵ_l, respectively. These remain somewhat stable across all robustness checks, indicating our results were not driven by our choices of parameters and data to match.

Matching data. Rows 2-5 show that results hold if (i) we include all countries with urbanization rates below 30 percent (row 2) or 40 percent (row 3) in 1950, rather than only those with an urbanization rate below 20, and (ii) we include countries that had a maximum slum share over 20 percent (row 4) or 10 percent (row 5), rather than only those with a maximum slum share above 30 percent. These tests increase the number of countries. While our main sample includes mostly poor countries in 1950-2005, logically since our focus is on poor country urbanization, it is important to show that results hold when including more middle-income countries.

CDR shocks. In rows 6, 7 and 8, we limit the set of countries we match to based solely on the change in their crude death rate, so that we capture only countries that experienced a significant UMT. We include countries that saw their aggregate CDR fall by more than 7 per 1,000 people (the median drop across all countries), 12 (the 25th percentile), and 16 per thousand (the 10th percentile) between 1950-1980, respectively. In all cases the results are similar.

Migration restrictions. In rows 9 and 10 we exclude both China and India, and then eliminate the ex-Communist countries. In both cases, we are exploring whether countries that may have limited movement between rural and urban areas (whether due explicitly to policy or not) were driving our results. Eliminating these countries does not appear to affect the results.

Initial informal shares. In our baseline, we set the informal share of cities to 50% in 1950. However, altering this assumption to be 40% or 60% informal in 1950, as in rows 11 and 12, does little to change the outcome of removing the UMT. Therefore, whether we consider that cities in our sample were mostly formal or informal initially does not matter for our results.

Initial urban CDRs. In our baseline calibration, we use an initial urban CDR of 40, because that was the CDR of the poorest countries in our sample in the 1900s, before the UMT took place circa 1950 (see Section 1.2.). The urban CDR was also equal to 40 in rich countries before the Industrial Revolution. However, developing countries had on average an urban CDR of 30 in the 1900s. In rows 13 and 14, we set the urban CDR to 35 and 30, respectively. In both cases, the implied change in urbanization and informal share from removing the UMT are only slightly smaller than in our baseline. Row 15 sets up a differential in the formal and informal sectors CDR in 1950, at 30 and 40, respectively. In this case, the results are close to the baseline.

Rural mortality transition (RMT). In our baseline, we set the rural CDR to 20 throughout, implying that the RMT had already occurred, allowing us to focus purely on the UMT. Row 16 addresses this by setting the initial rural CDR to 40, and then letting it decline towards 20 over time. The counterfactual is then calculated removing the mortality transition for all locations. As can be seen, this results in even larger drops in the urbanization and informal share, indicating a bigger role for the mortality transition in general than we found for just the UMT.

Productivity/amenity growth. In our baseline model, we assumed that the formal sector had a growth rate of 5%, 2.5 percentage points higher than in the informal areas. The economy is thus rather dualistic, with a fast-growing modern sector and lagging traditional sectors. But as rows 17-20 show, reducing formal growth to 4% or 3% or raising informal growth to 3.5% of 4.5% does not eliminate the results, except that the amount of the informal share explained is lower.[29] This occurs because to match the observed data, the gap between the implied formal and informal elasticities has to decrease. With a smaller difference between formal and informal elasticities, the UMT does not drive as many people into informal areas. Lastly, results do not change if we decrease all growth rates by 1 percentage point (row 21) or increase them all by 1 percentage point (not shown), as these changes simply scale the absolute growth in welfare.

Preferences. Our baseline value of the life expectancy preference parameter $\beta = 0.41$ was obtained using the results for Africa in Becker et al (2005). Their implied value from Latin America is $\beta = 1.56$ and from South Asia is $\beta = 1.70$. The lower value from Africa, implying less utility weight on life expectancy, is consistent with recent work by Jones (2016) on how people's preference for consumption relative to health falls as they become richer. When using $\beta = 1.56$ (row 22) or $\beta = 1.70$ (row 23), the preference for living in low-mortality locations is higher, and as such removing the UMT makes people much less likely to live in cities. The effect of removing the UMT is to lower the urbanization rate by nearly 20 percentage points, and the informal share by almost 15. The UMT now explains essentially *all* of the urbanization and informal share increase.

Rural elasticity. Rows 24 and 25 examine the effects of changing the assumed rural elasticity, where our baseline assumption was that $\epsilon_r = 1.2$. Lee (1997) suggested a value of 1.0, an update on his initial estimate of 1.6 from Lee (1987). Our results hold when using such values.

Individually calibrated urban elasticities. While our baseline values of ϵ_f and ϵ_l are calibrated using the average urbanization rate and informal share from the set of 41 countries, we can calibrate values of ϵ_f and ϵ_l individually for each of the 41 countries. In each individual case, the formal elasticity (mean: 1.859; median: 1.245; min: 0.880; max: 11.546) is found to be larger than the informal elasticity (mean: 0.611; median: 0.573; min: 0.398; max: 1.183), indicating our baseline was not driven by using the average values. Interestingly, the informal elasticities are close to each other (standard deviation: 0.162), while the formal elasticity varies more across countries (standard deviation: 2.068), suggesting that informal sectors may not be that different when comparing countries, while formal sectors can be. We believe the estimated individual formal elasticities may measure country-specific constraints on formal development. For example, for the 41 countries we find a negative, and significant, correlation between the formal elasticity and the average regulatory quality index (-1.08*), rule of law index (-1.10*), government effectiveness index (-1.53*) and control of corruption index (-1.06*) for the whole period 1996-2015 (the only years for which data is available) when using the *World Governance Indicators* of the World Bank. We also find a positive and significant correlation of the ease of doing business index (1 = easiest to 185 = most difficult) (0.015*) when using the *Doing Business Indicators* of the World Bank. Moreover,

[29] A higher informal growth rate is consistent with recent work by Diao et al. (2016) on Tanzania's informal sector.

we do not find any correlation of these variables with the informal elasticity. This suggests that better institutions results in formal urban areas having more absorptive capacity.

In rows 26 and 27, we show the effect of the UMT if we use the mean and median of the individual elasticities found for the 41 countries. In both cases, the values of the elasticities are similar to the baseline, and the implied effect of the UMT is as well. Results also hold if we keep the 30 countries with the lowest formal elasticities (row 28), highest formal elasticities (row 29), lowest informal elasticities (row 30) or highest informal elasticities (row 31), to show that our results are not driven by outliers that that may have high, or low, elasticities for specific reasons.

3.7. Long-run Effects of the UMT, 1950-2100

With the UMT. We simulate outcomes 100 and 150 years from our start date (i.e. to 2050 and 2100). Rows 1-2 of Table 6 show the results under the assumption the UMT takes place starting in 1950, and persists over time, with the urban CDR asymptoting towards 15. In row 1, we allow the CBR to follow the hump-shaped pattern discussed above, but put a floor on the CBR in each location of the value it had in 1950. Thus the fertility bulge that followed the UMT is temporary, but birth rates remain high. In row 2, fertility is determined endogenously. Regardless of the fertility option, one can see that by 2050 the urban share and the slum share would be around 50% and 65-70%, respectively. Urban and informal areas would also be much larger. Using the first scenario as a baseline to normalize utility, we see that with endogenous fertility the increased size of the population lowers welfare to 78% of the baseline. Population growth pushes down wages, and this in turn pushes up fertility, which exacerbates population growth, and so on.

After 150 years, in 2100, the calibration suggests that urbanization would be 69-78%, with informal areas still making up about two-thirds of urban locations. Welfare is lower in the endogenous fertility case, emphasizing the possibility of a downward spiral in welfare.

Removing the UMT. Rows 3 through 5 perform a similar analysis, but remove the UMT, and leave urban CDRs at their 1950 levels throughout. Row 3, similar to row 1, allows CBRs to follow the hump-shaped pattern seen in the data, with a floor of the 1950 CBRs imposed. Row 4 holds CBRs constant at their 1950 levels in all periods, eliminating the hump-shaped response of fertility to the UMT. Finally, row 5 allows for CBRs to be determined endogenously. In each case, one can see that without the UMT, urbanization rates after 100 years are predicted to be around 33%, about 20 percentage points lower than with the UMT. The informal share without the UMT is predicted to be under one-half. Welfare is higher than in the baseline with the UMT, due to the slower population growth. When these simulations are extended out in time until 2100, urbanization rises to roughly one-half, and the informal shares continue falling to between 12% and 36%. Consistent with this, welfare in each simulation is predicted to be higher than in our baseline with the UMT. Note that welfare is highest under the endogenous fertility regime, where the lack of a UMT now allows for a virtuous spiral to occur. When population growth is low, wages are high, and hence CBR continue to fall, which limits population growth further, and so on.

