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Long term Projections of the World Economy – A Review

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Abstract

Economic growth projections are fundamental to long term investment planning by businesses and government. There is an extensive and well developed literature concerned with methodologies for projecting economic growth over short time horizons, but over long horizons, where the goal is to quantify the implications of a particular scenario, the literature is limited. This paper provides a review of publicly available projections of GDP per capita over long time horizons and compares them with projections from a multi-sector model of the world economy called the G-Cubed model. Although there appears to be some general agreement over methodology across the reviewed sources, the projections vary considerably, particularly for developing regions over long time horizons, highlighting the importance and influence of alternative model methodology and assumptions. The comparison with the G-Cubed model builds on previous research that has highlighted the importance of a detailed disaggregated approach to projecting output and productivity that accounts for the dynamic interactions between sectors and across economies. Long term economic issues are becoming increasingly important and economic growth projections are fundamental to both the design and the assessment of long term economic policy alternatives. In addition, our ability to analyse the impact of long term policy alternatives is linked to our ability to model and understand the impact of global economic shocks. Models need to be clear in their methodological design and assumptions, but they also need to be sufficiently complex to account for the important sectoral relationships and international linkages that drive economic growth.

Keywords

Economic growth, long term projections

JEL Classification

O40, O33, C53, C68

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Abstract

Economic growth projections are fundamental to long term investment planning by businesses and government. There is an extensive and well developed literature concerned with methodologies for projecting economic growth over short time horizons, but over long horizons, where the goal is to quantify the implications of a particular scenario, the literature is limited. This paper provides a review of publicly available projections of GDP per capita over long time horizons and compares them with projections from a multi-sector model of the world economy called the G-Cubed model. Although there appears to be some general agreement over methodology across the reviewed sources, the projections vary considerably, particularly for developing regions over long time horizons, highlighting the importance and influence of alternative model methodology and assumptions. The comparison with the G-Cubed model builds on previous research that has highlighted the importance of a detailed disaggregated approach to projecting output and productivity that accounts for the dynamic interactions between sectors and across economies. Long term economic issues are becoming increasingly important and economic growth projections are fundamental to both the design and the assessment of long term economic policy alternatives. In addition, our ability to analyse the impact of long term policy alternatives is linked to our ability to model and understand the impact of global economic shocks. Models need to be clear in their methodological design and assumptions, but they also need to be sufficiently complex to account for the important sectoral relationships and international linkages that drive economic growth.

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1. Introduction

Economic growth projections are fundamental to long term investment planning by businesses and government. There is an extensive and well developed literature concerned with methodologies for projecting economic growth over short time horizons. Over long horizons, however, where the goal is to quantify the implications of a particular scenario, the literature is limited. With the emergence of climate change as a key policy area the time horizon over which projections are required has been stretched dramatically. There has been substantial debate over appropriate methodology and its application but there are still many unsettled questions and some potential inconsistencies in much of the major work in this area.

This paper provides a review of publicly available projections of GDP per capita over long time horizons. The review covers projections from 10 alternative sources and considers time horizons of between 20 and 40 years. The reviewed projections and associated methodologies are compared to those of the G-Cubed model – an intertemporal general equilibrium model with detailed country and sector disaggregation and rich dynamic features.

Across the reviewed sources there appears to be some general agreement over methodology. Essentially, the models combine neoclassical growth theory with additional assumptions, including technology convergence, in order to generate projections of key model inputs. Despite the agreement over general methodology, the projections vary considerably, particularly for developing regions over long time horizons, highlighting the importance and influence of alternative model methodology and assumptions. The comparison of the reviewed sources with the G-Cubed model builds on previous research that has highlighted the importance of a detailed disaggregated approach to projecting output and productivity that accounts for the dynamic interactions between sectors and across economies (see McKibbin et al (2004, 2007, 2009)).

The survey presented here also highlights the fundamental difference between projections of economic growth over short time horizons, which are essentially forecasts and generally based on time series models, and projections of economic growth over long time horizons, which are undertaken to model a particular scenario and are generally driven by theoretical model assumptions.

The distinction made here between short run projections aimed at forecasting the future and long run projections that attempt to quantify a given scenario is critical. Over short time horizons, empirical trends and behaviour dominate and forecasts can be, and frequently are, judged against actual outcomes. Over long horizons, the objective is more complex. Projections represent an attempt to quantify a given scenario and alternative methodologies and assumptions can produce highly variable results. In addition, there is subjectivity in the interpretation of the scenarios and in the assignment of likelihood and relevance.[2] For this reason, it is fundamental that long run economic projections are accompanied by a clear and transparent description of the scenario with which they are associated and the assumptions and methodologies that underlie the scenario and its quantification.

When the projection horizon extends beyond 20 years, a high degree of uncertainty is associated not only with the underlying model and its parameterisation but also with the specification and evolution of the key drivers of economic growth. Granger and Jeon (2007) cleverly demonstrate the issues and difficulties associated with long run projections by considering forecasts of the year 2000 made by Kahn and Wiener (1967) in the year 1966. With respect to technical innovations, Granger and Jeon note that Kahn and Weiner successfully predicted "more reliable and longer-range weather forecasting; extensive and intensive use of high altitude cameras; new techniques for cheap, convenient, and reliable birth control; a general and substantial increase in life expectancy; 'high quality' medical care for undeveloped areas; automated grocery and department stores (becoming used); and home computers to 'run' households and communicate with the outside world" but they failed to predict "cloning [and] the human DNA genome sequence map" and made a number of

[2] For example, Researcher "A" may be interested in generating a scenario associated with the "most likely" outcome, whereas Researcher "B" may be interested in generated "worst case" and "best case" scenarios, neither of which are "most likely" and both of which require subjectivity in their interpretation. Researcher "C" may be interested in a scenario corresponding to the "most likely" outcome but may have a very different assessment of the characteristics of such a scenario compared with Researcher "A".

predictions including “control of weather and/or climate” and “human hibernation” that did not occur (Granger and Jeon, 2007, pp 541-542).

The Kahn and Wiener scenarios for the United States predicted increases in population and GNP per capita but they did not consider the implications of these trends. As argued by Granger and Jeon, “medical advances led to longer life expectancy and increased retirement requirements leading to less leisure, more women working and later retirement” rather than the predicted *increase* in leisure time. Furthermore, Granger and Jeon argue that several important social and political changes, including “the major decline of Communism in Europe, the consequent break-up of the USSR and the unification of Germany”, were not foreseen by Kahn and Wiener (p544). Despite these omissions, given the task at hand, Granger and Jeon conclude by assessing the Kahn and Wiener study as a “great contribution” to the literature.

When the objective is to quantify and assess the likelihood of alternative scenarios 20 to 40 years into the future, uncertainty is pervasive, particularly with respect to the fundamental drivers of economic growth. As argued by Martin Rees[3] (2009),”the most important [technological] advances, the qualitative leaps, are the least predictable. Not even the best scientists predicted the impact of nuclear physics, and everyday consumer items such as the iPhone would have seemed magic back in the 1950s.” The need to construct and quantify scenario assumptions regarding

[3] Astrophysicist, University of Cambridge and former head of the Royal Society in London

technological advances and social and political change complicate the projection of long run economic growth considerably.

The projections reviewed here are described as *baseline* projections. The assumptions underlying the projections are conservative with respect to major technological breakthroughs, socio-political change and innovative policy implementations. It is likely that over the projection period such shocks will occur but their nature is so uncertain that it can be difficult to justify their inclusion in projection exercises. Furthermore, a conservative approach allows the projections to function as a base foundation from which alternative policies can be considered and evaluated. Projected variables are unlikely to match with observed outcomes over long horizons and relevance and usefulness must be subjectively judged with reference to the particular policy question under consideration. If the intention is to inform economic and financial decision making, then success may be considered, not with reference to the accuracy of the projections themselves, but with reference to the appropriateness of the policy decisions based upon them.

The following section, Section 2, summarises and discusses the alternative methodologies used in the projection models surveyed in this paper. Section 3 describes and analyses the projections that result from these models. Section 4 discusses further issues, Section 5 contains the references and Section 6 is a short appendix.

2. Quantifying the Scenarios: Projection Methodology

2.1 General Discussion

The models used to generate the projections presented in this paper utilise the neoclassical growth model as a foundation.[4] They also incorporate some form of convergence assumption where one or more variables across countries are assumed to converge towards each other or to a frontier economy. The use of convergence assumptions in the IPCC Special Report in Emissions Scenarios (2000) (SRES) generated considerable debate and controversy over the appropriate execution and application of convergence assumptions in projection exercises. The debate was complicated by confusion over the extent to which theoretical models and empirical analyses of economic growth provide support for the use of cross country convergence assumptions.

The theory underlying the neoclassical growth model provides a path for an economy as it converges to its steady state[5]. The further an economy is from its steady state, the faster it grows. This is due to diminishing returns to capital. If all economies shared the same steady state characteristics, then relatively poor countries, with low levels of capital and output per worker, would grow faster than relatively rich countries

[4] The neoclassical growth model is often referred to as the Solow model or the Swan Solow after the two economists responsible for its development (Solow (1956), Swan (1957)). Empirical estimation of the underlying equations are often based on Mankiw, Romer and Weil (1992),

[5] In neoclassical growth theory, this is an equilibrium for the economy where growth in output and other variables of interest are constant or "steady". Factors that affect steady state values depend on the theoretical model under consideration; in empirical work, consideration is given to socio-demographic and political structures.

(because they are further from the shared steady state) and convergence in the absolute sense would occur. However, as pointed out by Barro (1996), if countries differ in their respective steady state characteristics[6], "then the convergence force applies only in a conditional sense" (p4). "The growth rate tends to be high if the starting per capita GDP is low *in relation to its long–run or steady state position*; that is, if an economy begins far below *its own* target position."(p4) [emphasis added] Neoclassical growth theory therefore predicts convergence of an economy to its own individual steady state. Under *conditional convergence*, poorer countries will only grow faster than relatively rich countries if they are further below their respective steady states.

Neoclassical growth theory does not provide a strong theoretical foundation for the use of 'catch up' assumptions in projection analyses. The neoclassical growth model provides a theoretical framework for convergence *to* individual steady states but not for convergence *of* steady states. This distinction is fundamental to the use of convergence assumptions in projection analyses.

In projection analyses, convergence assumptions often impose the assumption that economies converge towards each other, in one or a range of variables. This is often referred to as economic 'catch-up'. To remain consistent with standard neoclassical growth theory, models need to make the *additional* assumption that either (a) economies share the same steady state characteristics and convergence of economies to their

[6] Including saving, and population growth rates, access to technology, and government policies.

individual steady states corresponds to the convergence of economies to each other; or (b) economies are converging to individual steady states that are, in turn, converging to each other.

Under assumption (a) all regions under consideration are converging to the same steady state and steady state convergence and economic catch-up are equivalent. Empirical evidence on aggregate Gross Domestic Product (GDP) convergence suggests that while subsets of regions appear to share steady state characteristics (such as regions within the Organisation for Economic Co-operation and Development (OECD)) this type of assumption is not appropriate across the broad set of regions of the world.

An alternative is to assume that the steady state characteristics of regions are heterogeneous but converging towards each other over time. In the neoclassical growth model, steady state characteristics are explicit, but models could encompass a range of characteristics relating to tastes, preferences and technologies. The use of assumption (b) requires the development of a theoretical model of steady state convergence and is complicated by our limited understanding of the determinants of steady states and their evolution over time, particularly for developing economies.

In standard neoclassical growth theory, the fundamental driver of steady state, and therefore long run, growth is exogenous technological progress. Technology is usually introduced with a constant, homogenous growth specification[7], but the empirical evidence suggests that both the growth rate and the level of technology vary across countries and through time.[8] With regard to projection exercises, an alternative specification is a convergence model of technological progress based on technology transfer, diffusion and adoption. This type of model has support in both the empirical and theoretical literature.[9] All of the models surveyed in this review assume some form of convergence in technology or total factor productivity (TFP)[10]. Projections of TFP and other key inputs determine the projected levels and growth rates of GDP[11] per capita through an aggregate production function. The following sub-sections summarise the sources and the alternative specifications.

2.2. The Reviewed Sources

This paper reviews long run international GDP per capita projections from 10 different sources, 5 of which include detailed documentation of the models and

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[7] Because technical growth is homogeneous, once countries reach their respective steady states, they will grow at the same rate – the growth rate of technical progress. This is sometimes called 'conditional convergence' or 'growth convergence' in the empirical growth literature.

