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The world economy in 2050: a tentative picture

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THE WORLD ECONOMY IN 2050: A TENTATIVE PICTURE

NON-TECHNICAL SUMMARY

It is tempting perhaps to extrapolate current growth rates to figure out how the global economy will be reshaped in the next decades. On this measure, an 8% growth rate in China over the next 40 years would produce a 21-fold increase in the Chinese economy by 2050, and a 2% growth rate in the European Union would result in 21% economic growth over the same period. However, back-of-the-envelope calculations based on past trends can be extremely misleading.

Based on a three-factor production function of labour, capital and energy, plus two forms of technological progress, we propose a long-run growth scenario for 122 countries and a time horizon of 2050. The model is fitted with United Nations and International Labour Office labour projections, and econometric estimations of (i) capital accumulation, (ii) savings rates, (iii) relationship between savings and investment rates, and (iv) technological progress (which includes energy and total factor productivity). Our study provides four novelties. First, we account for the energy constraint by including it in the production function. Second, we estimate a non-unitary relationship between savings and investment, departing from assumptions of either a closed economy or full capital mobility. Third, we account for the 2008-09 global crisis by initialising our projection model in 2013 while relying on IMF projections between 2008 and 2012. Finally, we disentangle real gross domestic product (GDP) growth rates from relative price effects through a consistent Balassa-Samuelson effect.

Our results suggest that the Chinese and Indian economies could grow 13-fold between 2008 and 2050 at constant relative prices. Over the same period, the US economy would double and Europe's economy would inflate by 60%. Adjusting for relative prices results in a 16-fold increase in China's economy and a 21-fold increase for India, the US economy doubling and the European Union economy increasing by only 40%.

Taking account of relative price variations, China would represent 28% of the world economy in 2050, dominating the United States (14%), India (12%), the European Union (11%) and Japan (3%). Our results suggest that in approximately 2025 (or c. 2035 at constant relative prices) China could overtake the United States, and India could overtake Japan. However, in terms of living standards, measured as GDP per capita in purchasing power parity, only China would be close to achieving convergence to US levels, and only at the end of the simulation period.

As is the case with any exercise that produces projections over a long horizon, the work presented here should be considered tentative. We have tried to make it transparent, and rely on robust research for the determination of savings, investment and productivity growth. Although our results should be taken with a certain amount of caution, we believe they could

be useful benchmarks for downstream studies on world commodity demand, international trade, financing capacity, global power, etc.

ABSTRACT

We present growth scenarios for 128 countries to 2050, based on a three-factor production function that includes capital, labour and energy. We improve on the literature by accounting for the energy constraint through dynamic modelling of energy productivity, and departing from the assumptions of either a closed economy or full capital mobility by applying a Feldstein-Horioka-type relationship between savings and investment rates.

Our results suggest that, accounting for relative price variations, China could account for 28% of the world economy in 2050, which would be much more than the United States (14%), India (12%), the European Union (11%) and Japan (3%). They suggest also that China would overtake the United States around 2025 (2035 at constant relative prices). However, in terms of standards of living, measured through GDP per capita in purchasing power parity, only China would be close to achieving convergence to the US level, and only at the end of the simulation period.

JEL Classification: *E23, E27, F02, F47*
Key Words: *GDP projections, long run, global economy.*

UN SCENARIO POUR L'ECONOMIE MONDIALE A L'HORIZON 2050

RESUME NON TECHNIQUE

Il est toujours tentant d'extrapoler les taux de croissance observés pour imaginer comment l'économie mondiale pourrait se transformer au cours des décennies à venir. Dans cet esprit, avec un taux de croissance de 8% par an pendant quarante ans, l'économie chinoise serait multipliée par 21 à l'horizon 2050. Pendant ce temps, une Europe croissant à 2% par an ne verrait sa taille augmenter que de 21%. Cependant, ce type de calcul de coin de table, fondé sur des tendances passées, peut être trompeur.

Nous proposons ici un scenario de croissance de long terme pour 122 pays à l'horizon 2050, fondé sur une fonction de production à trois facteurs (capital, travail et énergie) et deux formes de progrès technique. On utilise les projections démographiques de l'ONU et de l'OIT ainsi que différentes estimations économétriques. Ces estimations portent sur (1) l'accumulation du capital, (2) les taux d'épargne, (3) le lien entre épargne et investissement et (4) le progrès technique (qui couvre à la fois la productivité énergétique et celle des facteurs travail et capital). Nous apportons plusieurs améliorations par rapport à la littérature existante dans ce domaine. Premièrement, nous prenons en compte la contrainte énergétique en insérant l'énergie comme facteur de production. Deuxièmement, nous nous situons entre l'hypothèse d'économie fermée et celle de parfaite mobilité des capitaux concernant la relation entre épargne et investissement. Troisièmement, nous prenons en compte la crise mondiale de 2008-2009 en utilisant les projections du Fonds monétaire international entre 2008 et 2012 et en ne démarrant notre propre projection qu'en 2013. Enfin, nous séparons explicitement la croissance réelle des variations de prix relatifs à travers un effet Balassa-Samuelson cohérent avec le modèle de croissance.

Selon nos résultats, les économies chinoise et indienne pourraient toutes deux être multipliées par 13 entre 2008 et 2050 à prix relatifs inchangés. Durant cette même période, l'économie américaine doublerait mais l'économie européenne augmenterait de seulement 61%. En tenant compte des ajustements de prix relatifs, les économies chinoise et indienne seraient multipliées respectivement par 17 et 20, tandis que l'économie américaine doublerait toujours et que l'économie européenne augmenterait de seulement 40%.

En tenant compte des évolutions de prix relatifs, la Chine pourrait représenter 28% de l'économie mondiale en 2050, soit beaucoup plus que les Etats-Unis (14%), l'Inde (12%), l'Union Européenne (11%) et le Japon (3%). La Chine dépasserait les Etats-Unis vers 2025 (vers 2035 à prix relatifs constants) et l'Inde dépasserait le Japon autour des mêmes dates. Cependant, en termes de niveaux de vie, la Chine serait la seule à s'approcher du niveau américain, et encore, uniquement à la toute fin de la période de simulation.

Comme tout exercice de projection sur longue période, ce travail doit être interprété avec beaucoup de précautions. Nous avons cependant tenté de rendre l'exercice le plus transparent possible et de nous appuyer sur des résultats robustes de la littérature relatifs à la détermination des taux d'épargne, de l'investissement et de la productivité. Même si les résultats ne peuvent être pris au pied de la lettre, ils constituent des points de repère utiles pour d'éventuelles études en aval sur la demande mondiale de matières premières, le commerce international, les capacités de financement, les puissances mondiales, etc.

RESUME COURT

On présente ici des projections de croissance à l'horizon 2050 pour 128 pays, à partir d'une fonction de production à trois facteurs – capital, travail et énergie. La prise en compte de la contrainte énergétique (avec une modélisation dynamique de la productivité énergétique), ainsi qu'une hypothèse intermédiaire entre l'économie fermée et la parfaite mobilité des capitaux pour ce qui concerne la relation entre épargne et investissement (grâce à une modélisation de type Feldstein-Horioka) constituent les principaux apports par rapport à la littérature.

Les résultats suggèrent que, en tenant compte des évolutions de prix relatifs, la Chine pourrait représenter 28% de l'économie mondiale en 2050, soit beaucoup plus que les Etats-Unis (14%), l'Inde (12%), l'Union Européenne (11%) et le Japon (3%). La Chine dépasserait les Etats-Unis vers 2025 (vers 2035 à prix relatifs constants). Cependant, en termes de niveaux de vie, seule la Chine s'approcherait du niveau américain, et ce uniquement à la toute fin de la période de simulation.

Classification JEL : *E23, E27, F02, F47*
Mots-clefs : *projections de PIB, long terme, économie mondiale.*

THE WORLD ECONOMY IN 2050: A TENTATIVE PICTURE

Jean Fouré[1], Agnès Bénassy-Quéré[2], Lionel Fontagné[3]

INTRODUCTION

The way that limited growth differentials have the ability to re-shape the world economy in few decades is quite striking. A growth differential of a single percentage point per year, cumulated over 40 years, for example, results in a 49% income gap, while a differential of two percentage points results in a gap of 121% and three percentage points a gap of 226%. Based on the same arithmetic and simple assumptions about productivity and demographic trends, Fogel (2007) predicts that the three largest economies in the world in 2040 will be China (40%), ahead of the United States (US) (14%) and India (12%).

However, the growth process is far from being mechanical. Accumulation of physical and human capital, growth in total factor productivity (TFP) and energy constraints may vary over time. For instance, assuming a constant annual 8% growth rate, China's economy will grow 21-fold in the next 40 years, while assuming a linear convergence of China's annual growth rate from 8% to 3% in 40 years would result in 'only' 8-fold growth. These two scenarios would have entirely different implications for the world in terms of commodity markets, multinationals' strategies, carbon emissions, the political order, etc. Although a very risky exercise, projecting the long run world economy is useful since it is indicative of magnitude that can change the face of the world. It also provides a useful baseline for global economic policy models, since the results of these simulations are often heavily dependent on the baseline path of the world economy.[4]

This paper contributes to the literature (Wilson and Purushothamam, 2003; Poncet, 2006; Duval and de la Maisonneuve, 2010) in various ways.

On the theoretical side, we rely on a three-factor production function: labour, capital and energy, plus two forms of technological progress. We derive explicitly both TFP and energy productivity. Capital-income and capital-labour ratios are determined in an original

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[4] This is the case of MIRAGE, a computable general equilibrium model developed at CEPII for the analysis of trade policies. See Decreux and Valin (2007).

framework that links investment and savings through a function that assumes imperfect international mobility of capital and savings determined by a life-cycle hypothesis.

On the empirical side, we propose a long-run growth scenario for 128 countries to 2050. The model is fitted with United Nations (UN) and International Labour Organization (ILO) labour projections as well as econometric estimations for (i) capital accumulation, (ii) savings rates, (iii) the relationship between savings and investment rates, and (iv) technological progress (which covers both energy productivity and TFP). We account for the energy constraint by including this factor in the production function. We assume a positive but non-unitary relationship between savings and investment thus departing from the assumptions of either full capital mobility or a closed-economy. Finally, we account for the 2008-09 global crisis by initialising our projection model in 2013, but relying on International Monetary fund (IMF) projections from 2009 to 2012.

What is important about this model is that it establishes the difference between the long-run path of the world economy in real terms, which is relevant to e.g. future greenhouse gas emissions, and the long-run path of the world economy in current dollars, which depends on the relative valuations of incomes. In order to address this difference it is necessary to model long run real exchange rates; we separate real GDP growth rates from relative price variations through a consistent Balassa-Samuelson effect. We demonstrate theoretically that real-exchange rate appreciation results from TFP and energy productivity catch-up, and that this effect is magnified by a higher share of non-tradables in the consumption basket.

The paper is organised as follows. Section 1 presents the theoretical framework. Section 2 describes the data and econometric estimations for the period 1980-2008. Section 3 reports projections up to 2050. Section 4 provides some assessment exercises. Section 5 concludes.

1. Theoretical framework

1.1. Production function

Long-run growth analyses are generally based on a Cobb-Douglas production function (see, e.g., Wilson and Purushothaman, 2003; Poncet, 2006; Duval and de la Maisonneuve, 2010). This has several advantages, including that assuming constant returns to scale, the parameters of the function match the distribution of income across different production factors.

This paper improves on the literature by introducing energy as a critical production factor. This means that the unitary elasticity of substitution implied by the Cobb-Douglas production function is no longer adequate: capital and labour can barely substitute for the scarcity of energy in the economy. We retain a Constant Elasticity of Substitution (CES) function with two factors: energy and a Cobb-Douglas combination of capital and labour. Therefore, we retain the traditional unitary elasticity of substitution between capital and labour, but embody this composite factor in a CES function with relatively low substitution between energy and the composite factor. If we denote energy, capital and labour by $E_{i,t}$, $K_{i,t}$ and $L_{i,t}$, respectively, for country *i* at time *t*, real GDP can be written as:

$$Y_{i,t} = \left[\left(A_{i,t}.K_{i,t}{}^{\alpha}L_{i,t}{}^{1-\alpha}\right)^{\rho} + \left(B_{i,t}.E_{i,t}\right)^{\rho}\right]^{1/\rho} \quad (1.1)$$

$A_{i,t}$ is the usual TFP, which in this case is the efficiency of the combination of labour and capital, and $B_{i,t}$ is a measure of energy productivity. The use of a nested CES production function was proposed by David and van de Klundert (1965) to encompass different kinds of input-augmenting technical change, and is employed also in van der Werf (2008) and Markandya and Pedrosso-Galinato (2007).

In line with the literature (see, e.g., Mankiw, Romer and Weil, 1992), we set $\alpha = 0.31$. For the elasticitity of substitution between energy and the composite factor, we calibrate this based on the simulated elasticity of substitution recovered from the MIRAGE model: $\sigma = \frac{1}{1-\rho} = 0.136$, hence $\rho = -6.353$.

We need to project each variable in Equation (1.1) to 2050. With the exception of labour force, which relies on the existing demographic projections, all our projected variables are based on econometrically estimated behaviours.

For labour force, we rely on UN projections to 2050 (medium fertility variant), and participation rates by age group from ILO, up to 2020, set constant by age group from 2020 to 2050:[5]

$$L_{i,t} = \sum_{c=1}^{15} l_{c,i,t} Pop_{c,i,t} \quad (1.2)$$

where $Pop_{c,i,t}$ is the population of age group *c* in country *i* at time *t*, and $l_{c,i,t}$ is the corresponding participation rate, with $l_{c,i,t}$ constant after 2020.

Econometric estimations are used to recover the projected value of the other variables of interest (except real exchange-rate variations, which are calibrated to be consistent with the growth model). In order to understand the logic underlying this exercise, it is useful to start with the process of capital accumulation.

Capital stock is accumulated through a permanent-inventory process:

$$K_{i,t} = (1-\delta)K_{i,t-1} + I_{i,t} \quad (1.3)$$

where $I_{i,t}$ denotes the gross fixed capital investment of country i at time *t*, and δ is the depreciation rate, which is set here at 0.06 (the value in the MIRAGE model).

[5] This assumption allows aggregate participation to vary over time according to the demographics, but the behaviour of each age group is remains constant after 2020. Alternatively, we could assume some convergence in participation rates across countries and genders. However no such convergence has been observed historically, and especially in the cases of China, the United States and Japan; hence, we preferred to keep these rates constant after 2020.

In the literature, the projection of gross fixed capital investment sometimes relies on the assumption of a closed economy, which allows gross investment to equal gross savings (see Poncet, 2006). This assumption is at odds with the large current-account imbalances observed especially in the 2000s. In the present paper, we rely on estimated error-correction, Feldstein-Horioka-type (FH) relationships between savings and investment rates, which allows for some discrepancy between these variables. Gross saving rates are derived from an econometric equation based on the life-cycle hypothesis (see Section 2).

We next describe our theoretical framework accounting for energy productivity and TFP (Section 1.2), and relative prices (Section 1.3).[6]

1.2. Energy and TFP

Energy consumption projections are based on energy prices, assuming that firms maximise profit along their nested CES production function (for greater clarity, country and time subscripts are dropped here):

$$max(Y - p_E E - p_K K - p_L L) \quad s.c.\ Y^\rho = (AK^\alpha L^{1-\alpha})^\rho + (BE)^\rho \qquad (1.4)$$

where p_E, p_K and p_L denote the real prices of energy, capital and labour, respectively, relative to output. This programme yields the following relation (see Appendix A):

$$E = Y\left(B^\rho\left(\frac{1}{p_E}\right)\right)^\sigma, \text{ with } \sigma = \frac{1}{1-\rho} > 0 \qquad (1.5)$$

Replacing E by its in the production function value yields:

$$Y = \left[1 - \left(\frac{p_E}{B}\right)^{\frac{\rho}{\rho-1}}\right]^{-\frac{1}{\rho}} AK^\alpha L^{1-\alpha} \qquad (1.6)$$

We use oil-price forecasts to 2030 provided by the Energy Information Agency (EIA).[7] For 2030 to 2050, the price of energy is set to increase at a constant rate equal to its average growth rate over the 2025-2030 period.[8]

Within this framework, energy intensity E/Y varies based on two different mechanisms: first, the level of energy-related technological progress B (or energy productivity) determines the number of units of GDP that is produced by 1 barrel of energy at given relative prices;

[6] Alternatively, Wilson and Purushothaman (2003) assume exogenous investment rates, while Duval and de la Maisonneuve hypothesize a convergence of capital-to-GDP ratios to the US level, the latter country being assumed to be on its balance growth path.

