Population dynamics, urbanisation without growth and the rise of megacities

[This draft: January 2018]

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Abstract

That urbanisation in many developing countries, especially in Sub-Saharan Africa, is not delivering the kind of benefits that might be expected in the light of experience elsewhere in the world is now widely acknowledged. This *urbanisation without growth* has been the focus of recent research in both the development and urban economics literature. In this paper, we focus on demographic factors and develop a simple dynamic model to describe internal migrations, the evolution of the urban rate and total productivity, and how these are affected by population growth and investments in urban infrastructure. Our model can predict basic trends in the data, including urbanisation without growth and the rise of (poor) megacities. We complement the model with empirical evidence using (i) international cross-country panel data; and (ii) regional data for Tanzania.

JEL codes: R11, R23, J11, O18

Key words: Dynamic modelling, population growth, internal migration, productivity, urbanisation, development, SSA

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1. Introduction

That urbanisation in many developing countries, especially in Sub-Saharan Africa (SSA), is not delivering the kind of benefits that might be expected in the light of experience elsewhere in the world is now widely acknowledged. This *urbanisation without growth* has been the focus of recent research in both the development and urban economics literature, and has also attracted increasing attention from a policy perspective. In a rapidly urbanising world, understanding this phenomenon is a key challenge for academics and policy makers alike.

In this paper, we try to shed more light on this urbanisation-without-growth phenomenon. To do so, we analyse recent urban trends using international cross-country panel data. We focus on demographic dynamics and their connection with urbanisation and economic performance. To understand the role of demographic dynamics, we develop a simple theoretical model including population growth as well as rural-urban and urban-urban migration. Our model allows us to track the evolution of the urban rate and total productivity, and how these are affected by population growth and investments in urban infrastructure. We validate our model using data from Tanzania.

Urbanisation is mainly determined by rural-urban migration and natural population growth. Traditionally, the focus has been given to rural-urban migration, as historically urbanisation has primarily been associated with in-migration (Jedwab and Vollrath 2015). In this line, urbanisation has been associated with a process of structural change in which resources are reallocated from agricultural to industrial activities, and people move from rural to urban areas. This change has usually been linked to productivity growth and therefore considered as a fundamental element in the process of economic development. However, nowadays in many poor countries, especially in SSA, urbanisation is not necessarily associated with economic growth. At least three characteristics of the process of urbanisation in SSA countries arise as relevant. First, rural-urban migration in SSA seems more the outcome of "push" rather than "pull" factors; deteriorating agricultural conditions - worsen by climate change, high volatility in agricultural prices, natural disasters, and even violent conflict in rural areas "push" people to urban areas, without any increase in productivity. This has been noted and studied already by many authors (see for instance Lipton 1977; Bates 1981; Bairoch 1988; Barrios et al. 2006; Swanson and Buckley 2013).[1] Second, urban infrastructure has hardly kept pace with urban explosion, with only about a quarter of the urban population in SSA having access to basic services like improved sanitation facilities and electricity (Castells-Quintana 2017). Finally, recent data suggests that urbanisation in SSA countries is mostly explained by natural

[1] "Pull factors" can also lead to urbanisation without growth. Expectations of high returns from moving to urban areas do not necessarily materialise - the Todaro Paradox (Todaro 1969). More recently, Jedwab and Vollrath (2015) show how several "pull factors" can represent what they call a positive source of urbanisation without growth. Similarly, Gollin *et al* (2016) show how urbanisation may be associated with natural resource rents, service industries and consumption expenditure rather than industrialisation.

population growth (see for instance Cobbinah et al. 2015; Jedwab et al. 2017). This role of population growth has been much less studied than that of migration.

In relation to the literature, this paper is closely linked to others studying recent urbanisation trends and economic performance in developing countries. Many of these papers highlight the phenomenon of urbanisation without growth (Kojima 1996; Fay and Opal 2000; Bloom et al. 2008; Vollrath 2009; Jedwab and Vollrath 2015; Gollin *et al* 2016), as well as the need for more emphasis on the role of demographic factors as drivers of urbanisation (Jedwab et al 2017; Fox 2017). The paper also relates to works studying the effects of population growth on economic development (see for instance Srinivasan 1988; Brander and Dowrick 1994; Ahituv 2001; Aguirre 2002; Klasen and Nestmann 2006; Birchenall 2016). Some papers in this literature focus on the link between high rates of population growth and disappointing economic performance in SSA (Huth 1984; Otani and Villanueva 1990). Finally, the paper relates to those in the urban economics literature studying agglomeration effects in developing countries. Some of these papers emphasise the importance of specific characteristics of the urban context like basic infrastructure (Bertinelli and Black 2004; Turok and McGranahan 2013; Castells-Quintana 2017). While many of all these papers give insights into the phenomenon of urbanisation without growth, to the best of our knowledge, an integral theoretical framework linking population dynamics - including both internal migrations and population growth - urban trends, capital accumulation and the evolution of productivity, is still missing. We aim to fill that gap.

The contribution of our paper is twofold. Firstly, it provides a (tractable) theoretical model of urbanisation without growth. In line with recent evidence, our model offers a simple explanation of this phenomenon based on population dynamics. Secondly, the paper provides a framework able to connect urbanisation without growth with other empirical findings, like i) the rise of (poor) megacities characteristic of urbanisation in many developing countries, ii) the relevance of urban capital for the benefits of urban concentration, and iii) recent evidence of slowdowns in the speed of urbanisation in SSA despite continued growth of the largest cities in the region (see Potts 2009, 2015).

The remainder of the paper is organised as follows. Section 2 provides a look at international data, highlighting some stylised facts on urbanisation without growth and a potential role of population growth. In Section 3, we develop our simple theoretical model that accounts for this potential role of population growth in the evolution of urbanisation and productivity. To more easily visualise how the model can predict urbanisation without growth, we perform some simulations. We also validate the model using regional data for Tanzania. Finally, Section 4 concludes and derives policy implications from the results.

2. *Urbanisation and economic growth: a look at the data*

What does a look at data tells us about urbanisation and growth in recent decades? Using international data, we can highlight at least three interesting stylised facts: i) *urbanisation without growth*, especially in countries in SSA, ii) an association between high population growth and lower economic performance, and iii) the rise of (poor) megacities. In the rest of this section, we study each of these facts empirically, before trying to understand them together in a simple theoretical model (in Section 3).

The phenomenon of urbanisation without growth

The phenomenon of *urbanisation without growth* becomes evident in the data when we differentiate levels in the variables from their evolution over time. Looking at levels, we find the well-known positive correlation between urban rates and GDP per capita (see Figure A.1 in Annex A). However, looking at evolutions over time, there is no clear association between *the process* of urbanisation and economic growth. Table 1 shows rates of economic growth, urbanisation, population growth and fertility, looking at world averages and different world regions, between 1970 and 2010 (and splitting the period in 5-year periods). Figure 1 plots the association between growth in urban rates and economic growth (Panel A for the world sample and Panel B for SSA).[2]