[8] In the theoretical literature this limitation led to the development of endogenous growth models. As recently pointed out by Solow (2007): "We all believe that the determinants of long-run growth are somehow endogenous, but the 'somehow' is not obvious" (p 14). See Aghion and Howett (1998) for further discussion of endogenous growth models.

[9] See Bernard and Jones (1996) for a theoretical introduction and Dowrick and Rogers (2002) for empirical analysis. Phillips and Sul (2007a, 2007b, 2009) develop a flexible econometric alternative based on technological progress paths.

[10] TFP can be defined as the portion of output not explained by the amount of inputs used in production. In the growth accounting framework TFP is measured as a residual after calibrating a production function based on the Solow model and is often referred to as the 'Solow Residual'.

[11] GDP attempts to measure the output of an economy and under the framework of national accounts alternative approaches are equivalent. Income and Output are used interchangeable in the projection literature surveyed here. There is no interpretation, in this paper, of GDP as a measure of welfare.

assumptions used to generate the projections. Table 1 summarises the key features of each projection. The G-Cubed model is included in Table 1 but is discussed separately in Sub-Section 2.5.

The regional economic growth projections published by the Intergovernmental Panel on Climate Change (IPCC) in its Special Report on Emissions Scenarios (SRES) are not directly comparable to individual country projections considered here and are not included in the statistical analysis of variance undertaken in this paper.

The economic growth projections in the SRES correspond to four regions: OECD90, ASIA, ALM and REF and they are used to provide context and for comparison purposes where appropriate.[12]

[12] OECD90 corresponds to members of the OECD as of 1990. REF corresponds to countries undergoing economic reform – East European countries and Newly Independent States of the Former Soviet union. ASIA corresponds to all developing countries and regions in Asia. ALM corresponds to developing countries in Africa, Latin America and the Middle East.

Table 1 Projection summary

Projections	Year of publication	Time coverage	Country/regional coverage	Conversion Factor*
SRES-MESSAGE	2000	1990-2100, 10-year intervals	World-wide, Regional level, including world total	MER and PPP
USDA	2011	2000-2030, annual	World-wide, both on country and regional level, including world total	MER
EIA	2011	2006-2035, 5-year intervals	World-wide, both on country and regional level, including world total	MER and PPP (PPP used)
CEPII**	2010	1980-2050, annual	World-wide, both on country and regional level, including world total	MER and PPP (PPP used)
GS2011#**	2011	1980-2050, 10 year intervals	World-wide, both on country and regional level, including world total	MER, PPP and real growth (Real growth rates used)
OECD ENV-L**	2011	2010-2050, 10-year intervals to 2030, then 20-year intervals	Short list of countries and regions, including world total	PPP
PWC**	2011	2009-2050, point projection	Country level only, no world total	Real growth, MER and PPP (Real growth rates used)
K2008	2008	2000-2050, 25-year intervals	World-wide, key countries such as G7 and BRICs, including world total	PPP
DM2010**	2010	2000-2050, 10-year interval to 2025, then 25-year intervals	World-wide, short list of several key countries and regions, including world total	MER and PPP (PPP used)
JCER	2007	2006-2050, 10-year interval	Short list of major economies and regions, no world total	PPP
G-CUBED	2011	2006 – 2050, annual	World-wide, aggregated to 11 regions	MER, PPP and real growth (Real growth rates used)

Notes:
* It is not always clear when conversion factors have been applied ex-post and when they fundamentally matter to model calibration.
** These projections have detailed projection documentations.
# GS2011 real growth projections published for GDP only. Projections for GDP per capita are constructed by adjusting by the population growth rates implied by taking the published GDP USD levels and dividing by the published GDP per capita USD levels.
Further details in coverage are contained in Appendix Table A1. PPP = purchasing power parity conversion factor, MER = market exchange rate conversion factor.

2.3 The Production Function

Generally, the GDP projections surveyed here are based on an aggregate Cobb-Douglas production function for output. The standard specification with constant returns to scale and Hicks-neutral technology[13] is

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{1-\alpha} \tag{1}$$

where Y is output, K is (physical) capital, L is labour, A is the technological progress variable, α is the output elasticity of capital (generally assumed to be 1/3), i is the country subscript and t is a time subscript.

The GS2011 model projections utilise this simple production function. The PWC model augments this model with human capital:

$$Y_{it} = A_{it} K_{it}^{\alpha} H_{it}^{1-\alpha} \; = A_{it} K_{it}^{\alpha} (h_{it} L_{it})^{1-\alpha} \tag{2}$$

where K is physical capital, H is skilled labour, h is human capital per worker and Y, L, A, α and t are as before.

In DM2010 and OECD ENV-L, the standard Solow Model specification, with Harrod-neutral technology, is augmented with human capital:

$$Y_{it} = K_{it}^{\alpha} (A_{it} H_{it})^{1-\alpha} \; = \; K_{it}^{\alpha} (A_{it} h_{it} L_{it})^{1-\alpha} \tag{3}$$

where all variables are as before.

[13] Technology is Hicks-neutral if the marginal product of capital to marginal product of labour ratio is constant for a given capital/labour ratio. Harrod neutral technology is labour augmenting: relative factor shares are constant for a given capital/output ratio. In the standard Cobb-Douglas specification these two technology specifications are equivalent.

In the DM2010 and OECD ENV-L model documentation it is acknowledged that an aggregate approach to economic projections is limited, particularly when energy and emissions are of concern, and a sectoral adjustment is applied to those countries where fossil fuels are regarded to be important. For the OPEC economies, as well as Russia and Norway, the general model is used to project GDP excluding the mining and quarrying sector and value added in the mining and quarrying sector is projected using the OECD's ENV-Linkages model based on long term projections of energy prices and energy demand. The OECD ENV-Linkages model is a detailed, sectoral, dynamic general equilibrium model where GDP projections can be endogenously determined in policy simulations, but are exogenously determined by the methodology described here in the baseline.

The CEPII model accounts for sectoral heterogeneity due to energy by explicitly augmenting the standard production function:

$$Y_{it} = [(A_{it}K_{it}^{\alpha}L_{it}^{1-\alpha})^{\rho} + (B_{it}E_{it})^{\rho}]^{1/\rho} \tag{4}$$

where E is the energy input, B is energy productivity, A is the efficiency or productivity of K and L, $1/(1-\rho)$ is the elasticity of substitution between the composite K and L factor and E, and Y, K, L and α are as before.[14]

[14] Substitution is assumed to be relatively low between energy and the composite capital and labour factor (ρ = -6.353).

Energy consumption projections are based on energy prices and by assuming firms maximise profit subject to (4) giving:

$$Y_{it} = \left[1 - \left(\frac{p_E}{B}\right)^{\frac{\rho}{\rho-1}}\right]^{-\frac{1}{\rho}} A_{it} K_{it}^{\alpha} L_{it}^{1-\alpha} \tag{5}$$

where p_E is the real price of energy and all other variables are as before.

The price of energy to 2030 is projected using oil price data from the Energy Information Agency. From 2030 to 2050 the price of energy is assumed to increase at a constant rate equal to its average growth rate over 2025 to 2030.

The IPCC (2000) Special Report on Emissions Scenarios (SRES) employed a "multi-model approach" where six different models where used to generate 40 alternative scenarios. Each scenario is associated with an economic growth projection.[15] The scenarios are grouped into four main "families" – A1, A2, B1 and B2 – that correspond to a given storyline, and each family is represented by an illustrative "marker scenario". The model methodologies across the SRES are varied. The SRES economic growth projections have been extensively reviewed and debated (see Castles and Henderson (2003a, 2003b), McKibbin, Pearce and Stegman (2004, 2007, 2009), Stegman (2006), Nakicenovic et al (2003), Holtsmark and Alfsen (2004), Vuuren and O'Neill (2006)). The debate has largely focused on the marker scenario projections. This paper focuses on four alternative scenario projections, one from each family or storyline, generated by a single model, the MESSAGE model. This

[15] It is not always clear to what extent the economic growth projections are exogenous inputs as opposed to endogenous outputs.

approach has two main advantages that facilitate comparison: firstly, the model methodology is consistent across the scenario projections; and secondly, the economic growth projections from this model are specified in both MERs and PPPs. The available MESSAGE model documentation suggests a similar foundation to the production function framework specified above. When considering the four alternative A1, A2, B1 and B2 scenario projections it is important to be aware that throughout the SRES: "no judgment is offered ... as to the preference for any of the scenarios and they are not assigned probabilities of occurrence". Furthermore, the SRES states that "there is no single most likely, "central", or "best-guess" scenario" and "all are equally valid". It does however seem appropriate to question the likelihood of assumptions such as the "very rapid economic growth" and "rapid introduction of new and more efficient technologies" assumed in the A1 scenario which is based on an assumption of "convergence among regions". The inclusion of such a scenario is not questioned here. As argued above, a range of alternative scenarios, including those regarded as unlikely, may be important in policy formulation and debate. Rather, the point is that it is difficult to determine relevance and usefulness without a clear understanding of the underlying model assumptions and driving forces, and without forming some judgement as to relative likelihood, which the SRES does not facilitate.

The EIA projections are based on exogenous projections of economic growth supplied by IHS Global Insight. Access to the projection methodology is not available. The available documentation suggests that their model of the United States economy is consistent but more sophisticated than the framework presented here, but it is not clear how their international projections are generated.

Klinov (2008) (K2008) provides a detailed review of the projection literature and a discussion of alternative assumptions and driving forces but does not provide any formal projection model.

The Japan Centre for Economic Research (JCER) and the United States Department of Agriculture (USDA) do not provide any documentation for their economic projections.

For the sources that provide explicit model documentation (DM2010, PWC, CEPII, GS2011 and OECD ENV-L) projections of labour, capital and productivity are critical model inputs.

Labour Assumptions

International population projections out to 2050 are readily available from the United Nations (http://www.un.org/esa/population/). The PWC, DM2010, GS2011, OECD ENV-L and CEPII models use the United Nations population projections (medium variant where specified).

In the PWC and GS2011 models, growth in the working age population is used to proxy labour force growth and employment rates are assumed constant. The CEPII methodology takes the UN population projections out to 2050 and applies the participation rates by age group from the International Labour Organization (ILO) up to 2020, and an assumption of constant participation rates by age group from 2020 to 2050. In the OECD ENV-L and DM2010 models, explicit assumptions regarding participation and unemployment are applied to the UN population projections.

In the DM2010, OECD ENV-L and PWC models, the labour input is augmented with a human capital variable. Human capital is measured using estimates of educational attainment or average years of school education of the working age population. Growth rates are based on extrapolating historical trends and assumptions of convergence to either a frontier economy or a world average. In DM2010 and OECD ENV-L, assumptions are applied to the 25 to 29 age group and educational attainment is determined for the working age population by cohort effects. Educational attainment projections are converted into human capital stock estimates based on return to education assumptions.

Capital Assumptions

The Capital stock is generally assumed to accumulate according to the perpetual inventory method[16], but there are differences in the way investment is projected. The DM2010 model assumes a constant investment to output ratio at long time horizons, whereas the OECD ENV-L and PWC models assume some form of

[16] $K_{t+1} = (1-\delta)K_t + I_t$, where It is the flow of investment and δ is the depreciation rate.

convergence in investment to output ratios; towards 20 percent in PWC, and towards the United States' ratio in OECD ENV-L.

In CEPII, the relationship between investment and saving is explicitly modelled (rather than the closed economy assumption that investment equals savings), the latter being determined by a life-cycle hypothesis.

In the GS2011 model, each country's investment rate is explicitly modelled as a function of demographics and past history, allowing for systematic differences across countries and time.