Table 6 suggests that demographic conditions can have large long-run effects on the "nature" of urbanization. Note that in rows 3-5, the lack of UMT does not preclude countries from urbanizing. By 2100 urbanization rates are predicted to be between 46.2 (row 5) and 51.4 (row 3). This long, slow, urbanization process with a high urban CDR is consistent with the path followed by rich countries. In 1800, both Europe and the U.S. had an urbanization rate of about 10%, similar to the starting position of our sample. At the eve of WW2, roughly 150 years later, their urbanization rate was about 55%, close to our simulated values that range from 46.2-51.4%. The dominance of formal locations, and the associated improvement in welfare, are consistent with the development of these countries over this period. The model predicts informal shares of 12.5-36.5%. This is within range of the slum share of rich country urban areas around WW2. The 1950 *U.S. Census* reports that 21.2% of the U.S. urban population lived in "dilapidated" housing units and/or units without running water, which are characteristic of slums. Another example is London where according to the 1921 *Census*, 17.7% of people lived in "overcrowded" dwellings, and 25% and 15% of dwellings were occupied by at least 2 and 3 families, respectively. One last example is Paris, where according to *Annuaires Statistiques de la Ville de Paris* the share of "insalubrious" housing units was 35% in the 1930s, half of which were "dangerous" to live in.[30]

3.8. Simulating Policy Effects, 2005-2055

Baseline. Row 1 of Table 7 shows our starting point in 2005, with urbanization of 31.0% and an informal share of 64.2%. We normalize the size of the urban sector and of the informal sector to one in 2005. The second panel presents the simulated effects of various policy experiments, for which we use the parameters of Table 3, but update the demographic rates to match observed 2005 rates. We use the sample averages in the location-level data for the 19 poor countries (minus China, due to the one-child policy) for which we have demographic data in the 2000s. CBRs in informal locations and rural locations are set to 35, and formal locations to 20. CDRs are set to 10 in rural locations, and 7.5 in urban locations. Row 2 shows our baseline outcomes 50 years later in 2055, i.e. an urbanization rate of 50.8%. As a comparison, United Nations (2014) projects an urbanization rate of 54%. The informal share of urban areas remains roughly the same as in 2005, at 63.6%. Welfare in 2055 is normalized to one for comparison to the alternatives below.[31]

Productivity growth. One strategy is to foster rapid productivity growth, either through industrialization in formal locations or "green revolutions" in rural ones. To see these effects, we separately raise productivity/amenity growth by one percentage point in each sector. Raising rural growth to $G_r = 0.035$ (row 3) reduces urbanization to 38.3%, while welfare is now 24% higher. Compared to this, raising informal growth to 3.5% (row 4) increases welfare by 30%, even though urbanization would be 61.2% and the informal share 75.5% in this scenario. Welfare is higher in the informal case because we are raising growth in a location with a low congestion elasticity, and this allows a large group of people to move into that location to take advantage of the higher level of G_l. Raising G_f to 6% (row 5) for formal locations increases urbanization

[30] Relative urban size varied greatly when comparing the U.S. and Europe between 1800 and WW2. In the U.S., urban areas became 150-250 times larger, depending on the dates chosen. Our simulations do not indicate such a massive gain, but we model a closed economy while the U.S. accepted massive amounts of immigrants. For the United Kingdom, the urban population was 16 times larger in 1950 than in 1800, in range with our endogenous fertility scenario.

[31] The pattern of results is similar if we simulate the policies for 100 or 150 years forward (not shown, but available upon request). We also find similar results if we replicate the entire analysis using endogenous fertility (not shown).

rates slightly, but also lowers the informal share. Welfare is 10% higher in this scenario, lower than in the informal scenario (row 4) because the congestion elasticity in formal locations is much higher. Rows 6 and 7 increase formal growth to 8% and 10%, respectively, to explore the effects of rapid industrialization. In both cases, the urbanization rate rises and the informal share falls dramatically. The welfare gains appreciate very quickly as G_f rises.

Lower formal elasticity. An alternative policy is trying to lower the cost of population growth in locations with high wage/amenity growth (i.e. formal locations) by improving urban planning, relaxing land-use regulations, building infrastructure, facilitating the growth of secondary cities, and/or creating well-planned large cities ex nihilo. There are reasons to believe that the formal location elasticity is lower in rich countries, since they use better urban production, housing and transportation technologies, and have better urban institutions. However, we cannot estimate their elasticities using the same computation exercise as for poor countries, since this would require us having historical century-old data on slum shares for enough rich countries. But we can test how urban areas in poor countries would evolve if we were to improve the "absorption capacity" of their formal sector. In row 8, we examine the effect of lowering the formal elasticity of 1.32 by about 10% to the value we use for rural locations (1.20). This raises the urbanization rate slightly to 52%, while lowering the informal share slightly to 58.9%, and welfare is 4% higher. In row 9, we lower the formal elasticity to 0.90, which is close to the minimal individual formal elasticity found for the 41 countries. This is equivalent to assigning the formal elasticity of the "best" country in our sample to the full sample. The informal share decreases to 41.8% and welfare is 24% higher. A more dramatic change is seen in row 9, where we lower the formal elasticity by about 50% to equal the informal sector elasticity (0.60). In this case, the urbanization rate rises to 67.3%, as more workers are able to move into formal sectors with little effect on wages/amenities. This shows up as well in the informal share falling to 19.4%, and this implies a welfare gain of 82%. Row 10 drops the formal elasticity even further to $\epsilon_f = 0.44$, which is about two-thirds of the calibrated value of 1.32. Here, the same pattern of results holds, with urbanization much higher at 74.8%, an informal share of only 9.9%, and welfare 162% higher. The welfare effect is then similar to the effect of raising formal location wage/amenity growth to 10% per year.[32]

Higher informal congestion. Policies may alternatively be aimed at reducing the attraction of informal locations. This could take the form of enforcing property rights within these locations (or regulations in their sectors), or physically destroying these locations (i.e. clearing slums). In row 11 we simulate these policies by raising the informal elasticity to the level of the formal elasticity, $\epsilon_l = 1.32$. 1.32 is also close to 1.183, the maximal individual informal elasticity found for the 41

[32] A formal elasticity half of the value we calibrated for poor countries could make sense for rich countries, although this is entirely speculative. The fact that urban areas are more highly congested than in poor countries than in rich countries, whether in terms of housing, infrastructure or unskilled workers, is consistent with this difference in elasticities. First, while the price elasticity of housing supply ranges from 0.5-2.0 in developed countries (Caldera and Johansson, 2013), it ranges from 0.1-0.5 in developing countries (see Malpezzi and Mayo (1997) for Malaysia and Lall et al. (2007) for Brazil). Second, various sources indicate that an one-way commute is about 40 min in rich megacities and 80 mins in poor megacities. Struyk and Giddings (2009) writes: "One-way average commute times in Jakarta, Kinshasa, Lagos, and Manila are over 75 minutes." Lastly, another example of congestion is that various sources show rich megacities have pupil-teacher ratios in primary education around 15-20, while in poor megacities these ratios range from 30-70 (e.g. 69 in Dar es Salaam according to the World Bank's *Service Delivery Indicators Report*).

countries. This is thus equivalent to assigning the informal elasticity of the "worst" country in our sample to the full sample. This lowers the informal share to 41.6%. However, welfare is lower, at only 79% of the baseline. Lower welfare is a result of raising the average elasticity of welfare with respect to population. Informal areas, while they have low productivity growth, provide an outlet for population growth that alleviates congestion effects in the aggregate. Making them unable to absorb that population reduces their size at the cost of lower welfare for all individuals.

Migration restrictions. Another policy approach, such as with China's hukou system, is to limit in-migration to cities. We can evaluate the effect of such policies by adding a migration restriction to our model that generates a wedge in welfare growth between locations. Let the value λ_{ur} measure the wedge between welfare growth in rural and urban areas. If $\lambda_{ur} = -0.01$, for example, this means that migration restrictions keeping rural residents from leaving lead to 1% slower growth in welfare in rural locations compared to urban ones (either formal or informal). For our simulation, we set $\lambda_{ur} = -0.01$ in row 12. These kinds of migration restrictions limit urbanization to 38.3%. However, welfare is only 90% of the baseline. The migration restrictions lower welfare by forcing a large portion of the population to stay in relatively high-congestion rural locations.[33] In row 13, we flip the migration restrictions, imposing limits on the movement of urban people into rural areas. This may reflect either an explicit urban-biased policy, or the fact that with the UMT an increasing share of urban residents are urban-born, and urban-born individuals may acquire from birth a strong preference for urban living. Setting $\lambda_{ur} = 0.01$, which implies faster welfare growth in rural areas, this raises urbanization rates to 62.8%, well above the baseline, and informal areas would be larger. In order to achieve higher rural welfare growth, even more people must enter urban areas to keep population low in the rural areas.

Family planning. In row 14 we impose zero population growth by setting the CBR and CDR to be equal in each location. This results in urbanization of only 39.8% by 2055. The informal share of urban areas drops to 38.1%. Welfare is 213% higher than in the baseline. Lowering population growth slows down the growth of the low-congestion informal locations, resulting in lower urbanization and informal shares, and higher welfare. Zero population growth is an extreme policy, and in row 15 we explore a policy of family planning, making all CBRs equal to 20, similar to those achieved in China, Singapore or South Korea during the late 1970's (Bangladesh, Ethiopia and Indonesia have been touted as family planning success stories but they still have CBRs above 20). 20 is also the average formal CBR that we obtained for 7 poor mega-cities today (see section 1.2.). Urbanization would only be 44.2% in 2055, while the informal share would fall to 50.3%. Welfare would be 82% higher. In rows 16 and 17, we show separately the effects of family planning in informal and rural areas, respectively. Informal family planning lowers urbanization and informal shares relative to the baseline scenario, and raises welfare by 19%. Rural family planning has larger effects, lowering urbanization to 45.8% and informalization to 54%, while raising welfare by 55%. The larger effect of rural family planning is due to the relatively large size

[33] We obtain similar results if we extend the model to see how slum-constraining policies impact poor mega-city growth when there are cross-location congestion effects (not shown, but available upon request). We could indeed imagine that informal areas in cities create congestion effects in the formal areas of the same cities.

of the rural population. However, rural family planning may be costlier to implement than urban family planning due to the rural population being much more scattered spatially.

3.9. Discussion of Policy Implications

Here we note briefly the possible costs and feasibility of these policies. The most direct way of improving urban conditions in poor countries is to raise the formal wage growth rate. Raising this rate from 5% to 10% per year would more than double welfare and reduce the size of informal areas within cities. The open question here is how exactly one accomplishes this increase in the growth rate. There is not an obvious set of policies that would generate an industrial revolution of the type experienced by China recently, especially as many countries in our sample do not appear to have a comparative advantage in manufacturing (Gollin et al., 2015; Venables, 2016).