[7] www.eia.doe.gov/oiaf/forecasting.html

[8] The sensitivity to this assumption is tested in Section 4.

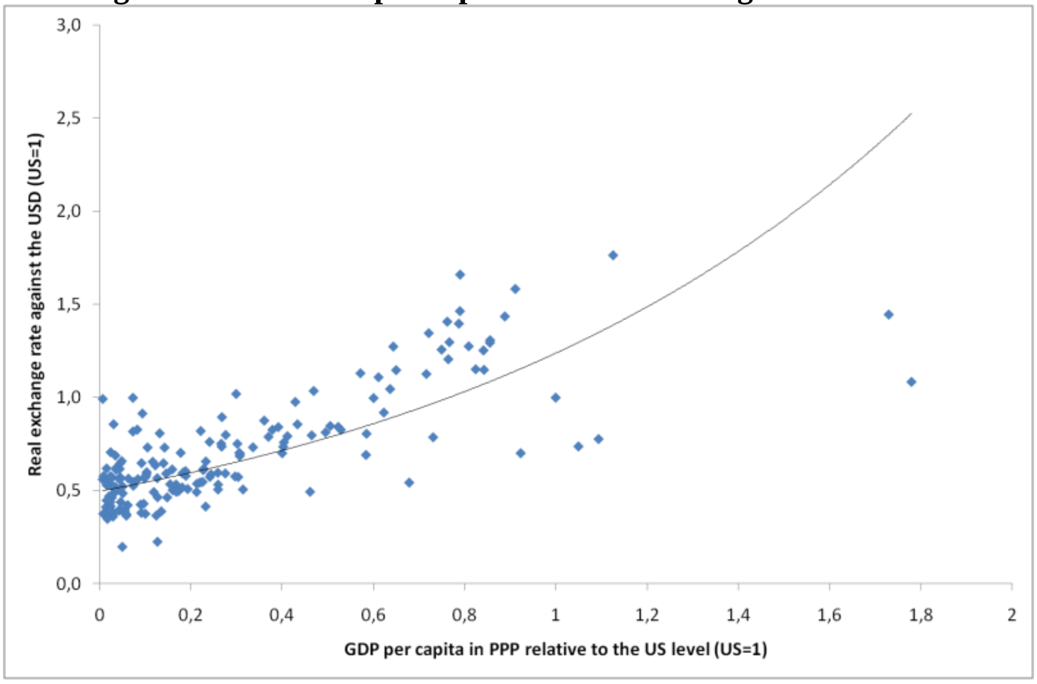
second, energy can be substituted depending on its real price p_E and the elasticity of substitution σ.

Past values of the two forms of technological progress *A* and *B* are computed according to the theoretical model described above (Equation 1.5 for $B,$ and then Equation 1.6 for A). Based on the recovered series and to obtain a formula that can be projected, we estimate two catch-up models (see Section 2). Specifically, we estimate a two-dimensional catch-up process for energy productivity that results in a U-shaped relationship between economic development and energy productivity. TFP, in its turn, is supposed to follow an estimated Nelson-Phelps catch-up model in which speed of catch-up is related to human capital.

1.3. Real exchange rate and the Balassa-Samuelson effect

The long-run growth model presented above depicts the evolution of GDP at constant prices. It is sufficient to study the possible impact of global growth on commodity and energy markets, or to predict greenhouse gas emissions. However, the relative sizes of the different countries and zones in terms of markets and financial power depends also on the relative valuations of incomes. For instance, the weight of China in the world economy is likely to increase due both to high real growth rates, and to a progressive real appreciation of the renminbi (China's official currency). It is crucial to disentangle the two dimensions of the dynamics of world GDP. Hence, we need to model long run real exchange rates. The underlying theory is the Balassa-Samuelson effect, which relates TFP growth to progressive appreciation of the relevant currency in real terms. Currency appreciation is based on diverging evolutions of the prices for non-traded and traded activities. Figure 1 shows that there is a positive relationship between the purchasing power of per capita GDP and the real exchange rate.

Figure 1 – PPP GDP per capita and real exchange rates in 2008



Source: IMF, World Economic Outlook, April 2010, and own calculations.

In the Balassa-Samuelson framework, the real appreciation of catching-up countries derives from an increase in the relative price of non-tradables to tradables. Consistent with this, and following Obstfeld and Rogoff (1996), we assume that every national economy has two sectors: traded-goods (denoted by *T*), and non-traded goods (denoted by *N*). Both sectors have the same production functions as above. However, their productivity diverges in terms of both primary factors and energy:

$$\begin{cases} Y_T = [(A_T Q_T)^\rho + (B_T E_T)^\rho]^{1/\rho} = F(A_T Q_T, B_T E_T,) \\ Y_N = [(A_N Q_N)^\rho + (B_N E_N)^\rho]^{1/\rho} = F(A_N Q_N, B_N E_N) \end{cases} \tag{1.7}$$

where Q denotes the Cobb-Douglas combination of capital and labour ($Q = K^\alpha L^{1-\alpha}$). Let p denote the relative price of non-tradables to tradables: $p = P_N/P_T$. Writing the first order-conditions and assuming that the share of energy in income (denoted by μ) is the same across the two sectors, we get (see Appendix B):

$$\dot{p} = (1-\mu)(\dot{A}_T - \dot{A}_N) + \mu(\dot{B}_T - \dot{B}_N) \tag{1.8}$$

where $\dot{X} = \frac{dX}{X}dt$. Assuming a Cobb-Douglas consumption bundle ($C = Y_T^\gamma Y_N^{1-\gamma}$ 0<γ<1), the consumer price index, in terms of the tradable good can be written as: $P = p^{1-\gamma}$. If we ignore productivity growth in the non-traded sector, we get:

$$\dot{p} = \frac{1}{\gamma}\left(\mu\dot{B} + (1-\mu)\dot{A}\right) \quad (1.9)$$

Finally, if we denote the real exchange rate (i.e. the relative price of the home consumption basket to the foreign one) by RER, and the foreign country by an asterisk, we get:

$$R\dot{E}R = \frac{1-\gamma}{\gamma}\left[(1-\mu)\dot{A} + \mu\dot{B}\right] - \frac{1-\gamma^*}{\gamma^*}\left[(1-\mu^*)\dot{A}^* + \mu^*\dot{B}^*\right] \quad (1.10)$$

Hence, real-exchange rate appreciation is based on TFP and energy productivity catch-up, and the effect is magnified by a higher share of non-tradables in the consumption basket.

2. DATA AND ECONOMETRIC ESTIMATIONS

We referred above to the four relationships that need to be estimated:

- a life-cycle model of the gross savings rate;
- the relationship between savings and investment rates;
- a Nelson-Phelps catch-up model for TFP;
- a double catch-up model for energy productivity.

This section describes the econometric strategy and the data used for the estimations and presents results for each model.

2.1. Data for 1980-2008

Our estimations cover the period 1980-2008. In addition to increasing data collection problems, earlier data are unlikely to be meaningful for emerging economies, and also less significant in relation to international capital mobility (cf. the relationship between savings and investment rates).

We recovered GDP series in 2005 constant US dollars from (i) GDP in current dollars for 2005, and (ii) GDP growth rates in real terms for the period 1980-2008 (sources: World Bank, IMF and UN databases).

Labour force (1980-2008) data are from the ILO. They cover the economically-active population, i.e. all persons of either gender supplying labour for the production of goods and services, and come from population censuses (where available) or labour force surveys. Human capital is proxied by average years of education, taken from the Barro & Lee dataset for the period 1980-2000 (education is measured at the beginning of three sub-periods, see Section 2.4).

Energy consumption (total primary energy) data (1980-2008) are from the EIA. They measure total primary energy consumption in British thermal units (Btu),[9] net of electricity generation (in order to avoid double counting). This means direct use at source, or supplied to users without transformation, including fossil energy used to produce electricity, but excluding corresponding electricity consumption.

Annual average oil prices for 1980-2008 are also from EIA, expressed in 2005 constant US dollars.[10] We assume that the price of energy is indexed on the oil price, and that this price is common across the world. Although this is a crude approximation, this assumption is consistent with the fact that the variance in real energy prices is related mostly to oil price fluctuations.

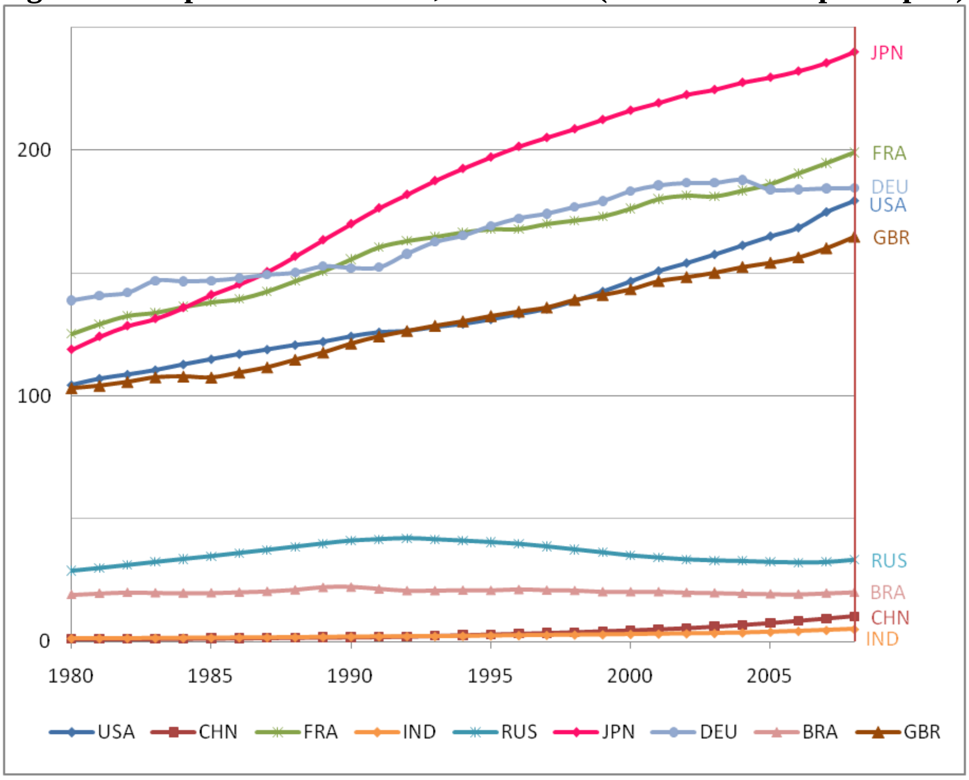
The ratios of savings and investments to GDP are from the World Bank World Development Indicators. They cover private and public savings and investments. We use both gross *fixed* capital formation, and gross capital formation (see Section 2.3).

Our capital-stock series from 1960 to 2008 is constructed using the permanent inventory method (see Equation 1.3 in Section 1). Where data on initial capital stock are not available, we set it to three times GDP in 1960. Since our econometric estimations start in 1980, when most of the 1960 stock had been scrapped, this crude assumption is benign. Figure 2 reports the implied capital-labour ratios for a selection of large economies.

[9] 1 million Btu = 0.025 metric tons of oil equivalent = 0.17 barrels.

[10] Converted from 2007 US dollars by applying a deflation factor of $\frac{1}{1.062}$.

Figure 2 – Capital-labour ratios, 1980-2008 (2005 USD '000 per capita)



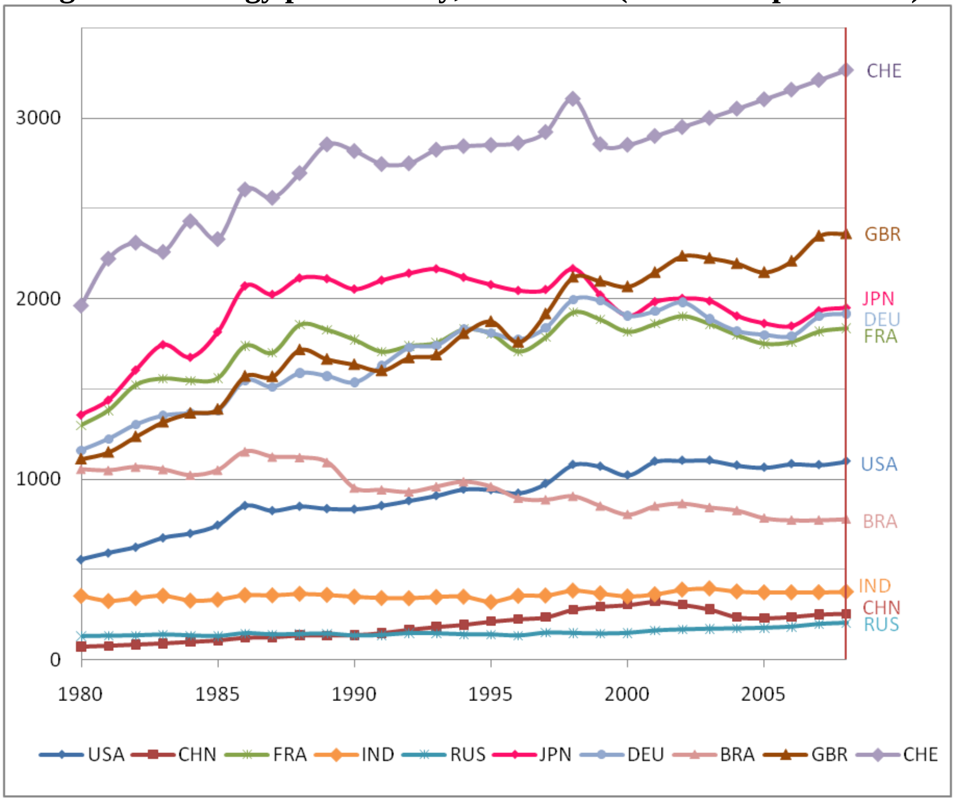
Source: own calculations.

Energy productivity for 1980-2008 is obtained by inverting the relation between optimal energy consumption E and the price of energy p_E (Equation (1.5) in Section 1):

$$B = (p_E)^{\frac{\sigma}{\sigma-1}} \left(\frac{E}{Y}\right)^{\frac{1}{\sigma-1}} \tag{2.1}$$

Figure 3 depicts the resulting series for a selection of large economies. The developed country with the highest energy productivity in the 1980-2008 period is Switzerland (CHE in Figure 3), with a level well above the group made of the United-Kingdom (GBR), Japan (JPN), Germany (DEU) and France (FRA). The declining energy productivity of Brazil over the period may be related to this country's specific energy mix. Its main energy source is biomass, whose price has not evolved in line with world oil prices. Our model indicates that a high price for energy in Brazil, but this is not the real price paid for an equivalent amount of energy. This may result in Brazil's energy productivity being underestimated (recall that $\sigma < 1$ in Equation 2.1).

