UNDERSTANDING AND APPLYING LONG-TERM GDP PROJECTIONS

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Abstract

We project gross domestic product (GDP) for 140 world economies from 2020 to 2050 based on United Nation's demographic projections, the International Monetary Fund's GDP statistics and estimates of potential labour productivity derived from the World Economic Forum's Global Competitiveness Index (GCI) and a methodology published by the Australian Treasury. We review the conceptual framework underpinning this model, and identify its core assumptions. Finally, we highlight potential applications for this model, including: considering the dispersion of global economic activity; assessing the potential scale of activity across different trading blocs; and quantifying the impact of domestic policy reform scenarios in individual economies. Rather than provide an exhaustive analysis of the results, we make the data and results freely available.

JEL codes: C82, E17, F01, F43, O11, O40, O50

Key words: economic growth, conditional convergence, policy reform

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Many decisions of public policy makers, strategists and private business-people depend on judgements about how a country's economy might grow over decades. Such decisions might relate to the design of regional and global governance institutions and trading arrangements, investment in strategic capacity, infrastructure and long-term corporate investment. In the Asia-Pacific region, decisions might turn on the sustainability of Chinese growth, the potential for India to become the world's second largest economy, and the possibility that Indonesia might surpass Japan's economic size. On the reverse side of the ledge, to what extent will declining populations in Europe and Japan erode their previous economic importance?

Judgements of such magnitude should be founded in some evidence base, underpinned by a coherent conceptual framework. This paper explains the framework that underpins the long-term GDP projections prepared by the Australian Treasury for the Australian Government's *Australia in the Asian Century White Paper* (2013), and subsequent publications. Using more recent data, we follow Treasury's published methodology (Au Yeung et al. 2013) with minor modifications in order to project GDP and per capita GDP growth for 140 economies from 2020 to 2050.[1] We make available the dataset and results to allow others to test alternative assumptions. We encourage readers to explore and develop the model further.

While no simple model can capture the full gamut of considerations and risks in future growth paths, these projections can serve as a plausible scenario. At all stages, we make explicit the model's limitations explicit in order to highlight the other factors that decision makers might choose to consider. Applications of this model include thinking about the dispersion of global economic weight, the trade liberalisation in the global economy, and modelling policy reform in individual economies.

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[1]Other long term projections have been made by the OECD (to 2060, https://data.oecd.org/gdp/gdp-long-term-forecast.htm), the Carnegie Endowment for International Peace (to 2050, http://carnegieendowment.org/files/World_Order_in_2050.pdf), PWC (to 2050, https://www.pwc.com/gx/en/issues/the-economy/assets/world-in-2050-february-2015.pdf), and the European Commission (https://ec.europa.eu/research/social-sciences/pdf/policy_reviews/global-europe-2050-report_en.pdf). We do not review them here.

1 Growth framework

Before the industrial revolution, a country's entire annual production (its gross domestic product or GDP) was roughly proportional to the size of its population. Thomas Malthus' Essay on the Principle of Population (1798) argued that gains in economic surplus are literally consumed by a growing population. In the long run, this kept per capita GDP close to subsistence levels (Box 1).

Box 1

GDP per capita $\approx$ subsistence

GDP $\propto$ population

This view was historically grounded at the time. Around the turn of the 18th century, average per capita output in the world's richest economy was perhaps four times greater than in the world's poorest (The Maddison-Project 2013). While not much by today's standards, it was enough to induce Adam Smith to publish his Inquiry into the Nature and Causes of the Wealth of Nations in 1776 (Smith and Cannan 1776). Although published before the industrial revolution, Smith's insights foreshadowed the capital accumulation, the division of labour and exchange through markets that would allow the economy to grow faster than population an escape from the Malthusian trap.

Starting in the United Kingdom, and spreading across the North Atlantic, the accumulation of capital and the discovery and application of new technology enabled growth in the average worker's productivity. GDP depended not just on the number of workers, but on their productivity (Box 2). Per capita incomes began to rise well above subsistence, and so population was no longer a good proxy for a country's economic weight. The potential for labour to increase its productivity by employing more capital, adopting new technology and learning new skills allowed a radical departure from the assumption that all countries' workers were more or less equally productive.

GDP = labour force × average labour productivity

GDP per capita = $\frac{\text{labour force} \times \text{average labour productivity}}{\text{total population}}$

By the end of the 19th century, per capita GDP in Switzerland had leaped to ten times that of the world's poorest (Figure 1). This process accelerated in the 20th century, seeing the United States become by far the world's largest economy, and amongst the richest in per capita terms. Its immediate strategic competitor, the Soviet Union had a similar sized population, but never matched it on productivity. By contrast, India and China were both much more populous countries, but their relative poverty prevented them from being global powers.

