Global alternative long-term urbanization projections

Leiwen Jiang and Brian C. O'Neill

National Center for Atmospheric Research

Abstract

Projections of urban growth are critical to assessment of many socioeconomic and environmental issues. Global change studies in particular require consistent sets of projections to cover sufficiently long time horizons and span a wide enough range of uncertainty. Existing projections do not meet these needs. Here we present a new, global set of urbanization projections that describe fast, central and slow urbanization pathways for all countries over the 21st century. Derived based on historical urbanization experiences over the 1950-2010 period, the projections cover a wide but plausible range of outcomes and are further tested by deriving implied rural-urban migration flows in selected countries. Results show a wide range of plausible urbanization outcomes varies much more widely than indicated by available projections, and indicate that by the end of the century urbanization levels across regions could either converge under the Fast scenario or remain diverse under the Slow scenario.

1. Introduction

Urbanization in the developing world is central to demographic, economic, and environmental challenges of the 21st century. Virtually all world population growth in the next several decades is expected to occur in the urban areas of developing countries (National Research Council, 2003; United Nations, 2010). Cities in developing regions will account for the majority of global economic growth (Martine et al., 2008) and will be critical to poverty alleviation and social advancement (UN-Habitat, 2006). The pace and form of future urbanization will also be a key factor in society's vulnerability to, and capacity to respond to, various environmental challenges (Grimm et al., 2008; McDonald et al., 2011; McGranahan et al., 2007; Parrich and Zhu, 2009; Zhou et al., 2004).

However, there are few global urbanization scenarios available for use in interdisciplinary analyses. Although there are some national projections conducted by institutions within specific countries, the most notable set of global, country-specific projections are from the UN (United Nations, 2010). The UN projections have two main limitations: (1) they include only a single scenario for each country and therefore give no indication of uncertainty in urbanization trends; and (2) they extend only to 2050 and therefore cannot be used in longer-term analyses. The only other global urbanization projections from the International Institute for Applied Systems Analysis (IIASA; Grubler et al., 2007) extrapolate UN projections to 2100 and provide three alternative scenarios by making exogenous assumptions about long-term maximum urbanization levels. However, these projections do not capture uncertainty over the next few decades, a period of critical importance to urban transitions. Moreover, both the IIASA and UN urbanization projections are independent of population projections and therefore provide no information on the evolution of urban and rural population compositions and on the rural-urban migration implied by different urbanization scenarios (O'Neill and Scherbov, 2006; Rogers, 1982).

Although the UN has begun developing probabilistic urbanization projections to help communicate the uncertainty associated with future urbanization (Alkema et al., 2011), probabilistic projections are not well suited to integrating urbanization into interdisciplinary analyses of future socioeconomic and environmental trends, which typically explore alternative scenarios rather than characterizing the future in a probabilistic manner. Such demographic projections have been widely used in the scenario-based assessments of climate change (Nakicenovic et al., 2000), ecosystems (United Nations, 2007), agriculture (Mclntyre et al., 2009), and energy (GEA Writing Team, 2012). Demographic projections will again be used in an ongoing effort to develop new socio-economic scenarios for climate change research (Moss et al., 2010), but currently there are no global urbanization projections suitable for use in that effort.

The urbanization scenarios presented here are designed to meet the needs of interdisciplinary global environmental change research. Our approach extends and modifies the method used by the UN (United Nations, 2010), which draws on historical experience with urbanization at the national level to derive single urbanization projections for each country of the world. While there are critiques of the UN's approach (Bocquire, 2005; Dyson, 2011; Becker and Morrison, 1999; Hardoy and Satterthwaite 1986), our modifications to the methodology address several shortcomings. For example, while the UN assumes that all countries eventually follow a single "global norm" relating differences in urban and rural growth rates to the level of urbanization based on historical data (United Nations, 1998), the

national urbanization paths however vary due to different economic, demographic, and institutional conditions and the future urbanization trends in the long run may not be the direct extrapolations of their past experiences (Satterthwaite 1996). We therefore define this "norm" of the UN approach separately for each country in our projections. We also employ the historical data twice to carry out a two-stage projection to 2100, allowing for the possibility of capturing multiple phases of the urbanization process over the century. Finally, we define nine alternative urbanization pathways (rather than a single scenario) for each country based on the range of various urbanization experiences of countries, although we focus on three principal variants that we term our Fast, Central, and Slow projections. The details are described in the next section.