Lowering the formal elasticity is promising. Creating new urban locations by "better building elsewhere" is one strategy, though there may be drawbacks. First, it may have massive costs. For example, we find that the cost of creating new large cities may be between 3 and 25% of one year of GDP (mean of 12.5%), based on information from Brasilia in Brazil (1956-1960; 11-13%), Islamabad in Pakistan (1960s; 6%), Abuja in Nigeria (1978-1991; 23-25%), 50 ghost cities in China (2000s-2010s; 7-24%), Kilamba outside Luanda in Angola (2008-2012; 3%), and the future potential new capital of Egypt (2020s; 13%). Second, it does not appear that countries that have created new cities in our sample period have shown any significant reduction in urban congestion in their other cities.[34] Third, these cities may be motivated more by a desire to isolate elites within a country (Campante et al., 2013). "Building back better" in existing cities is another strategy. Improving urban governments and markets could help poor countries (Glaeser, 2014; Brueckner and Lall, 2015; Henderson et al., 2016b; Ashraf et al., 2016). It may not be feasible though, as building back better is socially costly. It requires clearing slums. Further, there is a question of whether poor countries will try to address their own government and market failures.

Table 7 suggests that population policies may be effective in managing urban growth in the future. While these are not typically thought of as urban policies per se, population growth itself is a significant contributor to the pace and nature of urbanization. Today, most low-income countries still have CBRs of about 40 per thousand. Family planning programs aimed at lowering the CBR to 20 limit the size of slums and raise welfare by up to 82% if extended across the economy. Hong Kong, Singapore, and South Korea all implemented similar "two is enough" campaigns in the 1960's and 1970's, bringing down their birth rates dramatically. Such policies can be highly effective, and have contributed to the fertility convergence at the world level (De-Silva and Tenreyro, 2015).[35] The WHO estimates costs for family planning programs that would lower CBRs to 20 of 1.2% of one year of GDP in Africa (Cleland et al., 2006). These policies may thus be more cost-effective than rebuilding existing cities or building new cities.

[34]Ten poor cities in our data are in countries that created a new capital: Karachi and Lahore in Pakistan (Islamabad became the capital in 1960), Belo Horizonte, Rio and Sao Paulo in Brazil (Brasilia; 1960), Dar es Salaam in Tanzania (Dodoma; 1974), Abidjan in Ivory Coast (Yamoussoukro; 1983), and Ibadan, Kano and Lagos in Nigeria (Abuja; 1991).

[35]The World Bank (2007) documents that family planning policy is not based on income levels. China, India, Indonesia and South Korea adopted strong family planning policies at low income levels, while many African and Latin American countries had weak family planning policies given their income level for most of the post-WWII period.

Lastly, similar to the conclusions of Au and Henderson (2006), Feler and Henderson (2011) and Desmet and Rossi-Hansberg (2014), migration restrictions are counter-productive. They limit both the size and informal share of cities, but at the cost of decreasing aggregate welfare as they do not allow population to flow into the low elasticity locations.[36] Policies meant to eliminate slums *lower* welfare because they eliminate a valuable outlet for rapid population growth.

4. Conclusion

Poor country urbanization is a relatively new phenomenon. Using a novel dataset of location-level demographics over time, we document that poor countries urbanized at the same time as the urban mortality transition (UMT) following WW2, which lowered their urban mortality rates to rich-country levels. To assess the quantitative importance of the UMT, we develop a general equilibrium model of location choice that has heterogeneity in congestion costs and demographics across locations. The model shows that population growth has a direct effect on the distribution of population across locations. Calibrating our model to a sample of poor countries, we find that the UMT may have doubled their urbanization rate as well as the size of their slums between 1950 and 2015. One-third of these effects could be traced to direct preferences for living in locations with lower mortality rates, while the remaining two-thirds are possibly accounted for by faster population growth pushing people into informal locations. The calibrated model allows us to assess various policies, and we find that family planning programs might be as effective as urban infrastructure and institutions, and more effective than migration restrictions and slum clearance, at improving the urbanization process in low-income countries. While we believe our results are both novel and important, we also note that they should be taken with caution, and more research is needed on how population growth can affect the pace and nature of urbanization.

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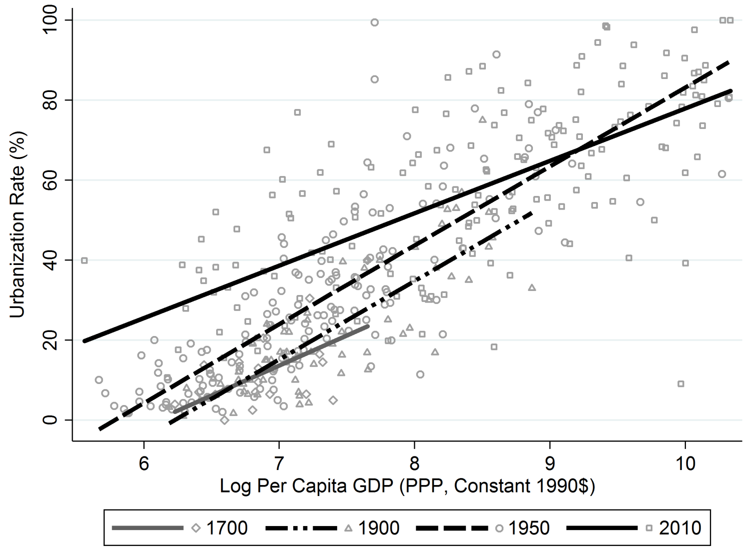
Figure 1: **URBANIZATION AND ECONOMIC DEVELOPMENT ACROSS TIME, 1700-2010**

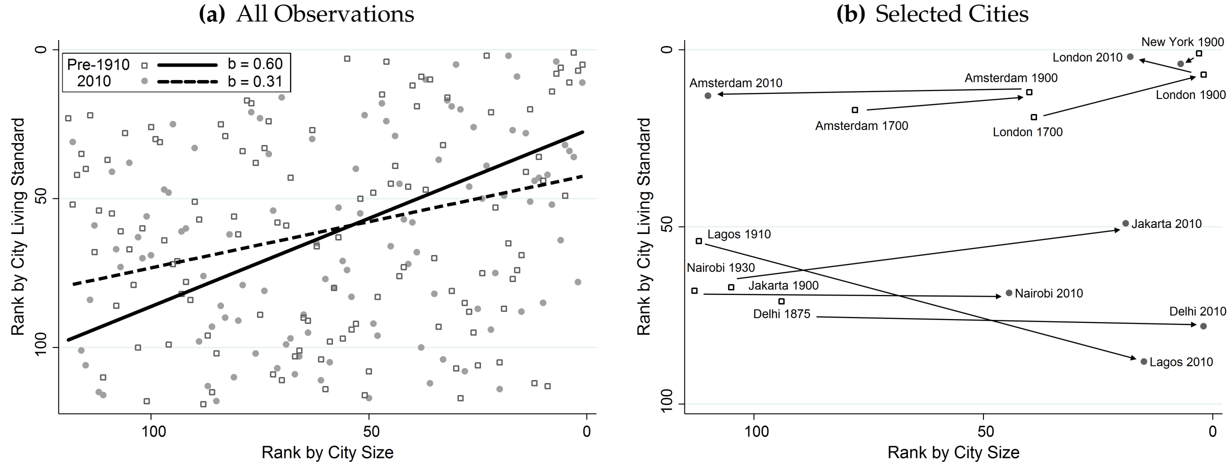


Notes: This figure shows for selected years the relationship between urbanization and economic development. For development, we use log GDP per capita (PPP, constant 1990 dollars) from Bolt and van Zanden (2014), who update Maddison (2008). We base our sample of the 159 countries available from these sources, which account for 99% of the world population in 2010. To the information on GDP per capita we add observations on urbanization rates circa 1700, 1900, 1950 and 2010. We use primarily Bairoch (1988), Acemoglu et al. (2002), Malanima and Volckart (2007), United Nations (2014) and Jedwab and Moradi (2016). The availability of urbanization and GDP data leaves us with 406 total observations. The distribution of observations across time is for 1700 (18 observations), 1900 (70), 1950 (159), and 2010 (159).