Table 1. Economic growth, urbanisation and population growth: 1970-2010

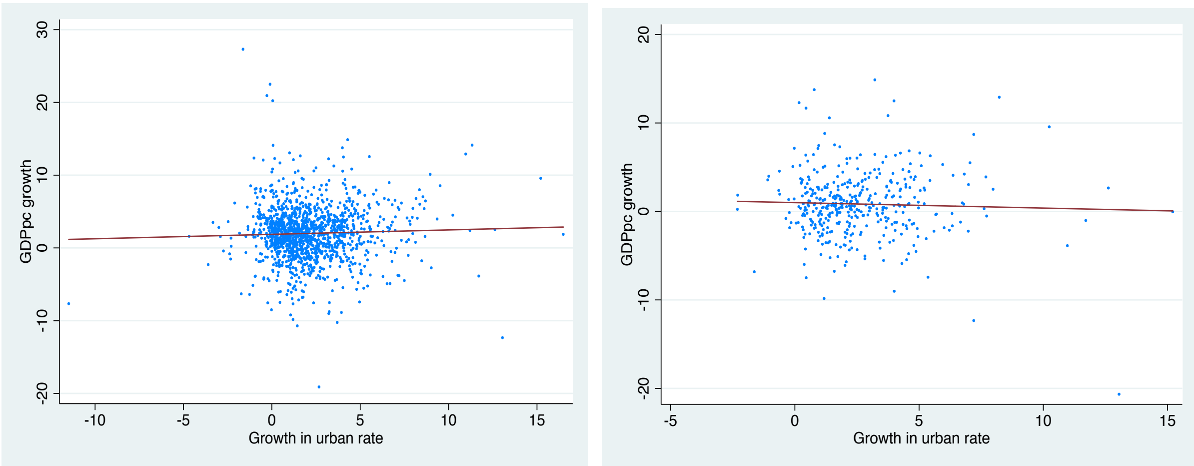
	GDPpc growth	Growth in urban rate	Growth in primacy rate	Population growth	Fertility rate	Fertility rate 2005-2010
Europe	2.7844	1.9058	-0.3504	2.4809	1.9958	1.5396
Asia	3.1440	2.0945	-0.5425	12.3737	4.3559	2.5117
Latin America	1.6179	2.6825	-0.4392	10.0427	4.2614	2.6241
SSA	**1.1166**	**2.5154**	**0.0632**	**12.8007**	**6.0089**	**4.7806**
Developing countries	1.8996	2.2553	-0.3858	10.4003	4.7684	3.2860
World	2.0792	2.2066	-0.4125	9..4211	4.1595	2.896

Note: GDPpc growth is calculated as annual compound rate. All other *growth* figures are calculated using 5-year changes (5-year log difference times 100 in the case of population growth). Fertility rate is calculated using 5-year averages. Figures show the 1970-2010 mean for countries in each group.

[2] Table A.1 in Annex A gives definitions and sources for all data used. Table A.2 in Annex A shows correlations between economic growth, growth in urban rates, population growth and fertility rates, for the world sample and for SSA countries only. Population growth and economic growth show a negative correlation of 0.45 for SSA countries.

Figure 1. Urbanisation and growth, 1970-2010

Panel A: World sample **Panel B: SSA sample**



Note: Growth in urban rates calculated as 5-year change. GDPpc growth calculated as annual compound rate.

Urbanisation without growth seems particularly manifest in SSA; during our period of analysis, the region experienced the poorest economic performance among all world regions, along with fast urbanisation. While the world average annual growth rate of GDP per capita was close to 2.08, in SSA it was only 1.11, significantly below than in other regions like Europe, Asia and Latin America. In fact, while on average Asian countries more than doubled their GDP per capita during the period, SSA countries only increased it by an average of 32 per cent. We find the opposite in terms of the pace of urbanisation: during the 50 years from 1970 to 2010, SSA countries where among those where the urban rate increased the most (around 20 points on average and only matched by Latin-American counterparts).

The relationship between urbanisation and subsequent economic performance in terms of economic growth can further be tested through simple econometric analysis. To do so, we use a panel dataset for up to 139 countries from 1960 to 2010. We rely on reduced-form specifications and run simple cross-country regressions. The base specification in these regressions is given by equation (1):[3]

$$\Delta y_{it} = \theta_1\left(logy_{i,t-1}\right) + \theta_2\left(urb_{i,t-1}\right) + X_{i,t-1}\psi + \varepsilon_{it} \quad (1)$$

where Δy_{it} is per capita growth rate of country i, $y_{i,t-1}$ is initial income per capita (*income*), $urb_{i,t-1}$ the urban rate, $X_{i,t-1}$ a vector of variables reflecting factor accumulation (i.e. the standard Solow determinants) plus a constant term, and ε_{it} a country-period specific shock. To control for

[3] From a neoclassical perspective, economic growth is related to growth due to technological progress and to the gap between the initial level of output and the steady state to which the economy converges, with the expectation that countries with lower levels grow faster. See Durlauf et al. (2005) for a more detailed explanation of how to derive cross-country growth regressions from neoclassical economic growth theory.

the business cycle, and as standard in the literature, the analysis uses observations in five-year intervals. As control variables (X_{it-1}) we begin by considering investment (*ki*), as share of GDP, and average years of secondary and higher education of the adult population (*schooling*), following the literature on cross-country economic growth. Appendix A lists all variables' names, definitions and sources. For robustness, other control variables are also considered (including total population, density, life expectancy and sectoral composition of the economy).

Table 2 shows results for the association between urbanisation and growth. Column 1 to 3 show results for our world sample, considering different estimation techniques (OLS, Random Effects -RE, and Fixed Effects –FE). Controls have the expected signs and tend to be significant, with a negative coefficient for initial income levels (suggesting conditional convergence), and positive coefficients for investment rates and years of schooling (supporting the relevance of capital accumulation). Regarding urbanisation, and in line with our stylised facts, there does not seem to be a clear association with economic growth. Under OLS and RE (which mainly consider variation across countries) the coefficient is positive and significant. But when we introduce country fixed effects (which relies on variation within countries over time) it turns negative and significant.

Table 2: Urbanisation and growth

	(1) OLS	(2) RE	(3) FE	(4) RE	(5) RE	(6) FE
Dependent variable: *growth* (Average cumulative annual growth rates of per-capita GDP)						
l(income)	-0.5687***	-0.7399***	-4.1180***	-0.9161***	-0.9356***	-4.3109***
	(0.1589)	(0.1669)	(0.7155)	(0.1721)	(0.1797)	(0.7415)
ki	0.0776***	0.0771***	0.0774***	0.0782***	0.0783***	0.0703***
	(0.0136)	(0.0134)	(0.0219)	(0.0139)	(0.0141)	(0.0218)
schooling	0.3149**	0.3299***	0.1944	0.2558**	0.2339**	-0.0436
	(0.1220)	(0.1217)	(0.2930)	(0.1173)	(0.1187)	(0.2864)
urb	0.0184**	0.0237**	-0.0567*	0.0197**	0.0241**	-0.0053
	(0.0089)	(0.0094)	(0.0287)	(0.0091)	(0.0094)	(0.0286)
SSA				-1.7068***	-0.8562	
				(0.3114)	(0.6135)	
urb*SSA					-0.0296*	-0.1018***
					(0.0168)	(0.0366)
Year FE	YES	YES	YES	YES	YES	YES
Country FE	NO	NO	YES	NO	NO	YES
R square	0.123	0.206	0.206	0.287	0.281	0.217
Observations	1206	1206	1206	1206	1206	1206
No. countries	138	138	138	138	138	138

Note: *growth*, *ki* are calculated as averages over 5 years. The time span goes from 1960 to 2010. All remaining variables are measured at the beginning of the period. Robust standard errors clustered by country in parentheses. *** p<0.01, ** p<0.05, * p<0.1

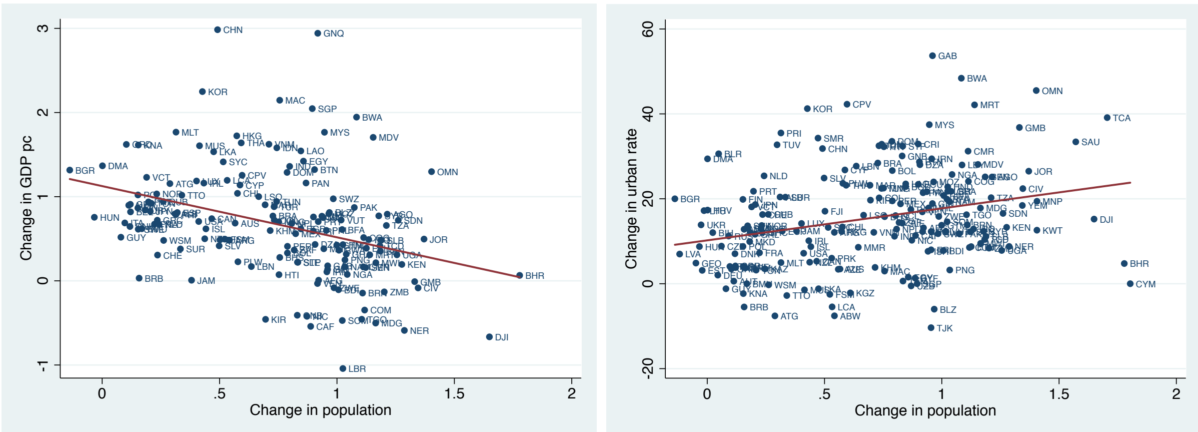
As we saw before, countries in SSA tend to display lower rates of economic growth and rapid urbanisation. To take this into account, in column 4 of Table 2, we consider a dummy for SSA countries and in columns 5 and 6 also an interaction between this dummy and urban rates, to capture a potential differential relationship between urbanisation and economic growth in SSA. As results show, compared to the rest of the world, SSA countries have had on average lower growth rates, even when controlling for capital accumulation. Furthermore, when we allow for a differential association between urbanisation and economic growth for SSA than for the rest of the world, we find a negative and significant coefficient for urbanisation for SSA (both under RE and FE). In other words, whilst urbanisation may be positively associated with growth in the rest of the world, it is negatively so in SSA countries.