2. Data and Methods

The urbanization projections were developed using an approach that produces nine scenarios for each country of the world with population greater than 1 million and land area greater than 1000 km^2 in 2010. Projections extend from 2010 to 2100 and consist of projected percent urban population for each country. In order to produce numbers of people in urban and rural areas, these projections need to be combined with a population projection for each country. The NCAR methodology extends and modifies the approach used by the UN (United Nations, 2010). This approach assumes that countries at particular stages of the urban transition (Zelinsky, 1971) follow similar urbanization paths even when they pass through those stages at different points in time, a view for which there is substantial evidence (United Nations, 1980; Preston, 1979; Brockerhof and Brennan, 1998; Cohen, 2004). In the UN model, the urbanization level for each country (i.e., the proportion of the total population that is urban) is projected as a function of the difference between the urban and rural growth rates. A linear relationship between this growth rate difference and the urbanization level itself is defined based on historical data. More specifically, the urbanization level (PU_t) can be defined in terms of the urban-rural ratio (URR_t, the ratio of urban population to rural population),

$$PU_t = URR_t/(1 + URR_t)\ .$$

Changes in URR_t and therefore in the urbanization level can be modeled as a function of the difference between the urban and rural population growth rates urr_t, where the growth rate difference is itself a function of the urbanization level:

$$URR_{t+1} = URR_t * e^{urr_t}$$

$$urr_t = f(PU_t)$$

where f is the linear, empirical relation derived from the data. Countries are assumed to converge to this global relationship over a 20-year transition period.

We adopt the UN's approach of assuming a linear relationship between urban-rural population growth difference and urbanization level, but modifies the UN methodology by defining it separately for each country (rather than using a single global norm) and for fast, central, and slow urbanization scenarios

(rather than a single scenario). Relationships between the urban-rural population growth difference and urbanization level for each country and scenario are defined based on a set of reference countries that are drawn from historical data (United Nations, 2010). Data from small island or city countries whose land areas are smaller than 1000 km^2 and populations in 2010 less than 1 million persons are discarded, leaving 151 countries with urbanization records for the period of 1950-2010 as the core data set.

In order to select reference countries for a particular target country and scenario, we take three steps. First, we choose from the database all countries that have ever achieved an urbanization level within 5 percentage points of the level in the target country. This step collects countries that were similar to the target country in terms of urbanization level at some time in the past. Second, in most cases we eliminate from this sample the 25% of countries whose urbanization growth rates over the decade prior to reaching the target urbanization level differ the most from the target country's growth rate. This step ensures that reference countries were similar to the target country at a certain point in time not only in terms of urbanization level, but also in terms of how fast they were urbanizing at that time. Third, we divide the remaining sample into three different groups: the 25% of countries with the highest urbanization levels 30 years after they reached the target level, the 25% of countries with the lowest urbanization levels at that point, and the 50% of the sample in between. These three groups serve as the reference countries for the fast, slow, and central projections, respectively, for the target country.

The choice to distinguish fast, slow, and central reference countries based on their urbanization level 30 years after the base year was made on the basis of an analysis of the rank correlation of their urbanization levels over time. The analysis indicates that a country's rank in terms of urbanization level as compared to other reference countries is positively correlated over time and is less likely to change significantly the farther into the future one looks. For example, for India's group of reference countries after step 2, the rank five years after the base year does not predict well the rank 25 years later (correlation coefficient = 0.65). In contrast, the rank 30 years after the base year predicts rank 25 years after that much better (correlation coefficient = 0.92). Thus, it would be ideal to distinguish fast, slow, and central reference countries using their urbanization level far beyond the base year. However, the sample size of countries that have a long enough time series of data to support such a distinction diminishes as the length of this time horizon increases. Considering both factors, we decided to use 30 years of prospective data to distinguish among fast, central and slow reference countries.

However, this set of reference countries is not sufficient to support a projection over a 100-year period, given the relatively short (60-year) historical record. For example, a country currently at a low urbanization level may go through several different regimes of growth: slow increases in urbanization, a fast takeoff period, and then a slowing as it converges to a long term level. Using a single set of reference countries over a limited time period will frequently not be able to capture well these multiple regimes. We therefore adopt a two-stage projection approach to generate additional reference countries for use in the model.