Figure 1: Ratio of highest and lowest GDP per capita country to 2000 CE
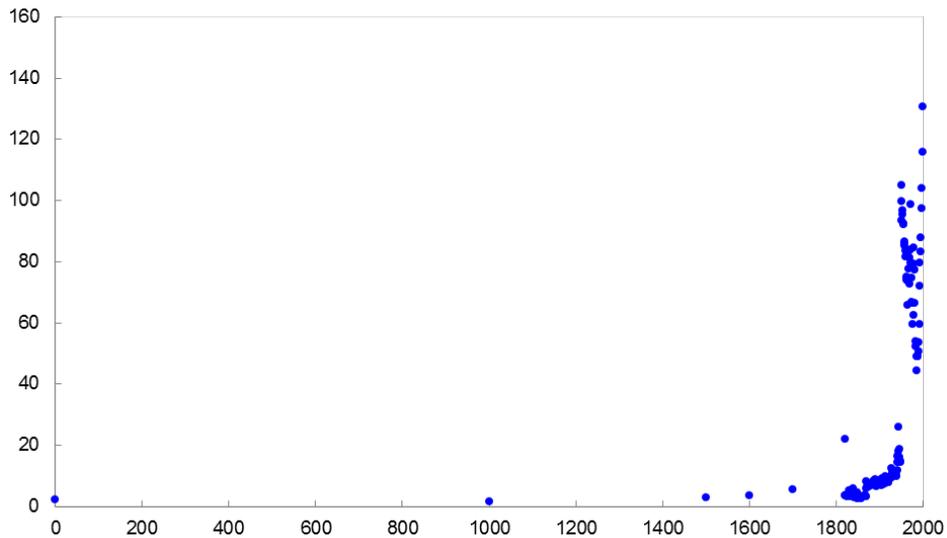
Source: The Maddison Projection 2013

Demographers project the future size and structure of a population and its workforce given the size and structure of the population today. In order to project future economic size, population dynamics need to be supplemented with changes in output per employed person and hours worked a measure

4

of labour productivity.

For the United States, and other countries that already have well-developed markets and technology, the growth of labour productivity has historically been around 2 per cent per year. Economists generally consider this to be roughly the rate of technological improvement over time plus the effects of capital deepening. Countries whose labour productivity grows at roughly the same rate as the United States are said to be on a 'balanced growth path' or in 'steady-state'.

Being in 'steady-state' doesn't imply a country doesn't have potential for faster growth. For example, from 1993 to 2013 labour productivity growth of[2] Pakistan, El Salvador, Namibia and Jordan was only the same as that in the United States, even though their labour productivity was only 10, 16, 20 and 22 per cent respectively of United States' levels. The fact that countries like these aren't growing beyond these 'middle income' levels gives the idea of a 'middle income trap' (Kharas and Gill 2015). In our terms, a country is in a 'middle income trap' if its steady state productivity levels are well below the frontier set by advanced economies.

The 'steady state' relative productivity level appears to be conditional on the quality of its economic institutions. For the countries that are in this 'steady state', there are statistical regularities between the quality of its economic governance and its relative labour productivity levels. Economies, such as Singapore or Japan, with institutions that allow markets to develop, labour to specialise, capital to be accumulated and technology to be employed have labour-productivity levels close to the United States. Conversely, countries that stifle markets, control labour, prohibit private investment and close themselves off to global technology will have low levels of labour productivity and remain poor. Most countries are somewhere in the middle.

Looking at these 'steady state' countries allows us to judge the necessary quality of economic institutions required in order to reach a particular level

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[2]We use the medium fertility variant published by the United Nations. Alternative scenarios can easily be constructed by changing the population projections fed into the model.

of labour productivity. We can then apply this relationship to estimate the potential productivity level of countries that appear to be 'catching up'. By making the same measure of current institutional quality in such countries, we can conditionally project what they are catching up to, relative to the United States. This estimate of potential labour productivity allows us to calculate their potential GDP and per capita GDP (Box 3).

> **Box 3**
>
> Potential GDP = projected labour force × potential labour productivity based on current institutions
>
> Potential GDP per capita $= \frac{\text{potential GDP}}{\text{total population}}$

Of course, potential for growth cannot necessarily be realized as productivity. It takes time, trial and error, to accumulate capital, to develop markets, for workers to learn skills, and to adapt technology to local conditions. For this reason, we can estimate an amount of 'catch-up' growth that a country might experience in a single year as being some proportion of the gap between its current productivity level and its estimated potential (Box 4). This is additional to the ordinary rate of technological change that might apply to all countries.

> **Box 4**
>
> $$\text{Labour productivity growth} = \alpha + \gamma$$
>
> Where: α = rate of technological change
> γ = a proportion of the gap between current and potential labour productivity levels

Now that we have an idea of how labour productivity may grow, we combine this with the demographic forecasts to give an indication of how GDP (and per capita GDP) might proceed based on current levels (Box 5).

GDP growth $\approx$ labour productivity growth + working age labour force growth

GDP per capita growth $\approx$ GDP growth - total population growth

2   Data and Model Estimation

We follow the methodology of Au-Yeung et al (2013). Deviations from their data sources and methodology are described in the Appendix.