Population growth, urbanisation and (poor) economic performance

The second relevant fact, key in our analysis, relates to population growth and their association with urbanisation and economic performance. As shown in Panel A of Figure 3, countries with higher population growth over the 1970-2010 period had on average a lower increase in their GDP per capita. By contrast, we find a positive association between population growth and urbanisation (Panel B of Figure 3).[4] Once again, SSA stands out: along poor economic performance and rapid urbanisation, SSA countries have also experienced the fastest rates of population growth. Between 1970 and 2010, on average, countries in the region doubled its population. And this demographic explosion in SSA has not stopped; while in most regions of the world fertility rates have declined to around 2, they remain close to 5 in SSA countries.

Figure 3. Population growth, GDPpc and urbanisation, 1970-2010

Panel A **Panel B**



Note: Changes in population and GDP pc calculated as log-differences (2010 compared to 1970).

[4] A simple regression of growth in urban rates on population growth, in the current period and lagged up to two periods, yields significant coefficients for population growth. From this regression, we can also divide urban growth in two parts: one explained by population growth and one that is not. If we correlate this two parts or urban growth with economic growth, we find opposing results: urbanisation driven by population growth is negatively correlated with economic growth, while urbanisation not driven by population growth is positively correlated with it.

We can check whether population dynamics can help us account for the relatively lower economic performance of SSA countries during the period of analysis, and the phenomenon of urbanisation without growth in the region. To do so, we introduce fertility rates (*fertility*) in our econometric model escribed in equation (1). Table 3 shows the results. In column 1 we estimate by RE to see what happens to the SSA dummy, while in column 2 we introduce fixed effects. Fertility rates yield negative and highly significant coefficients, in line with empirical evidence elsewhere.[5] Comparing column 1 of Table 3 with column 4 of Table 2, we can see how the coefficient for the SSA dummy remains significant but lowers in magnitude by more than half (from 1.71 to 0.78). This suggests that at least part of the relatively lower economic performance of SSA may be explained by higher fertility rates. In columns 3 and 4 of Table 3, we consider urban rates along fertility. In columns 5 and 6, we allow for a differential relationship between urbanisation and economic growth in SSA than in the rest of the world. In all cases, fertility remains highly significant. By contrast, compared to results in Table 2, the interaction between urbanisation and the SSA dummy is now lower in magnitude (and only significant under FE).[6] These last results suggest that part of association between urbanisation and economic growth that we found for SSA countries may be explained by higher fertility rates. In other words, econometric analysis using cross-country data support the idea of a relevant role of population dynamics (i.e., high fertility rates) in the phenomenon of urbanisation without growth in SSA.

[5] According to the literature, the negative effect of population growth is mainly driven by high fertility rates (see for instance Otani and Villanueva 1990; Brander and Dowrick 1994; Ahituv 2001). Both, population growth and fertility yield negative coefficients, but when we introduce both variables fertility trumps population growth. The negative role of fertility rates is found irrespectively of the estimation technique (including System GMM to partially address endogeneity concerns) and holds when we consider only SSA countries. Results are also robust to further controls like total population, density, life expectancy and sectoral composition of the economy. Interestingly, the coefficients for fertility are very similar when we consider the world sample or only SSA countries.

[6] Under SysGMM estimations, fertility remains highly significant, the interaction between urbanisation and the SSA dummy also losses significance, and urbanisation in the rest of the world even turns positive and significant.

Table 3: Urbanisation and growth, a role for population growth

	(1) RE	(2) FE	(3) RE	(4) FE	(5) RE	(6) FE
Dependent variable: *growth* (Average cumulative annual growth rates of per-capita GDP)						
l(income)	-1.1088***	-4.3094***	-1.2343***	-4.1923***	-1.2393***	-4.3168***
	(0.1489)	(0.6839)	(0.1719)	(0.7024)	(0.1749)	(0.7264)
ki	0.0572***	0.0789***	0.0758***	0.0773***	0.0760***	0.0722***
	(0.0120)	(0.0210)	(0.0122)	(0.0218)	(0.0124)	(0.0217)
schooling	0.0252	0.1288	0.002	0.1867	-0.0109	0.0168
	(0.1067)	(0.2795)	(0.1109)	(0.2860)	(0.1126)	(0.2813)
urb			0.0106	-0.0740***	0.0135*	-0.0336
			(0.0076)	(0.0270)	(0.0077)	(0.0321)
SSA	-1.0208***		-1.0112***		-0.3909	
	(0.2734)		(0.2773)		(0.5573)	
urb*SSA					-0.0215	-0.0734**
					(0.0141)	(0.0368)
fertility	-0.7832***	-0.5464***	-0.7628***	-0.6379***	-0.7583***	-0.5132**
	(0.0927)	(0.1820)	(0.0960)	(0.1879)	(0.0967)	(0.1996)
Year FE	YES	YES	YES	YES	YES	YES
Country FE	NO	YES	NO	YES	NO	YES
R square	0.422	0.217	0.42	0.22	0.203	0.225
Observations	1216	1216	1206	1216	1206	1206
No. countries	139	139	138	138	138	138

Note: *growth*, *ki* and *fertility* are calculated as averages over 5 years. The time span goes from 1960 to 2010. All remaining variables are measured at the beginning of the period. Robust standard errors clustered by country in parentheses. *** p<0.01, ** p<0.05, * p<0.1