Using data points derived from the initial set of reference countries, we project the target country's urbanization level forward to 2040 through conducting a regression analysis of difference of urban and rural growth rate against urbanization level. For the regression analysis, we exclude the data points with

too small number of cases and too large variations at 95% confidence interval. We then use the projected 2040 level, and recent growth rate, to repeat the reference country selection process and derive a second set of reference countries to characterize urbanization after 2040. This creates nine possible combinations of reference countries across stages 1 and 2 (fast, central, and slow in stage 1, and then in each case fast, central and slow in stage 2). However, we define our three scenarios of interest as the fast-fast, central-central, and slow-slow combinations over the two stages. Data from these combinations of reference countries are used to define country-specific linear relationships between the urban-rural growth rate difference and the urbanization level, which are in turn used to generate the urbanization projections according to the equations above. One exception to the production of three scenarios for each country is that, because there is little uncertainty in future changes in urbanization among countries that have already achieved very high urbanization levels, we produce only one urbanization scenario for countries that have already reached an urbanization level of 80% or more.

Our projections produce the national percent urban for each country over the 21st century. To illustrate outcomes at the level of world regions, we aggregate the country-specific results by combining them with projected population sizes from the UN (United Nations, 2011) and adding up projected urban and rural populations across countries within each region. This aggregation assumes that all countries in a region follow the same Fast, Central, or Slow urbanization path simultaneously, whereas in reality countries could follow diverse trends across or within regions (Smith and London, 1990; Gugler, 1996). We use a homogenous aggregation as a benchmark to simplify the presentation; it is not a necessary assumption and users can select the mix of outcomes across countries that best suits their application.

3. Results

Results show that the world continues to urbanize under each of the three scenarios relative to its current level of 50.4% urban, reaching 92%, 79%, and 60% by the end of century under the Fast, Central, and Slow scenarios, respectively (Figure 1a). Results aggregated into More, Less, and Least Developed countries as defined by the UN show that the urbanization levels across these regions converge under the Fast scenario to 89-96% by the end of the century, or remain as diverse as today under the Slow scenario, covering a range of 45-88%. Within these regions, uncertainty is relatively small in the more developed region where the urbanization level is already high, with a difference of only 7 percentage points between the Fast and Slow scenarios by the end of the century (95% vs 88%). In contrast, in the least developed region many countries are at the beginning or in the midst of the urbanization transition, and there is therefore substantially more uncertainty in outcomes, leading to a 46% difference in urbanization across scenarios in this region (88% vs 42%).

Results aggregated to the level of continents (Figure 1b) illustrate this outcome in more detail. They show much larger differences across the three scenarios for the currently less urbanized Africa (50 – 89% by 2100) and Asia (55 – 90%) than for the more urbanized Europe (83 -96%) and Latin America (88 – 96%). We produce only a single scenario for Australia/New Zealand and North America given their already very high urbanization level. Neither Africa nor Asia reaches the current level of urbanization in

Europe or North America in either the Central or Slow scenario, and in the Fast scenario does so only after 2050.

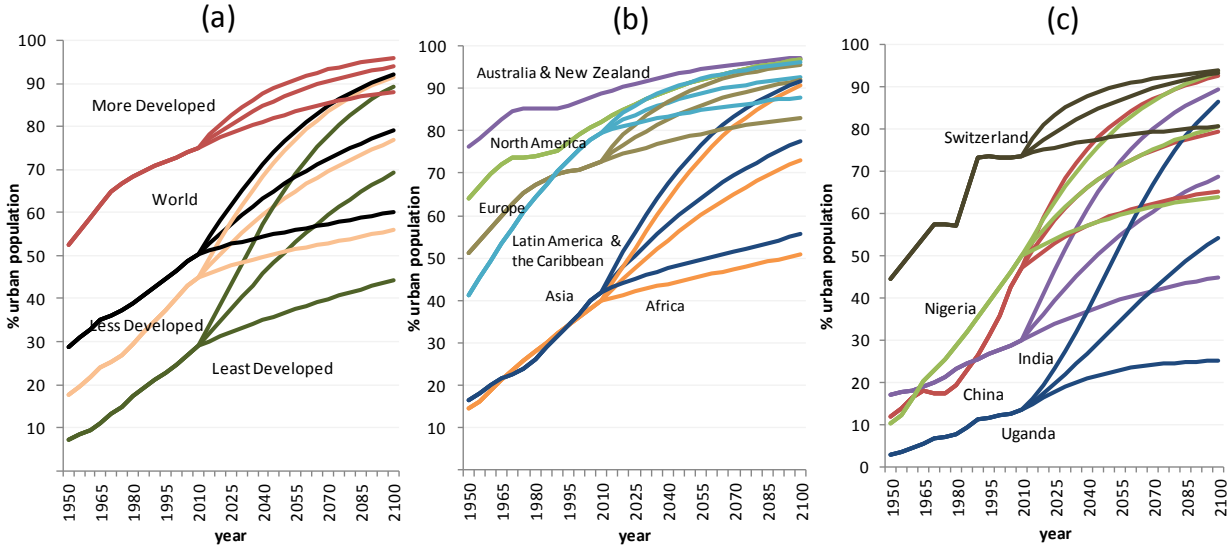


Figure 1 Urbanization projections for regions by level of development (a), continent (b), and selected countries (c).