Productivity Assumptions

The variable A in equations (1) through (5) is a technology or productivity variable. Increases in A are often referred to as technological progress or technical change.[17] In the growth accounting literature A denotes total factor productivity, or TFP, the efficiency with which inputs combine to produce output, and is estimated as a residual.[18]

In the Solow model, A is exogenous and technological progress is the fundamental source of labour productivity growth. In early empirical growth literature (largely based on Mankiw, Romer and Weil (1992)), the growth rate of A is assumed to be constant and homogenous. Technology is interpreted as freely

[17] Bradford De Long (1997) points out that since Solow's influential paper entitled "Technical Change and the Aggregate Production Function" economists have used the terms 'technical change' and 'technology' to refer to shifts in the production function. He argues that this has lead to confusion regarding the relationship between technology and productivity. Despite this criticism, it is standard in the economics literature to refer to growth in 'A' as technical change or technological progress.
[18] See Footnote 9.

available and readily implementable. Bernard and Jones (1996) question this specification and attempt to account for observed differences in empirical estimates of the level and the growth rate of *A* through a model based on technology transfer, where countries differ in their ability to adopt the most productive (frontier) technology. Subsequent empirical literature has focused on technology transfer and its role in explaining cross country labour productivity differences and convergence.[19]

The projection methodologies surveyed here are based on alternative specifications of technological progress, although they all assume some form of convergence. Generally, the growth rate of technology is driven by two processes: the speed of technological progress in innovating economies and the speed of technology diffusion and adoption in those economies that are lagging behind. Convergence models assume that the growth rate of technology in lagging economies facing a large technology gap can exceed the rate of innovation at the frontier, subject to the ability of lagging economies to adopt the available technology.

In the PWC, DM2010 and OECD ENV-L models, the growth rate of *A* is determined by the long run growth rate of *A* at the frontier and a convergence variable based on the technology gap:

$$ln\left(\frac{A_{i,t}}{A_{i,t-1}}\right) = ln\left(\frac{A_{F,t}}{A_{F,t-1}}\right) - \beta\, ln\left(\frac{A_{i,t-1}}{A_{F,t-1}}\right) \quad (6)$$

where *F* denotes the frontier and β is a convergence parameter.

[19] See Footnote 8.

In the PWC model, the frontier is represented by the United States where A is assumed to grow by a constant 1.3 percent per year. The convergence model starts with heterogeneous rates across countries. These rates then converge towards 1.5 percent.

In the DM2010 and OECD ENV-L models, the frontier A is an average of A or TFP in "high TFP" OECD countries[20] and is assumed to grow by 1.5 percent. In the DM2010 model, β is determined by a model similar to that used in PWC: up to 2015, β is set equal to its actual average value over the period 1995–2005 (zero in case of divergence); between 2015 and 2025, β is assumed to converge towards 2 percent; after that it remains constant. The value of β is not explicitly specified in OECD ENV-L model – countries other than those on the frontier are assumed to converge towards the frontier "gradually" – but the reader is directed to the DM2010 documentation for further details suggesting that the β specification is as documented for DM2010.

In the GS2011 model, the growth rate of A is determined by the long run growth rate of A at the frontier and a convergence variable based on respective gaps in *income per capita*:

$$ln\left(\frac{A_{i,t}}{A_{i,t-1}}\right) = ln\left(\frac{A_{F,t}}{A_{F,t-1}}\right) - CF_{i,t} \cdot ln\left(\frac{(\text{income per capita})_{i,t-1}}{(\text{income per capita})_{F,t-1}}\right) \quad (7)$$

[20] Includes Austria, Belgium, Canada, Denmark, Finland, France, Greece, Ireland, Italy, the Netherlands, Norway, Spain, Sweden, the United Kingdom and the United States.

The frontier is represented by the United States where *A* is assumed to grow by a constant 1.3 percent per year. The convergence factor, $CF_{i,t}$ is modelled as a function of an economy's Growth Environment Score (GES) "which incorporates the economic, political and social factors empirically linked to growth performance". The process of convergence is therefore modelled as "a combination of potential and conditions". This idea is consistent with the theoretical and empirical literature on technology convergence that distinguishes between the potential to adopt frontier technology and limitations in the ability to do so. Convergence rates are heterogeneous across countries and across time. The apparent endogeneity in this specification adds complexity and complicates the dynamics of steady state behaviour.

The CEPII production function includes two technological progress terms: *A*, a measure of the efficiency or productivity of capital and labour, and *B*, a measure of energy productivity. *A* is described as "the usual TFP" but comparison of equations (1) through (5) demonstrates that *A* is fundamentally determined by the production function specification. In particular, the residual estimation of *A* from equations (1), (2) or (3), will capture the effect of the omitted input energy.[21] Equation (5) explicitly splits these two effects.

[21] Likewise, residual estimation of A from (1) and (4) will include the human capital effects explicitly modelled in specifications (2) and (3).

The growth rate of A is determined by a convergence model where human capital drives growth directly, through an innovation effect, and indirectly, through an imitation or technology transfer effect:

$$ln\left(\frac{A_{i,t}}{A_{i,t-1}}\right) = \delta_i + \gamma_1 ln\left(H_{i,t}\right) + \gamma_2 ln\left(H_{i,t}\right)\frac{A_{i,t-1}}{A_{US,t-1}} \tag{8}$$

The growth rate of A is higher when human capital levels are higher – this is the innovation effect. The growth rate of A is also higher with distance to the technology frontier, and this effect is stronger for higher levels of human capital.

Importantly, the model allows for divergence below a threshold level of human capital. Human capital is also determined by a convergence model.

The growth rate of B is determined by a dual channel convergence model where distance from the energy productivity (B) frontier affects the growth rate positively and distance from the development (measured by GDP per capita) frontier affects the growth rate negatively:

$$ln\left(\frac{B_{i,t}}{B_{i,t-1}}\right) = \mu_1 ln\left(\frac{B_{F,t-1}}{B_{i,t-1}}\right) + \mu_2\ ln\left(\frac{(\text{income per capita})_{US,t-1}}{(\text{income per capita})_{i,t-1}}\right) \tag{9}$$

The CEPII model documentation argues that the empirical evidence supports a U-shaped relationship between economic development and energy productivity:

> *Low income countries are very energy-efficient because their economies are based on the primary sector. For developing countries, the industry sector, which is very energy demanding, becomes more important, making energy productivity lower; after industrial transition is completed, the technological efficiency of these countries tends*

to improve, and this is accompanied by the organisation of their economies around the services sector, which means that energy productivity starts to increase. (Fouré, Bénassy-Quéré and Fontagné ,2010)

The energy frontier is based on the average of the four most energy productive countries (excluding Switzerland): United Kingdom, Japan, Germany and France. The development (GDP per capita) frontier is the United States. The inclusion of a development gap appears to make the specification endogenous.

With all of the production functions described in this section, there is an issue of data availability. The documentation for the DM2010 and OECD ENV-L models notes that in some instances it is not possible to estimate the model described due to data limitations. In these cases a convergence assumption, similar to the specification for A (equation (6)), is applied to labour productivity; that is, they assume absolute convergence for these economies. Whilst this assumption lacks empirical support, it is unclear how best to project economic growth in developing economies for which data availability is a critical issue.

Parameterisation is also an issue for developing economies. The parameters of the production function are generally assumed to be constant over time, although some attempt has been made in the projection documentation surveyed here to account for changes over time in the convergence parameter associated with modelling technical change. The high rates of growth projected for developing economies are likely to lead to fundamental changes in the structure of economies that, in turn, are likely to affect assumed modelling relationships.

2.4 The Real Exchange Rate and Purchasing Power Parity Conversion Factors

In Sub-Section 2.1, it was noted that the convergence assumptions used in the SRES generated considerable debate in both the public and academic literature. To clarify, the debate centred on the use of market exchange rates (MERs) to convert and compare output across countries and the effect on projection variables, such as emissions, when output levels, converted using market exchange rate are combined with convergence assumptions to project economic growth.

Across the projection documentation literature surveyed here, MER converted GDP is projected in seven out of the ten sources. All but one of these, the USDA projections, also include either PPP adjusted projections or 'real growth' projections. Given the USDA projections are not accompanied by documentation, it is unclear if this specification affects the real GDP per capita projections.

DM2010 argue that the issues regarding conversion factors highlighted by Castles and Henderson are not an issue in their model because "PPPs, not MERs, are used to compare initial income per capita levels and compute the economic convergence scenario" (Duval and de la Maisonneuve, 2010).

The CEPII model includes a real exchange rate model to differentiate between the long run path of the economy in "real terms" and the long run path of the economy in "current dollars". The model, based on the Balassa-Samuelson effect, assumes that real exchange rate changes are a function of relative productivity growth.[22] The documentation argues that it "is crucial to disentangle the two dimensions of the dynamics of world GDP": real growth and real exchange rate adjustments (Fouré et al, 2010). This fundamentally depends on the assumption that the relative size of countries and zones *in terms of markets and financial power* is best measured by comparison of current GDP converted by current exchange rates. The CEPII model utilises convergence assumptions to project a number of key variables (TFP, energy productivity, human capital and saving rates) and appears to be initially calibrated using MER converted GDP levels. To the extent that this overstates the relative GDP per capita gaps that drive the model, the resulting growth rates may be relatively high for developing economies.

OECD ENV-L also includes a real exchange rate model and the documentation states that "the growth path for GDP per worker, expressed in PPP terms ... combines both a volume effect (GDP growth in constant national currency) and a relative price effect (the real exchange rate appreciation)" (Chateau et al, 2011).

[22] The Balassa-Samuelson effect refers the tendency for relatively high growth economies to experience real exchange rate appreciation. The real exchange rate is affected by changes in the relative price of tradable to non-tradable goods, which in turn are related to changes in the relative productivity of tradable to non-tradable sectors that occur as economies develop.

It is not clear why this should be so if the growth path of an individual economy across alternative conversion factors for levels is consistent.[23]

Likewise, the PWC model includes a real exchange rate specification to facilitate projections in both PPP and market exchange rates (MERs). The documentation argues that MERs "[do] not correct for price differences across economies but may be more relevant for practical business purposes". Specifically, they argue that "GDP at PPPs is a better indicator of average living standards or volumes of outputs or inputs, because it corrects for price differences across countries at different levels of development" while "GDP at MERs is a better measure of the relative size of the economies from a business perspective". (Hawksworth, 2006). Confusingly, the PWC documentation includes a figure (Figure 7) that breaks down the components of average real growth in GDP into real growth in GDP and "growth in GDP in dollar terms due to effects of changes in market exchange rates". This *real* series therefore includes the *price* effects of nominal exchange rate changes.

Similarly, in the GS2011 model, "less developed countries can grow richer in part as their exchange rates appreciate" and in the documentation GDP per capita levels are compared using current exchange rates projected using a real exchange rate model. GDP levels are compared using both PPP conversions and exchange rate conversions suggesting that Goldman Sachs sees value in both.

[23] See Nordhaus (2007) for further discussion of this point.

It is concerning that there is a tendency in the projection literature surveyed here to denote constant price or real GDP converted to a common currency unit using *current* exchange rates the same way that real GDP converted using a *constant* exchange rate is generally denoted: YYYY USD, or constant YYYY US$.

Almost a decade after Castles and Henderson first published their critique regarding the use of MERs in the SRES, the projection documentation surveyed here demonstrates that the issue remains confused and is confusing. There remains disagreement over how best to measure and compare cross country output with distinctions made between living standards, economic size and relative weight. There is no question that exchange rate movements are an important consideration in business and investment decisions. It is unclear, however, what role they should play in cross country comparisons of GDP levels.[24]

2.5. The G-Cubed Model

The G-Cubed model is a multi-country, multi-sector, intertemporal general equilibrium model that can be used to analyse a wide variety of policy alternatives and shock responses, as well as the associated dynamic adjustment processes. It combines key features of econometric general equilibrium modelling, international

[24] The issue extends beyond appropriate conversion factors, which for international comparisons of GDP or real production are PPPs. Attempts to include valuation effects in the sources surveyed here suggests that there is interest in income and demand: to compare not only the volume of output or production, but the value of that production and the demand that income from that production generates. These processes can only be modelled at the detailed sector level where production, prices and demand are endogenously determined. It is not clear what information is conveyed when relative prices changes are imposed ex post on projected GDP levels.

trade theory, and modern macroeconomics into a unique disaggregated and dynamic modelling framework. Key features of the model include the distinction between financial and physical capital (financial capital is tracked by currency and physical capital by region and sector where it is installed); and investment, saving and international asset markets that are driven by agents solving intertemporal optimization problems and having expectations driven by foresight (although not always perfect foresight). McKibbin and Wilcoxen (1999, 2012) provide an extensive discussion of the G-Cubed model methodology and its applications.

Complementary to its use in undertaking scenario and policy analysis, the model can be used to generate long term projections of key economic variables. The G-Cubed approach to long term projections is outlined in McKibbin et al (2004, 2007, 2009). Whilst long run projections are driven by a productivity model with underlying neoclassical features similar to the models surveyed above, there are a number of key model characteristics that distinguish the G-Cubed methodology from the sources reviewed here.