Figure 2: **CITY LIVING STANDARD VERSUS CITY SIZE RANK, HISTORICALLY (PRE-1910) AND IN 2010**

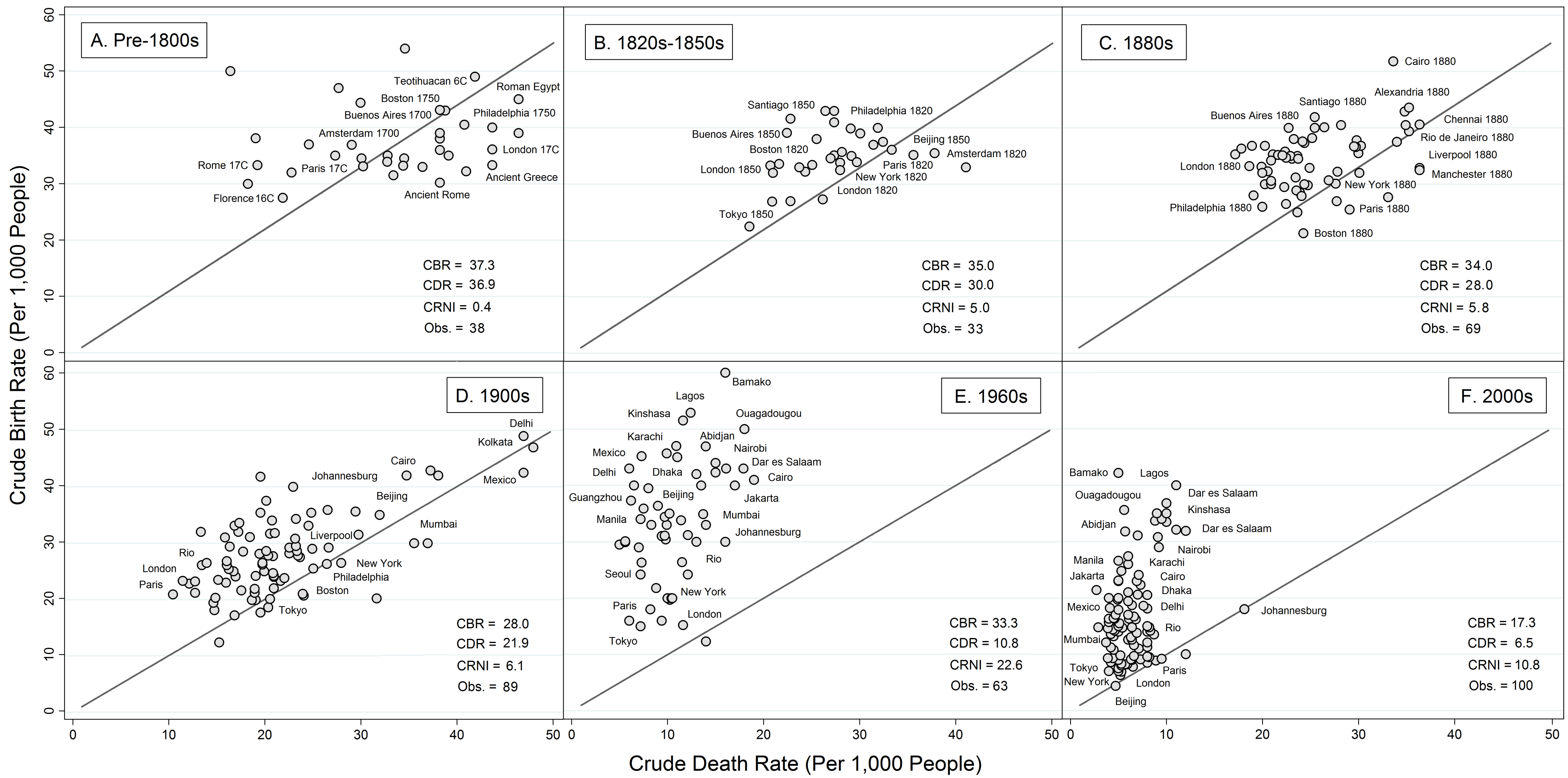
(a) All Observations

(b) Selected Cities



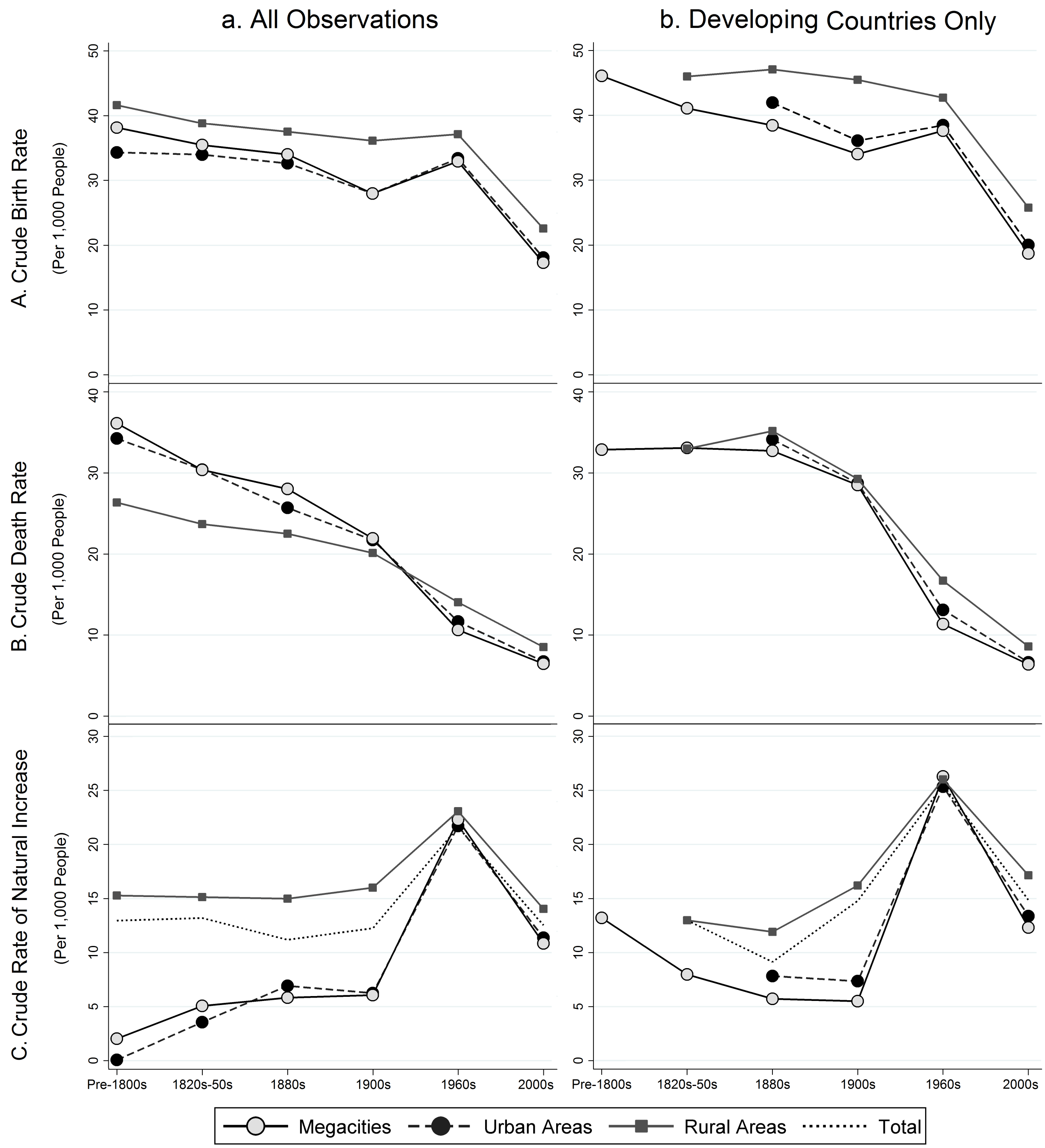
Notes: The left panel displays the relationship between city living standards and city population size for 118 city-year observations of more than 100,000 inhabitants pre-1910 (multiple observations for a same city) and 118 cities of more than 500,000 inhabitants in 2010. For each period, we rank the cities by living standards and population size and show the correlation between the two (linear fit estimated using as weights the population of each city-year). City living standards are proxied by city development indexes in 1998-2012 ("2010" in the figure) and welfare ratios for the pre-1910 period ("pre-1910"). The right panel shows the observations for selected cities in rich and poor countries today, with arrows indicating the evolution of their ranks over time. The sources for the city development index in 2010 are UN-Habitat (1998, 2012). The sources for the welfare ratios for the pre-1910 period (estimated for a "bare bones" consumption basket) are Allen (2007), Allen et al. (2011a), Allen et al. (2012), Frankema and Waijenburg (2012), Francis Jr. (2013) and Bassino et al. (2014). We obtain the size of each city from Chandler (1987) and United Nations (2014).

Figure 3: **CRUDE BIRTH AND DEATH RATES OF THE WORLD'S LARGEST CITIES, FROM ANTIQUITY TO DATE**



Notes: This figure shows the crude birth rates and the crude death rates for 392 city-period observations: 38 cities in the 1800s or before (Panel A), 33 cities in the 1820s or the 1850s (Panel B), 69 cities in the 1880s (Panel C), 89 cities in the 1900s (Panel D), 63 cities in the 1960s (Panel E), and 100 cities in the 2000s (Panel F). The cities in the 1900s and before (Panels A-D) were selected because they were among the 100 top cities in 1900. The cities in the 1960s-2000s (Panels E-F) were selected because they will be among the 100 top cities in 2030 according to United Nations (2014). The number of observations (Obs.), mean crude birth rates (CBR), death rates (CDR) and rates of natural increase (CRNI) are shown. See Table 2 for data sources.

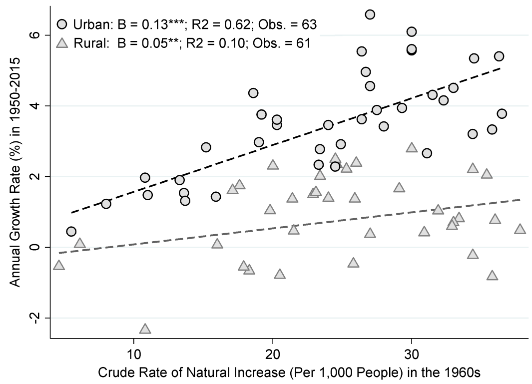
Figure 4: **HISTORICAL DEMOGRAPHY ACROSS LOCATIONS**



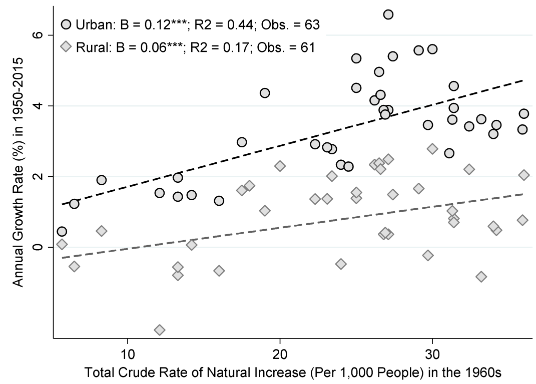
Notes: The left panel (*All Observations*) shows the unweighted mean crude rates of birth (Panel A), death (Panel B) and natural increase (Panel C) for the 392 *Megacities* as well as for the *Urban Areas*, the *Rural Areas*, and the whole area (*Total*) of the same countries as the mega-cities in the 1800s or before (N = 38), the 1820s-1850s (33), the 1880s (69), the 1900s (89), the 1960s (63), and the 2000s (100). The sample is the same as in Figure 3. The right panel shows the same evolutions for the subsample of 167 observations in *Developing Countries Only* – based on their 2015 GDP per capita, i.e. the countries whose income level is below the income of Slovakia, the last country to have become a developed country according to the International Monetary Fund – (N = 8 in the 1800s or before, 5 in the 1820s-1850s, 13 in the 1880s, 22 in the 1900s, 42 in the 1960s, and 77 in the 2000s). See Table 2 for data sources.