Projections are distinctive across countries as well (Figure 1c). India has been one of the slowest urbanizing countries for the past several decades and just reached 30% urban in 2010. Our projections range from a continuation of this slow pace, implying that the country remains largely rural (44% urban by 2100), to a rapid near-term take off leading to a 90% urbanization level in 2100. In contrast, China has been experiencing rapid urbanization and this trend continues for another four or five decades or levels off in the near term, leading to a range of urbanization outcomes in 2100 of 64-90%. Nigeria, the most populous African country, reached a somewhat higher urbanization level than China's in 2010, but has recently been urbanizing more slowly. As a consequence, its projected urbanization proceeds somewhat slower, leading to similar outcomes to China's in all three projections. Uganda is among the least urbanized countries and demonstrates a very large uncertainty in urbanization, spanning outcomes of 25 – 85% by the end of century. Switzerland illustrates the opposite case. It had already reached 74% urban in the early 1990s and has a much smaller range of uncertainty in long-term urbanization levels.

To characterize uncertainty in country-level outcomes more broadly, we assess the difference in projected urbanization between the Fast and Slow scenarios in all countries. Figure 2 shows that the average uncertainty range across countries increases over time and is largest for countries at moderate levels of urbanization that are in the middle of the urbanization transition. For example, the average difference between the Fast and Slow scenarios is only about 5% in 2015 and increases to as large as 25% in 2050 and 55% in 2100. These peak differences occur in countries that are around half urban, and the uncertainty range declines rapidly in countries that are more than 60-75% urban.

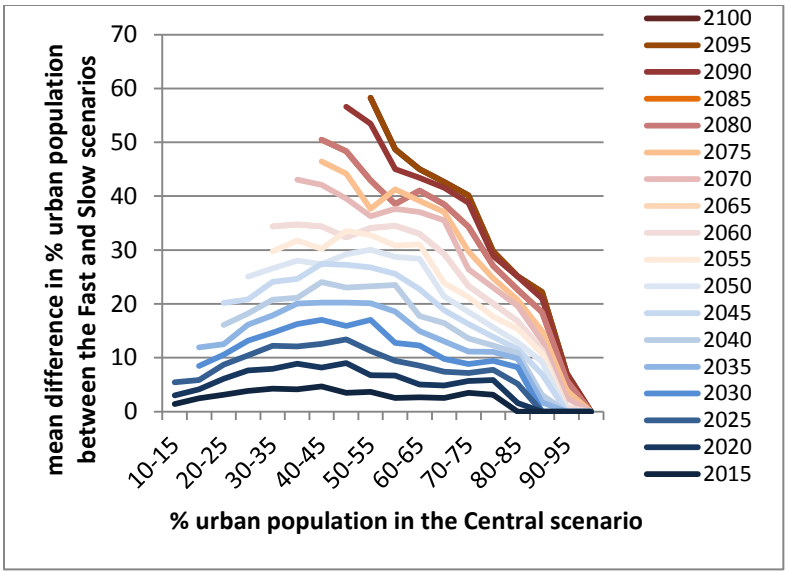


Figure 2 Mean differences in projected country-level urbanization between the Fast and Slow scenarios over time

Our results differ from those of the UN and IIASA, as shown in Figure 3 for the example of India and the World. Although our Central scenario is broadly similar to the UN projection through 2050 (differences for all countries are within -10 to +8 percentage points at all times; see Supplementary Figure S5a-b), before 2030 our Central scenario is generally higher than the UN projection, and afterwards it is generally lower. The main reason for faster urbanization in our projections in the near term is that the UN assumes a 20-year transition period in which each country urbanizes largely at its most recent urbanization growth rate before converging to the "global norm". In contrast, we assume each country urbanizes according to a pathway defined by a set of similar reference countries (see Data and Methods). The UN transition period approach has the benefit of ensuring a gradual evolution of urban growth, but has a cost in that it excludes the possibility of the types of rapid change observed in many countries historically, particularly in the 1950s-60s.