Importantly, projections in G-Cubed are undertaken at a detailed disaggregated level. Rather than a single aggregate approach, each economy or region in the model consists of several economic agents: households, the government, the financial sector and a number of interrelated production sectors. The projections discussed in this review are sourced from McKibbin et al (2011). The model version (Version D) disaggregates production into the 12 sectors and the world economy into the 11 regions listed in Table 2. Alternative model versions have been built with 2 sectors (macroeconomic issues), 6 sectors (trade and growth issues), 12 sectors (energy and environmental issues), 21 sectors (India) and 57 sectors (Australia).

Sectoral distinction is critically important when analysing economic growth. McKibbin et al (2004, 2007, 2009) identify several sources of growth within an economy: (1) increases in the supply of labor, capital and other inputs; (2) increases in the quality of these inputs, (3) improvements in the way inputs are used (technical change); and (4) changes in the allocated of inputs across industries. For the world economy as a whole an additional source of growth is the reallocation of inputs among countries. Without sectoral disaggregation, it is not possible to consider the impact of productivity growth in particular sectors on aggregate productivity growth or to analyse or project growth due to the reallocation of inputs across industries or economies. McKibbin et al (2004, 2007, 2009) highlight the importance of accounting for the contribution of sectoral productivity growth in aggregate productivity growth and demonstrate the heterogeneous impact of productivity growth in different sectors on aggregate productivity growth. This point is particularly relevant when convergence assumptions are used to project long run productivity growth.

Table 1: Overview of the G-Cubed Model

Regions
United States
Japan
Australia
Europe
Rest of the OECD
China
India
Eastern Europe and the former Soviet Union
Brazil
Other Developing Countries
Oil Exporting Developing Countries

Sectors
Energy:
(1) Electric Utilities
(2) Gas Utilities
(3) Petroleum Refining
(4) Coal Mining
(5) Crude Oil
(6) Gas Extraction
Non-Energy:
(7) Mining
(8) Agriculture, Forestry, Fishing and Hunting
(9) Durable Manufacturing
(10) Non-Durable Manufacturing
(11) Transportation
(12) Services

As with the projection models surveyed above, G-Cubed productivity projections are based on an underlying assumption of convergence, but the assumptions are applied to total factor productivity at the sectoral level. Although conceptually there is a strong argument that economic growth should be projected at a detailed sectoral level, in practice, data limitations mean that industry level relationships are difficult to uncover. The analysis in Stegman (2011) suggests that convergence trends in productivity are quite heterogeneous across countries, across sectors and through time. The finding of aggregate labour productivity convergence across developed economies is not uniformly reflected at the sectoral level and structural change (reallocation) is critical to the translation of sectoral productivity trends into aggregate convergence behaviour.

The approach in G-Cubed to projecting sector level productivity begins by specifying the expected productivity growth in each sector in the United States from 2006 to 2100 (in the case of the version summarized here). Productivity level gaps for each sector in each country relative to the United States in 2006, measured in terms of purchasing power parity, are then estimated and time varying rates of catch up between each sector in each country and the equivalent United States sector are specified. This time varying catch-up rate reflects assumptions about the ability of countries to catch-up and is intended to reflect the empirical evidence in the convergence literature. In G-Cubed therefore, convergence rates for TFP (A) are heterogeneous across sectors, countries and through time. There is a need, however, to formalise this type of model and improve the underlying empirical data. The analysis in Stegman (2011) provides some empirical foundation and research in this area is currently being undertaken.

As outlined in McKibbin et al (2004, 2007, 2009), once sectoral productivity growth projections have been exogenously generated, they are overlayed with exogenous assumptions about population growth for each country (taken from the United National 'medium-variant' projections) to generate two of the main sources of economic growth. Given these exogenous inputs for sectoral productivity growth and population growth, the model is then solved with the other drivers of growth, capital accumulation, and sectoral demand for other inputs of energy and materials all endogenously determined. In addition, the underlying assumptions that financial capital flows to where the return is highest, physical capital is sector specific in the short run, labour can flow freely across sectors within a country but not between countries and that international trade in goods and financial capital is possible subject to existing tax structures and trade restrictions are critical to the nature and scale of growth across countries. In G-Cubed, the economic growth of any particular country is not completely determined by the exogenous inputs for that country since all countries are linked through goods and asset markets.

Whilst market forces eventually drive the world economy to a neoclassical steady state growth equilibrium, the transition is designed to reflect observed empirical relationships, such as the existence of unemployment for long periods due to wage stickiness. Whilst the projection models surveyed above all utilise alternative specifications for investment (many of them dynamic), G-Cubed is unique in that savings and investment result from forward-looking intertemporal optimization.

With respect to the conversion factor issue, estimating productivity gaps at the sectoral level is particularly difficult due to data limitations. The approach in G-Cubed is to base in these estimates and the associated convergence rates on PPP adjusted data. Further research is needed to extend the availability of PPPs for developing regions, particularly at the sectoral level.

The G-Cubed projections used in this review are real growth projections. Generally, the model is used to compare policy and shock scenarios to a baseline projection within a given economy and the units or currency of measurement are not critical. Real growth rates can be applied to domestic currency, MER or PPP adjusted levels (as is done in this review) depending on the issue under consideration. The following section explains this approach in more detail.

3. Results

The projections reviewed here differ in terms of country coverage, projection horizon, model methodology and calibration, and variable measurement. These issues complicate the comparison of alternative projections of long run GDP per capita.

A critical issue is the starting point. The value of GDP per capita in the base year of the model and in the initial year of projection is fundamental to the projection of GDP per capita. Alternative base years are likely to lead to important differences in model dynamics. The information set at the time of publication or model calibration is also likely to influence the underlying model assumptions and parameterisations.[25] It is not appropriate to control for these effects as they are fundamental to the underlying model methodology. To facilitate comparison, however, an attempt is made to control for differences in starting dates and, to some extent, the use of alternative conversion factors.

Nordhaus (2007) argues that the best approach to constructing global economic models is to "start with the best estimate of the true current relative real outputs (i.e., the best PPP number) and then use correctly measured national growth rates at national prices" (p362).[26] Under this approach, the real (PPP) growth rate of an individual country or economy will be consistent with the real growth rate of the economy measured in local currency units and, if real GDP in local currency is converted to a common currency using a fixed base year exchange rate, will be consistent with the real growth rate of the economy measured in an alternative currency, such as US dollars. This suggests that if individual country projections are

[25] The Appendix contains two figures that may provide further insight into this issue. The PWC model has been used in three successive publications (Hawksworth (2006), PricewaterhouseCoopers (PWC) (2008), Hawksworth, J. and Tiwari, A. (2011)). The model is generally similar and successive publications may provide some insight into the impact of underlying data updates. Growth rates from the publications are shown in Figure A2. The GS2011 model is an updated version of the model used in Wilson, D. and Purushothaman, R. (2003). In this case the underlying model methodology was revised. Growth rates from the two models are shown in Figure A3.

[26] Nordhaus calls these "superlative PPP accounts". Discussion over alternative aggregate PPP measures is beyond the scope of this paper. See Hill (2000) and Dowrick (2009).

generated using best practice with respect to conversion factors, then alternative models can be consistently compared by considering the implied real growth rate projections. There are two important caveats. Firstly, this approach does not control or adjust for differences in level and growth rate projections due to the effect of alternative conversion factors on the underlying model parameters and relationships – this is one of the fundamental issues raised by Castles and Henderson. Secondly, alternative conversion factors will affect the real growth rates of regions because they change the relative weights in the regional aggregation.

In this section, GDP per capita projections are compared by constructing 5 year real growth rate projections of GDP per capita for each of the sources summarised in Table 1 over the projection horizon 2010 to 2050.[27] The effect of alternative *growth rate* projections on the *level* of real GDP per capita is considered by constructing indices of real GDP per capita normalised to 100 in 2010.

Variation is measured by estimating the coefficient of variation across the sample projections. The coefficient of variation is constructed by normalising the standard deviation by dividing by the mean. The coefficient of variation can be used to compare variation in data sets with different means and to compare changes in

[27] As described in Table 1, USDA and EIA model projections are only available out to 2030 and 2035, respectively. GDP per capita projections from GS2011 are affected by nominal exchange rate variations so the real growth rate is combined with the implied population projections from the model to construct real GDP per capita growth rate projections (see Table 1 notes).

variation over time.[28] The projections from the G-Cubed model provide a reference case and are not included in the average and variation statistics.

3.1. GDP per Capita Projections

The United States (US) is the starting point for this analysis because: (a) individual projections for the US are generated by all of the sources reviewed here (except the SRES); and (b) to the extent that the US acts as a frontier in convergence models for developing economies, variations in US projections will propagate through the entire projection exercise. The average projected growth rate for the US over the 20 year period from 2010 to 2030 is 39 percent (9 projections) (Table 3). Over the 40 year period from 2010 to 2050, the average projected growth rate is 93.3 percent (7 projections) (Table 4). If these rates are annualised and then the annualised rates are averaged across the sample, the average of the annualised rates is 1.65 percent growth per year over both the first 20 years and over the entire 40 year projection horizon. This average is slightly lower than the G-Cubed projections of 1.98 percent and 1.92 percent annualised growth per year over the periods 2010-2030 and 2010-2050, respectively. In part, this is due to design. G-Cubed is generally calibrated to provide a baseline for scenario analysis and this is true of the projections used in this review (see McKibbin et al (2011) for the full discussion). As such, the baseline is constructed by excluding the impact of future long term policy

[28] The statistical analysis is undertaken under the assumption of normality.

possibilities such as emissions policies, without consideration of the likelihood of such policies. It is, of course, possible to generate alternative scenarios that include future policy initiatives but the evolution of such policies is uncertain. Sources may differ in their definition of 'baseline' and the appropriate definition will be influenced by the question under consideration.

Overall, the spread or variability of the growth rate projections, measured by the coefficient of variation, is not strongly influence by the projection horizon. However, the spread or range of the *level* projections based on these growth rates increases with the projection horizon as alternative growth rate assumptions compound (Figure 1). The coefficient of variation falls slightly when the sample is restricted to the 5 sources that include detailed model documentation (PWC, DM2010, CEPII, GS2011 and OECD ENV-L) suggesting some inconsistency in the underlying models that do not include documentation.

The K2008 projection represents the upper bound of projections for the US, while the CEPII projection represents the lower bound.

The SRES-MESSAGE A2 and B2 scenario projections for the OECD90 region are below the K2008 lower bound for the US (Figure 2). The B1 projection lies just above this lower bound in terms of growth over 2010-2050. The implied SRES-MESSAGE A1 projections for the OECD90 region is close to the average of the survey sample growth projections at all horizons. In a convergence model, lower rates of growth at the frontier affect the growth projections of all regions and should, all other things being equal, lower the projected growth rates of developing economies. The MER and PPP projections are consistent within the A1, B1 and B2 scenarios. It is not clear what drives the significant, and increasing, deviation in the MER and PPP projections under the A2 scenario.

The growth rate projections for China provide a contrast to those of the US. These projections are characterised by high rates of growth and large variation. Alternative model assumptions and data availability issues appear critical.

Taking into account the higher level of growth rate projections for China, the coefficient of variation for the average annualised growth rates is over a third higher than the corresponding US statistic for the 2010 to 2050 horizon.

Due to the effect of compounding, the coefficient of variation for total growth over 2010 to 2050 is over twice as high for China than the for US. The variation in the subsequent *levels* projections is substantially higher (Figure 1).

The CEPII model projection represents the upper bound of the survey. Total growth over 2010 to 2050 under the CEPII projection is 897 percent, almost double the average.

The JCER projection represents the lower bound for China; the projected growth rate over 2010 to 2050 is less than a third of the rate projected by the CEPII model.

The G-Cubed projection for China is very close to the average of the reviewed sources: 491 percent total growth over the period 2010 to 2050 compared to the survey sample average of 495 percent.

The SRES-MESSAGE PPP growth projections for the ASIA region are, on average, lower than those of our survey sample for China, possibly reflecting the lower growth projections for other economies within the ASIA region and the lower growth projections for the OECD90 frontier region in those scenarios where convergence assumptions are important (Figure 2).