To estimate total population and labour force from 1980 to 2050, we use the United Nations Population Division's 2015 Revision of World Population Prospects based on its medium-variant fertility estimates. The labour force is defined as the 'working age population' aged between 15 and 64. We measure GDP 2012[3] purchasing power parity (PPP) using the International Monetary Fund's (IMF) World Economic Outlook October 2015 Revision. We use historic (from 1980) and forecast (to 2020) real GDP growth rates to calculate GDP levels in 2012 PPP terms from 1980 to 2020.

We measure institutional quality using the World Economic Forum's Global Competitiveness Report (2015-16). The Forum collects 114 indicators for each of 140 economies that are summarised into three 'pillars' - 'basic requirements' (institutions, infrastructure, macroeconomic environment, health and primary education), 'efficiency enhancers' (higher education and training, goods market efficiency, labour market efficiency, financial market development, technological readiness, market size) and 'innovation and sophistication factors' (business sophistication, innovation). We provide a consistent weighting to each of these three pillars (see Appendix), in order to derive an index of institutional quality for each country. For middle-income countries this is identical to the published 'Global Competitiveness Index' (GCI).

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[3]We use 2012 as this is the most recent year for which the IMF has the largest coverage of actual GDP levels.

The level of labour productivity is calculated by dividing real GDP by working age population every year, and labour productivity relative to the United States calculated accordingly.

We use the same 'steady state' national economies as Au-Yeung et al (2013) these are countries with labour productivity relative to the United States has been relatively stable over the last two decades. Next, we estimate a non-parametric relationship between the measure of institutional quality and relative labour productivity for the 55 economies in 'steady state'. We use this relationship to estimate the potential labour productivity level relative to the United States for each of the 85 economies in transition based on the index of institutional quality.[4]

Having estimated potential labour productivity, we assume labour productivity growth in the US after 2020 of 1.5 per cent, consistent with the Congressional Budget Office's January 2016 Budget and Economic Outlook. Each year we assume that that a country's labour productivity growth is the sum of a fraction of its productivity growth in the previous year (allowing a continuation of short term trends), the overall rate of technological progress in the global economy (as represented by labour productivity growth in the United States), and partly the distance between current labour productivity levels and the estimated potential. The empirical literature reviewed in Au-Yeung et al (2013) find the speed of this convergence to be around two per cent. We use a figure of 2.5 per cent.

Having estimated labour productivity growth for each year, we project GDP from 2021 to 2050 by multiplying labour productivity by the working age population in that year, and project per capita GDP by dividing total GDP by population estimate.

3   The Limits to Growth Models

Before to turning to the results, we make some fundamental warnings. This simple conditional convergence model depends on very few factors. This

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[4]See kernel summary tab in attached data spreadsheet.

makes it very easy to understand and to apply consistently across most countries. But the simplicity of the model also implies very strong assumptions that should be understood before applying the results.

The model has nothing to say about the mechanics of economic development or how growth transitions will actually take place. The model assumes a single sector in each economy which employs all of the labour force. We can project a change in average labour productivity, but not account explicitly for rural-urban migration, capital deepening or educational improvement, for example. It ignores the social and economic factors that might influence labour supply - especially the extent of female participation in paid employment, changes in hours worked (including shifts between full and part time employment) or changes to the concept of retirement. It takes demographic projections as given, and does not allow for large and unexpected emigration or immigration of workers.[5]

The construction of any single index of institutional quality necessarily abstracts from country-specific issues related to development and may not account for development paths that diverge from the ideal economy on which they might be based, or that have factors other than labour productivity that explains their economic fortunes. Calculating labour productivity simply by dividing total output by labour force ignores the contribution of natural resource rents that will add to the value of output even under dreadful economic institutions (for example, Venezuela ranks 130 out of 140 countries on the basis of institutional quality, but 59th in terms of labour productivity in 2013 due to its exploitation of oil). In this way, it does not distinguish from income natural resource endowments which contribute output potential a terms of trade boom which may increase the value of existing output, and policy reform that makes labour more productive.

Even if the measure of institutional quality was the only factor and could be measured, the model assumes that it is fixed for each country. This misses the potential for very large institutional shifts that radically change

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[5]We use the medium fertility variant published by the United Nations. Alternative scenarios can easily be constructed by changing the population projections fed into the model.

a country's economic trajectory. For example, China's transition from an ideologically-driven, planned economy under the leadership of Mao Zedong to a pragmatic market-driven economy under Deng Xiaoping entailed radical reform of institutions and the way that they worked over time. A projection of Chinese growth made before the death of Mao in 1976 would not have foreseen the dramatic improvements in Chinese living standards that accompanied reform and opening up after 1978. Similarly, if we were projecting growth in Zimbabwe at independence in 1980 we would not foresee the subsequent dramatic deterioration in governance that occurred subsequently. While governance measures might include forward-looking elements, it takes time for new policy and institutions to emerge and become credible to economic actors.

The model assumes that political entities that exist now and encompass well defined population will continue to exist. While many countries are long-lived, this heroic assumption of political stability leads to absurdity. During the cold war, many economists including Paul Samuelson expected United States' GDP to be overtaken by the Soviet Union in a matter of decades (Levy and Peart 2011). Instead, the Union disintegrated entirely. Less dramatically, new countries are sometimes created, borders change through negotiation and war, and old countries are sometimes joined with others. There is no consideration for how both good and bad economic performance might affect the political viability of regimes, nor how political factors affect economic choices, including to reform.