Figure 3 – Energy productivity, 1980-2008 (2005 USD per barrel)



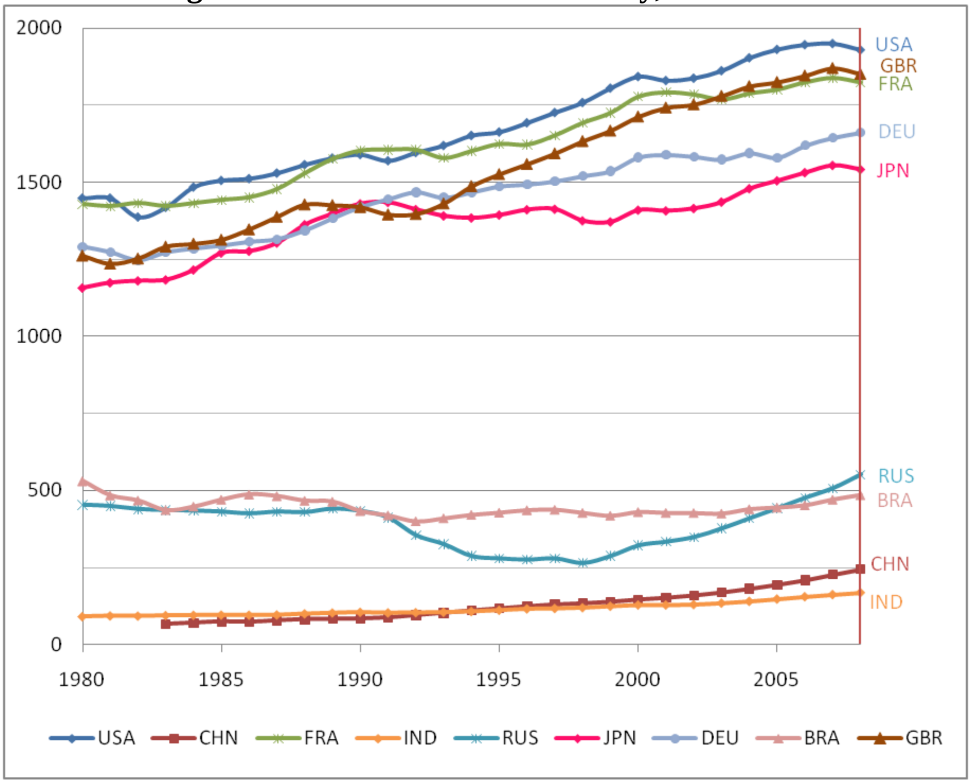
Source: own calculations.

Finally, we estimate TFP by inverting the production function:

$$A_{i,t} = \frac{\left[Y_{i,t}^{\rho} - (B_{i,t}E_{i,t})^{\rho}\right]^{\frac{1}{\rho}}}{K_{i,t}^{\alpha}L_{i,t}^{1-\alpha}} \quad (2.2)$$

Figure 4 depicts the resulting series. TFP generally increases in 1980-2008, except in periods of crises, such as occurred in Russia following the breakdown of the USSR. As expected, the US is the technological leader during most of the period.

Figure 4 – Total Factor Productivity, 1980-2008



Source: own calculations.

We next estimate the behavioural equations.

2.2. Savings rates

To project savings rates, we rely on Masson, Bayoumi and Samiei's (1998) lifecycle approach, already employed in Poncet (2006). In this approach, the gross savings rate depends on the age-structure of the population and the GDP-per-capita gap with the leading economy. We employ the methodology proposed in Higgins (1998) to characterise the age-structure through a simple polynomial of age groups. The estimated equation is as follows:

$$\left(\frac{S}{Y}\right)_{i,t} = \alpha_i + \beta_1 \frac{y_{i,t-1}}{y_{US,t-1}} + \beta_2 \left[\frac{y_{i,t-1}}{y_{US,t-1}}\right]^2 + \beta_3 g_{i,t-1} + \sum_{k=1}^{K} \varphi_k \, d_{i,t}^k + \sum_{k=1}^{K} \eta_k \, d_{i,t}^k . g_{i,t-1} + \varepsilon_{i,t} \tag{2.3}$$

where $(S/I)_{i,t}$ is the savings rate in country i at time t, $y_{i,t}$ is country i's per capita GDP, $g_{i,t}$, is the rate of growth of per capita GDP,[11] and the variables $d_{i,t}^{k}$ are demographic factors constructed as follows (for simplicity, country and year subscripts are dropped):

$$d^k = \left(\sum_{j=1}^{J} j^k p_j - \frac{1}{J}\sum_{j=1}^{J} j^k\right) \quad (2.4)$$

where $j = 1, \dots, J$ are the J population cohorts (0-4, 5-9, ..., 65-69 and 70+), and p_j is the proportion of cohort j in the population. This specification allows us to summarise the distribution of the population using only a few variables (see Appendix C). The number of demographic variables (K) is determined by an Akaike information criterion.

The behaviour underpinning Equation (2.3) is structural. Hence, it is expected to hold on average during relatively long periods of time (rather than year after year). However it may omit important determinants of savings rates, such as institutions, governance or culture, which move only slowly, hence cannot be introduced in a panel regression. These considerations led us to the following choices. Firstly, all variables are expressed as 5-year averages in order to correct for business cycles. Secondly the equation is estimated on the whole sample with country fixed effects in order to account for time-invariant heterogeneities not controlled for by right-hand side variables.[12] Omitting such key covariates could otherwise lead to a large bias in estimating the effects of our included variables. Still, these important underlying factors may well change gradually over such a long period. Accordingly, one of the robustness checks performed in Section 4 addresses the consequences of a half convergence of these unobserved determinants within our sample, at the 2050 horizon.

The results are presented in Table 1.[13] An increase in per capita GDP (GDPcap) relative to the US, or a higher per capita GDP growth rate, implies a rise in the savings rate. In terms of the demographic factors, only their interaction with growth has a significant impact on the savings rate. Hence our preferred specification is the one in Column (2) of Table 1, where additive demographic factors are dropped.

Appendix D describes that the impacts of the different cohort shares (p_j) on the savings rate can be deduced from the estimated coefficients of the d^k variables. These impacts are plotted in Figure 5, which assumes a 2% per capita GDP growth rate. Figure 2 shows that there is a strong, negative impact of ageing on the aggregate savings rate, which is consistent with life-cycle theory.

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[11] Both per capita GDP and its growth rate are lagged so that the equation can be used non-recursively in a projection exercise.

[12] Preliminary estimations tended to reject any systematic heterogeneity in the determinants of saving rates between OECD and non-OECD countries.

[13] The country fixed effects are displayed in Appendix C.

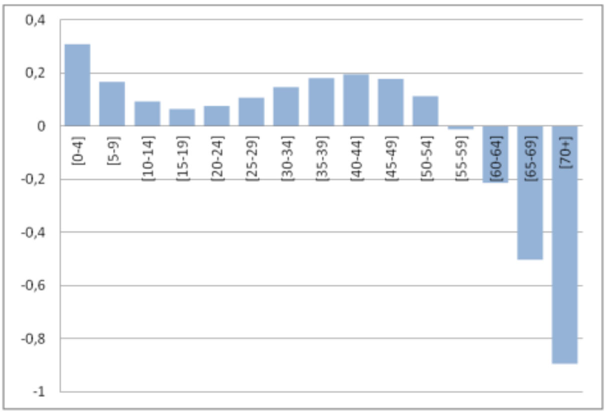
Table 1 – Determinants of the savings rate

Dependent variable : Savings rate	**(1)**	**(2)**
Constant	0.0598** (0.0291)	0.139*** (0.00531)
Lagged GDPcap rel. to the USA	0.135** (0.0527)	0.118*** (0.0172)
Lagged $GDPcap^2$ rel. to the USA	0.000374 (0.00 74)	
Lagged GDPcap growth	1.195*** (0.281)	1.201*** (0.234)
d^1	0.259 (0.202)	
d^2	-0.0256 (0.0344)	
d^3	0.000456 (0.00159)	
$d^1 \times GDPcap\ growth$	-14.98*** (3.883)	-12.99*** (3.273)
$d^2 \times \text{GDPcap}\ growth$	2.551*** (0.631)	2.276*** (0.529)
$d^3 \times \text{GDPcap}\ growth$	-0.115*** (0.0275)	-0.104*** (0.0230)
Observations	907	907
R-squared	0.192	0.177
Groups	163	163

Standard errors in parentheses
***** p<0.01, ** p<0.05, * p<0.1**

Source: own calculations.

Figure 5 – Impact of the life cycle on savings rates, (assuming a 2% GDPcap growth rate)



Source: own calculations.

2.3. From savings to investment: The FH relationship

Projecting gross investment raises some difficult methodological issues. Indeed, fixed capital investment, with inventories, is the most unstable component of demand. In the short run, it is driven mostly by an accelerator effect. In the long run, it is deemed to depend on capital stock and real interest rates. However, it is difficult to identify a robust, econometric relationship. The problem is magnified for developing countries where the cost of capital is a rather blurred concept. One solution is to rely on a model of savings rather than investment, and assume a long-run savings-investment balance (see Poncet, 2010). However, this assumption of a closed economy would be at odds with the recently observed savings-investment imbalances in the global economy. Here, we estimate an error-correction, FH-type relationship between the savings and the investment rates.

The basis of the contribution made by Feldstein and Horioka (1980) is that the relationship between savings and investment depends on financial openness: in a closed economy, domestic investment is constrained by domestic saving, whereas perfect capital mobility would require domestic investment being uncorrelated with domestic savings. The most general specification of the FH relationship is the following (see Herwartz and Xu, 2010):

$$\left(\frac{I}{Y}\right)_{i,t} = \alpha_i + \beta_i \left(\frac{S}{Y}\right)_{i,t} + u_{i,t} \tag{2.5}$$

where (I/Y) and (S/Y) respectively denote the investment and savings to GDP ratios. The lower is β, the higher will be capital mobility. For a sample of 16 OECD countries between 1960 and 1974, Feldstein and Horioka found that, on average, a one percentage point increase in the savings rate was related to a 0.89 percentage point increase in the investment rate ($\beta = 0.89$), meaning limited *de facto* international financial integration despite *de jure* liberalisation (hence the FH puzzle). Some subsequent estimations find lower values for β, especially within the Eurozone, but generally the coefficient remains relatively high.[14]

Measuring the link between savings and investment rates raises three issues. First, measuring capital formation is far from straightforward. Second, a FH-type estimation can be spurious if investment or saving rates are non-stationary. Third, non-stationarity requires the correct model to be implemented. These three points are developed below.

a. Measuring investment

There are two ways to measure capital formation: 'gross *fixed* capital formation' (GFCF), which corresponds to the purchase of fixed assets, and 'gross capital formation' (GCF), which includes changes to inventories:

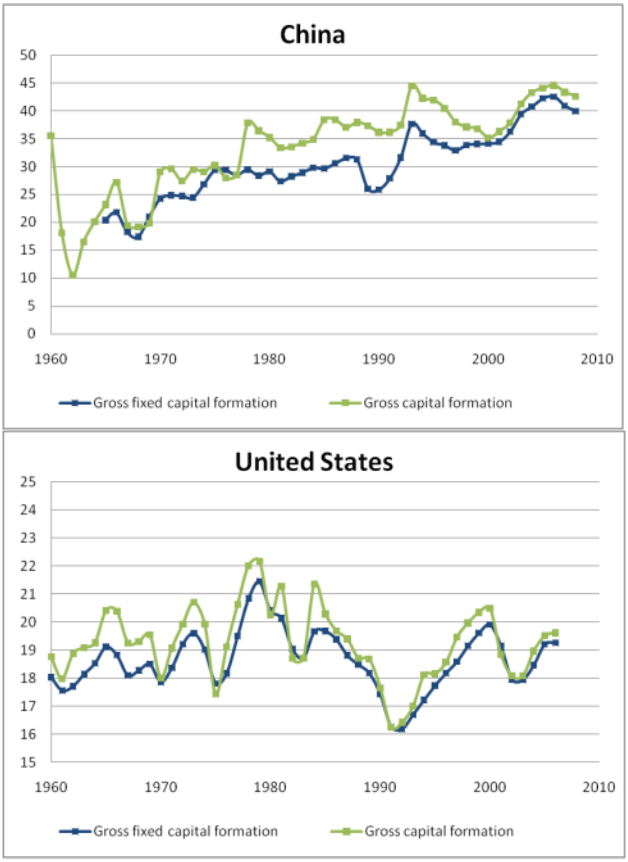
[14] E.g., Obstfeld and Rogoff (1996) found a coefficient of 0.69 for a sample of 22 OECD countries over the period 1982–91 and Blanchard and Giavazzi (2002) obtained a 0.58 coefficient for the 30 OECD countries in the period 1975–2001. It is interesting that in their estimation the coefficient is lower and declining in the euro area at only 0.14 in 1991–2001, down from 0.41 in 1975–90.

$$GCF = GFCF + \Delta Inventories \quad (2.6)$$

Our production function includes only fixed assets, and our capital accumulation, permanent inventory equation relies on GFCF. However, savings (the source of investments) are used to buy fixed assets and to accumulate inventories, so that the FH relationship holds only for GCF and savings. Hence, we need to use the GCF series to estimate our FH relationship, and then correct projected GCF to recover GFCF.

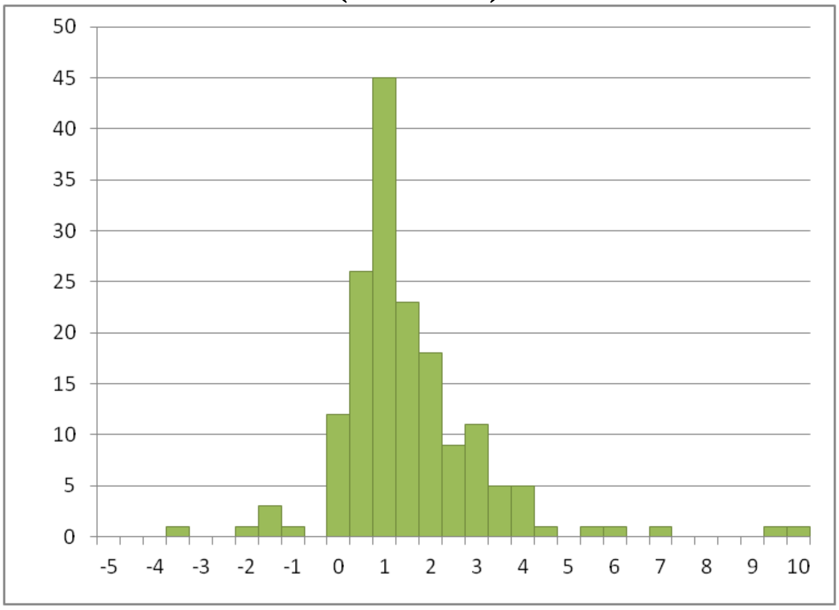
Figure 6 shows that the two series are fairly similar, although GCF is more volatile than GFCF, due to inventory changes. On average, though, the variance in the inventories is generally positive (Figure 7). Because our focus is on long-term accumulation, only long-run discrepancies need to be accounted for. Since the distribution of average inventory changes is clearly asymmetric, we subtract its median (0.87% of GDP) to correct GCF to obtain GFCF. Note, however, that this choice is not crucial since the correction is very small compared to the capital formation levels.

Figure 6 – Gross capital formation and gross fixed capital formation, % of GDP, 1960-2008



Source: World Development Indicators (World Bank).