The growth rate projections for the MER calibrations are higher than for the PPP calibrations. This disparity is highest for the convergent A1 scenario and lowest for the (possibly divergent) A2 scenario. This could support the Castles and Henderson argument that, within the SRES, higher growth rates are required to achieve a given income gap if the initial income gap is specified in MERs compared to PPPs. It could also support the Holtsmark and Alfsen (2004) argument that the SRES MER projections do not represent real economic growth because they are driven by market exchange rate changes. This uncertainty and confusion over model methodology and driving forces limits the usefulness and useability of the projections because the relevance of the projections cannot be determined. This issue is relevant to the assessment of all of the projections considered in this review. To the extent that methodology and driving forces cannot be ascertained, researchers cannot determine the relevance of the projection with respect to their specific policy question and they cannot apply probabilities or likelihoods. With respect to the SRES, because of uncertainty and limitations in comparability, and because these projections have been reviewed extensively in the literature, the projections for the REF and ALM regions are included in the appendix but the SRES projections are not discussed further in the body of this review.

Figure 3 contains graphs of the growth projections for Canada, Australia, Japan, Russia, Brazil, Mexico, India, South Korea, Indonesia, and South Africa.

Analysis and comparison of the growth projections illustrated in Figures 1 and 3 reveals that developing economies are projected to grow much faster than the developed economies (Figure 4) and that variation does not appear to be related to development level.

The regional projections are harder to analyse and compare due to inconsistencies in coverage and limitations in sample size. Overall, the variation in the regional projections appears to be in line with the variation in the individual country growth projections over 2010 to 2030 (Figure 5). The variation in the regional growth projections over 2010 to 2050 is relatively high, but the sample is restricted and developing economies are not considered.

Interestingly, the variation in the projections for some developing economies and regions such as Indonesia, Rest of Africa and Rest of Asia is relatively low.

3.2. Relative GDP Projections

In order to compare relative GDP per capita levels, the projected growth rates shown in Figures 1, 3 and 5 are applied to GDP per capita levels for 2010, measured in constant 2005 PPP international dollars sourced from the World Development Indicators database (http://data.worldbank.org/). The implied GDP per capita levels for 2050 are measured relative to the implied levels for the US and are compared to the relative level in 2010. The resulting series are shown in Figure 6.

Generally, the projected relative GDP per capita levels of developed economies do not change very much over the projection horizon, although a number of sources project slight divergence. In particular, over the 2010 to 2050 horizon, five out of six sources project Canada will fall further behind the US, three out of seven sources project Japan will fall further behind and one out of three sources project Australia will fall further behind.[29] In contrast, developing economies exhibit convergence: average relative GDP per capita rates for Indonesia almost triple, they triple for China, and they more than triple for India. These average growth rates correspond to annualised convergence rates – defined as the proportional closing of the gap in (average) relative GDP per capita with respect to the US – of 0.53, 1.33 and 0.58 percent per year for Indonesia, China and India, respectively. The CEPII projection of relative income per capita in China is comparably high: income per

[29] There is limited discussion of the processes driving this trend in the source documentations. In most cases, detailed discussion is focused on developing economies. In the CEPII documentation, where trends in driving forces are provided, TFP *levels* do not converge – converge is subject to human capital levels. In other cases, where absolute TFP convergence is assumed, such as in the OECD ENV-L model, labour and capital assumptions appear to be important. Divergence assumptions are not explicit and the trends, where they exist, are small.

capita is projected to reach 95 percent of the level projected for the US by 2050; the six other sources average just over 40 percent. The JCER projection of relative income per capita in India is comparably low; very little convergence is projected (the average annualised rate of convergence is 0.1 percent).

The G-Cubed projections of relative GDP per capita levels are generally below average for the developing countries. This is partly due to a relatively stronger growth projection for the United States and partly due to a conservative convergence specification: the implied annualised convergence rates for China and India over the 2010 to 2050 horizon are 1.02 and 0.26 percent per year, respectively.

Variation in relative GDP per capita appears to be lower for developed economies, compared with the BRIC and developing economies (Figure 6). The projected GS2011 relative GDP per capita levels are comparatively high. These projections have only just been released and revisions to both modelling methodology and underlying data resulted in higher projected growth rates for all economies except the US, where lower growth rates are projected, compared with the projections published by Goldman Sachs in 2003 (GS2003, see Appendix Figure A3 and footnote 22).

Overall, the projected gap between GDP per capita in developing economies and GDP per capita in the US remains large. By 2050, the average GDP per capita levels in China, India and Indonesia across the sample are 51 percent, 27 percent, and 27 percent of the US level, respectively.

Table 3 Descriptive statistics of 2010-2030 growth rates

Country/Region	Full sample (9 projections)					Selected sample (5 projections)				
	Mean		Coefficient of variation		Number of projections	Mean		Coefficient of variation		Number of projections
	Total growth	Average annual growth	Total growth	Average annual growth		Total growth	Average annual growth	Total growth	Average annual growth	
China	208.77%	5.70%	29.41	17.44	9	211.10%	5.74%	34.64	20.43	5
Russia	106.77%	3.66%	23.93	16.65	8	104.26%	3.59%	29.91	20.22	5
Brazil	99.66%	3.49%	19.44	14.23	8	93.72%	3.33%	27.61	19.75	5
Mexico	87.06%	3.17%	15.60	11.60	6	93.02%	3.33%	17.41	12.85	4
Canada	37.71%	1.60%	21.96	19.09	8	37.11%	1.59%	11.49	9.88	5
United States	39.00%	1.65%	18.46	15.65	9	37.67%	1.51%	15.22	11.17	5
Australia	38.40%	1.63%	13.63	11.86	5	36.88%	1.58%	22.16	19.11	3
Japan	41.32%	1.72%	31.03	27.21	9	45.89%	1.90%	17.28	14.75	5
Indonesia	135.76%	4.37%	12.58	8.52	5	137.30%	4.40%	16.12	10.96	4
South Korea	64.55%	2.50%	20.65	16.54	7	54.06%	2.18%	16.07	13.01	4
India	185.48%	5.31%	25.28	17.02	9	192.89%	5.51%	6.75	4.26	5
South Africa	104.56%	3.60%	23.46	17.27	4	91.04%	3.27%	21.37	16.58	3
Rest of South East Asia	91.57%	3.29%	16.54	12.56	3	-	-	-	-	0
Rest of Asia	88.35%	3.21%	6.07	4.57	2	-	-	-	-	0
Rest of Africa	49.64%	2.04%	0.68	0.57	3	-	-	-	-	1
European Union	39.07%	1.66%	16.15	14.02	6	40.36%	1.70%	24.82	21.79	3
Rest of Europe and FSU	97.45%	3.39%	35.32	25.42	3	-	-	-	-	1
Rest of Latin America and Caribbean	60.95%	2.38%	27.48	21.68	3	-	-	-	-	1
Middle East	77.78%	2.90%	18.78	14.74	5	86.36%	3.16%	13.84	10.35	3

*Coefficient of variation = Standard Deviation/Mean.

Table 4 Descriptive statistics of 2010-2050 growth rates

Country/Region	Full sample (7 projections)					Selected sample (5 projections)				
	Mean		Coefficient of variation		Number of projections	Mean		Coefficient of variation		Number of projections
	Total growth	Average annual growth	Total growth	Average annual growth		Total growth	Average annual growth	Total growth	Average annual growth	
China	494.93%	4.44%	41.06	18.73	7	561.50%	4.76%	35.55	15.09	5
Russia	248.08%	3.14%	21.44	12.14	6	248.08%	3.14%	23.98	13.59	5
Brazil	263.19%	3.24%	25.93	15.50	6	260.52%	3.21%	29.16	17.32	5
Mexico	234.52%	3.02%	28.34	18.05	4	234.52%	3.02%	28.34	18.05	4
Canada	90.82%	1.62%	17.98	13.50	6	87.45%	1.58%	18.00	13.44	5
United States	93.30%	1.65%	18.89	13.97	7	85.09%	1.55%	14.65	10.95	5
Australia	86.48%	1.55%	29.55	22.49	3	86.48%	1.55%	29.55	22.49	3
Japan	101.90%	1.76%	22.13	16.51	7	103.39%	1.78%	23.31	17.49	5
Indonesia	434.49%	4.26%	17.00	8.29	4	434.49%	4.26%	17.00	8.28	4
South Korea	116.14%	1.94%	16.85	11.88	5	114.50%	1.92%	19.38	13.57	4
India	568.53%	4.75%	31.69	19.09	7	661.42%	5.20%	7.20	3.17	5
South Africa	244.33%	3.08%	34.33	21.89	3	244.33%	3.08%	34.33	21.89	3
Rest of South East Asia	-	-	-	-	1	-	-	-	-	0
Rest of Asia	-	-	-	-	0	-	-	-	-	0
Rest of Africa	-	-	-	-	1	-	-	-	-	1
European Union	84.69%	1.51%	39.61	31.96	4	88.13%	1.55%	45.63	37.72	3
Rest of Europe and FSU	-	-	-	-	1	-	-	-	-	1
Rest of Latin America and Caribbean	-	-	-	-	1	-	-	-	-	1
Middle East	257.21%	3.16%	41.93	24.57	3	257.21%	3.16%	41.93	24.57	3

*Coefficient of variation = Standard Deviation/Mean.

Figure 1: Survey Projections of Real GDP per Capita Growth for the US and China

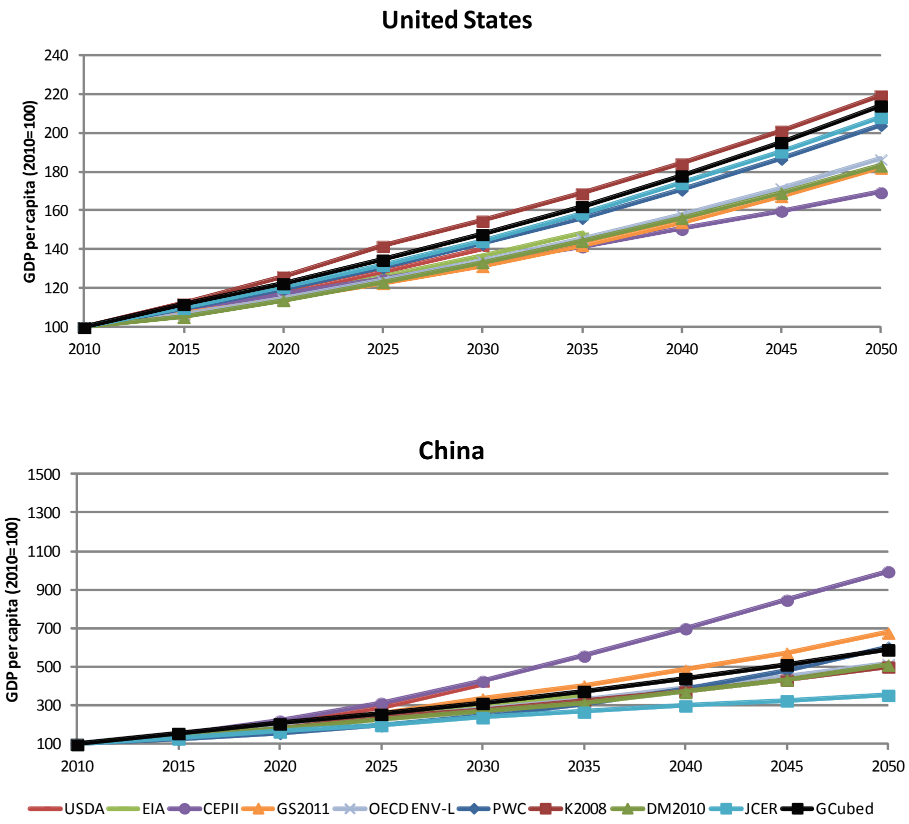


Figure 2: Survey Projections of Real GDP per Capita Growth for the OECD90 and ASIA Regions