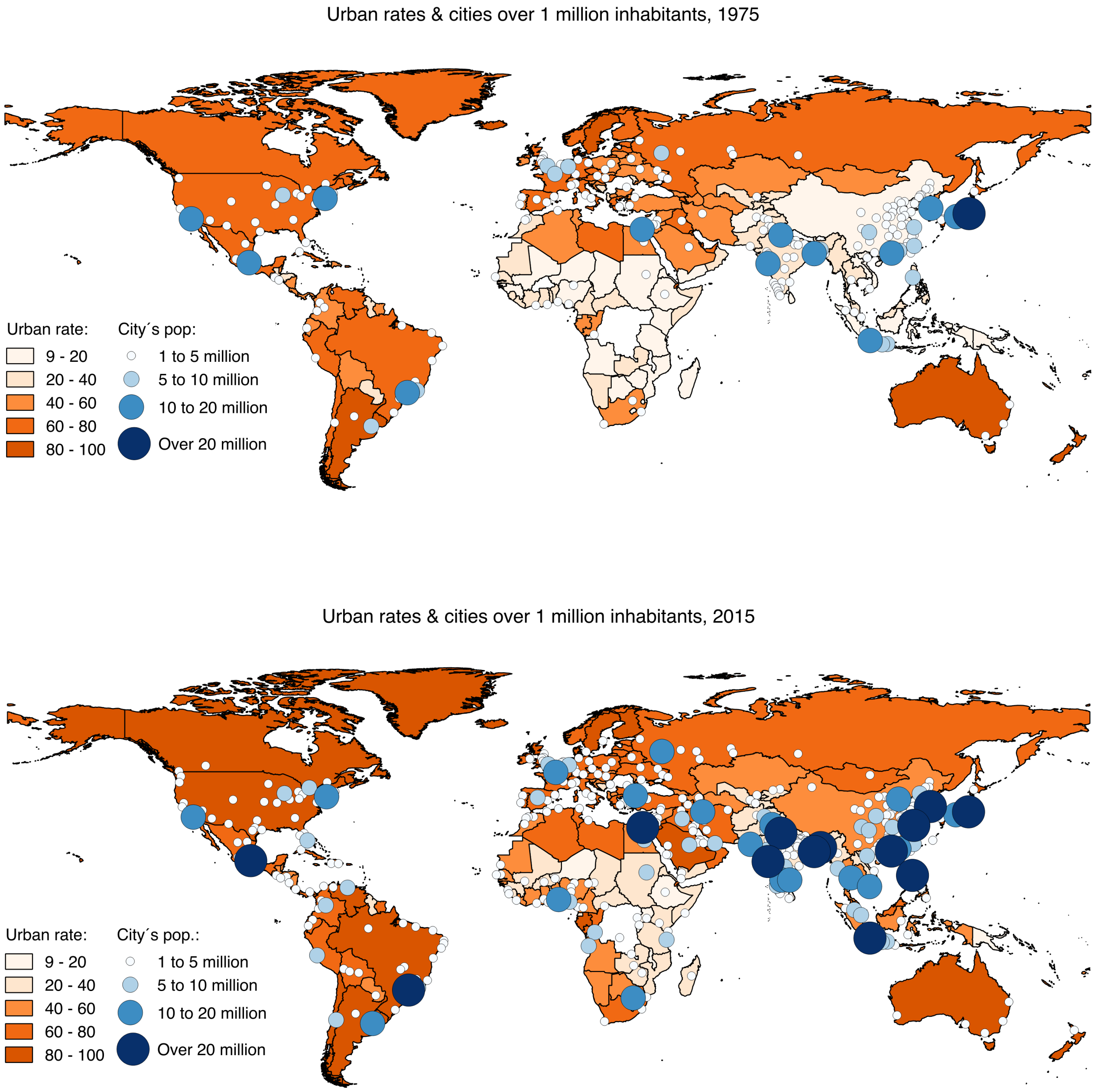
The rise of (poor) megacities

A final fact in international data on urban trends relates to the rapid growth in the number and size of cities along the process of urbanisation, especially in developing countries. Figure 2 maps urban areas (i.e., cities) of more than one million inhabitants worldwide, along with urban rates, in both 1975 and 2015.[7] In 1975, urban rates were already high in developed countries, but still low in most developing countries. Regarding cities, in developed countries there were 76 large cities – those with more than one million inhabitants – and 4 megacities – those with more than 10 million inhabitants. In developing countries there were 178 large cities and 9 megacities. The picture has significantly changed in 2015. Urban rates have increased significantly in developing countries, with the number of large cities having more than doubled in these countries, reaching 396 (of 494 worldwide). The rise of large cities in developing countries is even clearer if we look at megacities, that already count to 26 in these countries. In fact, the largest megacities in the world are

[7] We rely on novel data by the Urban Platform of the European Commission. Data refers to “urban areas”.

nowadays in developing countries (26 of the 32). Of these megacities of the developing world, 12 already have more than 20 million inhabitants (with Guangzhou, Cairo, Jakarta, Delhi and Calcutta at the top).[8] Looking at SSA, we can find nowadays 51 cities with more than one million inhabitants, 7 of these with more than 5 million, and 2 (Johannesburg and Lagos) with more than 10 million.

Figure 2. Urban rates and large cities, 1975 and 2015



Note: Urban rates come from WB data. Data on population size of cities comes from *Urban Audit*…

[8] In the developed world, only Tokyo has more than 20 million inhabitants.

3. *Population dynamics, urbanisation and growth: a simple theoretical model*

To better understand the role of population dynamics on the phenomenon of urbanisation without growth and the rise of poor megacities, we develop of a dynamic (but simple) theoretical model, able to capture the facts identified in the data.

According to classical two-sector models (i.e., Lewis 1954; Harris & Todaro 1970), urbanisation in developing countries is the consequence of rural-urban migration, itself driven by differential economic opportunities between rural and urban areas. Urbanisation is seen in these models as the result of structural change, with urbanisation and economic growth going hand in hand. However, as we have seen, the recent experience of many developing countries (especially in SSA) is one of urbanisation that not necessarily translates into economic development.

Following Fox (2017) on the need for more emphasis on the role of demographic factors as drivers of urbanisation (that may explain urbanisation without growth), we set up a modelling framework within which the effects of population growth, migration, and urbanisation can be studied.

Earlier works analysing urbanisation and growth in developing countries have often implicitly or explicitly assumed a fixed population size.[9] In SSA, population growth is still very high. In this line, Jebwab *et al* (2017) draw attention to the natural increase of the urban population as a rising component of urban population growth. However, the rural population, often three or four times as large as the urban population in SSA countries, is also growing rapidly, and this also has important implications for urbanisation. The role of population growth is twofold. On the one hand, high population growth in urban areas can increase urbanisation, even with limited rural-urban migration. On the other hand, high population growth in rural areas increases land pressure and environmental degradation, leading to lower agricultural product per capita and incentives to migrate to urban areas. Considering urban and rural areas in isolation could therefore be misleading.

We envisage a developing country with a large rural population, a primate city and several regions, each with its own urban centre. Urbanisation takes place due to internal migration, which is driven by differences in the marginal product of labour between the urban and the rural sector. However, urbanisation also depends on natural growth, as we allow for population growth in both rural and urban areas. We allow for internal migration to take place from a region's rural area to its urban centre, and from urban centres to the primate city. The primate city therefore grows due to immigration and natural growth. For simplicity, we leave the full set up of the model for the appendix of the paper (see Annex B), and focus here on the key elements of the model:

The rural production function in each region depends on its total population and the availability of natural resources, as given by equation (2):

$$Yr = a.Pr^{\alpha}.N^{\beta} \qquad (2)$$

[9] For example, Gollin *et al* (2012) say "… we should see workers move from agriculture to non-agriculture, simultaneously pushing up the marginal product of labour in agriculture and pushing down the marginal product of labour in non-agriculture" which is only the case if the population size is fixed.

where *Yr* is rural output, *Pr* is rural population and *N* is natural resources (including land).

As in rural areas, in regional urban centres the production function depends on its population, *Pu*. However, we assume that in urban centres there are potential agglomeration effects related to the size of the urban population, *S(Pu)*, and the need for urban capital, *Ku* (which includes infrastructure): [10]

$$Yu = b.S(Pu).Pu^{\gamma}.Ku^{\delta} \quad (3)$$

where *Yu* is urban output.

For the primate city, we assume a similar production function to that of urban centres, with *Yp*, *Pp* and *Kp* being output, population and capital respectively.

Agglomeration effects, *S(Pu)* for urban areas - and similarly *S(Pp)* for the primate city), are given by equation (4). We follow the literature and assume that a doubling of the urban population adds 5% to output, in line with international estimates (see for instance Rosenthal and Strange 2004):

$$S(Pu) = (1.05)^{\ln\left(\frac{Pu}{Po}\right)/ln2} \quad (4)$$

where *Po* is an arbitrary base level population.

We suppose that the rural-urban migration rate, m_r, in each region is a function of the difference between marginal labour productivities, *MPu* and *MPr* for the urban and the rural areas respectively:

$$m_r = \mu\left(\frac{MPu}{MPr} - 1\right) \quad (5)$$

where μ (< 1) indicates that migration is subject to frictions, with only partial adjustment in any period.[11] Similarly, the migration rate from regional centres to the prime city is given by:

$$m_u = \mu\left(\frac{MPp}{MPu} - 1\right) \quad (6)$$

where *MPp* is the marginal productivity in the primate city.[12]

To analyse the role of population growth, we introduce *g*, the population growth rate. The evolution of population in rural areas, urban centres, and the primate city, are therefore given by the following three equations:

$$Pr_{t+1} = Pr_t(1 + g - m_r) \quad (7)$$

$$Pu_{t+1} = Pu_t(1 + g - m_u) + Pr_t.m_r \quad (8)$$

$$Pp_{t+1} = Pp_t(1 + g) + \sum_1^J Pu_t.m_u \quad (9)$$

where *J* is the number of regions besides the primate city.

[10] Following the idea of agglomeration benefits associated with urbanisation and urban concentration as being critically dependent on adequate urban investment (Bertinelli and Black 2004), particularly on basic infrastructure and services (Castells-Quintana 2017).

[11] Previous research has suggested significant frictions to migration in SSA countries, even in the presence of important productivity gaps (see for instance Vollrath 2009; Beegle *et al.* 2011; Gollin *et al.* 2012; Young 2013).