Figure 7 – Distribution of average inventory changes over the 1980-2008 period (% of GDP)

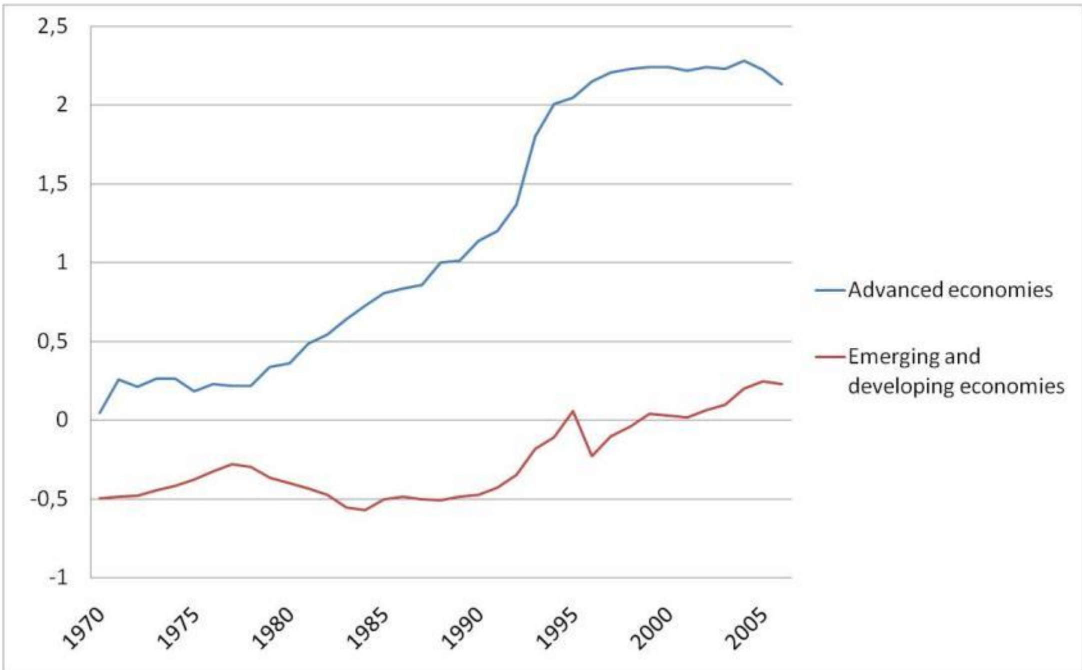


Source: own calculations.

b. Stationarity

As noted, e.g. by Coiteux and Olivier (2000), savings and investment rates are often non-stationary, requiring cointegration rather than simple ordinary least squares (OLS) regressions. However, the breadth of our sample means that it is likely to include both stationary and non-stationary series. In addition, for some countries we have missing or unreliable data. For these reasons, we prefer a panel to a country-by-country approach. We follow Chakrabarti (2006) and divide our sample into OECD and non-OECD countries and implement panel unit-root tests. This choice is motivated by the large differences in financial openness between the two types of countries (see Figure 8).

Figure 8 – Financial openness, 1970-2007



Note: The index is computed as the non-weighted average of 24 advanced economies and 128 emerging and developing economies of capital mobility index (taking into account exchange rates, restrictions on transactions and export parameters).

Source: Chinn and Ito (2008), based on the IMF Annual Report on Exchange Arrangements and Exchange Restrictions, 1970-2007.

Panel unit root tests, first proposed by Levin and Lin (1992), have been developed by several scholars, resulting in five different tests that can be implemented in Stata. Four of these tests (Levin Lin and Chu, Im Pesaran and Shin, Breitung and Fisher) consider the null hypothesis of a unit root (common or country-specific). The fifth (Hadri) sets the null as stationarity. The results of all five tests are presented in Appendix E, run for both series and country groups.

For both the OECD and the non-OECD sub-samples the null of non-stationarity is generally accepted (and the null of stationarity is rejected). Non-stationarity of the series is less compelling for savings rates than for capital formation, and especially for the OECD countries. Nevertheless, we can consider both savings and investment rates to be non-stationary. We check next for cointegration.

c. Cointegration

We implement two sets of panel-cointegration tests based on four tests in Westerlund (2007) and seven tests from Pedroni (1997), which differ in terms of the heterogeneity allowed within panels. For all these tests, the null hypothesis is of no cointegration. The results are reported in Appendix E.

It is important to note that Pedroni's tests assume that all countries are independent, which is not the case since the world sum of investment automatically equals the world sum of savings (with no statistical, world discrepancy). Although Westerlund tests are less frequent in the literature, they do not make this assumption of independence. Hence, we rely on the Westerlund tests, which all reject the null of no cointegration (at the 1% level for OECD countries, and at the 5% level for the non-OECD group). The results of the Pedroni tests are more mixed, but still tend to favour cointegration. Therefore, we need to estimate an error-correction model.

d. Error-correction model

The error-correction model is estimated using the Engle and Granger two-step method (see e.g. Coiteux and Olivier, 2000, or Herwartz and Xu, 2009). First, the long run relation (Equation 2.5) is estimated in panel, leading to estimates of α_i and β. This allows us to estimate the following relation:

$$\Delta\left(\frac{I}{Y}\right)_{i,t} = a_i + \theta_i\left(\left(\frac{I}{Y}\right)_{i,t-1} - \hat{\alpha}_i - \hat{\beta}\left(\frac{S}{Y}\right)_{i,t}\right) + b\,\Delta\left(\frac{S}{Y}\right)_{i,t} + \varepsilon_{i,t} \qquad (2.7)$$

where Δ is the first differences operator, $\hat{\alpha}_i$ and $\hat{\beta}$ are estimates from the first estimation, and θ_i is the speed of adjustment towards the long-run relationship.

Some authors estimate this relationship on a country-by-country basis (see Pelgrin and Schich, 2004 for a review). However, the coefficients obtained can be insignificant, especially among developing countries (Mamingi, 1997). Using panel data estimation techniques increases the degrees of freedom for the estimation.

Table 2 reports the cointegration vector for each panel of countries (OECD, and non-OECD). The FH coefficient obtained for the OECD panel (0.685) is in line with the literature (see Footnote 11, and Table 3). However, for the developing countries it is significantly lower, and lower than that obtained in Chakrabarti (2006) (see Table 3): despite lower *de jure* capital mobility, emerging and developing countries seem to display higher *de facto* capital mobility. In the period 1980-2008, the non-OECD countries tend to display larger current-account imbalances (in proportion to GDP) than the OECD group. The absolute value of their current accounts, on average, is 9.7% of GDP, compared to only 4% for the OECD countries.[15] In addition, our developing countries sample is larger than the sample in Chakrabarti (2006) and our results for the non-OECD group might be hiding some heterogeneity. In the following, we keep different FH coefficients for OECD and non-OECD countries. In results not reported here, we checked that the sensitivity of our results to this assumption was limited.

[15] Calculation based on the IMF, *World Economic Outlook* database, April 2010.

Table 2 – The FH relation, cointegration vector

Dependent variable : capital formation rate	**(1) OECD**	(1) **Non-OECD**
Savings rate	0.685***	0.204***
	(0.0180)	(0.0103)
Constant	0.0747***	0.189***
	(0.00450)	(0.0019)
Observations	1232	4418
R-squared	0.547	0.091
Number of groups	30	121

Standard errors in parentheses
***** p<0.01, ** p<0.05, * p<0.1**

Source: own calculations.

Table 3 – FH coefficient: comparison with the cointegration literature

Data	**Own**	**Chakrabarti (2006)**	**Coiteux and Olivier (2000)**	**Jansen (1998)+**	**Pelgrin and Schich (2004)**
OECD	0.685***	0.81***	0.63***	0.731	0.93***
Non OECD	0.204***	0.79***	-	-	-

[+] In Jansen 1998, the coefficient is the average of yearly coefficients between 1955 and 1994

The results of the error-correction models (ECM) are presented in Table 4. The Fisher test cannot reject the null hypothesis that all fixed effects are equal to zero. Hence, the ECMs are finally estimated with neither fixed effects nor a constant. The error correction coefficient θ is found to be significant and negative for both groups of countries, with similar magnitude: each year, approximately 20% of the discrepancy between the lagged investment rate and its (lagged) long-run value is erased. However, the impact of the short-term dynamics of the savings rate on the investment rate is higher for the OECD than in non-OECD group of countries.

Table 4 – Error correction model

Dependent variable : **Δ capital formation rate**	**(2) OECD**	**(2) Non-OECD**	**(3) OECD**	**(3) Non-OECD**
Error correction term	-0.211***	-0.245***	-0.211***	-0.245***
	(0.0181)	(0.0099)	(0.0180)	(0.0098)
Δ savings rate	0.767***	0.191***	0.767***	0.191***
	(0.0211)	(0.0105)	(0.0211)	(0.0104)
Constant	-0.000635	0.000653		
	(0.000615)	(0.000650)		
Observations	1202	4297	1202	4297
R-squared	0.564	0.184	0.563	0.184
Number of groups	30	121		
Fisher statistic	0.20	0.17		
Prob > F	1.0000	1.0000		

Standard errors in parentheses.
***** p<0.01, ** p<0.05, * p<0.1.**

Source: own calculations.

2.4. TFP growth

Similar to Poncet (2006), we model TFP growth based on a Nelson-Phelps catch-up model (see Benhabib and Spiegel, 2005). We divide the period 1980-2008 into three sub-periods: 1980-1989, 1990-1999 and 2000-2008, and calculate average TFP growth for each sub-period, denoted $\Delta ln(A_{i,t})$. For the already stressed reasons regarding uncontrolled heterogeneity, we then estimate the following relation with country fixed effects, excluding 1990-1999 for former soviet republics:

$$\Delta ln(A_{i,t}) = \delta_i + \gamma_1 ln(H_{i,t}) + \gamma_2 ln(H_{i,t}) \frac{A_{i,t-1}}{A_{US,t-1}} + \epsilon_{i,t} \quad (2.8)$$

where $H_{i,t}$ denotes the stock of human capital (average number of years of schooling taken from Barro and Lee, 1993) at the beginning of each 10 (or 8)-year period, and δ_i are the fixed effects. The results are reported in Table 5.[16] As expected, TFP growth is faster when human capital levels are higher; the speed of TFP growth reduces with nearness to the TFP frontier, and this effect is also stronger for higher levels of human capital.

[16] Country fixed effects are displayed in Appendix C.

Table 5 – TFP growth

Dep. Variable : $\Delta A_{i,t}$	(1) Within estimator
$ln(H_{i,t})$	0.0452*** (0. 0057)
$ln(H_{i,t})\frac{A_{i,t}}{A_{US,t}}$	-0.0663*** (0.00757)
Constant	-0.0191** (0.00961)
Observations	419
Number of groups	145
R-squared	0.336

Standard errors in parentheses

***** p<0.01, ** p<0.05, * p<0.1**

Source: own calculations.

Finally, we need to make projections of human capital. Again, we rely on a catch-up model: each country increases its average mean level of education up to the education frontier, which the data reveal to be the US level. The speed of education catch up is assumed to vary across broad regions of the world. We therefore estimate the following relation:

$$ln\left(\frac{H_{i,t}}{H_{i,t-1}}\right) = \lambda_i^{region} ln\left(\frac{H_{US,t-1}}{H_{i,t-1}}\right) + \epsilon_{i,t} \quad (2.9)$$

where i denotes the country, t is a 5 year period and λ_i^{region} is the speed of catch-up of the region to which country i belongs. Regions are defined here according to INGENUE, which is an international, general-equilibrium, overlapping-generation model focusing on ageing and growth, co-developed by CEPII, CEPREMAP and OFCE.[17] We do not add country or region fixed effects to this specification to avoid the TFP leader being overtaken before 2050. Educational attainment is assumed to grow by 0.3% per year in the US (average growth rate in the 1990s). The results are presented in Table 6. Not surprisingly given the efforts made in the 1980-2008 period, education catch-up is faster in Europe and the Mediterranean region than in the other regions. On average, a 10% education gap with the US triggers a 1% growth in human capital in the succeeding 5 years (0.8% for Africa, 1.2% for Western Europe).

[17] See Borgy et al. (2009).

Table 6 – Educational catch-up speed

Dependent variable :	$ln(H_{i,t}/H_{i,t-1})$
Western Europe	0.120*** (0.0230)
Eastern Europe and former USSR	0.136** (0.0568)
North America and Japan	0.0700*** (0.0155)
Latin America	0.0894*** (0.00883)
Mediterranean region	0.162*** (0.0101)
Chinese region	0.108*** (0.0167)
Sub-Saharan Africa	0.0760*** (0.00458)
Indian region	0.0891*** (0.00811)
Observations	835
R-squared	0.507

Standard errors in parentheses
***** p<0.01, ** p<0.05, * p<0.1**

Source: own calculations.

2.5. Energy productivity

Energy productivity, like TFP, can be seen as the result of cumulated innovation. The data seem to emphasise two determinants of energy productivity catch-up. In addition to the distance to the energy-productivity frontier, we need to consider the distance to the development frontier. The latter tends to impact negatively on energy-productivity growth, whereas the catch up of energy productivity is accelerated by higher distance to the energy-productivity frontier.

The underlying empirical evidence shows a U-shaped relation 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.

Thus, we estimate the following relationship:

$$ln\left(\frac{B_{i,t}}{B_{i,t-1}}\right) = \mu_1 ln\left(\frac{B_{F,t-1}}{B_{i,t-1}}\right) + \mu_2 ln\left(\frac{y_{US,t-1}}{y_{i,t-1}}\right) + \varepsilon_{i,t} \quad (2.10)$$

where B_F denotes the energy-productivity frontier. In our sample, Switzerland (*CHE*) appears the most energy-productive country over the whole 1980-2008 period. However, due to its specificities (small landlocked country based mainly on the service sector), this country cannot be used the energy-efficiency frontier. We define the frontier based on the mean of the next four most energy productive countries (United Kingdom, Japan, Germany and France). The estimation results are presented in Table 7. For the whole sample of countries, the data support the idea of a double-catch-up process. In terms of distance to the development frontier, there is no significant impact on energy-productivity catch-up for the OECD countries, which contrasts with the results for non-OECD countries. It is only countries in the non-OECD group that are faced with a trade-off between economic and energy catch-up. In the following, we retain the OECD/non-OECD grouping for energy productivity.

Table 7 – Energy productivity

Dependent variable : Growth of B	**(1) OECD**	**(2) OECD**	**(3) Non-OECD**
Distance to energy-productivity leader	0.0238*** (0.00481)	0.0207*** (0.00319)	0.0161*** (0.00301)
Distance to GDP-per-capita leader	-0.00404 (0.00459)		-0.00465*** (0.00126)
Observations	779	783	3607
R-squared	0.05	0.05	0.01

Standard errors in parentheses
***** p<0.01, ** p<0.05, * p<0.1**

Source: own calculations.

2.6. The Balassa-Samuelson effect

As described in Section 1, the evolution of real exchange rates for each country compared to the US can be expressed as a simple function of productivity and energy-productivity catch up, with proportionality factors that depend on the share of traded sectors and the returns to energy in each country and in the US.

The share of traded sectors for each country is calibrated based on the Global Trade Analysis Project (GTAP) database[18] for production and bilateral trade in year 2004, at the industry level. We consider all the 57 GTAP sectors (including services). For each sector, we compute a world level exposure rate according to the following formula:

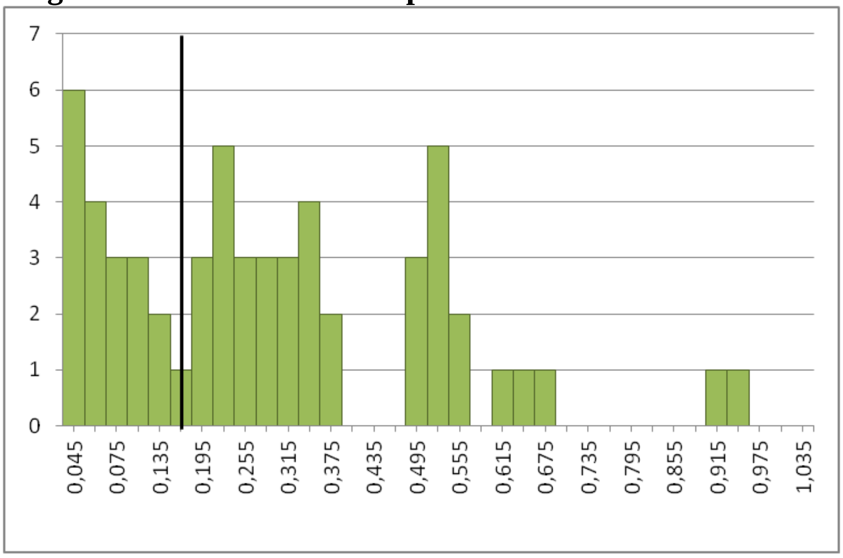
$$\tau^s = \frac{X^s}{Y^s} + \left(1 - \frac{X^s}{Y^s}\right) \cdot \frac{M^s}{Y^s + M^s - X^s} \quad (2.11)$$

with Y^s denoting the world production of sector s, X^s world exports, and M^s world imports.