Figure 5: **URBAN NATURAL INCREASE AND CHARACTERISTICS OF URBAN AREAS**

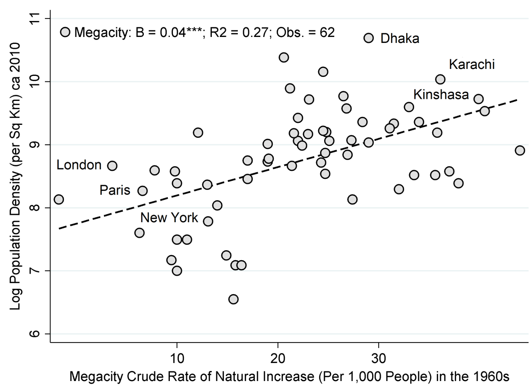
(a) Urban vs. Rural Natural Increase



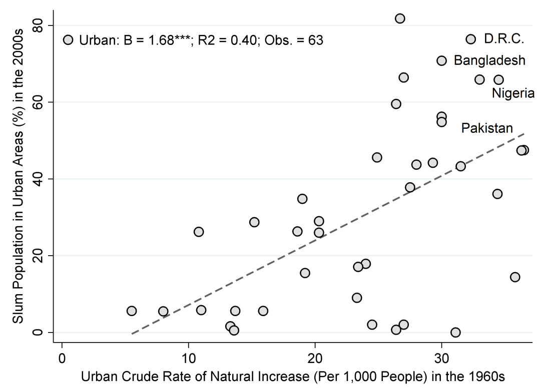
(b) Total Natural Increase



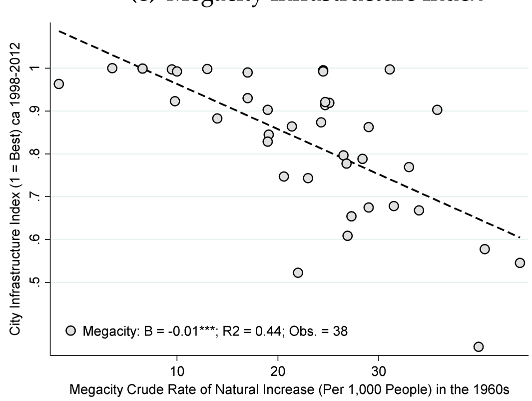
(c) Megacity Population Density



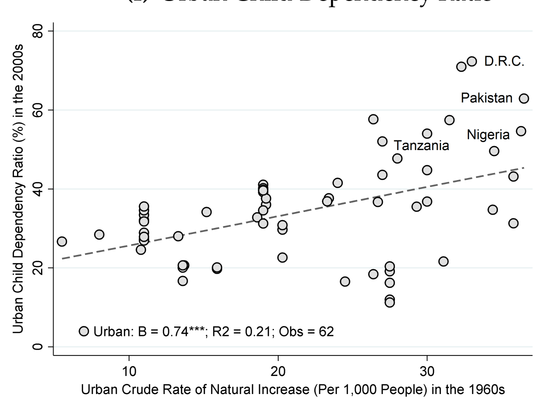
(d) Urban Slum Share



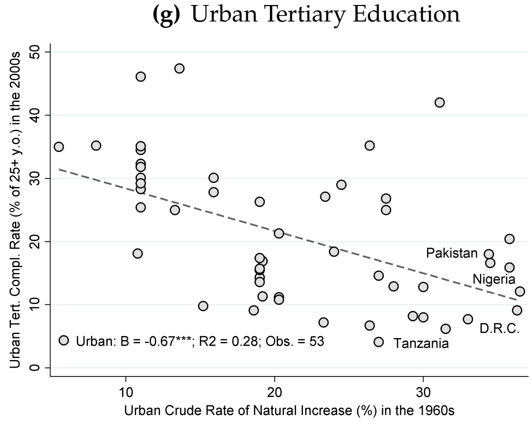
(e) Megacity Infrastructure Index



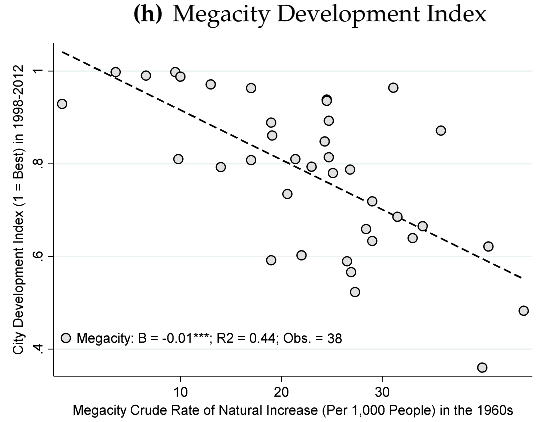
(f) Urban Child Dependency Ratio



(g) Urban Tertiary Education



(h) Megacity Development Index



Notes: See text for details on the data sources and the figures.

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

Rank	1700		1900		1950		2015 (△% 2015-2030)		
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	Mumbai	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	Beijing	20.4	(2.1)
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	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	3	Kolkata	14.9	(1.7)
15	Lisbon	0.2	Boston	1.1	StPetersburg	2.9	Istanbul	14.2	(1.1)
16	Cairo	0.2	Glasgow	1	Mexico	2.9	Chongqing	13.3	(1.8)
17	Xian	0.2	Osaka	1	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	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	Mumbai	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	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 table shows the population (millions) of the world's largest urban agglomerations in 1700, 1900, 1950 and 2015. An urban agglomeration comprises the city proper and also the suburban fringe or thickly settled territory lying outside. (△% 2015-30) is the projected annual growth rate (%) of the urban agglomeration 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. The main sources of the data are Chandler (1987) and United Nations (2014). See text for details on the data sources.

Table 2: **NATURAL INCREASE SOURCE INFORMATION BY COUNTRY 1/3**

Panel A: Largest Mega-Cities of the Future (2030)

Rank	City in 2030 [*Slum*]	Data Years	Main Sources (See Excel File for Details)
1	Tokyo	1960s, 2000s	Historical Studies. CICRED Monograph. Population Censuses.
2	Delhi	1960s, 2000s	Historical Studies. CICRED Monograph. Population Censuses.
3	Shanghai	1960s, 2000s	Historical Studies. Population Censuses.
4	Mumbai [*Dharavi*]	1960s, 2000s	CICRED Monograph. Population Censuses.
5	Beijing	1960s, 2000s	Historical Studies. CICRED Monograph. Population Censuses.
6	Dhaka [*Korail*]	1960s, 2000s	CICRED Monograph. Population Censuses.
7	Karachi [*Orangi*]	1960s, 2000s	CICRED Monograph. Population Censuses.
8	Cairo [*Manshiet*]	1960s, 2000s	Historical Studies. CICRED Monograph. Population Censuses.
9	Lagos	1960s, 2000s	CICRED Monograph. DHS.
10	Mexico [*Neza*]	1960s, 2000s	CICRED Monograph. Population Censuses.
11	Sao Paulo	1960s, 2000s	CICRED Monograph. Population Censuses.
12	Kinshasa	1960s, 2000s	Demographic Study. DHS.
13	Osaka	1960s, 2000s	Historical Studies. CICRED Monograph. Population Censuses.
14	New York	1960s, 2000s	Historical Studies. Population Censuses.
15	Kolkata	1960s, 2000s	CICRED Monograph. Population Censuses.
16	Guangzhou	1960s, 2000s	Historical Studies. Population Censuses.
17	Chongqing	2000s	Population Census.
18	Buenos Aires	1960s, 2000s	Historical Studies. CICRED Monograph. Population Censuses.
19	Manila [*Tondo*]	1960s, 2000s	CICRED Monograph. Population Censuses.
20	Istanbul	1960s, 2000s	Historical Studies. CICRED Monograph. Population Censuses.
21	Bangalore	1960s, 2000s	CICRED Monograph. Population Censuses.
22	Tianjin	1960s, 2000s	Population Census.
23	Rio de Janeiro [*Rocinha*]	1960s, 2000s	CICRED Monograph. Population Censuses.
24	Chennai	1960s, 2000s	CICRED Monograph. Population Censuses.
25	Jakarta	1960s, 2000s	CICRED Monograph. Population Censuses.
26	Los Angeles	1960s, 2000s	Population Censuses.
27	Lahore	2000s	Population Census.
28	Hyderabad	1960s, 2000s	CICRED Monograph. Population Censuses.
29	Shenzhen	2000s	Population Census.
30	Lima	1960s, 2000s	CICRED Monograph. Population Censuses.
31	Moscow	1960s, 2000s	Historical Studies. CICRED Monograph. Population Censuses.
32	Bogota	1960s, 2000s	CICRED Monograph. Population Censuses.
33	Paris	1960s, 2000s	CICRED Monograph. Population Censuses.
34	Johannesburg	1960s, 2000s	DHS. Historical Studies.
35	Bangkok	1960s, 2000s	CICRED Monograph. Population Censuses.
36	London	1960s, 2000s	Historical Studies. CICRED Monograph. Population Censuses.
37	Dar es Salaam	1960s, 2000s	CICRED Monograph. Population Censuses. DHS.
38	Ahmadabad	1960s, 2000s	CICRED Monograph. Population Censuses.
39	Luanda	2000s	DHS. Population Census.
40	Ho Chi Minh	2000s	DHS. Population Census.
41	Chengdu	2000s	Population Census.
42	Tehran	1960s, 2000s	CICRED Monograph. Population Censuses.
43	Seoul	1960s, 2000s	CICRED Monograph. Population Censuses.
44	Nanjing	1960s, 2000s	Population Census.
45	Baghdad	2000s	DHS. Population Census.
46	Chicago	1960s, 2000s	History Books. CICRED Monograph. Population Censuses.
47	Wuhan	2000s	Population Census.
48	Kuala Lumpur	1960s, 2000s	CICRED Monograph. Population Censuses.
49	Nagoya	2000s	Population Census.
50	Hangzhou	2000s	Population Census.
51	Dongguan	2000s	Population Census.
52	Surat	2000s	Population Census.
53	Foshan	2000s	Population Census.
54	Kabul	2000s	DHS. Population Census.
55	Khartoum	2000s	DHS. Population Census.
56	Suzhou	2000s	Population Census.
57	Pune	2000s	Population Census.
58	Riyadh	2000s	Demographic Study.
59	Shenyang	2000s	Population Census.
60	Xian	2000s	Population Census.
61	Hong Kong	1960s, 2000s	Wikipedia.
62	Abidjan	1960s, 2000s	Population Censuses. DHS.
63	Nairobi [*Kibera*]	1960s, 2000s	CICRED. Population Censuses. DHS.
64	Santiago	1960s, 2000s	CICRED. Population Censuses.
65	Toronto	2000s	Population Censuses.
66	Xiamen	2000s	Population Census.
67	Haerbin	2000s	Population Census.
68	Houston	1960s, 2000s	Population Censuses.
69	Chittagong	2000s	Population Census.
...	...	...	...