Even though the model can project GDP for all countries in the world, it assumes absolutely no interaction between them. One of the few consistently positive predictors of economic growth in large scale studies is openness to trade (Sachs and Warner 1997), but the model here has no trade in goods or services. Similarly, despite the importance of international capital flows in funding new capital investment in places where domestic savings may not be sufficient, this model does not explicitly include capital, let alone provision for international capital flows (foreign direct or portfolio investment). There is no prospect for growth to be undone by a financial crisis or debt over-hang simply because the model contains no money and no debt. This also

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precludes us from using a better measure of living standards, such as gross national income (GNI), which includes income from abroad. For example, a country with an ageing population such as Japan might been able to offset slow growing in Japanese production by investment in faster growing Asian neighbours or productivity improving technical change with Japan.

The absence of trade also means that there are no international prices or even exchange rates. Instead the value of output assumes purchasing power parity. In the long run, prices for traded goods might become more or less equalised across economies, but we cannot assume that this will hold at any point in time. The model privileges economic governance at the national level, but ignores the influence of economic governance at a regional and global level. There is no room for external political, strategic or geographic factors that influence real economic performance.

# 4 Results and applications - country projections

Figure 2 shows potential GDP paths for what are projected to be the seven largest economies by 2050. Based on these projections, China's economy by 2050 could be roughly double the United States'. India almost catches up to the United States by this time. Indonesia is projected to overtake Japan around 2030 to become the fourth largest economy. Mexico is a 'steady state' country in the model, so is not project to experience any 'catch up' growth;[6] however, its population dynamics mean that it could overtake France to become the world's seventh largest economy by 2050.

Table 1 shows the projected decade-average growth rates, decomposed into the contribution from labour productivity growth, and working age population growth. Having enjoyed the 'demographic dividend' of working age population growth in the 1990s and first decade of the 2000s, we see not only that Chinese productivity growth is moderating, but that a shrinking working age population further slows growth. The United States, for which

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[6]Mexico is identified in steady state with labour productivity being 33 per cent of the United States'. The relative steady state predicted by Mexico's GCI score is only 24 per cent of the United States', so if Mexico were allowed in our model to be in transition, its productivity growth would be being 'dragged down' rather than 'catching up'.

Figure 2: Projected GDP of 7 largest economies by 2050
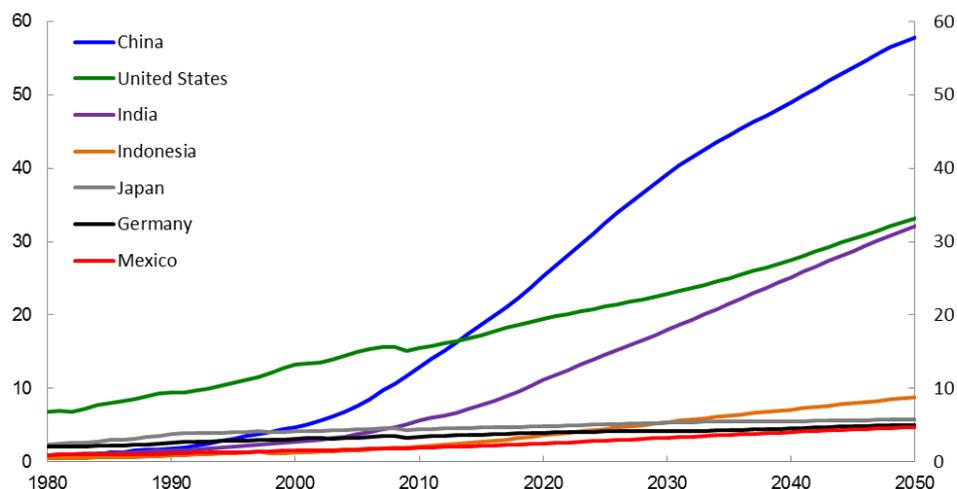
Source: IMF and authors' calculations. All amounts are in trillion USD 2012 (PPP).

productivity growth is assumed to be 1.5 per cent, achieves higher growth on account of projected population expansion. India, while projected to have lower average productivity growth than China over the period may be able to benefit from a young and growing workforce. Indonesia faces a similar trajectory, although with slightly lower projections for both productivity and population. Japan and Germany face low GDP growth over the entire period due to a contracting population and no expected 'catch-up' growth productivity growth.