[18] See www.gtap.agecon.purdue.edu.

The distribution of these exposure rates is displayed in Figure 9. It appears that there are two modes, which we identify as the non-traded goods (low exposure rate) and traded goods (high exposure rate). The threshold then is $\tau^{thresh} = 0.165$. The share of traded sectors in each country is recovered by adding the shares of traded goods in total production. In turn, the share of energy in income (the m coefficient in Equation (1.8) of Section 1) is derived from the simulation itself.

Figure 9 – Distribution of exposure rates for GTAP sectors



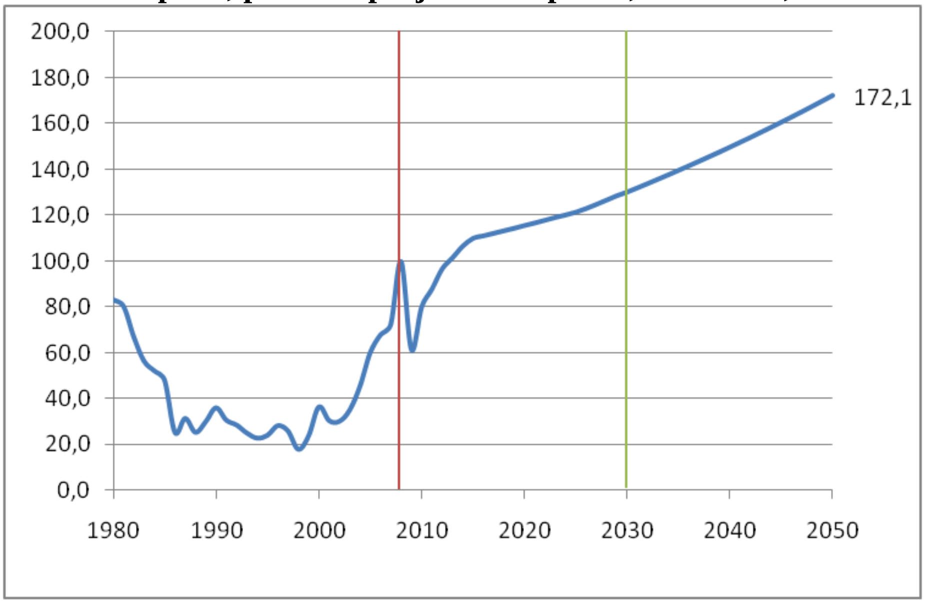
Source: own calculations based on GTAP data.

3. THE WORLD ECONOMY IN 2050

The methodology described in the previous section allows us to make long-run economic projections for 128 countries. It relies on the assumption that in the long run, only supply-side factors (labour, capital, TFP, energy productivity) matter for economic growth. Thus, the starting point for the projections should be a year when GDP was at its potential level in most countries. However, we are left with the problem of the 2008-09 global crisis. We could take as our starting point a pre-crisis year – say 2007, but the crisis involved falls in production and income and also a collapse in investments, which is likely to have a long-lasting impact on potential output. Therefore, we (i) rely on IMF GDP forecasts to 2012, (ii) assume that the output gap has been closed at that date, (iii) adjust TFP levels accordingly, and (iv) perform supply-side projections for 2013 to 2050. This methodology may overstate the drop in TFP during the crisis since we are unable to account for the temporary fall in investment rates and the rise in unemployment, whose effects could extend beyond 2012. However, this feature is benign since our interest is in GDP, not employment or TFP.

A key assumption in our projections is the (real) price of oil. As mentioned in Section 1, we use EIA projections up to 2030, and apply a constant growth rate from 2030 to 2050 (see Figure 10). We also test the sensitivity of our results to this assumption (see Section 4).

Figure 10 –Real price, past and projected oil prices, 1980-2050, constant USD



Source: EIA (1980-2030), own calculations (2031-2050).

Finally, we are faced with the n[th] country problem: with *n* countries in the world, there are only *n*-1 independent savings-investment imbalances. In other words, savings-investment imbalances should sum to zero across our 128 countries (assuming that the weight is negligible for the remaining world countries). Rather than dropping the savings and investment equations for one country that might be considered the 'rest of the world', we choose to distribute the discrepancy across all 128 countries, proportional to their share in world investments. We denote the projected GCF of country *i* at time *t as* $I_{i,t}$ and projected savings as $S_{i,t}$, making the corrected value of investments $\tilde{I}_{i,t}$ such that:

$$\tilde{I}_{i,t} = \frac{I_{i,t}}{\sum_j I_{j,t}} \sum_j S_{j,t} \tag{3.1}$$

We turn next to the projections, starting with the different production factors (Section 3.1) and to GDP at constant relative prices (3.2) and variable relative prices (3.3). At each step, the results for a few large economies are displayed and discussed: the detailed results are reported in Appendix F.

3.1. Production factors

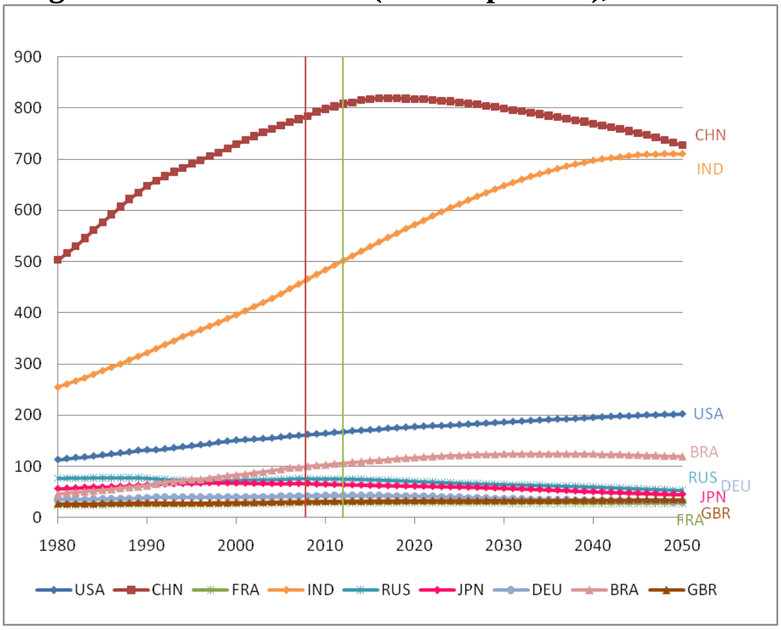
a. The labour force

Figure 11 depicts the evolution of the labour force for a few large economies. Note that China's labour force starts to decline around 2015, while India's continues to grow (although at a slower pace after 2035). At the 2050 horizon, both labour forces are similar with slightly more than 700 million individuals.

Over the same period, the US labour force is fairly dynamic, with a 34% increase between 2008 and 2050. In 2050, the US labour force is around 200 million individuals, which is 3.5 times smaller than China or India.

Japan and Russia, on the other hand, show a large decrease in their labour force, along the 2008-50 period, which will make it more difficult for them to maintain positive growth rates.

Figure 11 – Labour force (million persons), 1980-2050

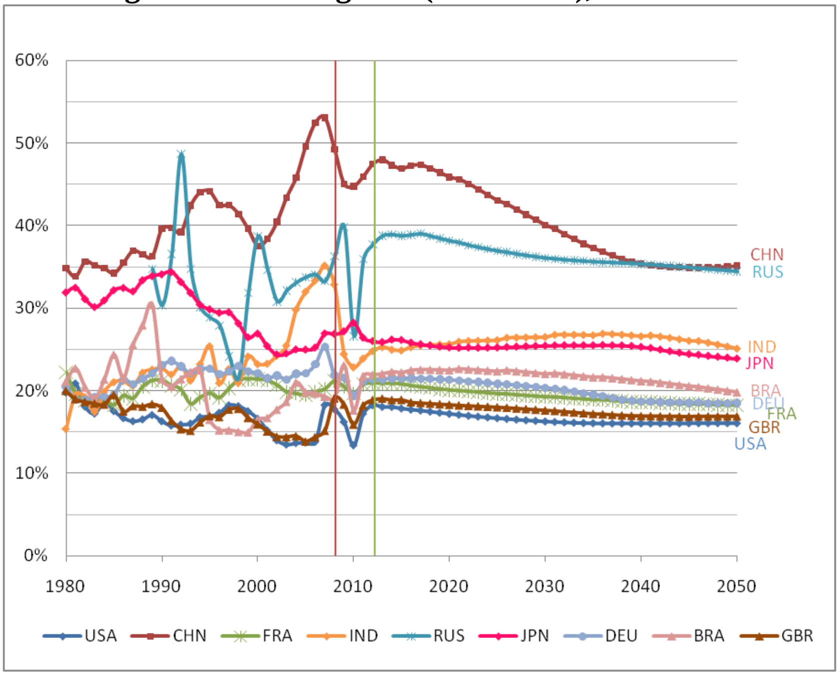


Source : own calculations.

b. Saving and investment

According to our estimated equations, savings rates are an increasing function of GDP per capita levels (relative to the US) and growth rates, and a decreasing function of the share of older people in the population. The progressive ageing of China's population triggers a dramatic reduction in China's savings rates (Figure 12). The impact of ageing is evident for Russia and to a lesser extent for the other countries in the graph in Figure 12. In India, the savings rate increases slightly up to 2040, and then declines.

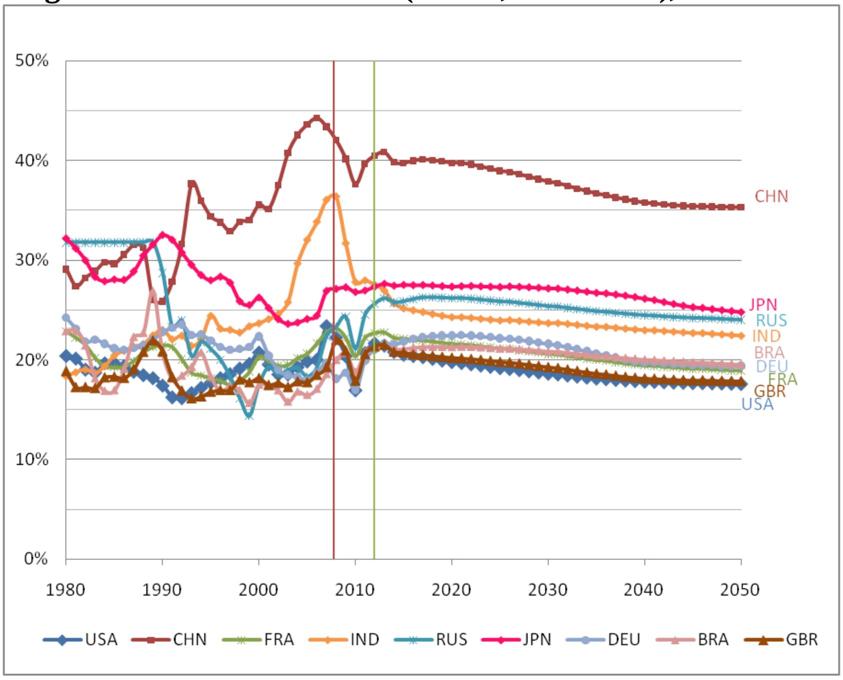
Figure 12 – Saving rate (% of GDP), 1980-2050



Source: own calculations.

The decline in savings rates implies a decline in investment rates, although not necessarily in parallel with savings rates (Figure 13). For example, in China, investment rates and savings rates fall respectively by 5% and more than 8% of GDP. In India, the rate of investment falls steadily while savings rates increases slightly. In the US and in the UK, the rate of investment falls much more than the savings rate.

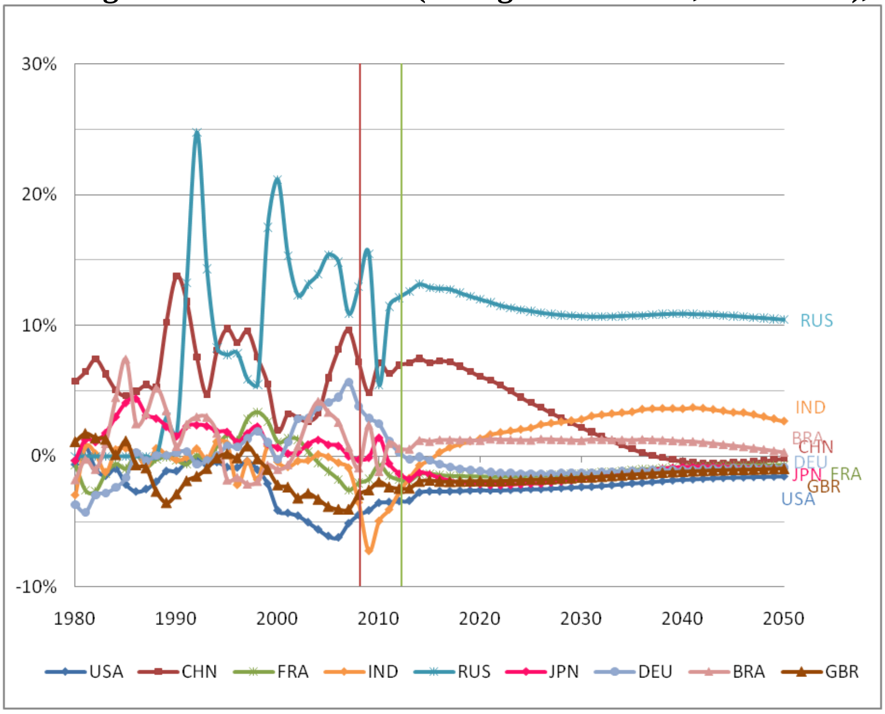
Figure 13 – Investment rate (GFCF, % of GDP), 1980-2050



Source: own calculations.

Figure 14 plots the implications of savings and investment developments for current accounts. Between 2020 and 2040 China's surplus and the US deficit disappear. In contrast, India has a current-account surplus after 2020 and Russia has a large surplus over the whole projection period.

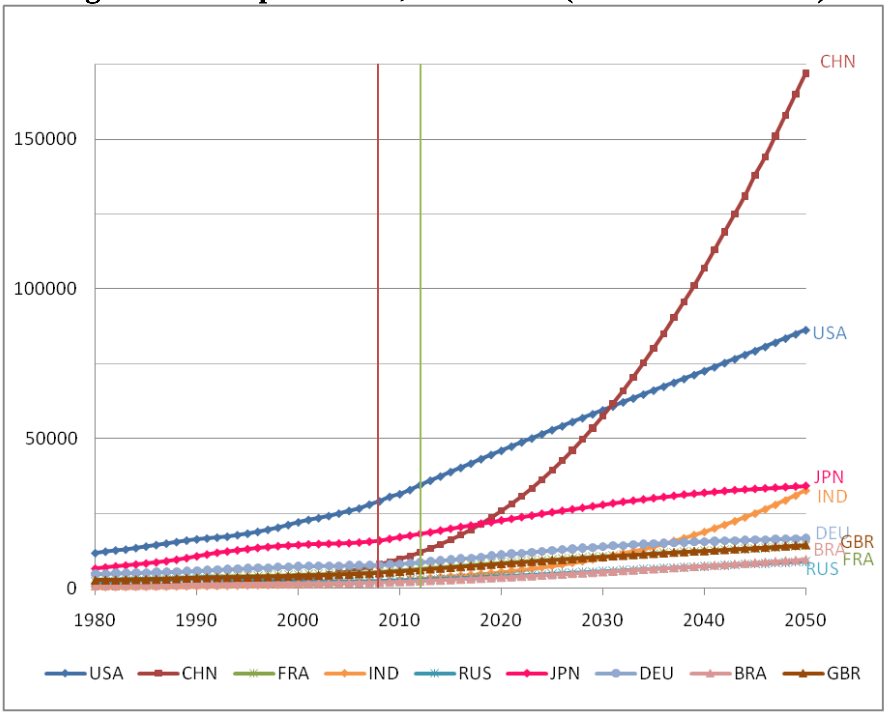
Figure 14 – Savings-Investment balance (savings minus GCF, % of GDP), 1980-2050



Source: own calculations.