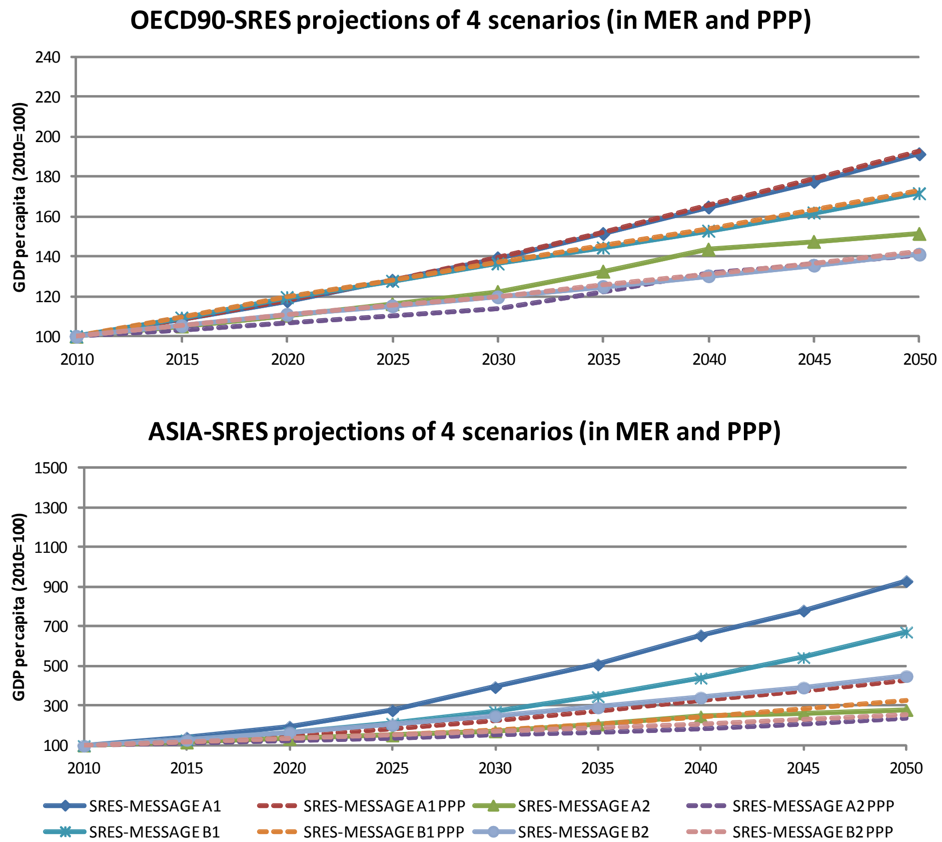


Figure 3: Survey Projections of GDP per Capita for Individual Countries

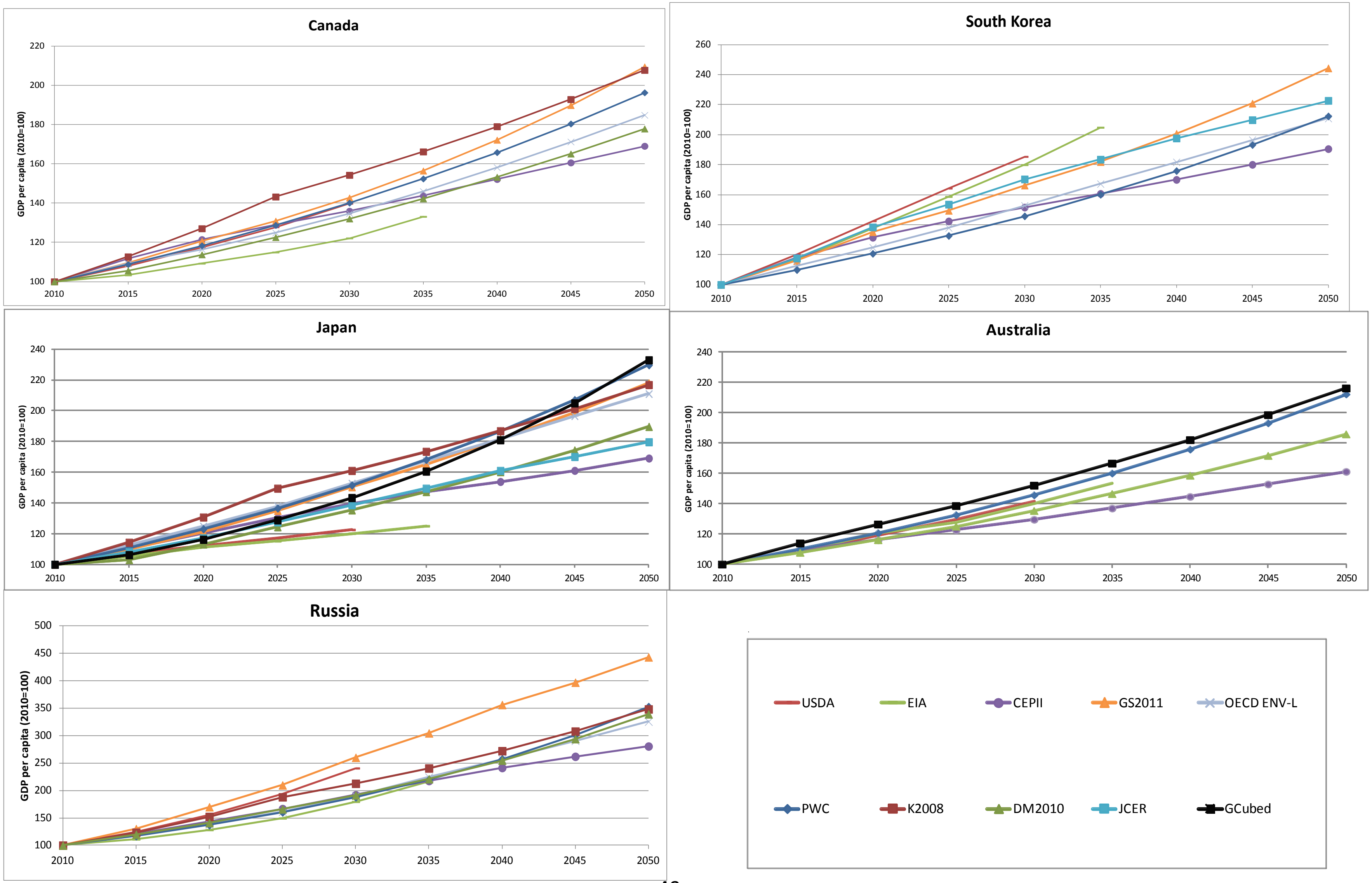


Figure 3: Survey Projections of GDP per Capita for Individual Countries (continued)

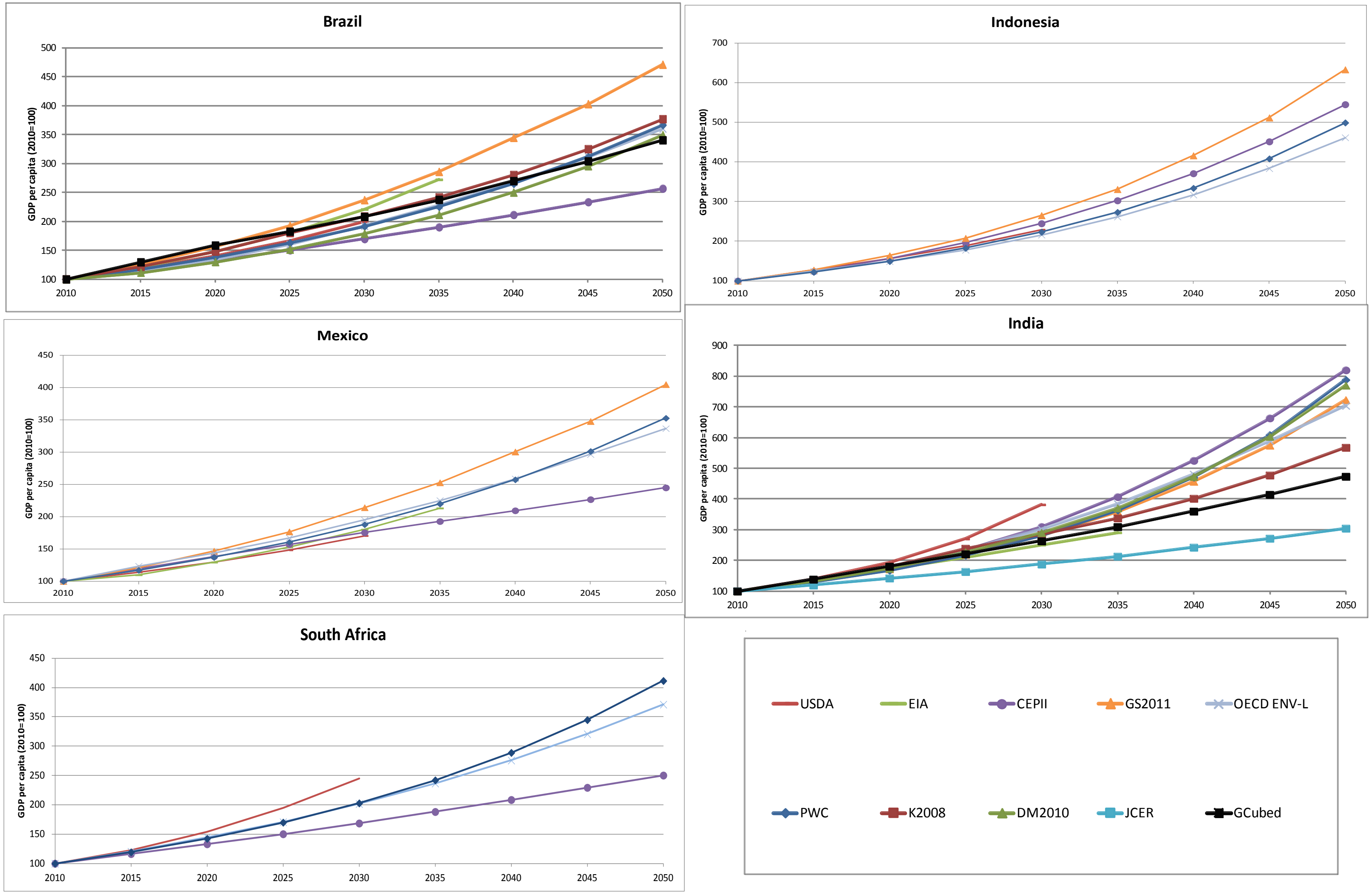


Figure 4: Total Growth Projections of GDP per Capita for Individual Countries

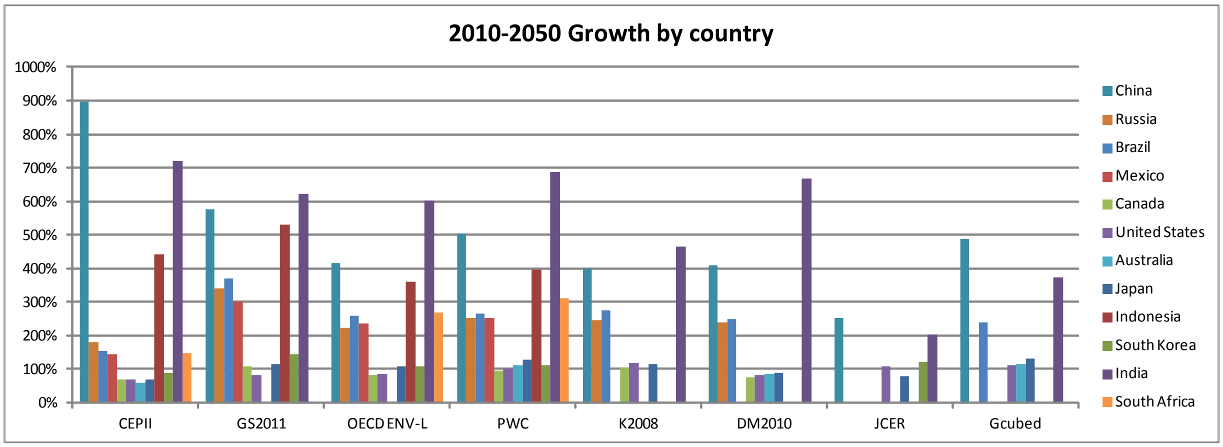
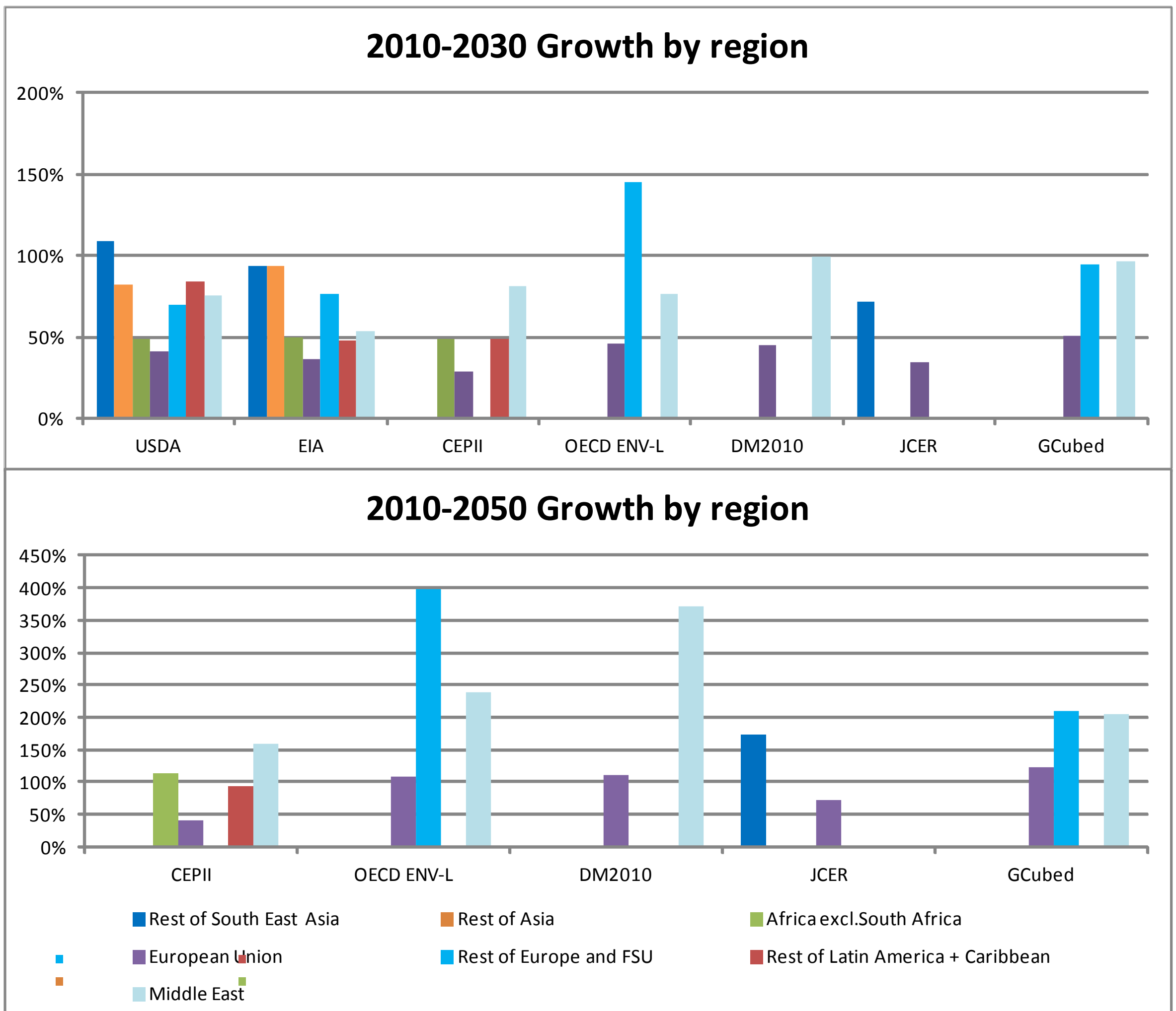