Table 1: Decade average growth rates

| | IMF | | | | | |
| | Historic | | Outlook | Long Term Projections | | |
	1991-2000	2001-2010	2011-2020	2021-2030	2031-2040	2041-2050
China	**9.9**	**10**	**6.8**	**4.4**	**2.2**	**1.7**

Continued on next page

Table 1: Decade average growth rates

|	Historic		Outlook	Long Term Projections		
	1991-2000	2001-2010	2011-2020	2021-2030	2031-2040	2041-2050
Productivity	*8.6*	*8.6*	*6.8*	*4.7*	*3.3*	*2.5*
Working pop.	*1.3*	*1.4*	*0*	*-0.3*	*-1.1*	*-0.9*
USA	**3.4**	**1.6**	**2.3**	**1.6**	**1.9**	**1.9**
Productivity	*2.2*	*0.6*	*1.9*	*1.5*	*1.5*	*1.5*
Working pop.	*1.2*	*1*	*0.4*	*0.1*	*0.4*	*0.4*
India	**5.4**	**7.3**	**6.9**	**4.8**	**3.4**	**2.5**
Productivity	*3.1*	*5.2*	*5.3*	*3.8*	*2.7*	*2.2*
Working pop.	*2.3*	*2.1*	*1.6*	*1.1*	*0.7*	*0.3*
Indonesia	**4.1**	**5.3**	**5.4**	**4.1**	**2.8**	**2.1**
Productivity	*1.8*	*3.7*	*4.0*	*3.2*	*2.4*	*2*
Working pop.	*2.3*	*1.6*	*1.4*	*0.9*	*0.4*	*0.1*
Japan	**1.1**	**0.8**	**0.7**	**1.0**	**0.4**	**0.5**
Productivity	*1.1*	*1.3*	*1.7*	*1.7*	*1.6*	*1.5*
Working pop.	*0.1*	*-0.5*	*-1.0*	*-0.7*	*-1.2*	*-1.0*
Germany	**1.9**	**0.9**	**1.5**	**0.6**	**0.8**	**1.0**
Productivity	*1.7*	*1.4*	*1.7*	*1.6*	*1.5*	*1.5*
Working pop.	*0.3*	*-0.6*	*-0.2*	*-1.0*	*-0.7*	*-0.5*
Mexico	**3.3**	**1.8**	**2.9**	**2.8**	**2.1**	**1.6**
Productivity	*0.8*	*-0.2*	*1.2*	*1.7*	*1.6*	*1.6*
Working pop.	*2.5*	*2*	*1.7*	*1*	*0.5*	*0*

Source: IMF, UN and author's calculations.

Because the 140 countries in our model represented 98 per cent of global GDP in 2014,[7] we can consider the projected distribution of global economic weight. Figure 3 shows the significant growth in the share of global output

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[7]Compared to the 188 included in the IMF World Economic Outlook.

coming from Asia after 1995 (after the collapse of the USSR) to 2050. East Asia's share, which includes China, could peak in 2030 at around 30 per cent. However, projected higher growth in South Asia (led by India) and Southeast Asia (primarily, Indonesia) would see Asia's share of the world economy expanding to around half by 2050. By contrast, the economies of North America and Europe which had accounted for half of global output in 1995 could fall to less than a third by 2050. This is driven primarily by the fact that advanced Europe has little prospect for 'catch-up' growth to offset the demographic decline.

Figure 3: Share of global GDP by region (2012 PPP)
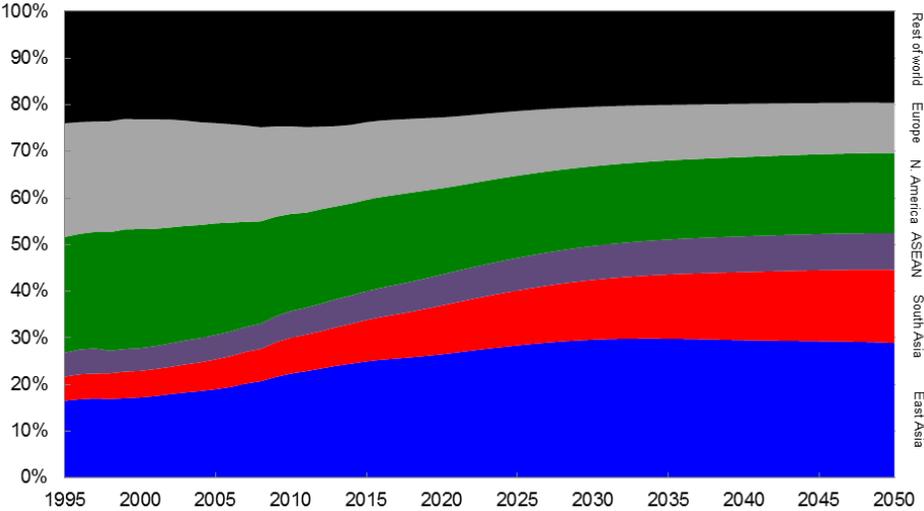
Source: Authors calculations.

Aggregate shares can also be expressed on the basis of trade groupings (or potential groupings). For example, Figures 4a and 4b show the size of potential trade grouping the Trans Pacific Partnership (TPP), involving the United States and eleven other economies, and the Regional Comprehensive Economic Partnership (RCEP), currently involving the members of ASEAN, China, Korea, Japan, Australia, New Zealand and India.