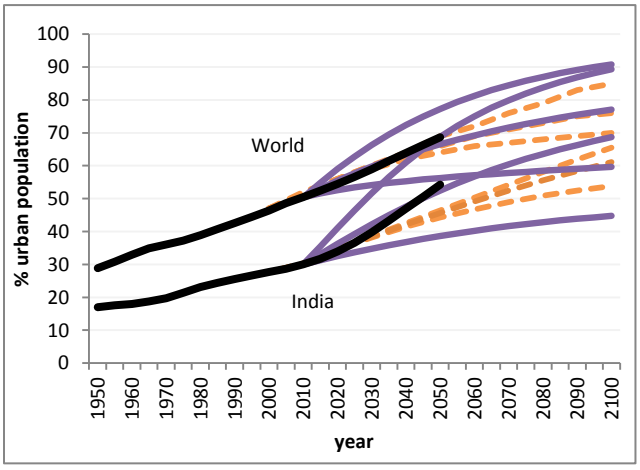


Figure 3 Urbanization projections from NCAR (purple), the UN (black) and IIASA (orange dashed)

After the 20-year transition period, the UN projects significantly higher urbanization, with more than 70% of countries having higher urbanization in 2050 than in our projections. This is because the UN assumes all countries urbanize following a global norm after 2030, which is weighted toward the experience of countries in the early decades of the historical record. Our projections use norms that are tailored to the circumstances of each individual country, and we also use a second stage that allows for slow-down and saturation of the urbanization level. The resulting lower projections can be regarded as an improvement relative to the UN, since several existing studies have suggested that the UN projects urbanization growth rates that are generally too high (National Research Council, 2003; Alkema et al., 2011; Bocquire, 2005; Montgomery, 2008).

Our projections differ from IIASA in that they span a substantially wider range of uncertainty over the next few decades (Figure 3). This is not only the case for individual countries such as India, but also true for the world as a whole. The IIASA projections focused on uncertainty in long-term outcomes (Grubler et al., 2007) and were constrained to be close to a UN projection through 2030 (the horizon of UN projections at that time).

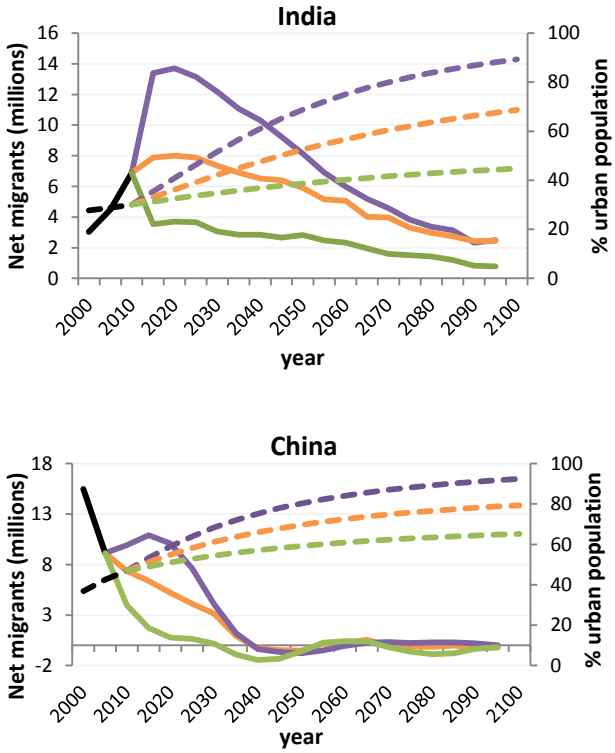


Figure 4 Implied net rural-urban migrants (solid lines) and projected urbanization level (dashed lines) under Fast (purple), Central (orange), and Slow (green) urbanization scenarios for India and China

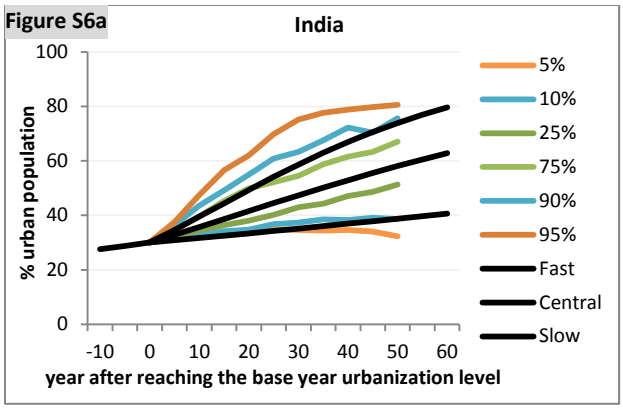
To further test the plausibility of the urbanization projections, we use a multiregional population/urbanization projection model (Jiang and O'Neill, 2009; O'Neill et al., 2010) and the assumptions on total fertility rates and life expectancies under the medium scenario of the UN Long Range Population Projection (United Nations, 2004) to calculate the implied gross and net rural-urban