[12] Marginal labour productivities can be easily obtained from our production functions (see Annex B).

Accordingly, the evolution of population in rural areas depends positively on the population growth rate and negatively on rural-urban migration. Regional urban centres gain population from natural population growth and rural-urban in-migration, but lose from out-migration to the primate city. Finally, the primate city grows in population due to natural population growth and in-migration.

Some simulations

Equations (7), (8) and (9) constitute an inter-connected set of difference equations. Given some starting values for *Pr*, *Pu*, *Pp*, *Ku*, *Kp* and *N*, together with assumed values for some parameters, the system can be iterated over several periods to more easily study its evolution over time. By defining the evolution of population in rural and urban areas, the model allows us to track the evolution of the urban rate, and its connection with marginal and average productivity. As we differentiate by urban centres and the primate city, the model also allows us to track urban-urban migration and the rise of megacities. To keep the analysis simple, we assume four regions, each with an initial urban population (*Pu*) of 1 and an initial rural population (*Pr*) of 4. We also set the availability of natural resources, *N*, to 4 and urban capital, *Ku*, to 1. For the prime city, we set both the initial population and capital to 4. We further assume constant returns to scale and set $\alpha = \beta = \gamma = \delta = 0.5$.[13] For migration frictions we assume μ = 0.1. To obtain values for *a* and *b*, we set initial values for *MPr* and *MPu* at 1.0 and 1.5 respectively, assuming and initial difference of 50% in the productivity gap between urban and rural areas. With these assumptions, *a = 2*, *b = 2.63*, and the marginal productivity of the primate city, *MPp*, starts in 1.654, a bit higher than that of other urban areas.[14]

We start with a simulation in the absence of population growth (i.e. *g* = 0), to provide a base case. The experiment is run over 20 periods and the results are shown in Table 4. These allow us to see the evolution of population (*Pr*, *Pu* and *Pp*) after 5, 10, 15 and 20 periods, together with the related evolution of marginal productivities (*MPr*, *MPu* and *MPp*).

Table 4: Results of simulations with no population growth (*g* = 0)

Time	Rural Pop (*Pr*)	Urb Pop (*Pu*)	Pop primate (*Pp*)	Total Pop	Mg Prod rural (*MPr*)	Mg Prod urban (*MPu*)	Mg Prod primate (*MPp*)
0	4	1	4	24	1	1.5	1.654
5	3.41	1.467	4.488	24	1.083	1.272	1.574
10	3.172	1.539	5.156	24	1.123	1.246	1.483
15	3.022	1.551	5.707	24	1.15	1.242	1.42
20	2.916	1.55	6.137	24	1.171	1.242	1.376

[13] We follow Gollin *et al* (2012) in adopting this useful simplification.

[14] Our numerical assumptions may look somehow arbitrary, but we chose values that somehow reflect common ratios in SSA. For example, they give an urban rate of 33% and a primacy rate of 16%, which replicates the reality of most SSA countries. In any case, we check that the qualitative predictions of our model are not affected by our numerical assumptions. Below, we also test the fit between our model and Tanzania data.

Simulation results show that rural-urban migration leads to an improved ratio of rural population (*Pr*) to natural resources (*N*), and consequently rises rural marginal productivity. However, the growing urban population in the regional centres, in the absence of any increase in urban capital (*Ku*), leads to a decline in marginal productivity in these urban centres. Agglomeration economies *S(Pu)* do not operate strongly enough to offset the deteriorating ratio of population to urban capital. A similar effect is seen in the primate city, given the absence of any increase in urban capital in the primate city (*Kp*). Regarding urbanisation, the urban rate has risen from 33% (8/24) to 51% (12.337/24), but with marginal productivities converging, the incentive for further rural-urban migration is becoming weaker. In fact, by the end of the simulation, rural-regional centre migration just matches regional centre-primate city migration so that only the primate city continues to grow. This last result matches recent evidence suggesting that urbanisation in SSA is now slowing down with most internal migration mainly leading to growth of the primate city (Pott 2015).

Results in Table 4 can now be compared with a case with population growth. We set g = 0.03, representing a population growth of 3%, which is approximately the annual rate during the last decades in most SSA countries. Results are shown in Table 5.

Table 5: Results of simulations with population growth (g = 0.03)

Time	Rural Pop (*Pr*)	Urb Pop (*Pu*)	Pop primate (*Pp*)	Total Pop	Mg Prod rural (*MPr*)	Mg Prod urban (*MPu*)	Mg Prod primate (*MPp*)
0	4	1	4	24	1	1.5	1.654
5	3.956	1.699	5.204	27.82	1.006	1.194	1.477
10	4.244	2.092	6.909	32.25	0.971	1.092	1.308
15	4.658	2.474	8.864	37.39	0.927	1.016	1.175
20	5.169	2.899	11.074	44.35	0.88	0.95	1.068

With high population growth, as is the case in SSA countries, rural-urban migration is now insufficient to absorb the growth in rural populations, leading to a deteriorating ratio of rural population to natural resources and declining rural marginal productivity. Furthermore, the more rapid increase in the population of the regional urban centres, due to a combination of natural growth and in-migration, leads, in the absence of additional urban investment, to a more rapid decline in marginal productivity there too. This happens despite some onward migration to the primate city and agglomeration economies in urban centres. Similarly, the more rapid increase in the population of the primate city, due to both natural growth and in-migration, leads to a decline in marginal productivity that happens faster than in the zero-population growth case. An again, this happens despite some offset from agglomeration economies in the primate city. The urban rate has risen from 33% (8/24) to 52%, very like the zero-population growth case. However, over this period, the total population has grown by 75% with the rural population growing by about 29%, regional urban populations growing by about 190%, and the population of the primate city growing by about 177%. With marginal productivity falling well below the levels seen in Table 4, simulation results in

Table 5 therefore point to the negative impact of population growth, despite rapid urbanisation (i.e., urbanisation without growth). Similarly, declining productivity and population explosion in the primate city are in line with our stylised facts (see Figure 2) and recent empirical evidence on the rise of poor megacities in SSA (see for instance Jedwab and Vollrath 2015).[15]

To underline the role of urban capital, we can now consider urban capital growing in line with urban populations. Simulation results are shown in Table 6. As shown, now urban areas are sufficiently attractive to more than absorb rural population growth while urban growth is accompanied by rising marginal productivity (urbanisation with growth), driven by both urban investment and agglomeration economies. Urbanisation now rises to 74%. But in contrast with the previous cases of limited investment in urban capital, regional urban centres now grow much faster than the primate city. This is interesting as it highlights the connection between a balanced urban growth (i.e., not dominated by a single megacity) and good economic performance, in line with several papers in the urban economics literature (see for instance Duranton and Puga 2004; Barca et al. 2012; Castells-Quintana 2018).

Table 6: Results of simulations with population growth and urban capital growing in line with urban populations

Time	Rural Pop (*Pr*)	Urb Pop (*Pu*)	Pop primate (*Pp*)	Total Pop	Mg Prod rural (*MPr*)	Mg Prod urban (*MPu*)	Mg Prod primate (*MPp*)
0	4	1	4	24	1	1.5	1.654
5	3.606	1.13	4.88	27.82	1.053	1.582	1.677
10	3.272	3.306	5.939	32.25	1.106	1.632	1.7
15	3.012	4.539	7.189	37.39	1.152	1.669	1.723
20	2.81	5.861	8.662	43.35	1.192	1.7	1.746

What happens to average productivity (loosely speaking, GDP per capita) in the different scenarios? Table 7 shows average productivity figures covering both rural and urban areas for each of the three cases considered: no population growth and fixed urban capital (simulations in Table 4), population growth and fixed urban capital (simulations in Table 5), and population growth and investment in urban capital (simulations in Table 6). In the case of no population growth and fixed urban capital, average productivity slowly increases overtime. In the case of fast population growth, we see the opposite: average productivity falling overtime. But when we allow for investments in urban capital to keep pace with population growth, not only urbanisation increases but also overall productivity in both the urban and rural sectors (see last column).[16]

[15] Also note that if we take our numbers in terms of millions, results in Table 2, where we assume high population growth, suggest that the primate city grows from 1 to 11 million inhabitants in only 20 periods. This is an accurate estimate of the real evolution of many primate cities in SSA. According to WB data, Kinshasa, for instance, went from around 2 million inhabitants at the beginning of the 80s to more than 11 million in 2015.