In 2007, the collective GDP of potential RCEP members surpassed the

Figure 4: Share of global GDP by trade groupings

(a) TPP Economies   (b) RCEP Economies
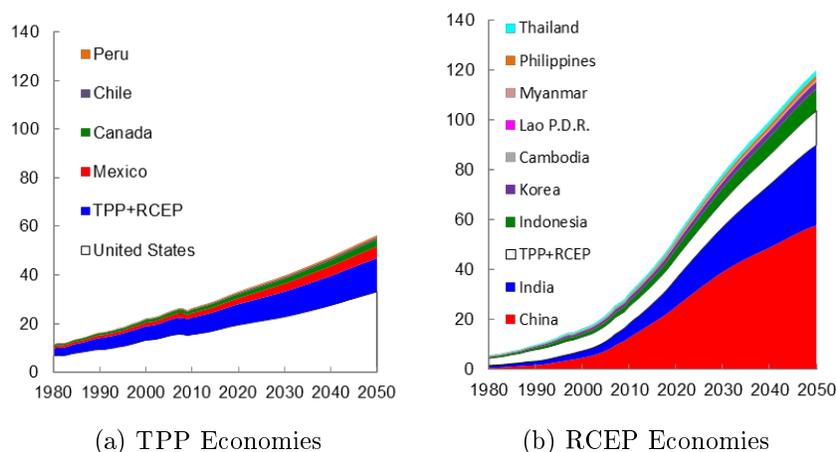
Source: Author's calculations. All amounts are in trillion USD 2012 (PPP).

collective GDP of TPP members. These projections do not include the potential impact on economics institutions from commitments also undertaken as part of TPP or RCEP and the impact of these on economic activity within the blocs or between blocs.

The projected emergence of China, India and Indonesia as three of the world's four largest economies around 2030 does not mean that they could by then be considered 'rich' on a per capita basis. Even though each of these countries is projected to grow faster than the United States until 2050, they would still have substantially lower projected per capita income levels than the United States, Germany, and Japan (Figure 5). Nevertheless, it is noteworthy that by 2050, average per capita incomes in China might be higher than present-day Japan.

This methodology can also be used to construct alternative scenarios based on policy reforms in a particular country. Figure 6 shows baseline and reform scenarios for per capita GDP in China, Indonesia and India. The Chinese reform scenario assumes that after 2020, China's institutions are improved to the point that China's GCI score (and therefore estimated

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Figure 5: Per capita GDP of seven largest economies in 2050 (2012 PPP)
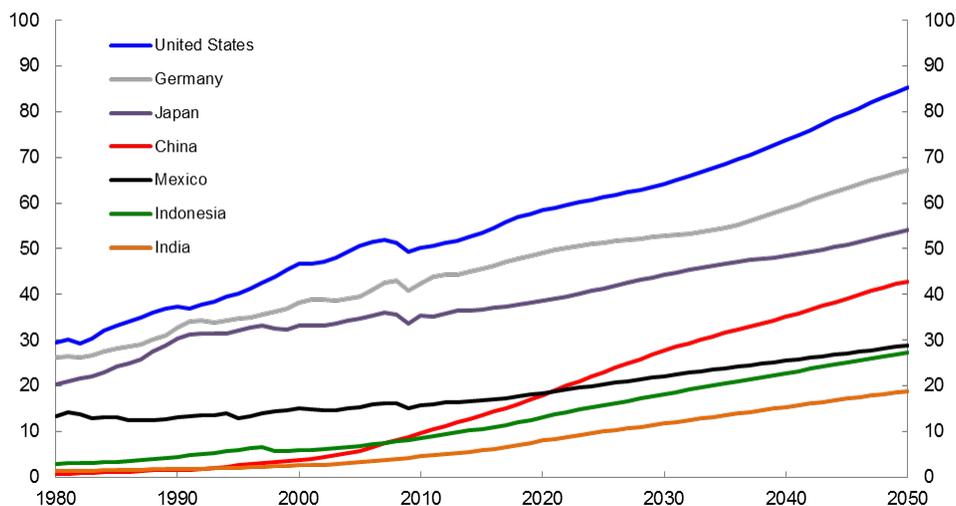
Source: Author's calculations. All amounts are in USD thousands (2012 PPP).

potential labour productivity) is the same South Korea. The Indian and Indonesian reform scenarios assume policy reforms that increase their GCI score to the level of China today. Under these scenarios, by 2050 China could raise per capita GDP by a quarter, Indonesia by two thirds, and India more than double what it would otherwise be in the baseline case. This demonstrates that while there is some role for demographics in a country's economic prospects, there can be huge dividends from early domestic reforms.