TABLE CONTINUED ON THE NEXT TWO PAGES (TABLE NOTES ON THE PAGE AFTER THE NEXT PAGE).

Table 2: **NATURAL INCREASE SOURCE INFORMATION BY COUNTRY 2/3**

Rank	City in 2030 [*Slum*]	Data Years	Main Sources (See Excel File for Details)
...	...	...	...
70	Madrid	1960s, 2000s	Population Censuses.
71	Dallas	1960s, 2000s	Population Censuses.
72	Yangon	1960s, 2000s	Historical Studies. Population Censuses. DHS.
73	Singapore	1960s, 2000s	Wikipedia.
74	Miami	1960s, 2000s	Population Censuses.
75	Belo Horizonte	2000s	Population Censuses.
76	Alexandria	2000s	Population Censuses.
77	Kano	2000s	DHS. Population Census.
78	Philadelphia	1960s, 2000s	Historical Studies. Population Censuses.
79	Atlanta	1960s, 2000s	Population Censuses.
80	Dakar	1960s, 2000s	Population Censuses. DHS.
81	Qingdao	2000s	Population Census.
82	Zhengzhou	2000s	Population Census.
83	Ankara	2000s	Population Census.
84	Ouagadougou	1960s, 2000s	Population Censuses. DHS.
85	Addis Ababa	1960s, 2000s	Population Censuses. DHS.
86	Dalian	2000s	Population Census.
87	Guadalajara	2000s	Population Census.
88	Washington	1960s, 2000s	Population Censuses.
89	Barcelona	1960s, 2000s	Population Censuses.
90	Zhongshan	2000s	Population Census.
91	Ibadan	2000s	DHS. Population Census.
92	Hanoi	2000s	DHS. Population Census.
93	Monterrey	1960s, 2000s	CICRED Monograph. Population Censuses.
94	Faisalabad	2000s	Population Census.
95	Kitakyushu	2000s	Population Census.
96	Sydney	1960s, 2000s	Population Census.
97	Jinan	2000s	Population Census.
98	Bamako	1960s, 2000s	Population Censuses. DHS.
99	Yaounde	1960s, 2000s	Population Censuses. DHS.
100	Aleppo	2000s	DHS. Population Census.

Panel B: Largest Mega-Cities of the Past (1900)

Rank	City in 1900 [*Slum*]	Data Years	Main Sources (See Excel File)
1	London [*Slums*]	17C, 1700s, 1750s, 1800s, 1820s, 1850s, 1880s, 1900s	Population Censuses. Historical Studies.
2	New York [*Tenement wards*]	1820s, 1850s, 1880s, 1900s	Population Censuses. Historical Studies.
3	Paris [*Quartiers pauvres*]	17C, 1700s, 1750s, 1800s, 1820s, 1850s, 1880s, 1900s	Population Censuses. Historical Studies.
4	Berlin	1800s, 1820s, 1850s, 1880s, 1900s	Historical Studies.
5	Chicago	1880s, 1900s	Population Censuses. Historical Studies.
6	Vienna	1880s, 1900s	Historical Studies.
7	Tokyo	19C, 1880s, 1900s	Historical Studies.
8	St. Petersburg	1880s, 1900s	Historical Studies.
9	Manchester [*Townships*]	1880s, 1900s	Population Censuses. Historical Studies.
10	Philadelphia	1700s, 1750s, 1800s, 1820s, 1850s, 1880s, 1900s	Population Censuses. Historical Studies.
11	Birmingham	1880s, 1900s	Population Censuses. Historical Studies.
12	Moscow	1880s, 1900s	Historical Studies.
13	Beijing	19C, 1900s	Historical Studies.
14	Kolkata	1900s	Historical Studies.
15	Boston	1700s, 1750s, 1800s, 1820s, 1850s, 1880s, 1900s	Population Censuses. Historical Studies.
16	Glasgow	1880s, 1900s	Historical Studies.
17	Osaka	1900s	Historical Studies.
18	Liverpool	1880s, 1900s	Population Censuses. Historical Studies.
19	Istanbul	1900s	Historical Studies.
20	Hamburg	1880s, 1900s	Historical Studies.
21	Buenos Aires	17C, 1700s, 1750s, 1800s, 1820s, 1850s, 1880s, 1900s	Historical Studies.
22	Budapest	1880s, 1900s	Historical Studies.
23	Mumbai	1880s, 1900s	Historical Studies.
25	Rio de Janeiro	1880s, 1900s	Historical Studies.
26	Warsaw	1900s	Historical Studies.
29	Newcastle	1880s, 1900s	Population Censuses. Historical Studies.
30	St. Louis	1880s, 1900s	Population Censuses. Historical Studies.
31	Cairo	1880s, 1900s	Historical Studies.
33	Naples	1880s, 1900s	Historical Studies.
...	...	...	...

TABLE CONTINUED ON THE NEXT PAGE (TABLE NOTES ON THE NEXT PAGE).

Table 2: **NATURAL INCREASE SOURCE INFORMATION BY COUNTRY 3/3**

Rank	City in 1900	Data Years	Main Sources (See Excel File)
...	...	...	...
34	Pittsburgh	1880s, 1900s	Population Censuses. Historical Studies.
35	Brussels	1850s, 1880s, 1900s	Population Censuses. Historical Studies.
36	Barcelona	1880s, 1900s	Historical Studies.
37	Dresden	1880s, 1900s	Historical Studies.
38	Madrid	1880s, 1900s	Historical Studies.
39	Leipzig	1900s	Historical Studies.
40	Amsterdam	1700s, 1750s, 1800s, 1820s, 1850s, 1880s, 1900s	Historical Studies.
41	Lyon	1880s, 1900s	Historical Studies.
42	Baltimore	1880s, 1900s	Population Censuses. Historical Studies.
43	Chennai	1880s, 1900s	Historical Studies.
44	Munich	1850s, 1880s, 1900s	Historical Studies.
45	Milan	1900s	Historical Studies.
46	Melbourne	1880s, 1900s	Historical Studies.
47	Sydney	1880s, 1900s	Historical Studies.
48	Prague	1880s, 1900s	Historical Studies.
49	Copenhagen	17C, 1700s, 1750s, 1880s, 1900s	Historical Studies.
51	Odessa	1900s	Historical Studies.
52	Hyderabad	1880s	Historical Studies.
53	San Francisco	1880s, 1900s	Population Censuses. Historical Studies.
54	Rome	17C, 1700s, 1880s, 1900s	Historical Studies.
55	Cologne	1900s	Historical Studies.
56	Leeds	1880s, 1900s	Population Censuses. Historical Studies.
57	Wroclaw	1880s, 1900s	Historical Studies.
58	Cincinnati	1880s, 1900s	Population Censuses. Historical Studies.
59	Marseille	1880s, 1900s	Historical Studies.
60	Sheffield	1880s, 1900s	Population Censuses. Historical Studies.
61	Edinburgh	1880s, 1900s	Historical Studies.
63	Cleveland	1880s, 1900s	Population Censuses. Historical Studies.
64	Dublin	1850s, 1880s, 1900s	Historical Studies.
65	Mexico	1900s	Historical Studies.
66	Rotterdam	1880s, 1900s	Historical Studies.
68	Minneapolis	1900s	Population Censuses. Historical Studies.
69	Lisbon	1880s, 1900s	Historical Studies.
70	Kyoto	1900s	Historical Studies.
71	Antwerp	1800s, 1820s, 1850s, 1880s, 1900s	Population Censuses. Historical Studies.
72	Buffalo	1900s	Population Censuses. Historical Studies.
76	Belfast	1900s	Historical Studies.
77	Turin	1880s, 1900s	Historical Studies.
78	Montreal	1850s, 1880s, 1900s	Historical Studies.
79	Bristol	1880s, 1900s	Population Censuses. Historical Studies.
80	Alexandria	1880s, 1900s	Historical Studies.
81	Bordeaux	1880s, 1900s	Historical Studies.
82	Bradford	1880s, 1900s	Population Censuses. Historical Studies.
83	Stockholm	1700s, 1750s, 1800s, 1820s, 1850s, 1880s, 1900s	Historical Studies.
86	Wuppertal	1850s, 1880s, 1900s	Historical Studies.
87	Detroit	1900s	Population Censuses. Historical Studies.
88	Riga	1880s, 1900s	Historical Studies.
88	Liege	1850s, 1880s, 1900s	Historical Studies.
90	New Orleans	1880s, 1900s	Population Censuses. Historical Studies.
91	Santiago	1850s, 1880s, 1900s	Historical Studies.
92	Lille	1880s, 1900s	Historical Studies.
93	Hanover	1850s, 1880s, 1900s	Historical Studies.
94	Milwaukee	1900s	Population Censuses. Historical Studies.
95	Bucharest	1880s, 1900s	Historical Studies.
97	Washington	1880s, 1900s	Population Censuses. Historical Studies.
99	Genoa	1900s	Historical Studies.
100	Montevideo	1750s, 1800s, 1820s, 1850s, 1880s, 1900s	Historical Studies.
_	Florence 16C	16C	Historical Studies.
_	Teotihuacan	6C	Historical Studies.
_	Roman Egypt	Antiquity	Historical Studies.
_	Ancient Rome	Antiquity	Historical Studies.
_	Ancient Greece	Antiquity	Historical Studies.