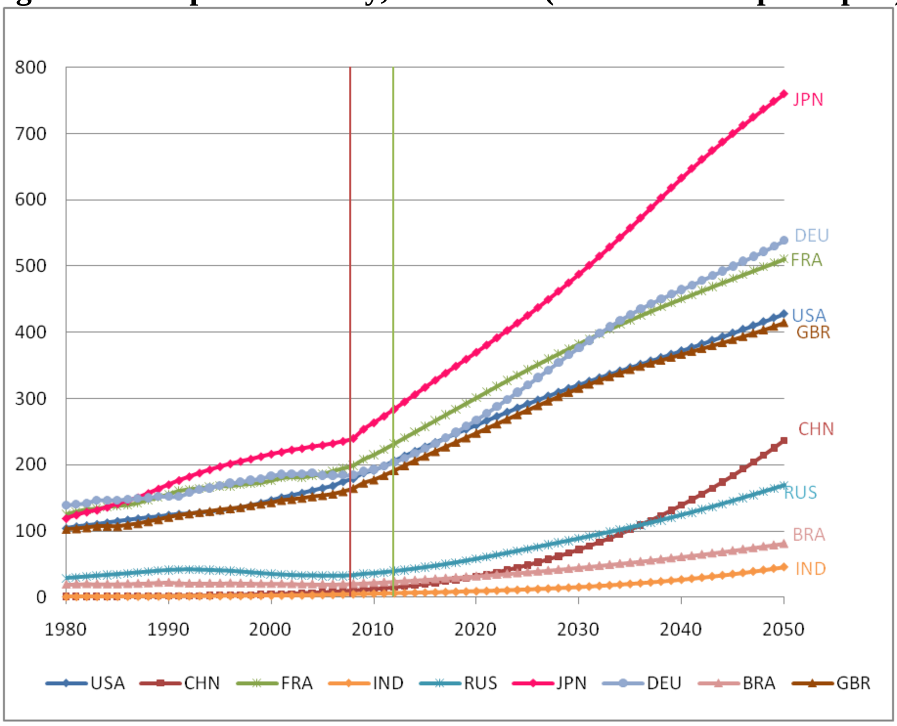
Since in China, GDP continues to increase rapidly over the period, even a falling investment rate fuels fast-growing capital stock. After 2035, China's capital endowment is larger than that of the US, at 2005 US dollars (Figure 15). However, given the difference in the sizes of these countries' labour forces, China's capital intensity (K/L) is still half that of the US in 2050. It is interesting that given the pace of accumulation and declining demography, Germany's capital intensity is larger than that of France in 2035 (Figure 16). Finally, Japan's leading position for capital intensity is unchallenged: steady investment and declining demography lead to a sharp increase in the K/L ratio.

Figure 15 – Capital stock, 1980-2050 (2005 USD billions)



Source: own calculations.

Figure 16 – Capital Intensity, 1980-2050 (2005 USD'000 per capita)

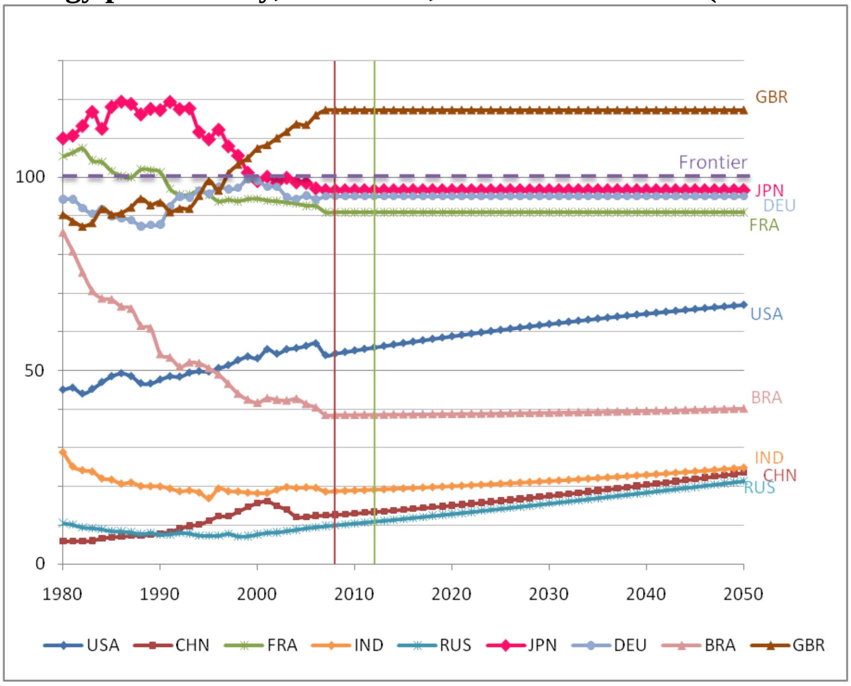


Source: own calculations.

c. Energy Productivity

In our projections, the energy productivity hierarchy remains broadly unchanged for the developed countries. The four frontier countries grow at a constant exogenous rate (+0.5 percent per year, which corresponds to their average growth rate over 1998-2008), with the remaining OECD countries catching up to this frontier. The Brazil, India and China catch up to the energy productivity frontier at a similar rate to the US (Figure 17).

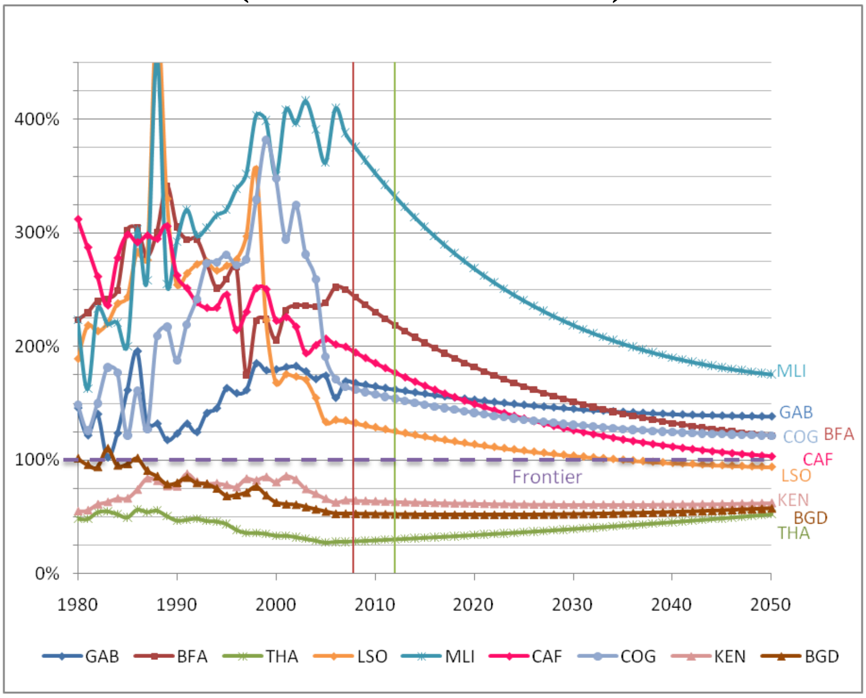
Figure 17 – Energy productivity, 1980-2050, OECD and BRICs (in % of frontier level)



Source: own calculations.

The dynamics of energy productivity is very different for developing economies; the poorest ones show a U-shaped evolution (Figure 18). Following a phase of high energy efficiency characterised by low level of industrial development, limited use of fossil fuels for transport and extensive use of technology in the agricultural sector, there is an increase in per capita GDP and more energy-intensive production (e.g. increased industry share). There is evidence of economic development leading to progressive improvement in energy productivity in approximately 2007 for Thailand or 2035 for Kenya.

Figure 18 – Energy productivity, 1980-2050, developing countries (as a % of the frontier level)

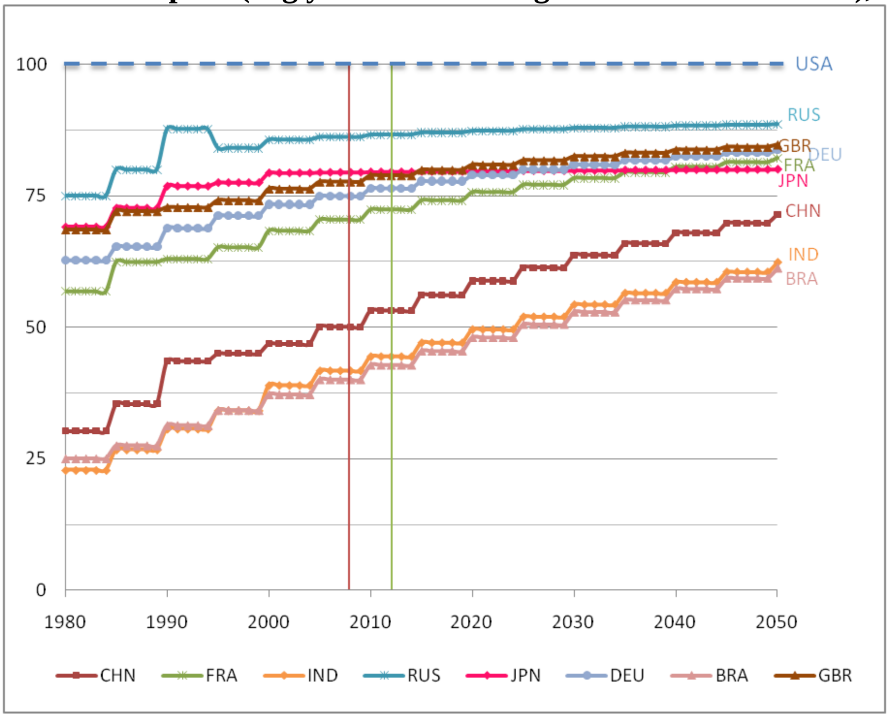


Source: own calculations.

d. TFP

Education is the main driver of TFP catch-up. Given our specification without fixed effects, but with different catch-up speeds across the world's regions, the ranking of education levels remains broadly at 2000 levels (latest available data), although China, India and Brazil are shown to be catching up fast (Figure 19).

Figure 19 – Human capital (avg years of schooling as a % of the US level), 1980-2050



Source: own calculations.

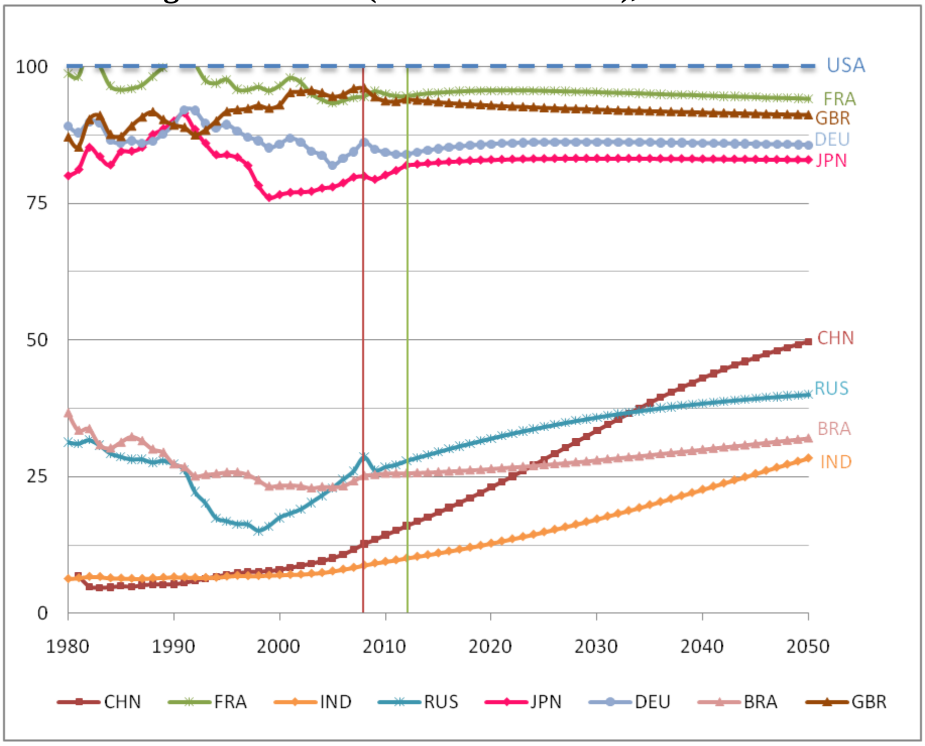
TFP growth can be computed on rates of education catch-up. Figure 20 shows clear convergence in TFP growth rates. For some countries (e.g. Russia, Brazil), however, there is a downward convergence in TFP growth rates, leading to very slow catch-up of TFP levels. In contrast, China's high TFP growth rates over an extended period, fuel impressive catch-up of its TFP level (Figure 21). However, our results indicate that China's TFP level is likely to be only half that of the US by 2050.

As already mentioned, the 2008-09 global crisis resulted in a dramatic drop in TFP in our model since we do not account for its impact on production factors (capital, labour, energy productivity). Because all countries are affected by the crisis, the effect on TFP growth rates is minor, but the impact on TFP levels is more substantial.

Figure 20 – TFP growth, 1980-2050, % per year

Source: own calculations.

Figure 21 – TFP (in % of USA level), 1980-2050

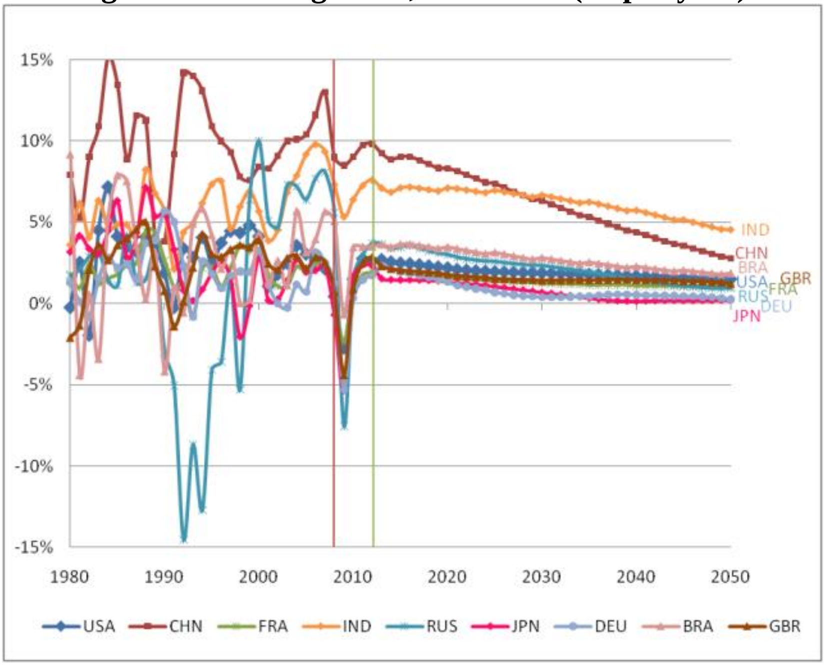


Source: own calculations.

3.2. GDP

To project volume of GDP for our sample of 128 countries from 2013 to 2050, we need to combine labour, capital, TFP and energy productivity. Figure 22 depicts GDP growth rates. Up to 2030, the highest growth rate is achieved by China, but in 2030 to 2050 it is overtaken by India. After 2030 Japan and Germany experience very low growth rates. This reflects their reduced labour force which is not fully compensated for by capital accumulation and TFP growth.