[16] Our simulation results derive from a model which is very basic, together with the specific assumptions that have been incorporated in it. However, the main implications would seem to be robust to a range of different starting parameters.

Table 7: Average Productivity matching simulations in Tables 4-6

Time	Average Prod (Table 4)	Average Prod (Table 5)	Average Prod (Table 5)
0	2.255	2.255	2.255
5	2.293	2.14	2.457
10	2.306	2.01	2.619
15	2.314	1.884	2.744
20	2.318	1.763	2.842

To sum up, our simulation results suggest i) that the benefits of urbanisation are by no means automatic, even with zero population growth, ii) that high population growth can lead to declining productivity and the rise of poor megacities, and iii) that agglomeration effects alone are unlikely to be sufficient to deliver urbanisation benefits in the absence of investment in urban capital that matches the growth in urban populations. These simulations results match the experience of many SSA countries in the last decades, as reflected in the data analysis presented in section 2; urbanisation in SSA countries has been fast, characterised by the rise of megacities, and not necessarily associated with economic growth.

The Tanzanian case

We now look data for one SSA country. We rely on data for Tanzanian regions for the last decades.[17] Table C.1 in Annex C shows some population statistics for Tanzanian regions. Given our focus on urbanisation, we distinguish rural and urban areas, and disaggregate the latter into the primate city, regional capitals and 'other urban'. Tanzania, as most countries in SSA, is still relatively rural but has experienced rapid urbanisation along high population growth, in both rural and urban areas, during the last decades. Also, as common in the continent, the primate city (Dar es Salaam) is much larger and has grown faster than other regional capitals.

Using our Tanzanian regional data, first we run regressions using specifications like those used in the cross-country analysis, relating growth of *GDPpc* to urbanisation rates and population growth. Using regional data adds important insights compared to our cross-country analysis. It also avoids concerns about the comparability of data across countries (Jerven 2013) and eliminates the need for some controls. However, using regional data reduces our sample to only 54 observations.

As Table 8 shows, using regional data for Tanzania gives interesting and complementary results to those using our cross-country dataset. The urban rate yields either nonsignificant coefficients (under OLS and RE, in columns 1 and 2 respectively), or even negative and significant coefficients (under FE, in column 3). When we consider a role for population growth, under OLS and RE the coefficient for the urban rate becomes positive and significant, while population growth

[17] We use data compiled by Wenban-Smith (2015) using Tanzanian censuses. We have data for 19 regions for 4 moments in time (1967, 1988, 2002 and 2012). Annex C describes the Tanzanian data used.

yields negative and highly significant coefficients (columns 5 and 6).[18] This suggests that the negative association between urban rates and economic growth can be accounted by population dynamics. In other words, controlling for the negative role of increasing populations, regions with higher urban rates tend to have higher economic growth. However, under FE the coefficient for the urban rate remains negative: considering only the evolution over time, urbanisation (the process rather than the level) is not positively associated with economic growth. If anything, rapid urbanisation seems negatively associated with growth: an interaction term between urbanisation and population growth (column 7) yields a negative and significant coefficient, reinforcing the negative role of fast urbanisation along with high population growth. These results are consistent with our model and with findings using cross-country data.[19]

Table 8: urbanisation, population growth and economic performance, Tanzania 1987-2012

	(1) OLS	(2) RE	(3) FE	(4) OLS	(5) RE	(6) FE	(7) FE
Dependent variable: *growth* (Average cumulative annual growth rates of per-capita GDP)							
l(gdp_pc)	-4.9380***	-5.2331***	-7.5441***	-5.0244***	-5.0244***	-7.6954***	-8.0911***
	(0.9804)	(1.0077)	(0.9276)	(0.9939)	(0.9939)	(0.9797)	(1.0087)
urb	0.0293	0.0310	-0.1247**	0.0545**	0.0545***	-0.1326**	0.0451
	(0.0254)	(0.0255)	(0.0557)	(0.0203)	(0.0203)	(0.0550)	(0.1275)
popgrowth				-0.8551***	-0.8551***	-0.4249	0.2780
				(0.2528)	(0.2528)	(0.4265)	(0.5995)
urb*popgrowth							-0.0422*
							(0.0242)
Year FE	YES	YES	YES	YES	YES	YES	YES
Region FE	NO	NO	YES	NO	NO	YES	YES
R square	0.88	0.88	0.76	0.9	0.92	0.75	0.74
Observations	54	54	54	54	54	54	54
No. of regions	19	19	19	19	19	19	19

Note: The time span goes from 1978 to 2012, split in 3 periods due to data availability: 1978-1988, 1998-2002, and 2002-2012. urb is measured at the beginning of the period. Popgrowth is measured as annual rate during the period. Robust standard errors clustered by region in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Second, we use Tanzanian data to validate the consistency of our model to the experience of a SSA country in recent decades in what refers to the relationship between population dynamics and urbanisation. We set population growth rate at 3%, which resembles the recent experience of

[18] We use population growth, rather than fertility rates as in the cross-country analysis, as we do not have fertility rates for Tanzanian regions. Interestingly, the size of the coefficient does not very too much between our regional and cross-country analyses. Results are also robust to controlling for some controls like initial population size, and literacy rates (to account for human capital) but at the expense of losing observations.

[19] Note that in regional analysis internal migration introduces a strong element of endogeneity. That is because more successful regions not only exhibit stronger GDP growth but also attract more migrants, urbanise quicker and experience higher population growth, at the expense of less successful regions. This introduces an upward bias in our coefficients for urban rates and population growth. This bias goes against us, reassuring our key finding urbanisation without growth in contexts of high population growth.

Tanzanian (as that of most countries in SSA). The model predicts surprisingly well the evolution of the urban rate and of the population of the major city in recent decades (see Figure 1 in the Annex C).

Finally, to further validate our model, we perform estimations for migration propensities in our model. Rural-out migration in our model is a function of productivity differentials between rural and urban areas, but subject to some migration frictions, μ. Productivity differentials depend on population and capital dynamics in both areas. Thus, according to our model, out-migration should be increasing in urban scale and capital (*Pu* and *Ku/Pu*, respectively), but decreasing in favourable ecology and a less dense rural population (*N/Pr*).[20] This can be easily tested with our data using a simple linear specification, as follows:

$$Qr = c + \phi_1(Pu) + \phi_2\left(\frac{Ku}{Pu}\right) + \phi_3\left(\frac{N}{\mathrm{Pr}}\right) + \varepsilon \qquad (10)$$

where Qr is rural-out migration. To proxy for urban capital (*Ku*), we build an *infrastructure index* (*Inf*). To proxy for natural resources in rural areas (*N*) we use area planted to *maize*. Given data availability, for these estimations we must rely on cross-section data, and therefore cannot control for time-invariant omitted variables through fixed effects. To compensate, we control for climate and other ecological factors building an *ecological index* (*Eco*), which includes data on rainfall, soil quality and mean altitude. As Tanzania is still highly dependent on agriculture (as most SSA countries), these factors are relevant to explain productivity differences across regions. Results from estimations for migration propensities are in line with our theoretical model. Rural out-migration is positively and significantly associated with urban scale and capital, but negatively associated with higher natural resources per capita and favourable climatic and ecological conditions in rural areas. Results are given in Table C.2 in Annex C. The positive and significant role of urban scale and capital can be related to traditional *pull* factors, attracting individuals to urban areas. Analogously, the significant role of climatic and ecological factors can be understood as *push* factors, in line with recent papers highlighting deteriorating ecological and climatic conditions, in a context of high population pressure, as key elements behind urbanisation in SSA (see for instance Barrios et al. 2016). This has been specially the case in semiarid countries in the Sahel, like Tanzania, highly affected by desertification driven by climate change (see for instance Castells-Quintana et al. 2017).

4. Discussion and conclusions

Urbanisation plays a key role in the process of economic development; richer countries tend to be more urbanised. However, urbanisation does not necessarily translate into economic growth. The recent experience of many countries in the developing world is one of *urbanisation without growth*. This seems to be especially the case in countries in Sub-Sharan African (SSA), where urbanisation is particularly influenced by high population growth, in both rural and urban regions.