5 Conclusion

We have described a simple model of long-run economic growth. While the model relies on strong assumptions and has obvious limitations, it provides a coherent framework for thinking about growth, particularly for those countries that appear to be experiencing substantial structural change and associated rapid economic growth. Rather than provide an exhaustive analysis of results for many countries, we provide a few examples of how this

Figure 6: Per capita GDP - Baseline and Reform scenarios
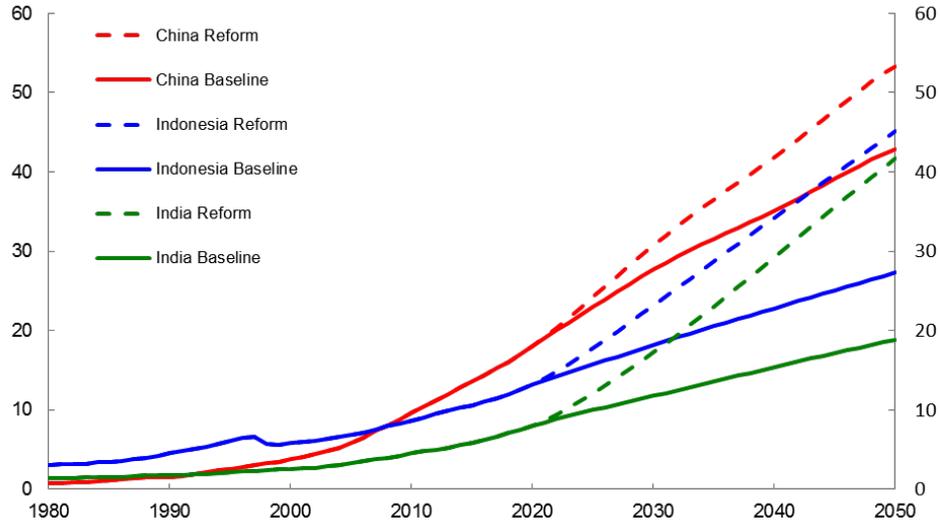
Source: Author's calculations. All amounts are in USD thousands (2012 PPP).

framework can be used to think about economic prospects, shifting global economic weight, the market size with respect to domestic policy reforms and trade liberalisation. We make available the complete results of the model in order to allow others to test different assumptions and scenarios, and develop the model further.

Given that the USSR's population was roughly comparable to that of the United States, historic projections of the USSR eclipsing the United States economically depended on ever increasing productivity growth. By contrast, China and India are much larger in terms of population than the United States, and so can become economically bigger at productivity levels well below the United States' productivity levels. For advanced countries which limited scope for 'catch up' growth, economic trajectories are likely to follow demographics and trend growth in productivity. But for low and middle-income countries with labour productivity levels well below the United States, domestic policy reforms that lift growth potential can sustain

growth for decades.

6   Technical Appendix

In most technical matters, we follow Au Yeung et al (2013), although we differ in a few small respects. We use IMF World Economic Outlook data rather than the Conference Board Total Economy Database (TED) for GDP estimates. We make projections only for the 140 countries that are scored by the World Economic Forum, unlike the Treasury working paper which projects GDP for 155 countries by estimating missing GCI scores based with scores estimated based on the World Bank World Governance Indicators. Omission of these mostly very small countries would have only a minor effect on our global economic estimates.

Au-Yeung et al (2013) use published GCI scores for all countries as the measure of institutional quality. The World Economic Forum applies different weights to the subindices of GCI score depending on the per capita income level of the country in question. Higher-income 'innovation driven' economies apply more weight to 'innovation and sophistication' factors than do middle income 'efficiency driven' economies for example (see Table A).

Table A

Country classification	Basic requirements	Efficiency enhancers	Innovation and sophistication factors
Factor driven	0.60	0.35	0.05
Efficiency driven	0.40	0.50	0.10
Innovation driven	0.20	0.50	0.30

This leads to problems when seeking to compare countries between income groups and to transitioning economies between income groups. For example based on published scores, China's GCI score is higher than that of Iceland, Thailand's GCI is higher than Spain's, and Indonesia's is higher

than Portugal.[8] This is not the case when a consistent weighing method is applied to all economies. Because the most potential for 'catch-up' growth occurs in the middle income level, we chose 'efficiency driven' weights.

Model equations follow Au-Yeung et al (2013). Equation A.1 is calculated in the "Kernel Estimation" tab of the attached spreadsheet. It estimates a relative productivity level for any possible GCI score.

6.1 Equation A.1[9]

$$\overline{\varphi}(GCI) = \frac{\sum_{i=1}^{n} K(\omega_i)\varphi_i}{\sum_{i=1}^{n} K(\omega_i)}$$

Where the kernel $K(\omega_i)$ is calculated as follows:

$$K(\omega_i) = \frac{1}{\sqrt{2\pi}} exp\left[\frac{-1}{2}\left(\frac{GCI_i - GCI}{h}\right)^2\right]$$

In words, this equation estimates a relative long-run productivity level ($\overline{\varphi}$) for any given GCI score, given n comparator countries for which each country's GCI score (GCI_i) and relative long-run productivity level (φ_i) is already known. Au-Yeung et al (2013) use Hodrik-Prescott filters to estimate the trend and cyclical components of GDP, productivity and working age population. To keep things simple we omit this step. While point estimates differ, the results remain broadly consistent with Au-Yeung et al (2013).