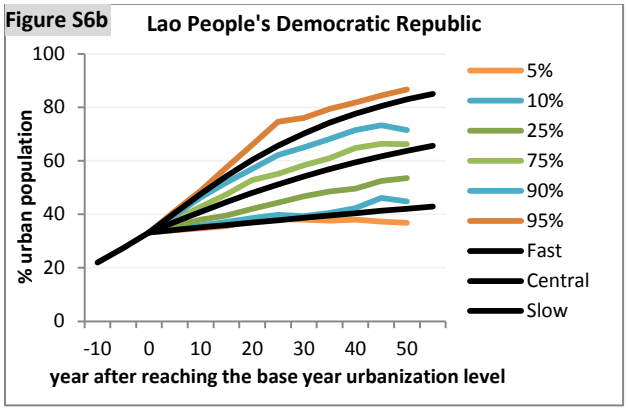
migrants for India and China under each of their urbanization scenarios. Figure 4 shows that the number of rural-urban net migrants in India and China differs significantly across different urbanization scenarios, but they are all within plausible ranges. India historically has had rather low rural-urban migration rates but recently migration has increased owing to rapid economic growth. In the Fast and Central scenarios, net urban in-migration continues to increase for 1-2 decades, as much as doubling in the Fast scenario. In the Slow scenario, net migration quickly returns to the level in 2000 and steadily declines to almost zero by the end of the century. The number of net urban in-migrants in China has been declining in recent decades and continues to decline in the Central and Slow scenarios. However, under the Fast scenario the trend reverses for a decade before continuing to move downward. Migration differs across scenarios mainly in the first three decades; after 2040, the number of net urban in-migrants is near zero and occasionally negative in all three scenarios, although natural population growth in urban areas more than offsets this factor so that urbanization levels continue to increase slowly. This information is also valuable for integrating urbanization scenarios with consistent scenarios for drivers of migration such as economic growth and environmental change.

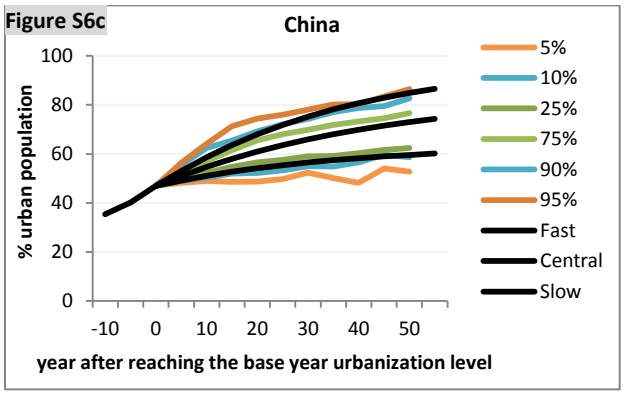
4. Discussion and Conclusion

Our projection results, grounded in data on the historical experience of all countries over the past half century, show that the range of plausible urbanization outcomes is much wider than indicated by available projections even over the next few decades. These scenarios produce urbanization pathways that are typical of countries in different stages of urbanization, including outcomes in which urbanization stalls or is substantially delayed, as well as outcomes in which it proceeds rapidly to high levels. The urbanization levels across regions may either converge under the Fast scenario or remain as diverse as today under the Slow scenario. Multi-state projections for China and India show that the scenarios produce plausible implied levels of net rural-urban migration over time, and that the migration information can also be useful to designing internally consistent integrated scenarios that also describe socioeconomic and environmental conditions linked to migration.

The wide range of urbanization outcomes represented by these projections is consistent with historical experience. Results for each country fall within the range of 90% of historical urbanization outcomes when compared to countries that at some point in the past reached a level of urbanization similar to that in the base year (Figure 5). Fast scenarios are below the 95th percentile, slow scenarios above the 5th percentile, and central scenarios within the 50% interval. This consistency is ensured by the methodology, which relates urbanization growth rates to urbanization levels for each country and scenario based on historical experience. Figure 6 compares our projections to historical data for an average of one measure of the urbanization growth rate, the urban-rural population growth difference (United Nations, 1980; Preston, 1979), as a function of urbanization level. The Central scenario generally represents the overall historical mean, while the Fast and Slow scenarios are near the upper and lower bounds of historical experience.