Figure 22 – GDP growth, 1980-2050 (% per year)

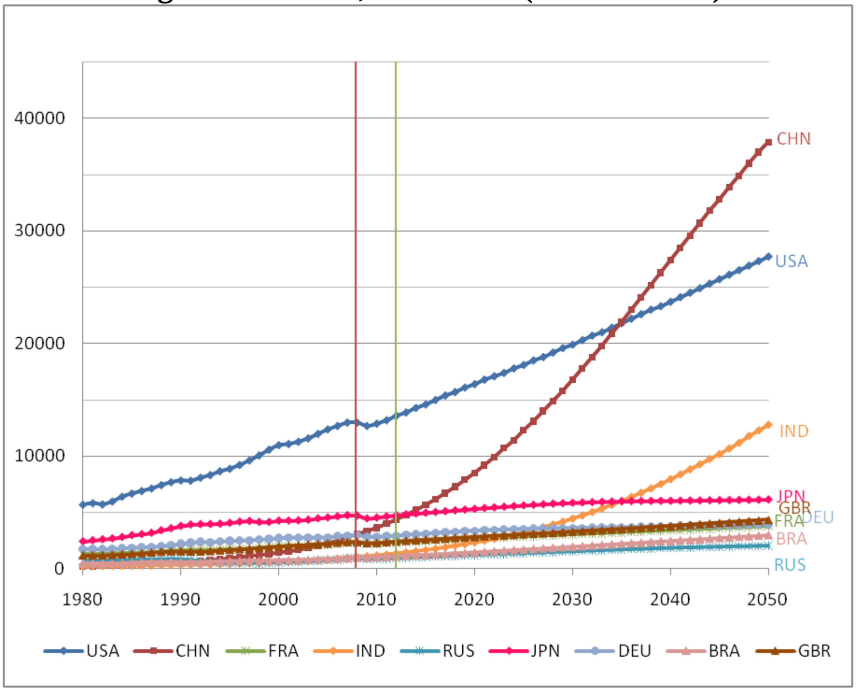


Source: own calculations.

In the introduction to this paper, we showed that assuming a constant 8% GDP growth rate for China would result in this economy growing 21-fold in 40 years. Here, we project a reduction in this growth rate for China, from 8.6% per year in 2008-25 to 4.6% per year in 2025-2050, resulting in a 13-fold growth between 2008 and 2050 (see Figure 23). The actual order of magnitude of China's economic growth is a direct indication of this country's demand for global natural resources. According to our calculations, measured in 2005 US dollars, China could overtake the US as the largest world economy around 2035, and could be 37% larger than the US in 2050. This would make China ten times larger than the largest EU country, i.e. the UK. At around the same time, 2050, India would be set to overtake to become the third largest world economy – twice the size of Japan's and half the US one.

The corresponding shares of global GDP of the main economies in 2008, 2025 and 2025 are depicted in Figure 24. At constant relative prices, the US would account for only 19% of the world economy in 2050, compared to 27% in 2008. The loss of position of the US would occur between 2025 and 2050. By 2050, according to this projection, China would account for 25% of global GDP (compared to 7% in 2008) and India would have a 9% share in 2050 (compared to 2% in 2008). The shares of the European Union and Japan would be roughly halved during this period while the shares Brazil and Russia would remain unchanged at 2% each. Within the BRIC (Brazil, Russia, India, China) group there are wide differences: while the shares of China and India are multiplied by a factor of at least four by 2050, Russia and Brazil manage only to keep their shares constant within a rapidly expanding world economy.

Figure 23 – GDP, 1980-2050 (2005 USD bn)



Source: own calculations.

Figure 24 – Shares of the world economy, 2008, 2025 and 2050, (in % of world GDP)

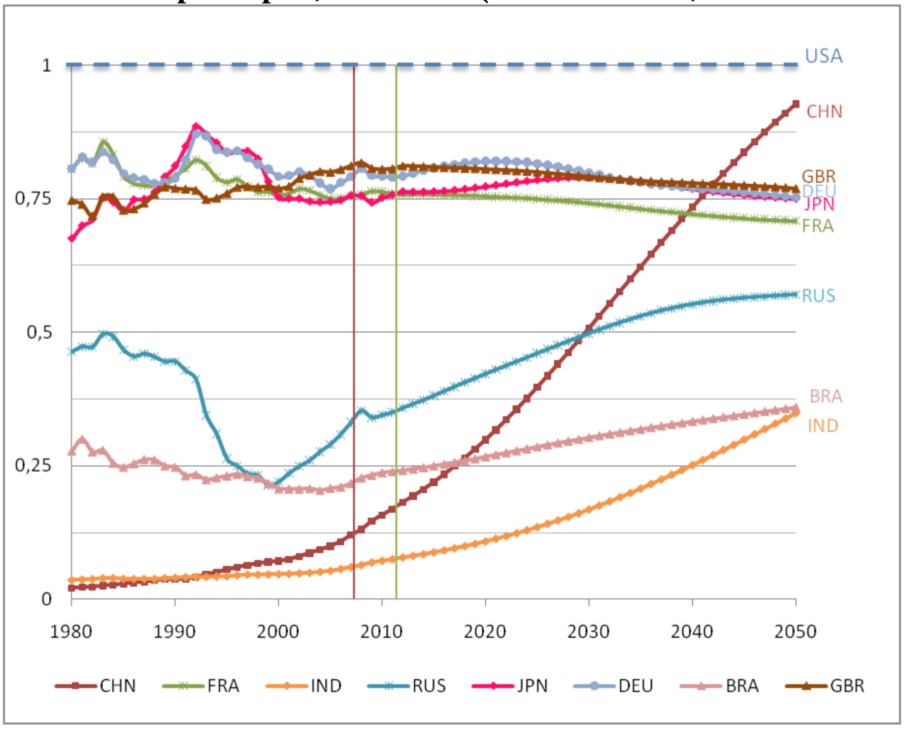
Source: own calculations.

To estimate standards of living, we convert projected GDP into purchasing power parity (PPP) and divide this by projected population. Denoting by *PPP* the PPP conversion factor (taken from The World Bank for year 2005) and by *N* the total population, we have:

$$\text{GDPcap} = \frac{Y}{L} \times \frac{L}{N} \times PPP \quad (3.2)$$

Hence, GDP per capita in PPP differs from labour productivity due to (i) the employment rate *L/N*, and (ii) the PPP conversion factor. Our calculations suggest that China's GDP per capita would reach almost 90% of the US level in 2050, thanks to both a relatively high employment rate and a high conversion factor (Figure 25) while India would catch up with Brazil to be 36% of the US level. Japan, France and Germany would regress substantially after 2025 according to this criterion, which is not to indicate absolute impoverishment because the US level would continue to grow.

Figure 25 – GDP per capita, 1980-2050 (2005 PPP USD, in % of USA level)



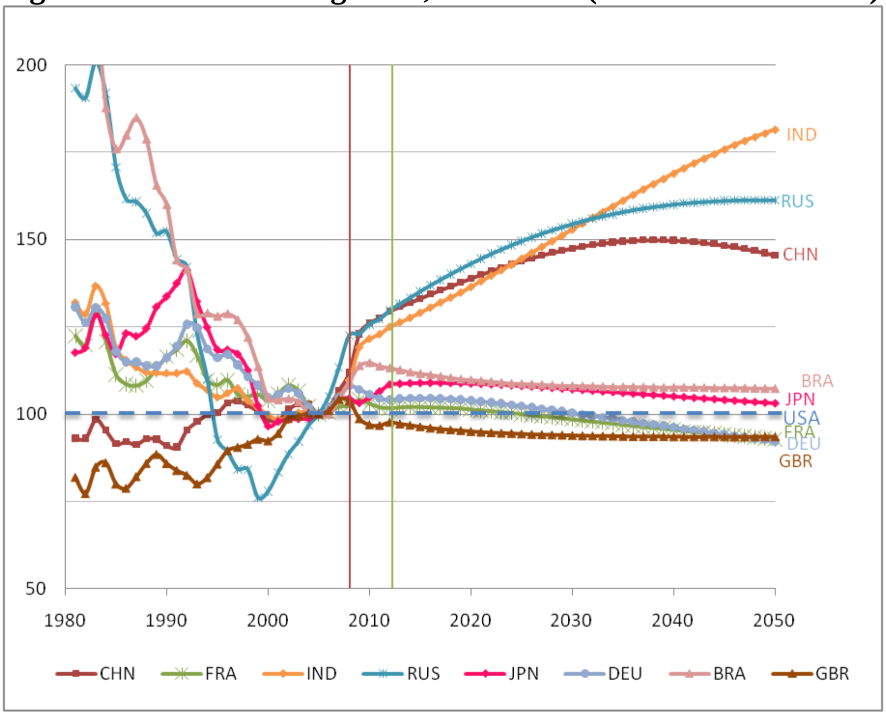
Source: own calculations.

3.3. GDP with relative-price variations

In the scenarios so far, we have not included valuation effects, and GDP growth rates and levels have been presented at constant prices, in 2005 US dollars (for GDP) or 2005 PPP dollars (for per capita GDP). The figures we obtained are the key to how global production will be reshaped, and have massive implications for demand for production factors (especially energy and human and physical capital) and carbon emissions. However, they do not provide an indication of the weight of each country in terms of global purchasing or financial power. For instance, the fast catch up of China in terms of per capita GDP will trigger an increase in the prices of Chinese goods relative to other countries' goods. This real exchange-rate appreciation will contribute to GDP growth and result in greater international purchasing and financial power. Taking into account this valuation effect does not radically change the picture of the world economy in 2050. Country rankings are unchanged even when the previously projected changes in world GDP shares are magnified.

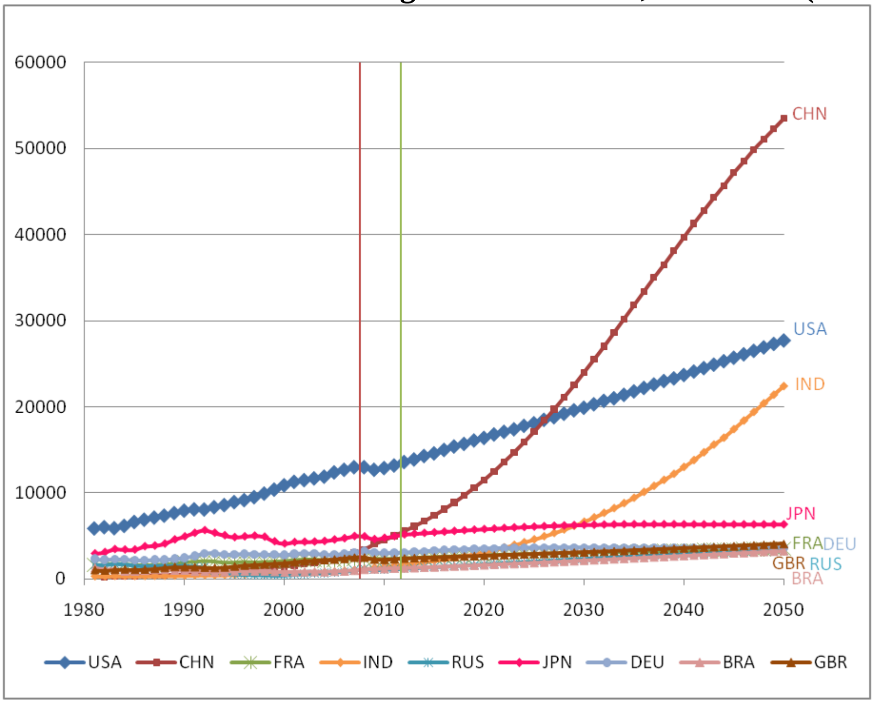
In the Balassa-Samuelson framework described in Section 1, TFP and energy productivity catch-up involve a real exchange-rate appreciation against the US dollar, at a speed that depends on the share of non-tradable goods in each economy (see Figure 26). As might be expected, India, China and Russia enjoy strong real exchange-rate appreciation up to 2035, but this is sustained only for India after this date. Accounting for these relative price projections, China overtakes US GDP at around 2025 (against 2035 at constant relative prices), and India will overtake Japan before 2030 (Figure 27). Hence, accounting for real exchange rate appreciation changes the relative levels but not the 2050 rankings of the three largest economies: China's economy will be twice that of the US in 2050, and India will reach 86% of the US level.

Figure 26 – Real exchange rate, 1980-2050 (in base 100 for 2005)



Source: own calculations.

Figure 27 – GDP with real exchange-rate variations, 1980-2050 (USD bn)

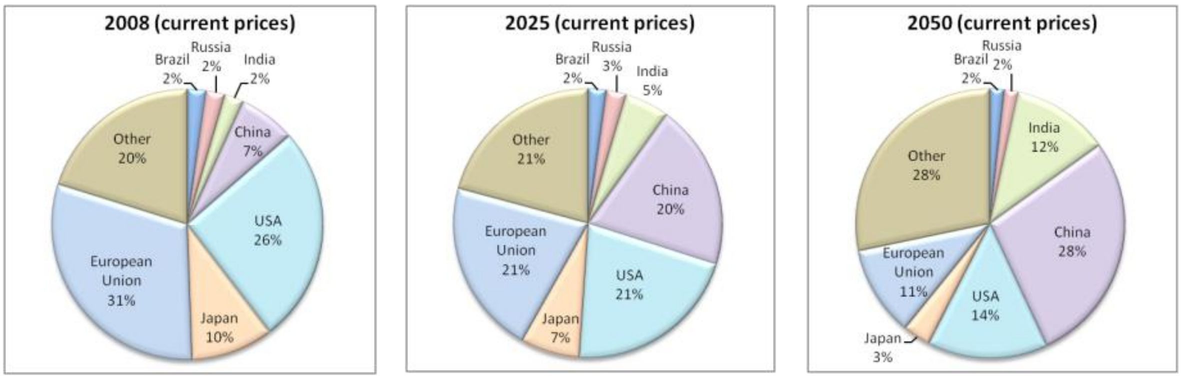


Source: own calculations.

The resulting shift in economic power between 2008 and 2050 is depicted in Figure 28. Adding valuation effects naturally increases the shift in the economy towards China and India. The US would account for 21% of world GDP in 2025 and 14% in 2050, compared with 26% in 2008; the European Union would drop from 31% of world GDP in 2008 to 21% in 2025 and 11% in 2050, and Japan would drop from 10% to 7% to 3% in the same periods. In contrast, the respective shares of China and India would grow from 7% in 2008 to 20% in 2025 and 28% in 2050, and 2% to 5% and then 12%. Brazil and Russia would remain relatively stable over the whole period with shares of around 2% each.[19] On this basis, the relative size of Europe would be a third less in value at the 2050 horizon, not half as estimated using GDP volume.

[19] Our projections for Brazil and Russia might appear conservative. This is because they are based on econometric relationships estimated for 1980-2008, a period when their average economic performance was relatively poor.

Figure 28 – Shares of the world economy, 2008, 2025 and 2050, (in % of world GDP, including valuation effects)



Source: own calculations.

4. ASSESSMENT

In this section we assess our projections in two ways. First, we perform sensitivity exercises to check the robustness of the projections to changes in certain key parameters. Second, we compare our projections with those in the literature.