The only parameter to choose here is the size of the estimation bandwidth, h. We choose a value of 0.294 - being the lowest possible value that ensures the relationship is strictly non-decreasing. This means that a higher GCI score can never result in a lower estimated labour productivity level (Figure 7). A bandwidth estimate that is too high results in more weight being given to distant comparators (Figure 8a) which eventually converges to an estimate that is simply the average of all comparator countries' relative productivity levels. By contrast, a bandwidth estimate that is too low (Figure 8b) results in estimates that weigh comparison countries too heavily

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[8]In contrast to Au Yeung et al, which used the GCI score weighted according to level of development.

[9]See Au-Yeung et al (2013) for detailed discussion.

and can therefore be dragged down in spite of overall positive relationship between GCI and relative productivity.

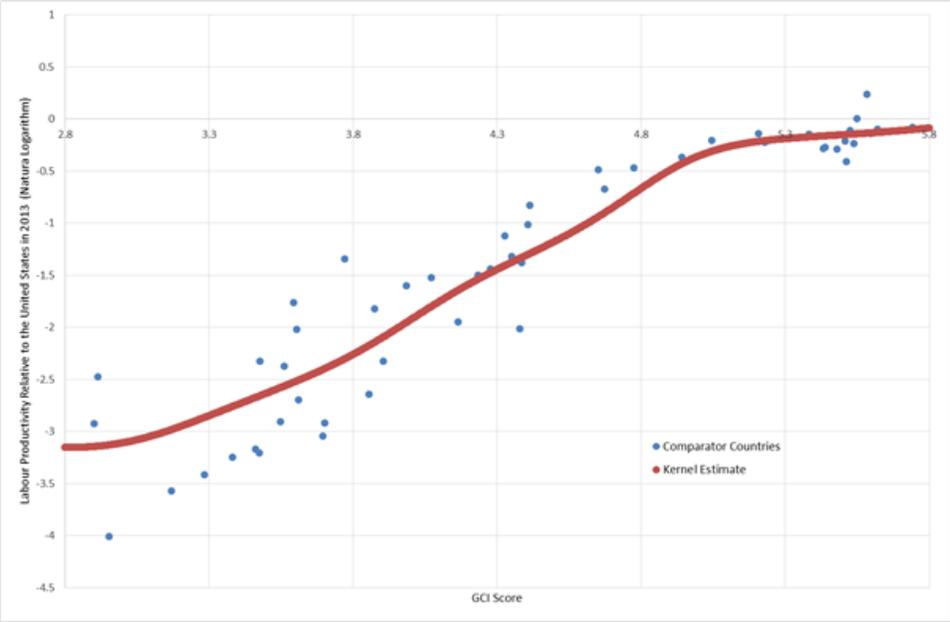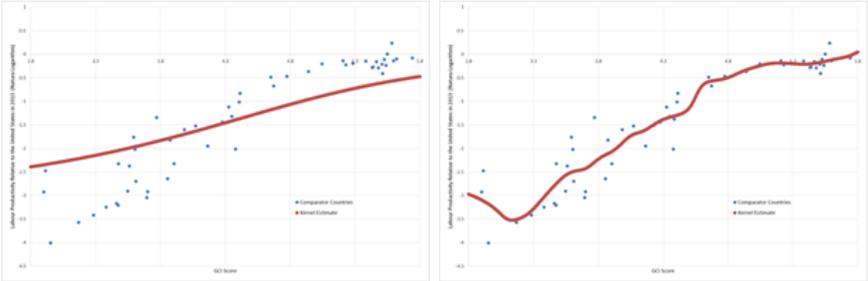Figure 7: Kernel Estimate based on comparator countries

Figure 8: Comparison of bandwidth estimates

(a) Kernel bandwidth too high   (b) Kernel bandwidth too low

Source: Authors' calculations.

Equation A.2 provides a transition path between current productivity

levels and the estimated long-run productivity level for any country. We modify its slightly[10] from Au Yeung et al (2013) to accord with intuition.

6.2 Equation A.2[11] Annual labour productivity growth

$$ln\left(\frac{\Lambda_{i,t}^{T}}{\Lambda_{i,t-1}^{T}}\right) = \gamma ln\left(\frac{\Lambda_{i,t-1}^{T}}{\Lambda_{i,t-2}^{T}}\right) + (1-\gamma)ln\left(\frac{\Lambda_{USA,t}^{T}}{\Lambda_{USA,t-1}^{T}}\right) + \beta\left[ln(\varphi_i) - \left(\frac{\Lambda_{i,t-1}^{T}}{\Lambda_{USA,t-1}^{T}}\right)\right]$$

In words, growth in labour productivity (Λ) in country i is equal to some proportion (γ) of growth in the previous period, plus some proportion $(1-\gamma)$ of growth in the frontier economy (USA). From this, we add some proportion (β) of the distance between the country's estimated long-run productivity level relative to the United States (φ_i) and its relative productivity level in the previous period. We choose γ to be 0.5, and β to be 0.025 (compared to 0.02 in Au Yeung et al). This gives slightly more 'catch up' growth at any point in time. Readers are of course welcome to test sensitivity to alternative parameters. For the United States the value of β is 0 - by definition, the United States cannot catch up with itself.

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[10]For low values of β, for example 0.025, the results are equivalent.
[11]See Au-Yeung et al (2013) for detailed discussion.

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