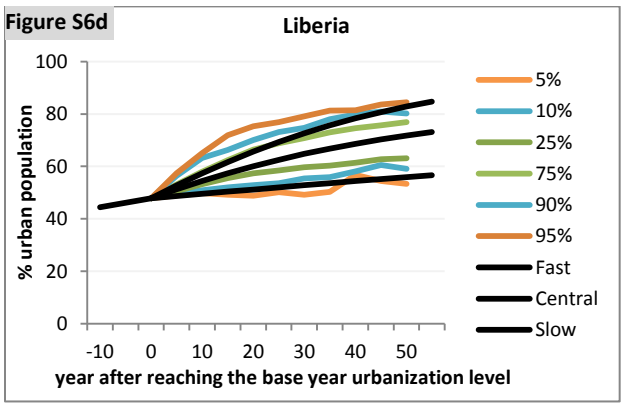


Figure 5 Comparison of produced urbanization scenarios with the range of observed urbanization changes of global nations

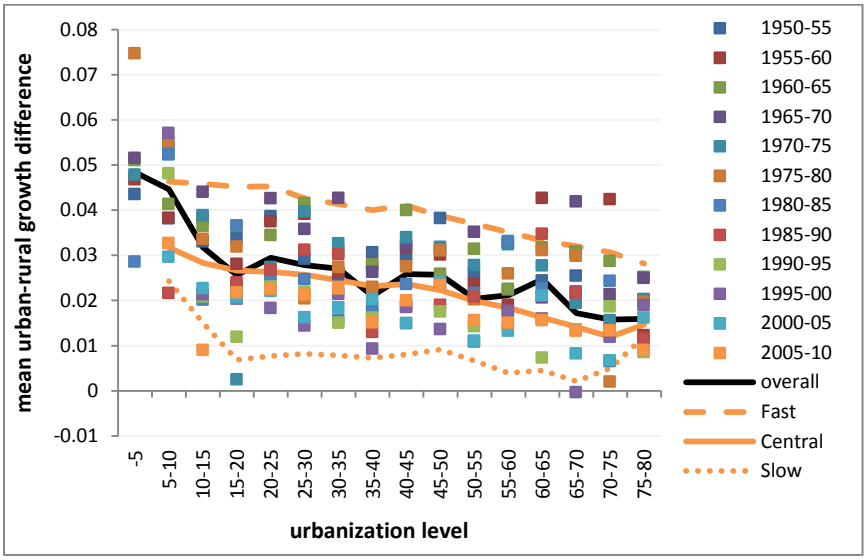


Figure 6 Mean urban-rural growth difference of the different urbanization scenarios comparing with the historical experiences

A full assessment of the relative likelihoods of different urbanization scenarios is beyond the scope of this paper. However, we note that the historical data can be taken to imply that not all scenarios are equally likely, and that the Central scenario is not necessarily the most likely one for each country. For example, compared to the reference countries used to derive our urbanization scenarios for China, China itself has been urbanizing relatively rapidly over the past decade (Figure 5). The subset of reference countries that experienced relatively rapid urbanization just prior to reaching China's current level of urbanization tend to more frequently follow a fast urbanization pathway subsequently, rather than a central or slow pathway. We therefore conclude that for China, the Fast scenario is more likely. By similar reasoning, we find that India is more likely to urbanize at a rate similar to its Slow scenario. A more comprehensive assessment of likelihoods is ongoing.

References:

Alkema, L., Gerland P., Buettner T., 2011. Probabilistic Projection of Urbanization for All Countries (Poster Session 2 at PAA Annual Meeting, 2011, Washington DC).

Becker, C.M., Morrison, A.R., 1999. Urbanization in transforming economies, in Mills ES and Cheshire P (eds.) *Handbook of Regional and Urban Economics* (Elsevier Science, Amsterdam).

Bocquire, P., 2005. World Urbanization Prospects: an alternative to the UN model of projection compatible with the mobility transition theory. *Demographic Research* 12(9): 197-236.

Brockerhof, M., Brennan, E., 1998. The poverty of cities in developing regions. *Population and Development Review* 24(1): 75-114.