Notes: This table shows the 100 largest megacities and their population in 2030 according to United Nations (2014) (*Panel A*), 86 of the 100 largest megacities and their population in 1900 according to Chandler (1900) (*Panel B*), and the main sources of information for the crude rates of birth, death and natural increase for each city-period. We also collect data for a number of cities that were among the richest cities before 1900 (below the dashed line). For most city-periods, we also obtained using the same sources the same demographic data for the other cities of the same country-period, the rural areas, and the entire country. The slums for which we also obtained using the same sources the same demographic data are shown into brackets after the name of the city. The sources are: *CICRED Monograph* = 1974 Country monograph from CICRED. *DHS* = Report(s) from the Demographic and Health Survey(s) of USAID. *Historical Studies.* Various academic or policy articles and books giving specific estimates of the demographic rates for the city-period observation. *Population Census(es)* = Summary report(s) of the population census(es). *Wikipedia* = Webpage "Demographics of X" on Wikipedia. See the excel file megacity_urban_rural_demographics.xlsx for details on each demographic rate and each source.

Table 3: **CALIBRATION PARAMETER VALUES**

Parameter	Value	Source
Set externally:		
Urbanization rate (%) in 1950	8.9	Sample average
Informal share of urban areas (%) in 1950	50.0	See text for details
Initial population size in 1950	1.0	Normalization
Pre-UMT formal CDR (per 000)	40	Location-level data, 1900s
Pre-UMT informal CDR (per 000)	40	Location-level data, 1900s
Post-UMT formal CDR (per 000)	15	Location-level data, 2000s
Post-UMT informal CDR (per 000)	15	Location-level data, 2000s
UMT half-life	3	See text for details
Initial rural CDR (per 000)	20	Location-level data, 1960s-2000s
Initial rural CBR (per 000)	43	Location-level data, 1960s
Initial informal CBR (per 000)	43	Location-level data, 1960s
Initial formal CBR (per 000)	38	Location-level data, 1960s
Informal productivity/amenity growth (G_l)	0.025	See text for details
Rural productivity/amenity growth (G_r)	0.025	See text for details
Formal productivity/amenity growth (G_f)	0.050	See text for details
Preference parameters (β)	0.41	From Becker et al (2005)
Rural congestion elasticity (ϵ_r)	1.20	See text for details
Targeted:		
Formal congestion elasticity (ϵ_f)	1.32	Urbanization rate in 2005 (mean 31.0%)
Informal congestion elasticity (ϵ_l)	0.60	Informal share in 2005 (mean 64.2%)

Notes: The table shows the parameter values used in the baseline simulation of the model. *Location-level data* refers to the data presented in section 1.2.. *Sample average* refers to the sample of 41 "poor" countries in 1950-2005 (28 from Africa, 11 from Asia, 1 from the Middle East, 2 from Latin America): Angola, Bangladesh, Benin, Burkina-Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, China, the D.R.C., Ethiopia, Ghana, Guinea, Haiti, Honduras, India, Indonesia, Ivory Coast. Kenya, Laos, Madagascar, Malawi, Mali, Mozambique, Myanmar, Nepal, Niger, Nigeria, Pakistan, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Togo, Uganda, Tanzania, Vietnam, Yemen, and Zambia.

Table 4: **CALIBRATED OUTCOMES AT DIFFERENT DEATH RATES, 1950-2005**

	Urbanization Rate (%)		Urban Size		Informal Share (%)		Informal Size		Welfare
	1950	2005	1950	2005	1950	2005	1950	2005	2005
Observed data:									
1. With UMT:	8.9	31.0	1.0	15.2	n/a	64.2	1.0	18.6	n/a
Calibrated model:									
2. With UMT	8.9	31.0	1.0	14.8	50.0	64.2	1.0	19.0	1.00
3. Without UMT	8.9	21.3	1.0	8.4	50.0	54.8	1.0	9.2	1.08
4. With UMT, $\beta = 0$	8.9	22.7	1.0	10.7	50.0	59.1	1.0	12.7	0.88
5. With UMT, $\epsilon_i = \bar{\epsilon}$	8.9	25.0	1.0	11.7	50.0	21.2	1.0	5.0	1.17
6. W/o UMT, constant fertility	8.9	19.9	1.0	6.5	50.0	50.1	1.0	6.5	1.33
7. W/o UMT, endogenous fertility	8.9	19.4	1.0	5.9	50.0	48.4	1.0	5.7	1.44

Notes: Row 1: Observed data. Row 2: Baseline model. The urban CDR falls from 40 (per thousand) to 15 exponentially, with a half-life of 3 years. The CBRs follow the observed path in the data. Row 3: We hold the urban CDR constant at 40 over the entire period, and also have CBRs follow the observed path. Row 4: We allow the UMT to occur, but shut down the preference of individuals for lower CDRs. Row 5: We allow the UMT to occur, and individuals to have a preference for lower CDRs, but set the congestion elasticity in each location to be equal to 1.014. Row 6: We hold the urban CDR at 40, but also hold the CBR in each location at the 1950 level. Row 7: We hold urban CDRs at 40, but have the CBR determined endogenously by changes in the CDRs and wages (see Web Appendix for details of this model).

Table 5: **SENSITIVITY CHECKS ON CALIBRATION, 1950-2005**

	Number of Countries	Difference in 2005 in Actual vs. no-UMT: Urb. Rate	Inf. Share	Welfare Ratio	Elasticities (ϵ_i): Formal	Informal
Scenario	(1)	(2)	(3)	(4)	(5)	(6)
1. Baseline	41	-9.7	-9.4	1.08	1.320	0.602
Panel A: Sample Changes:						
2. 1950 Urbanization Rate $\leq$ 30%	46	-9.9	-9.4	1.11	1.331	0.629
3. 1950 Urbanization Rate $\leq$ 40%	53	-10.4	-9.6	1.15	1.339	0.656
4. Max. Slum Share $\geq$ 20%	42	-9.7	-9.3	1.08	1.312	0.607
5. Max. Slum Share $\geq$ 10%	43	-9.7	-9.2	1.08	1.298	0.611
6. $\Delta CDR_{1950,1980} \leq -7$ (median)	59	-10.4	-8.5	1.21	1.269	0.711
7. $\Delta CDR_{1950,1980} \leq -12$ (25th pctile)	26	-10.7	-8.2	1.20	1.209	0.697
8. $\Delta CDR_{1950,1980} \leq -16$ (10th pctile)	8	-12.3	-8.8	1.14	1.081	0.604
9. Excluding both China and India	39	-9.9	-9.5	1.07	1.328	0.591
10. Excluding (Ex-)Communist Countries	27	-9.8	-9.4	1.08	1.330	0.601
Panel B: Parameter Changes:						
11. Initial Informal Share (s_l) 40%	41	-10.0	-11.2	1.07	1.432	0.558
12. Initial Informal Share (s_l) 60%	41	-9.6	-7.6	1.08	1.205	0.643
13. 1950 Urban CDR = 35	41	-8.7	-8.1	1.05	1.305	0.588
14. 1950 Urban CDR = 30	41	-7.4	-6.6	1.03	1.281	0.570
15. 1950 Formal/Informal CDR = 30/40	41	-9.0	-10.5	1.05	1.281	0.605
16. 1950 Rural CDR = 40	41	-13.1	-32.4	2.17	1.214	0.498
17. Informal Growth Rate $G_l = 0.035$	41	-8.2	-5.7	1.11	1.326	0.786
18. Informal Growth Rate $G_l = 0.045$	41	-7.0	-3.1	1.14	1.326	0.968
19. Formal Growth Rate $G_f = 0.03$	41	-10.7	-4.9	1.05	0.871	0.604
20. Formal Growth Rate $G_f = 0.04$	41	-10.2	-7.5	1.07	1.098	0.604
21. All Growth Rates -1%	41	-9.7	-9.4	1.08	1.326	0.604
22. Mortality Preference $\beta = 1.56$	41	-18.7	-14.6	0.91	1.756	0.942
23. Mortality Preference $\beta = 1.70$	41	-19.3	-14.9	0.90	1.808	0.982
24. Rural Congestion Elasticity $\epsilon_r = 1.0$	41	-10.5	-10.7	1.05	1.226	0.524
25. Rural Congestion Elasticity $\epsilon_r = 1.6$	41	-8.6	-7.6	1.14	1.526	0.764
26. Mean Formal and Informal Elasticities	41	-9.1	-8.9	1.07	1.859	0.611
27. Median Formal and Informal Elasticities	41	-10.7	-9.7	1.07	1.245	0.573
28. Keep 30 Lowest Formal Elasticities	30	-9.6	-8.3	1.09	1.168	0.621
29. Keep 30 Highest Formal Elasticities	30	-8.4	-8.9	1.08	1.830	0.635
30. Keep 30 Lowest Informal Elasticities	30	-11.9	-8.3	1.04	2.004	0.533
31. Keep 30 Highest Informal Elasticities	30	-8.1	-8.6	1.08	2.048	0.644

Notes: This table shows the results of various sensitivity checks. Columns (2) and (3) show the difference between the actual and no-UMT values of the urbanization rate and informal share, indicating the explanatory power of the UMT for those outcomes, as in our main results from Table 4, rows 2-3. The welfare ratio, in column (4), is the calibrated welfare without the UMT relative to with the UMT, as in our main results from Table 4, row 3. It is a unique value to each row, and cannot be compared across rows. The formal and informal elasticities, in columns (5) and (6), show the values of ϵ_f and ϵ_l calibrated so that the model matches the actual values for the urbanization and informal shares in 2005.