Figure 5: Total Growth Projections of GDP per Capita for Regions



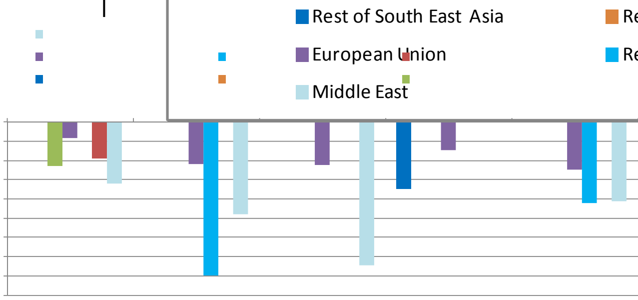
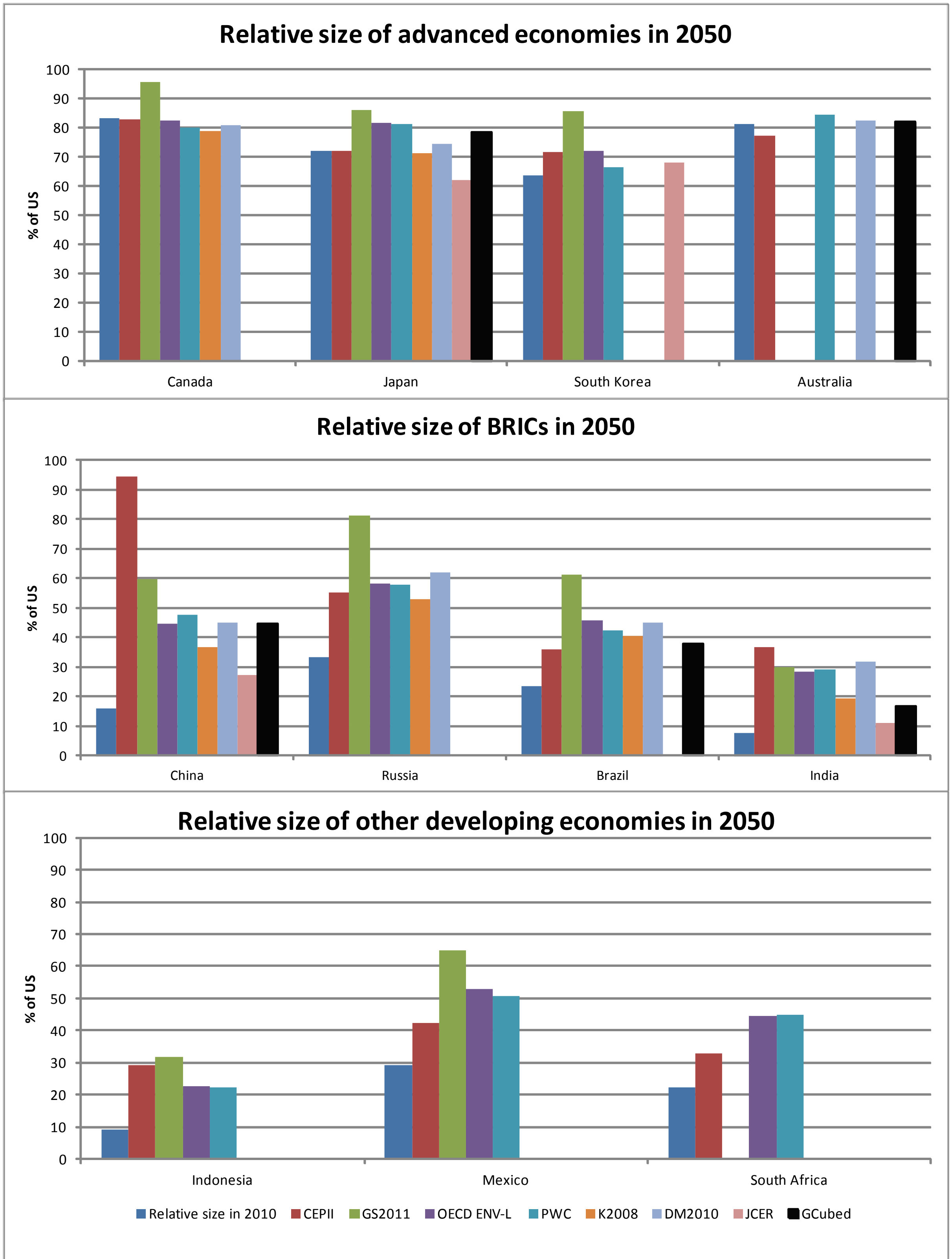


Figure 6: Projections GDP per Capita Levels Relative to the United States



It is difficult to isolate and assess the effect of alternative model assumptions, such as the inclusion of human capital or an energy sector, on the resulting projections. These variations do not appear to impact the projections across economies consistently. The inclusion of the CEPII model projections increases variation across the sample. The projections from this model are comparatively low for developed economies and comparatively high for developing economies, particularly for China and to a lesser extent India. This may be related to the calibration of the model using GDP measured in constant US$.

3.3 Conclusions

In order for comparisons of GDP per capita relative levels and growth rates to be meaningful, the series being compared must be consistent. It was difficult to determine and adjust for inconsistencies across the sources considered for this paper. Some sources did not provide documentation whilst others were difficult to interpret. Understanding the underlying model methodology is critical to determining the relevance of projections and expertise is therefore needed to ensure that the projections are used appropriately.

Section 2 outlined a range of model methodologies that were broadly consistent. The resulting projections of GDP per capita growth and implied relative GDP per capita levels, however, vary a great deal. Alternative parameterisations and assumptions are therefore an important source of variation across the sources.[30]

Uncertainty is likely to be higher when projecting GDP per capita for developing economies, relative to developed economies. In some cases, however, this uncertainty appears to result in a general consensus with respect to modelling assumptions and parameterisations, leading to consistency in projections across the sample. The developing economy projections are, however, also influenced by outliers, such as the CEPII projections for China and the JCER projections for India.

Variation across the implied projected relative GDP per capita levels is generally higher across developing economies, compared with developed economies. This suggests that uncertainty is treated differently with respect to developed and developing economies.

The G-Cubed projections are generally consistent with those of the survey sample. Projections for the United States are, on average, stronger than the sample average but they do not exceed the survey upper bound. This may reflect the conservative approach in G-Cubed with respect to future policy action. Projections for developing economies are, on average, weaker than the sample average but they do not exceed the lower bound of the survey sample. This weaker growth reflects relatively

[30] Similar model specifications generate relatively consistent projections. This is evident when the models that include human capital are compared.

low rates of sectoral productivity convergence and is very much dependent on the structure of the economy under consideration (growth in China for example is very close to the sample average whereas growth in India is projected to be weaker).

4. Discussion and Further Issues

This paper has surveyed the current publicly available long run projections of GDP per capita. Across the surveyed models, the methodology is generally consistent, although alternative parameterisations and calibrations result in a range of projections.

There appears to be general agreement that the neoclassical growth model should be the foundation for economic growth projections. The theoretical and empirical growth literature has developed considerably since the publications of Solow (1956), Swan (1957) and Mankiw, Romer and Weil (1992). Researchers interested in projecting economic growth could draw on this literature to help improve the relevance and usefulness of projection exercises.

In particular, the importance of structural change and sector driven growth is not considered in most the projection models surveyed here. The influence of the energy sector is controlled for in the DM2010 and OECD ENV-L models, but only the CEPII and G-Cubed models attempt to model it directly. Structural change and the influence of growth at the sectoral level are likely to be important and relevant to a range of economic issues and policy questions. McKibbin, Pearce and Stegman highlight and demonstrate this point in a number of papers (see 2004, 2007, 2009). In particular, a comparison of the surveyed projections with those of G-Cubed suggests that a sectoral approach may result in less convergence than is generally assumed at the aggregate level but that this very much depends on the structure of the economy under consideration. Further work is needed to formalise a disaggregated model of sectoral convergence.

More complex international linkages involving trade and financial flows are also important. Whilst the evolution of exchange rates is likely to be important in determining demand and investment, there continues to be considerable confusion in the literature over the role of market exchange rates and purchasing power parities in converting domestic output for the purposes of international comparison. Whilst the *baseline* projections from the surveyed sample are relatively consistent with those from G-Cubed, the rich sectoral detail and international linkages built into G-Cubed are critically important when analysing alternative policy scenarios and shock responses.

Long term economic issues are becoming increasingly important and economic growth projections are fundamental to both the design and the assessment of long term economic policy alternatives. In addition, our ability to analyse the impact of long term policy alternatives is linked to our ability to model and understand the impact of global economic shocks. Unfortunately the methodologies for longer term projections of the world economy are not well developed and what is in the public domain, and in many cases used as the basis of longer term planning, is not completely transparent. There is a tendency to trade off simplicity with respect to the projection approach in order to enable key long term sensitivities to be better understood against the inevitable complexity that exists when modeling the entire global economic system. The G-Cubed model is one approach that focuses on the changing sectoral composition of the world economy and the role of international capital flows and endogenous saving and investment decisions but it is still inevitably relatively simple. A great deal more research is needed in developing transparent models and frameworks to improve long term policy planning.