Cohen, B., 2004. Urban growth in developing countries: a review of current trends and a caution regarding existing forecasts. *World Development* 32(1): 23-51.

Dyson, T., 2011. The role of the demographic transition in the process of urbanization. *Population and Development Review* 37(Supplement): 34-54.

GEA Writing Team, 2012. Global Energy Assessment – Toward a Sustainable Future. Cambridge University Press.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X. and Briggs, J. M., 2008. Global Change and the Ecology of cities. *Science* 319:756-760.

Grübler, A., O'Neill, B. C., Riahi, K., Chirkov, V., Goujon, A., Kolp, P., Prommer, I., Scherbov, S., Slentoe, E., 2007. Regional, national, and spatially explicit scenarios of demographic and economic change based on SRES. *Technological Forecasting and Social Change* 74: 980-1029.

Jiang L., O'Neill, B.C., 2009. Household projections for rural and urban areas of major regions of the world. *IIASA Interim Report IR-09-026*. Laxenburg, Austria: IIASA.

Martine, G., McGranahan, G., Montgomery, M., Fernandez-Castilla, R., 2008. *The New Global Frontier: Urbanization, Poverty and Environment in the 21st Century* (Earthscan, London).

McDonald, R. I., Green, P., Balk, D., Fekete, B. M., Revenga, C., Todd, M., Montgomery, M., 2011. Urban growth, climate change, and freshwater availability. *Proc Natl Acad Sci USA* 108(15): 6312-6317.

McGranahan, G., Balk, D., Anderson, B., 2007. The rising risks of climate change: urban population distribution and characteristics in low elevation zones. *Environment & Urbanization* 19(1): 17-37.

McIntyre, B.D., Herren, H.R., Wakhungu, J., Watson, R.t., 2009. International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD): Global Report (Island Press, Washington DC).

Montgomery, M., 2008. The urban transformation of the developing world. *Science* 319(5864): 761-764.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F., Nakicenovic, N.,Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. Nature 463: 747-56.

Nakićenović, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., et al., 2000. Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change (Cambridge University Press, Cambridge).

National Research Council, 2003. *Cities Transformed – Demographic Change and its Implications in the Developing World* (The National Academy Sciences, Washington DC).

O'Neill, B.C., 2004. Conditional probabilistic population projections: an application to climate change. *International Statistical Review* 72(2): 167-184.

O'Neill, B.C., Dalton, M., Fuchs, R., Jiang, L., Pachauri, S., Zigova, K., 2010. Global demographic trends and future carbon emissions, *Proc Natl Acad Sci USA* 107(41):17521-17526

O'Neill, B.C., Scherbov, S., 2006. Interpreting UN urbanization projections using a multi-state model. *Interim Report IR-05-037*. Laxenburg, Austria: IIASA

Parrish, D.D., Zhu, T., 2009. Clean air for megacities. *Science* 326: 674-675.

Preston, S., 1979. Urban growth in developing countries: a demographic reappraisal. *Population and Development Review* 5(2): 195-215.

Rogers, A., 1982. Sources of urban population growth and urbanization, 1950-2000: a demographic accounting. *Economic Development and Cultural Change* 30:483-506.

Smith, D.A., London, B., 1990. Convergence in world urbanzation? A quantitative assessment. Urban Affairs Quarterly 25(4): 574-590.

UN-Habitat, 2006. *The State of the World's Cities 2006/7* (Earthscan, London).

United Nations, 1980. *Pattens of Urban and Rural Population Growth* (United Nations Publication, New York).

United Nations, 1998. *World Urbanization Prospects. The 1996 Revisions, Estimates and Projections of Urban and Rural Populations and of Urban Agglomerations* (United Nations Publication, New York).

United Nations, 2004. *World Population to 2300* (United Nations Publications, New York).

United Nations, 2007. *The Millennium Development Goals Report 2007* (United Nations, New York)

United Nations, 2010. *World Urbanization Prospects. The 2009 Revision* (United Nations Publication, New York).

United Nations, 2011. *World Population Prospects 2010 Revision*. (United Nations Pulcation, New York).

Zelinsky, W., 1971. The hypothesis of the mobility transition. *Geographic Review* 61:219-249.

Zhou, L., Dickson, R.E., Tian, Y., Fang, J., Li, Q., Kaufmann, R., 2004. Evidence for a significant urbanization effect on climate in China. *Proc Natl Acad Sci USA* 101(26): 9540-9544.

Gugler, J., 1996. *The Urban Transformation of the Develoing World* (Oxford University Press, Oxford).