Table 6: **LONG-RUN OUTCOMES USING THE CALIBRATED MODEL, 1950-2010**

From 1950 forward	100 years (in 2050):					150 years (in 2100):				
	Urb. Rate	Urb. Size	Inf. Share	Inf. Size	Welf.	Urb. Rate	Urb. Size	Inf. Share	Inf. Size	Welf.
1. With UMT, CBR floor	49.8	72.1	64.7	93.4	1.00	68.9	341.3	62.1	423.8	1.00
2. With UMT, endog fertility	53.0	99.6	69.5	138.5	0.78	77.6	996.5	77.0	1533.7	0.45
3. Without UMT, CBR floor	34.9	30.0	49.7	29.9	1.39	51.4	85.1	36.5	62.1	2.22
4. Without UMT, no chg in CBR	33.2	23.2	44.8	20.8	1.74	50.1	68.3	32.3	44.1	2.74
5. Without UMT, endog fertility	30.7	14.9	36.2	10.8	2.58	46.2	19.3	12.5	4.8	10.17

Notes: Row 1: Long-run outcomes with parameters set according to Table 3 and with the UMT occurring, meaning urban CDRs decline exponentially from 40 (per thousand) to 15 with a half-life of 3 years. CBRs match the observed data through 2005, and then are allowed to decline to their 1950 levels (which occurs in 2020). Row 2: Outcomes with the UMT, but allowing CBRs to be endogenous. Row 3: Outcomes if urban CDRs are held at 40, and birth rates follow the observed path to 2005 and then are allowed to decline to their 1950 levels. Row 4: We hold urban CDRs at 40 and birth rates at their 1950 levels. Row 5: We hold urban CDRs at 40, but allows CBRs to evolve endogenously.

Table 7: **LONG-RUN OUTCOMES UNDER DIFFERENT POLICIES, 2055**

	Urb. Rate	Urb. Size	Inf. Rate	Inf. Size	Welf.
1. Initial values (in 2005):	31.0	1.0	64.2	1.0	n/a
After 50 years (2055):					
2. Baseline (CDR_r = 10; CDR_l = CDR_f = 7.5; CBR_r = CBR_l = 35, CBR_f = 20; G_r = G_l = 0.025; G_f = 0.05; ϵ_r = 1.20; ϵ_l = 0.60; ϵ_f = 1.32)	50.8	5.2	63.6	5.1	1.00
Productivity changes:					
3. Higher rural growth rate ($G_r = 0.035$)	38.3	3.9	58.9	3.6	1.24
4. Higher informal growth rate ($G_l = 0.035$)	61.2	6.4	75.5	7.5	1.30
5. Higher formal growth rate ($G_f = 0.06$)	53.6	5.4	52.7	4.4	1.10
6. Higher formal growth rate ($G_f = 0.08$)	62.1	6.0	29.1	2.7	1.47
7. Higher formal growth rate ($G_f = 0.10$)	73.9	6.7	11.0	1.1	2.42
Changes in net congestion costs:					
8. Lower formal elasticity ($\epsilon_f = \epsilon_r = 1.20$)	52.0	5.3	58.9	4.8	1.04
9. Lower formal elasticity ($\epsilon_f = 0.90$)	57.0	5.6	41.8	3.6	1.23
10. Lower formal elasticity ($\epsilon_f = \epsilon_l = 0.60$)	67.3	6.2	19.4	1.9	1.82
11. Lower formal elasticity ($\epsilon_f = 1.32 \div 3 = 0.44$)	74.8	6.6	9.9	1.0	2.62
12. Higher informal elasticity ($\epsilon_l = \epsilon_f = 1.32$)	38.7	3.9	41.6	2.5	0.79
Changes in migration costs:					
13. Rural-to-urban migration restriction ($\lambda_{cr} = -0.01$)	38.3	3.9	58.9	3.6	0.90
14. Urban-to-rural migration restriction ($\lambda_{cr} = 0.01$)	62.8	6.4	66.7	6.7	1.11
Population growth changes:					
15. Zero population growth (CDR = CBR)	39.8	1.3	38.1	0.8	3.13
16. Family planning (CBR = 20)	44.2	2.4	50.3	1.9	1.82
17. Informal family planning (CBR_l = 20)	48.7	4.2	59.9	3.9	1.19
18. Rural family planning (CBR_r = 20)	45.8	3.0	54.0	2.5	1.55

Notes: Simulated outcomes 50 years later, in 2055, using different policy interventions. Each simulation uses the parameters of Table 3, except that CDRs and CBRs are set to observed rates in 2005. Welfare is the equivalent variation in net wage necessary for the baseline economy (row 1) to match welfare in the given scenario.

NOT FOR PUBLICATION - Web Appendix: Endogenous Fertility

To incorporate endogenous fertility into the model, we modify the utility function to be as follows

$$V_j = \ln w_j + \ln Q_j + \beta \ln(1/CDR_j) + \gamma \ln n(w_j, CDR_j, \tau_j) \tag{16}$$

where $n(w_j, CDR_j, \tau_j)$ is the number of births as a function of the wage, w_j, and the crude death rate, CDR_j. τ_j is a location-specific cost of having children. This function is the optimal outcome of a choice problem facing individuals who take the wage and crude death rate in a location as given, deciding how many children to have.

Putting this in terms of growth rates, we have the following

$$\hat{V}_j = \hat{w}_j - \beta C\hat{D}R_j + \gamma\phi^n_w \hat{w}_j + \gamma\phi^n_{CDR} C\hat{D}R_j. \tag{17}$$

The term ϕ^n_w is the elasticity of fertility with respect to wages, and ϕ^n_{CDR} is the elasticity of fertility with respect to the death rate. There are several assumptions located in this expression. First, we assume that $\hat{Q}_j = 0$, or that amenities do not grow. We do this because the fertility decision is directly related to wages, and we have no way of separately tracking amenity from wage growth in the model. Hence, to solve the model we need a way of pinning down wage growth, and assuming that amenities do not grow is the most direct way of doing this. Second, we have assumed that τ_j does not change over time, although it drives level differences between locations in crude birth rates.

Re-arranging this expression for the growth rate of welfare, we have

$$\hat{V}_j = (1 + \gamma\phi^n_w)\hat{w}_j - (\beta - \gamma\phi^n_{CDR}) C\hat{D}R_j, \tag{18}$$

which shows that welfare growth is a combination of wage growth and changes in mortality, similar to the baseline model. Here, the effect of wage growth is modified by the effect that it has on optimal fertility behavior (the $\gamma\phi^n_w$ term) and the effect of mortality is modified by the effect it has on fertility (the $\gamma\phi^n_{CDR}$ term).

Based on parameter values from the literature noted below, $\phi^n_w < 0$, meaning that fertility is negatively related to wages. Thus the effect of wage growth on welfare growth is *smaller* with endogenous fertility. An increase in wages raises welfare, but also lowers optimal fertility, and as people value fertility ($\gamma > 0$), this lowers welfare.

For mortality, the literature also indicates that $\phi^n_{CDR} < 0$, or lower mortality raises net fertility. Combined with the assumptions that $\gamma > 0$, this implies that endogenous fertility makes the effect of changes in mortality even larger in absolute size. A decline in mortality directly raises welfare, but through its effect of raising fertility has an additional positive effect on welfare. Endogenous fertility thus tends to put greater weight on mortality rates and less on wage growth in determining welfare.

With wage growth determined by $\hat{w}_j = \hat{a}^w_j - \epsilon^w_j \hat{N}_j$, as in the original model, we have that

$$\hat{V}_j = G_j - \epsilon_j \hat{N}_j - \theta_j C\hat{D}R_j \tag{19}$$

In terms of our prior notation, this implies that now

$$\begin{aligned} G_j &= (1+\gamma\phi_w^n)\hat{a}_j^w \\ \epsilon_j &= (1+\gamma\phi_w^n)\epsilon_j^w \\ \theta_j &= (\beta - \gamma\phi_{CDR}^n) \end{aligned} \tag{20}$$

Note that the structure of utility growth is identical to what we have in the baseline model, as it depends on welfare growth not related to population, G_j, population growth, $\hat{N}_j$, and changes in the crude death rate, $C\hat{D}R_j$. The interpretation of G_j, ϵ_j, and the term θ_j are now different, as they incorporate terms involving fertility, but solving the model from here is identical to our baseline model.

What does change is the exact specification for growth in population. Rather than our set-up from before, now we have that

$$\hat{N} = \sum_{j=1}^{J} s_j \left(n(w_j, CDR_j, \tau_j) - CDR_j \right). \tag{21}$$

Aggregate population growth will change over time both because of changes in the allocation of individuals across locations, the s_j terms, but also because of changes in fertility due to wages and crude death rates across locations.

To simulate the model, we require several additional parameters. Work by Vogl (2016) suggests that the utility weight on fertility is roughly equal to that on consumption, which in terms of this model implies that γ should be roughly equal to one.

For simulation, we need the elasticity of the crude birth rate with respect to both wages and crude death rates. Jones et al. (2010) provide elasticities of fertility with respect to income for the U.S. from 1826-1960, and find that they generally decline from between -0.30 and -0.40 in the 1800's to about -0.20 in the 1950's. Young (2005) estimates an elasticity of fertility with respect to wages of -0.35 using household survey data from South Africa. Total fertility rates and crude birth rates may deviate because of age structure. As a check on these elasticities, we use cross-country evidence from the United Nations (2012), and regressed the log crude birth rate on log GDP per capita using a panel of developing countries between 1950-2010, finding an elasticity of -0.20. We use a value of $\phi_w^n = -0.3$ in our calibration.

The elasticity of crude birth rates with respect to crude death rates, ϕ_{CDR}^n is much harder to pin down. In the end, the exact value does not turn out to be important, and the calibration is not sensitive to the exact choice of this elasticity. We use a value of $\phi_{CDR}^n = -0.30$ as a baseline, but modifying this between 0 and -1 does not create material differences in our results. The value of θ_j follows directly from the values of β, γ, and ϕ_{CDR}^n.

Finally, we require that the crude birth rates in each location in the initial period of the calibration are identical to those obseved in the data from 1950, $n(w_j, CDR_j, \tau_j) = CBR_{j,1950}$, which would implicitly set the values of τ_j. As we only require the changes in fertility over time, solving for these is not necessary.

To keep the simulations with endogenous fertility comparable, we keep the values of the G_j and ϵ_j terms identical to the baseline calibration. From (21) we know that these terms have a slightly different interpretation in the model with endogenous fertility. An alternative would be to entirely recalibrate the model in the endogenous fertility setting, and then replicate all aspects of the baseline analysis. We have done this, and the overall results are not demonstrably different from our baseline model. So for comparison purposes, we present the endogenous fertility results in the paper holding the values of the G_j and ϵ_j terms equal to their values in the baseline.

Web Appendix References

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