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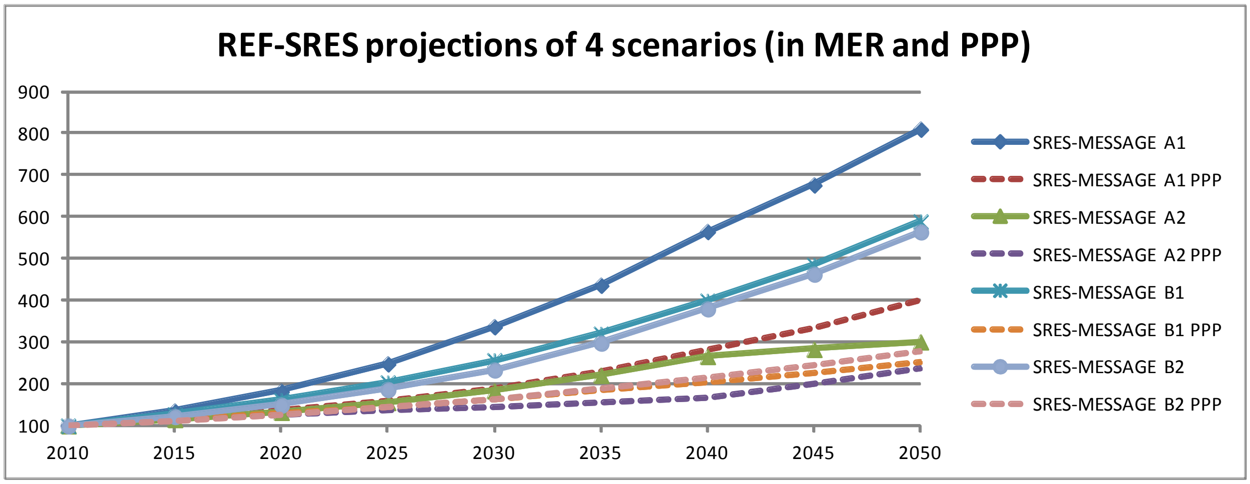
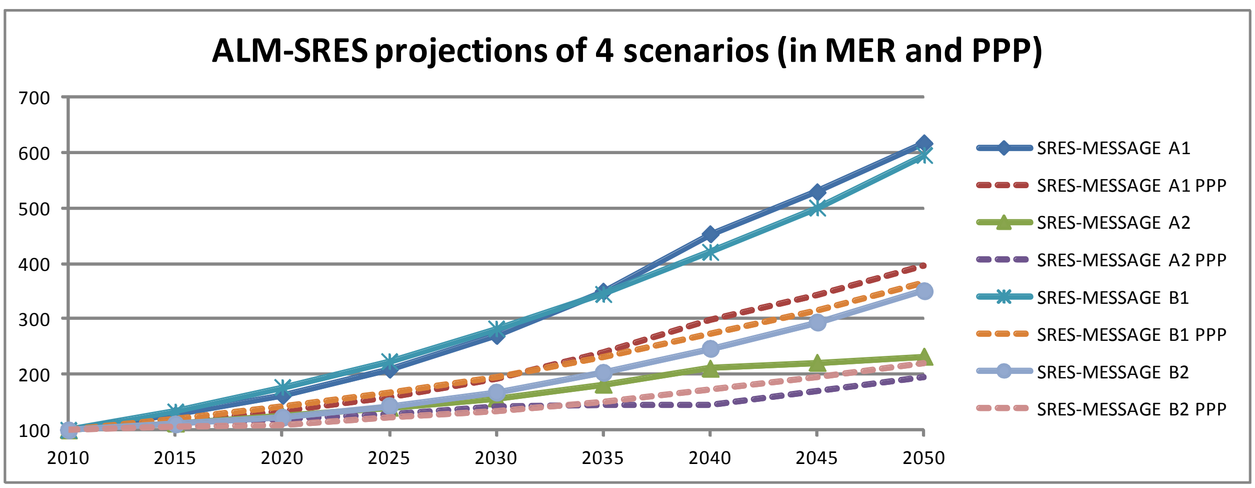
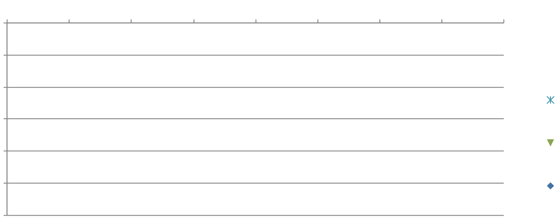
6. Appendix

Figure A1: SRES-MESSAGE REF and ALM Projections







The Impact of the Data and Model Revisions

Figure A2: 5-year Growth Rate from PWC2006, PWC2008 and PWC2011[31]

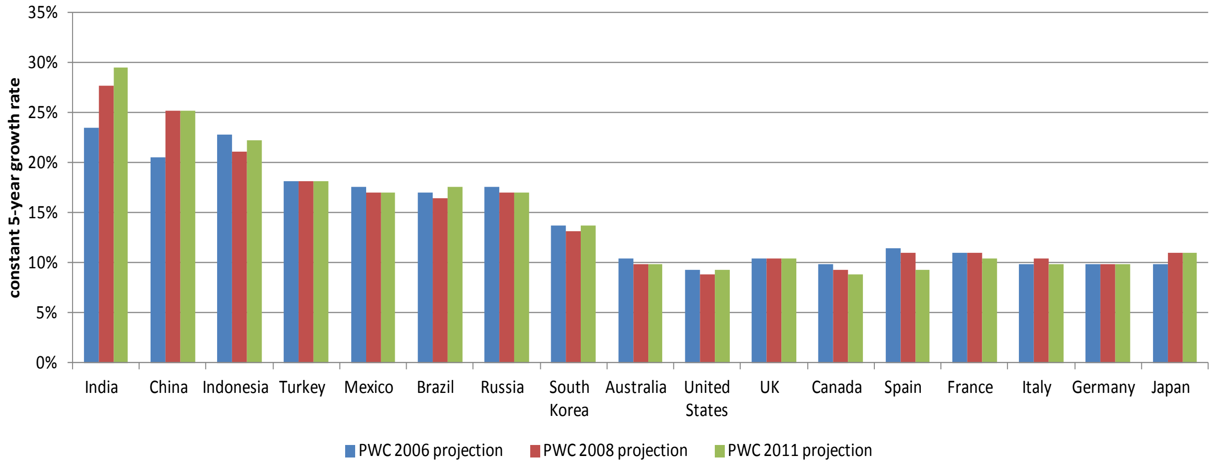
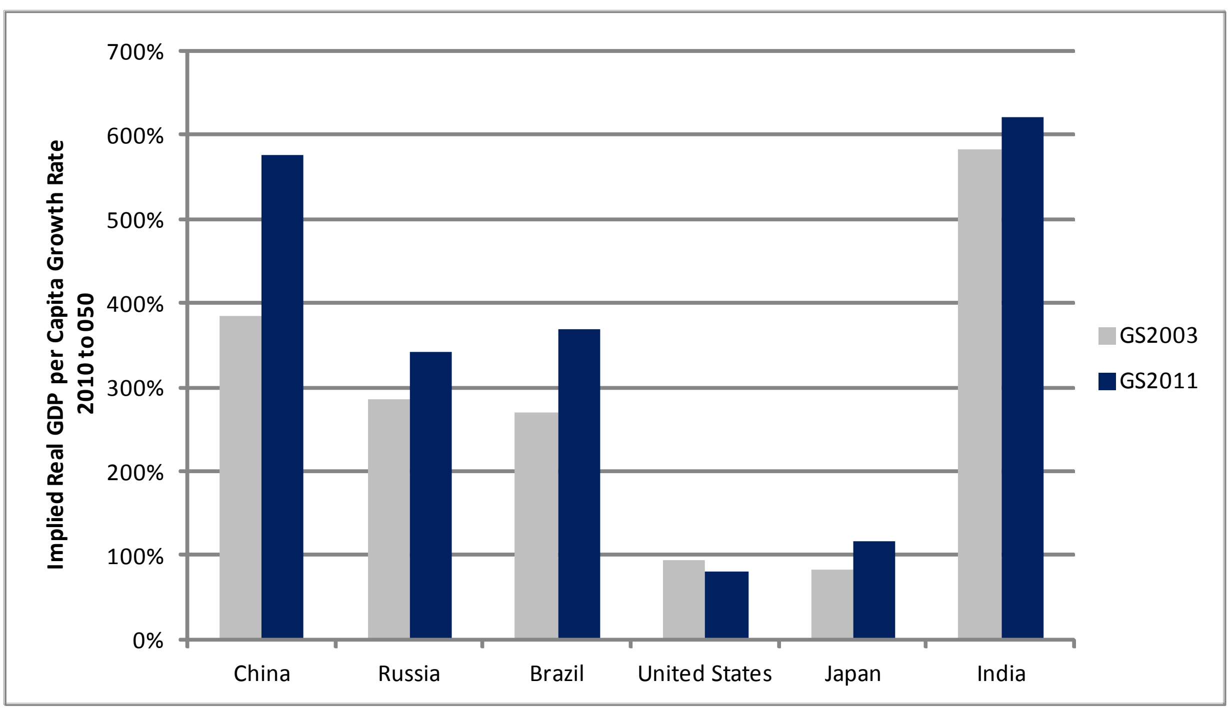


Figure A3: Total 2010 to 2050 Growth from GS2003 and GS2011



[31] This 5-year growth rate is constant for each country and is calculated from PWC's average annual growth rate over the entire projection period (projection starting year-2050).

Details of Projection Sources

Table A1 Projection summary

Projections	Reference
SRES-MESSAGE	IPCC (2000)
USDA	U.S. Department of Agriculture Economic Research Service projection, updated in 2011.
EIA	U.S. Energy Information Administration, International Energy Outlook 2011, released in September 2011, Table A3, A4, A11.
CEPII	Fouré, J. Bénassy-Quéré, A. and Fontagné, L. (2010)
GS2011	GS2011: Wilson, D., Trivedi, K., Carlson, S. and Ursúa, J. (2011) GS2003: Wilson, D. and Purushothaman, R. (2003)
OECD ENV-L	Chateau, J., C. Rebolledo and R. Dellink (2011),
PWC*	PWC2006: Hawksworth, J. (2006) PWC2008: PricewaterhouseCoopers (PWC) (2008) PWC2011: Hawksworth, J. and Tiwari, A. (2011)
K2008	Klinov, V.G. (2008)
DM2010	Duval, R. and de la Maisonneuve, C. (2010)
JCER	Long term forecast team, Economic Research Department, Japan Center for Economic Research (2007)
G-CUBED	McKibbin W. Morris, A. And Wilcoxen, P (2011)

* All the graphs and tables with PWC in the main text of this paper are based on PWC 2011 projection alone

Table A2 Regional Aggregation in All Projections

G-CUBED	USDA	EIA	CEPII	GS2011	OECD ENV-L	PWC	K2008	DM2010	JCER
Country									
China	China	China	China	China	China	China	China	China	China
	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia	
Brazil	Brazil	Brazil	Brazil	Brazil	Brazil	Brazil	Brazil	Brazil	
	Mexico	Mexico	Mexico	Mexico	Mexico	Mexico			
	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada	
United States	United States	United States	United States	United States	United States	United States	United States	United States	United States
Australia	Australia	Australia	Australia			Australia		Australia	
Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan
	Indonesia		Indonesia	Indonesia	Indonesia	Indonesia			
	South Korea	South Korea	South Korea	South Korea	South Korea	South Korea			South Korea
India	India	India	India	India	India	India	India	India	India
	South Africa		South Africa		South Africa	South Africa			
Region									
Other Developing Economies (LDC)	**Southeast Asia** (7 countries)**-Burma Myanmar**	**Other Non-OECD Asia = Non-OECD Asia excl.China and India**							**ASEAN** (Indonesia, Malaysia, the Philippines, Singapore,Thailand, Brunei, Burma (Myanmar), Cambodia, Laos, and Vietnam)
	East Asia, other Southeast Asia, South Asia and other South Asia (17 countries)**-China, Japan, Korea and India**								
	Africa (52 countries) **-South Africa**	**Africa incl. South Africa**	**Rest of Africa**						
	Latin America (35 countries)**- Mexico and Brazil**	**Other Central and South America = Central and South America excl. Brazil**	**Rest of Latin America**						
Western Europe (Europe)	**EU27**	**OECD Europe**	**European Union**		**EU27 & EFTA**			**EU27 + EFTA**	**EU**
Rest of OECD (ROECD)									
Eastern Europe and the former Soviet Union (EEFSU)	**Other Europe+ Former Soviet Union** (20 countries)**-Russia**	**Other Non-OECD Europe and Eurasia = Non-OECD Europe and Eurasia excl. Russia**			**Rest of Europe**				
	Latin America (35 countries)**- Mexico and Brazil**	**Other Central and South America = Central and South America excl. Brazil**	**Rest of Latin America**						
Oil Exporting Developing Countries (OPEC)	**Middle East** (14 countries)	**Middle East**	**Arabian World**		**M.East & N.Africa**			**OPEC + other oil producers**	