[20] See Annex B to see how these can be deduced from our theoretical model.

In this paper, we have tried to shed more light on this urbanisation-without-growth phenomenon. To do so, first, we have analysed recent urban trends using international cross-country panel data and paying special attention to demographic dynamics, and their connection with urbanisation and economic performance. Econometric analysis supports the idea of urbanisation without growth in SSA, and a relevant role for the high population growth that countries in the region still experience. Second, we have developed a simple theoretical model including population growth as well as rural-urban and urban-urban migration. We have validated our model using data from Tanzania.

Our model suggests that countries with high population growth can experience rapid urbanisation with declining productivity (i.e., urbanisation without growth). This is consistent and complements recent papers on urbanisation without growth highlighting the relevance of natural population increase in urban dynamics in SSA (Jebwab *et al.* 2017; Fox 2017). Our framework is also able to predict additional patterns in the data. First, the rise of (poor) megacities - characteristic of urbanisation in many developing countries (van der Ploeg and Poelhekke 2008; Jedwab and Vollrath 2015). Second, the relevance of urban capital for the benefits of urban concentration (Castells-Quintana 2017). Finally, evidence on the recent slowdown in the speed of urbanisation in SSA, despite continued growth of the largest cities in the region, and mainly due to declining economic opportunities in urban areas (Potts 2009, 2015).

At least three important policy implications arise from our results. First, the fundamental importance of investment in urban infrastructure in the context of rapid urban expansion. Countries in SSA show worrying deficiencies in terms of basic urban services that need to be urgently addressed if the benefits of urbanisation are to be realised.[21] Second, the desirability of more balanced urban systems, in line with recent evidence (see for instance, Duranton and Puga 2004; Barca et al. 2012; Castells-Quintana 2018). And third, the urgent need for SSA countries to complete their demographic transition (maybe suggesting the desirability of policies to reduce fertility), to ease the pressures of population growth on rural as well as urban resources. In urban regions, high population growth represents a "urban-push" factor (Jedwab et al. 2017). In rural areas, in a context of deteriorating ecological and climatic conditions - plus the presence of violent conflict in many cases, population growth translates into a significant rural-push factor. In the absences of sufficient investment in urban areas - to keep pace with population growth - the concentration of population in urban areas does not necessarily increase overall productivity, and can even decrease it (Marx et al., 2016; Castells-Quintana 2017).

Finally, for the sound design of policies aiming at sustainable development paths that allow for the full realisation of the benefits of urbanisation, further research could be of great value. As we have shown in this paper, one relevant issue relates to the better understanding of population dynamics in the context of poor countries experiencing rapid urbanisation, as in SSA. Similarly, research is needed to also understand the role of other potentially relevant factors besides rapid

[21] There are of course also potential benefits from greater investment in improving rural productivity, whether by upgrading skills in the rural sector or by improving the land and other natural resources, although this is not something we have explored in this paper.

population growth, such as international migrations, the high cost of transport, difficult access to international markets and weak industrial and institutional development (not fully explored in our model), which may also be contributing to urbanisation without growth.

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Annex A: International data used

Table A.1: Cross-country dataset: names, definitions and sources of all variables

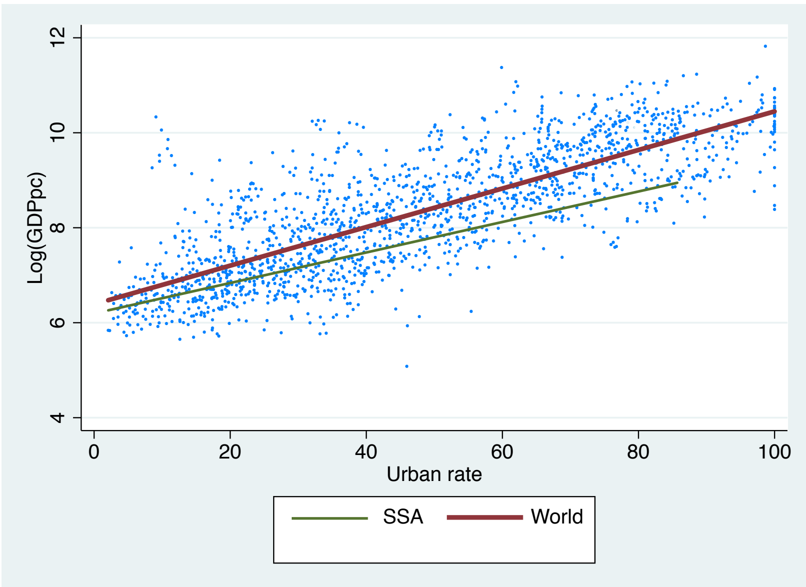
Variable name:	Description:	Source:
growth	Cumulative annual average per capita GDP growth rate	Constructed with data from PWT 7.1 (Heston et al. 2012), using real GDP chain data (rgdpch)
urb	Population living in urban areas (% of total pop.)	World Bank - World Development Indicators
log(income)	Per capita GDP (in logs)	Constructed with data from PWT 7.1 (Heston et al. 2012), using real GDP chain data (rgdpch)
ki	Investment share (% of GDP) (5-year average)	Constructed with data from PWT 7.1. (Heston et al. 2012)
pop	Total population	World Bank - World Development Indicators
popgrowth	Population growth (5-year change)	Calculated using total population data from World Bank - World Development Indicators
fertility	Fertility rates (5-year average)	Calculated using fertility rates from World Bank - World Development Indicators
schooling	Average years of secondary and tertiary schooling of adult population	Barro and Lee dataset
SSA	Dummy for Sub-Sahara African countries	Constructed by the author
density	Population density	World Bank - World Development Indicators
life expectancy	Life expectancy at birth	World Bank - World Development Indicators
sectoral comp.	Share of agriculture (%GDP)	World Bank - World Development Indicators

Table A.2: Correlations between economic growth, growth in urban rates, population growth and fertility rates, for the world sample and for SSA countries only

		GDPpc growth	Growth in urban rate	Growth in primacy rate
World				
	GDPpc growth	1		
	Growth in urban rate	0.0160	1	
	Growth in primacy rate	-0.1562	-0.1157	1
	Population growth	**-0.3594**	0.2003	-0.1557
SSA				
	GDPpc growth	1		
	Growth in urban rate	0.1029	1	
	Growth in primacy rate	-0.2878	-0.1512	1
	Population growth	**-0.4526**	0.0174	0.0145

Note: Correlations using the evolution in the variables (calculated as log-differences) for countries in each sample (World and SSA) between 1970 and 2010.

Figure A.1. Urbanisation and GDP pc



Annex B: A theoretical model of population dynamics, urbanisation and growth

We build a basic dynamic model to study the evolution of marginal and average productivity in a developing country. We consider a number of regions within the country, each with a rural and urban area, and a primate city (with no rural area). Rural and urban areas have different production functions. The model allows for internal migration, driven by differences in the marginal product of labour between areas. Migration may take place from a region's rural area to its urban area, and from urban areas to the primate city. The model further allows for population growth in both rural and urban areas, as well as in the primate city.

The rural production function

The rural production function in each region is:

$$Yr = aPr^{\alpha}N^{\beta} \tag{B.1}$$

where *Yr* is rural output, *Pr* is rural population and *N* is natural resources (including land). The marginal product of rural labour in a region is then given by:

$$MPr = \frac{\partial Yr}{\partial Pr} = a\alpha Pr^{\alpha-1}N^{\beta} \tag{B.2}$$

The urban production function

The production function for regional urban areas is:

$$Yu = bS(Pu)Pu^{\gamma}Ku^{\delta} \tag{B.3}$$

where *Yu* is urban output, *S(Pu)* is a scale factor incorporating agglomeration effects related to the size of the urban population, *Pu* is the urban population and *Ku* is urban capital, including infrastructure. The primate city production function is of the same form but with *Yp*, *Pp* and *Kp*.

S(Pu) is specified so that a doubling of the urban population adds 5% to output (in line with estimates from the urban economics literature):

$$S(Pu) = (1.05)^{\ln\left(\frac{Pu}{Po}\right)/ln2} \tag{B.4}$$

where *Po* is some base urban population level. We set *Po=1*, so:

$$Yu = b(1.05)^{lnPu/ln2}Pu^{\gamma}Ku^{\delta} \tag{B.5}$$

The marginal product of urban labour is then given by:

$$MPu = \frac{\partial Yu}{\partial Pu} = b(1.05)^{lnPu/ln2}\left(\frac{ln1.05}{ln2} + \gamma\right)Pu^{\gamma-1}Ku^{\delta} \tag{B.6}$$

With these equations for marginal productivities, we can now define internal migration (and a potential role of population growth), and study urbanisation and the evolution of productivity.

Rural-urban migration and the evolution of rural population

We suppose that the rural-urban migration rate m_r in each region is a function of differences in the productivity of labour, namely the difference between *MPu* and *MPr*:

$$m_r = \mu\left(\frac{MPu}{MPr} - 1\right) \tag{B.7}$$

where μ (< 1) indicates that migration is subject to frictions, with only partial adjustment in any period. We allow for population growth, given by *g*. The rural population in a region at time *t+1* will then be given by:

$$Pr_{t+1} = Pr_t(1 + g - m_r) \quad \text{(B.8)}$$

Urban migration and the evolution of urban population and the primate city

The regional urban areas gain population from natural population growth and rural-urban migration, but lose from migration to the primate city. Thus, for each regional urban area:

$$Pu_{t+1} = Pu_t(1 + g - m_u) + Pr_t.m_r \quad \text{(B.9)}$$

where $m_u = \mu\left(\frac{MPp}{MPu} - 1\right)$, and consequently,

$$Pu_{t+1} = Pu_t\left[1 + g - \mu\left(\frac{MPp}{MPu} - 1\right)\right] + Pr_t\mu\left(\frac{MPu}{MPr} - 1\right) \quad \text{(B.10)}$$

And for the primate city:

$$Pp_{t+1} = Pp_t(1 + g) + \sum_1^J Pu_t\mu\left(\frac{MPp}{MPu} - 1\right) \quad \text{(B.11)}$$

Equations (B.8), (B.10) and (B.11) give us the evolution of population in rural areas, urban areas and the primate city, respectively.

Introducing simplifying numerical assumptions

We use our model to study urbanisation, the rise of megacities, and the evolution of marginal and average productivity, and in particular how these depend on migration frictions (μ) and population growth (g). For simulations presented in the main text of our paper, we make some numerical assumptions. We assume four regions, each with an initial urban population (*Pu*) of 1 and an initial rural population (*Pr*) of 4, and a primate city with an initial population (*Pp*) of 4. Units are arbitrary but chosen to give an urban rate of 33% and a primacy rate of 16%, which replicates the reality of most SSA countries. We also set *N = 4* and *Ku = 1*, so initial endowments per capita (*N/Pr* and *Ku/Pu*) equal 1. We further assume that $\alpha = \beta = \gamma = \delta = 0.5$ (following Gollin et al. 2012).

With these numerical assumptions, the marginal product of rural labour in (B.2) becomes:

$$MPr = \frac{a}{2}\left(\frac{4}{Pr}\right)^{0.5} \quad \text{(B.12)}$$

And the marginal product of urban labour in (B.6) becomes:

$$MPu = b(1.05)^{lnPu/ln2}\left(\frac{1}{Pu}\right)^{0.5}\left(\frac{ln1.05}{ln2} + 0.5\right) \quad \text{(B.13)}$$

To obtain values for *a* and *b*, we set initial values for *MPr* and *MPu* at 1.0 and 1.5 respectively. With these assumptions, *a = 2* and *b = 2.63*. For the prime city, we set *Pp = 4* and *Kp = 4* (so *Kp/Pp* equal to 1). With these values, *MPp* starts at *1.654*. These values allow us to numerically simulate the evolution of population and productivities in rural areas, urban areas and the primate city, respectively (for given values for migration frictions and population growth, namely μ and g):

For the rural population, using (B.12) and (B.13) in (B.8) gives:[1]

$$Pr_{t+1} = Pr_t\left[1 + g - \mu\left(\frac{1.5(1.05)^{lnPu_t/ln2}.\left(\frac{1}{Pu_t}\right)^{0.5}}{\left(\frac{4}{Pr_t}\right)^{0.5}} - 1\right)\right] \quad \text{(B.14)}$$

[1] Note that $2.63\left(\frac{ln1.05}{ln2} + 0.5\right) = 1.5$.

For the urban population, (B.10) becomes: (B.15)

$$Pu_{t+1} = Pu_t \left[1 + g - \mu\left(\frac{(1.05)^{(lnPp_t - lnPu_t)/ln2}(\frac{4}{Pp_t})^{0.5}}{(\frac{1}{Pu_t})^{0.5}} - 1\right)\right] + Pr_t\mu\left[\frac{1.5(1.05)^{lnPu_t/ln2}(\frac{1}{Pu_t})^{0.5}}{(\frac{4}{Pr_t})^{0.5}} - 1\right]$$

And for the primate city, (B.11) becomes:

$$Pp_{t+1} = Pp_t(1 + g) + 4\mu. Pu_t\left(\frac{(1.05)^{\ln(Pp_t - Pu_t)/ln2}.(\frac{4}{Pp_t})^{0.5}}{(\frac{1}{Pu_t})^{0.5}} - 1\right) \quad (B.16)$$

Annex C: Tanzanian data

We use data compiled by Wenban-Smith (2015) using Tanzanian censuses to identify regional trends in rural-urban migration and urbanisation. In the data, the 2002 regional structure was adopted, with 20 mainland regions. However, in this paper Pwani (Coast) and Dar es Salaam have been treated as a single region giving effectively 19 regions. Below we describe the data used.

Population: Total, urban, and rural population for each region, from census data.

Urban rates (*urb*): Measured as urban population over total population.

GDP per capita (*gdp_pc*): Regional GDP estimates are published in 'National Accounts of Tanzania' (various years). *Gdp_pc* is then obtained by dividing by the regional population for the relevant year.

Population growth (*popgrowth*): Annual cumulative growth rate. Calculated using total population for each region.

Ecological index (*Eco*): This is a combined index of soil conditions, rainfall and altitude above sea level.

Infrastructure index (*Inf*): This is a combined index of the percentage of households in a region with non-earth flooring and access to electric lighting and piped drinking water, as recorded in the 2002 and 2012 censuses.

Propensities for rural out-migration (*Qr*): This is the percentage of the expected rural population in a region that migrates either to the urban parts of the same region or to other regions (a negative value indicating a net inflow to the region's rural areas).

Natural resources in rural areas (*N*): We proxy for this using *maize*: total maize yield (in kilograms per hectare).

Figure C.1: Model predictions vs. real data, Tanzania

TO BE INCLUDED

Table C.1: Population in Tanzania, 1967-2012

	Population (millions)				
Census year	Rural	Dar es Salaam	Regional capitals[2]	Other urban	Total
1967	11.3	0.3	0.4	-	12
1978	14.8	0.8	0.9	0.6	17
1988	18.5	1.2	1.5	1.3	22.5
2002	25.9	2.3	2.6	2.6	33.5
2012	30.9	4.4	4	4.3	43.6

[2] In 1978, 1988 and 2002, there were 20 regions in mainland Tanzania, including Dar es Salaam. Here, Dar and Pwani have been treated as a single region with Dar as the regional capital, giving 18 regional capitals other than Dar. In 1967, there were 17 regions with Dar forming part of Pwani (Coast) region, so in this year there were 16 other regional capitals.

Table C.2: Estimates for propensities for rural-out migration

	(1) OLS	(2) OLS
Dependent variable:	Rural-out migration (Qr), 2002-2012	
log(Pu)	0.1068**	0.1173**
	(0.0355)	(0.0405)
log(Ku/Pu)	0.1294**	0.1347**
	(0.0533)	(0.0527)
log(N/Pr)	-0.0404	-0.0629
	(0.0636)	(0.0595)
Eco	-0.1885*	-0.1762*
	(0.0938)	(0.0965)
Year FE	NO	YES
Region FE	NO	NO
R square	0.44	0.44
No. of regions	17	17

Note: In column 1 Pu, Ku, N and Pr are measured in 2002.
In column 2 uses N and Pr are measured in 1988.
Robust standard errors clustered by region in parentheses.
*** p<0.01, ** p<0.05, * p<0.1