4.1. Sensitivity analysis

First we test the robustness of our projections to changes in a number of key assumptions. Specifically, we simulate seven different world economy scenarios:

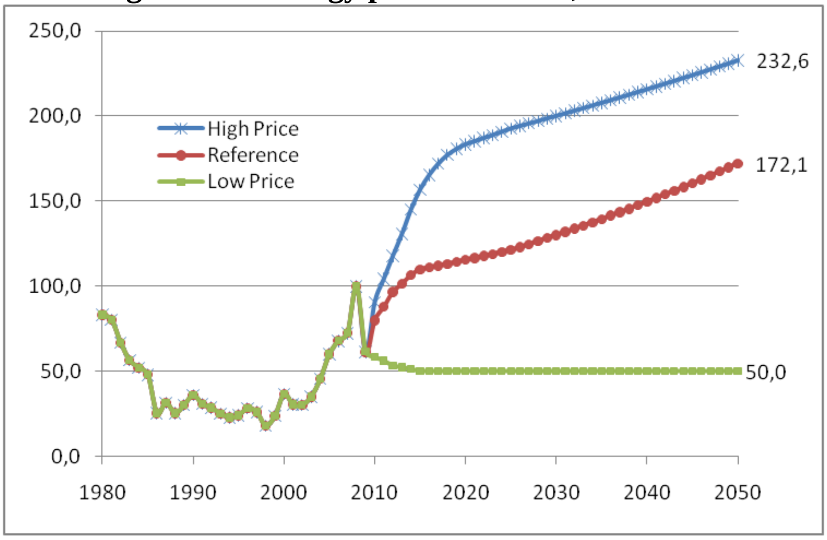
- the reference scenario is the one described above;
- 'low energy price' scenario assumes a lower oil price, according to the EIA low price scenario up to 2030 (and a price of USD 50 per barrel in 2050, instead of USD 172 in the reference case, see Figure 29);
- 'high energy price' scenario is based on the EIA high price scenario and USD 230 per barrel in 2050, see Figure 29;
- 'substitutable E' scenario combines two assumptions: a permanent, technological shock in 2012 leads to higher substitutability between energy and other factors ($\sigma = 0.22$ instead of 0.136), and the EIA low energy-price scenario.[20]

[20] Allowing for higher substitutability between energy and the other factors reduces global demand for energy, which is consistent with a lower energy price.

- 'closed economy', where the investment rate is set equal to the savings rate, for each country and each year, such that there is no capital mobility around the world.

- 'converging behaviors' whereby national idiosyncrasies in terms of institutions, preferences, governance would half-converge to the initial world average at the 2050 horizon. To this end, we linearly reduce half of the divergence to the sample mean for each country over the projection period. This last robustness check is warranted by the non-significance of a large number of country fixed effects (see Appendix C), combined with the possibility that country fixed effects correspond to non-permanent idiosyncrasies.

Figure 29 – Energy price scenarios, 1980-2050



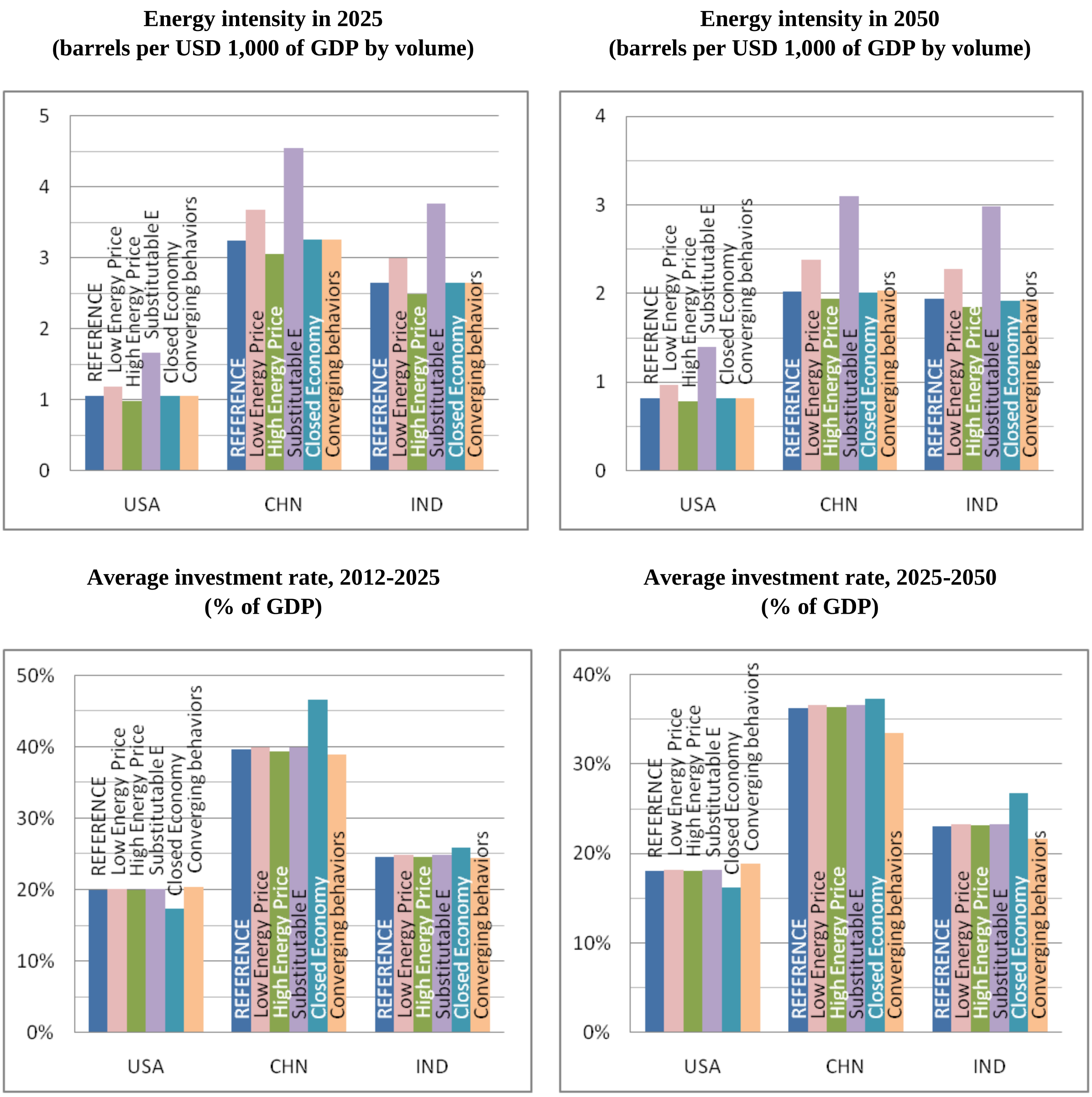
Source: EIA (1980-2030), own calculations (2031-2050).

Figure 30 provides comparisons of the various scenarios for three countries (the US, China and India), three variables (energy intensity, average investment rate and GDP in volume) and two time horizons (2025 and 2050). As expected, in all three countries energy intensity is higher in the low energy price scenario (or high substitutability *cum* low energy- price scenario) than in the reference scenario, and is also higher in the high energy price scenario. However this does not translate into major differences in GDP at 2025 and 2050. In China, the low energy price scenario results in a 4% increase in GDP by 2050, compared to the reference scenario, and a high energy price reduces GDP by around 3% at the same time horizon. These benign effects point to the minor contribution of energy to GDP growth, as opposed to the contributions of capital accumulation, labour supply and productivity growth.[21] The last panel of the figure presenting the alternative projections of GDP for China, India and the United States in 2050 also presents the robustness check on the fixed effects. The main

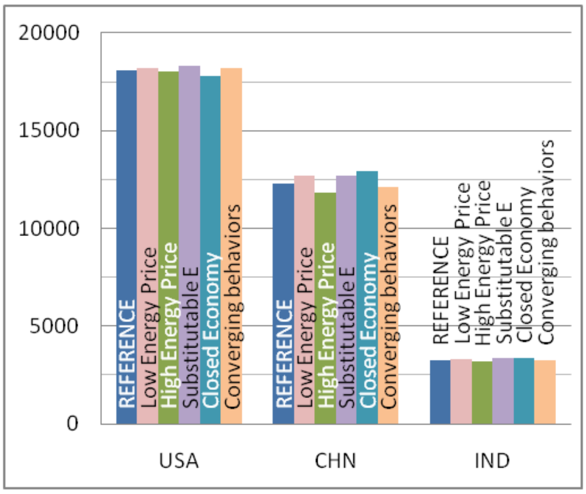
[21] Note that we do not take into account the impact of a low price of energy in terms of greenhouse gas emissions and the correlated impact on the climate and ultimately on GDP.

change is for China. Interestingly, it is at odds with what the intuition suggests, as the projection is less favourable in this case. The reason is straightforward: with declining fixed effects, Chinese savings are lower, as compared to our central exercise, and this reduces the accumulation of capital. Still, the limited change at the 2050 horizon suggests that our exercise is not put at risk by the use of fixed effects.

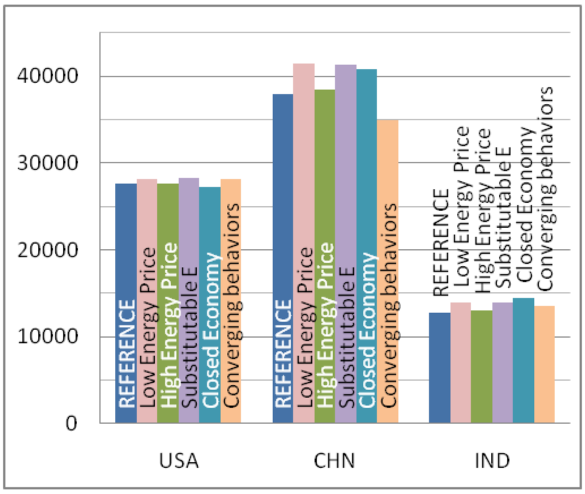
Figure 30 – Sensitivity analysis



GDP in 2025
(2005 USD bn)



GDP in 2050
(2005 USD bn)



Source: own calculations.

A closed economy scenario favours capital accumulation in China (high savings are invested locally), at the expense of the US (local investment can no longer be financed by foreign savings). The implications for GDP again are limited since net capital flows are a minor source of investment finance (compared to local savings) in the baseline scenario. Overall, our projections appear relatively robust to changes in the main assumptions concerning the price of energy or the regime of international capital flows.

4.2. Comparison with other projections

We compare our projections with those resulting from similar exercises conducted by Goldman Sachs (GS) and the OECD (based on Duval and de la Maisonneuve, 2010).

OECD projections are in PPP (which in terms of growth rates is the same as constant dollars); GS projections take account of relative-price variations through a Balassa-Samuelson effect. GS projections provide GDP levels for 2008-50, whereas the OECD publishes average growth rates for 2005-15, 2015-25 and 2025-50 Provided the appropriate horizon and unit (without or with valuation effects) are considered, our results can be compared to each of these sources.

Figure 31 compares the average growth rates obtained in our exercise[22] to those obtained by OECD and GS, over the same time spans, and Figures 32-33 report the composition of the global economy in 2025 and in 2050, according to these sources. Although broadly in line

[22] Geometric averages.

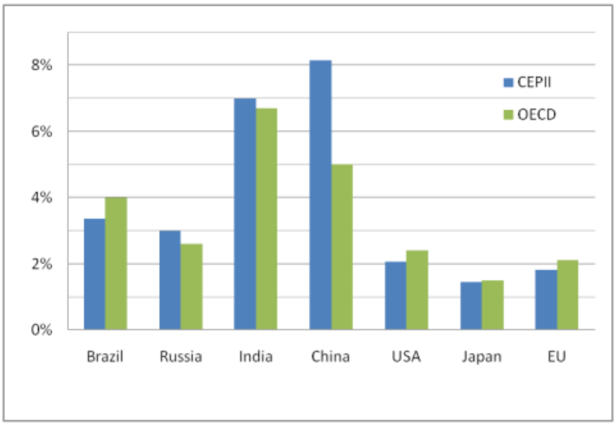
with their projections (in terms of country rankings), our results show some differences, especially with OECD data.

Up to 2025 (or 2030), our projections for China and India are optimistic compared to OECD projections at constant real exchange rates, but are close to GS in current exchange rates. On the other hand, our projections tend to underestimate growth in Brazil and Russia compared to the other sources. For the advanced economies, our results are slightly more optimistic for countries that show a surplus (Japan, Germany) and slightly more pessimistic for those with deficits (the USA, the UK, France). These differences may be due to our more ambitious modelling of capital accumulation: while the OECD assumes convergence of all countries to the US capital-to-GDP ratio and GS assumes an exogenous investment rate, we relate investment to savings through a progressive closing of the savings-investment gap in each country. This methodology leads to higher capital-to-GDP ratios in countries with a surplus than in the US, over the projection period (Figure 34).

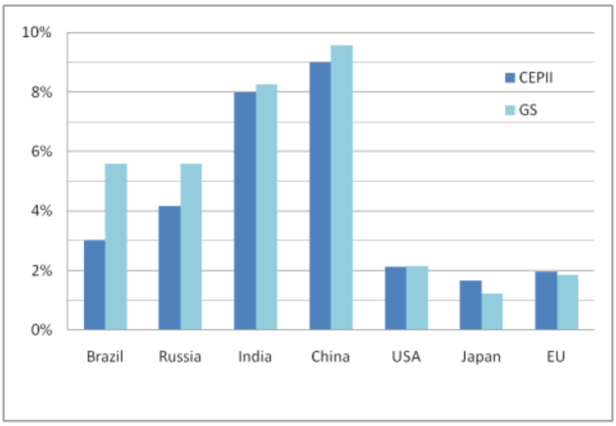
After 2025, our growth rates for China are still more optimistic than those of the OECD, but slightly below GS projections. For India, they are close to the OECD, but lower than GS. For the other countries, our projections are more pessimistic than both these sources. Some of the difference is based again on different assumptions about capital accumulation. Also the production function applied differs: whereas OECD and GS use a Cobb-Douglas production function (including respectively capital, labour force and human capital; and capital and labour force), we introduce energy constraints, which perhaps lead to the lower estimation of GDP growth in our exercise for the 2025-50 period. Finally, GS assumes a uniform 0.5 to 1 relationship between the productivity differentials and real exchange rate appreciation, whereas we use a country-by-country calibration based on the shares of traded goods and energy remuneration in each economy.

Figure 31 – Average GDP growth rates

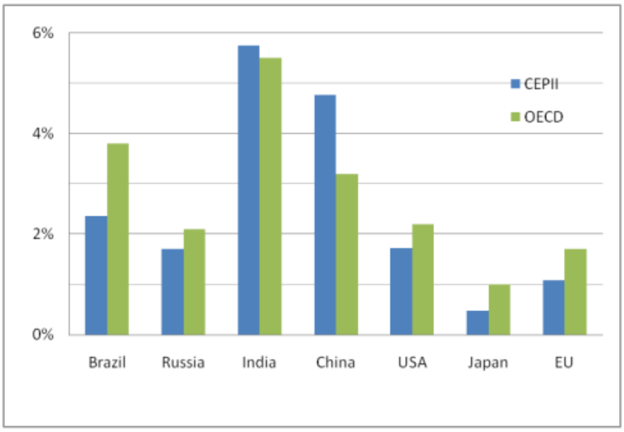
CEPII versus OECD, 2015-25, constant USD



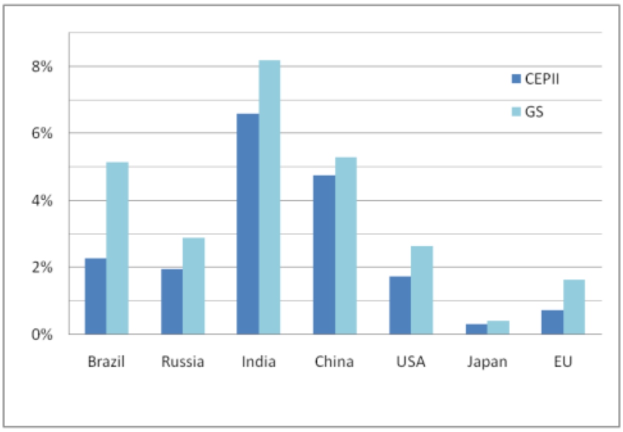
CEPII versus GS, 2012-25, current USD



CEPII versus OECD, 2025-50, constant USD



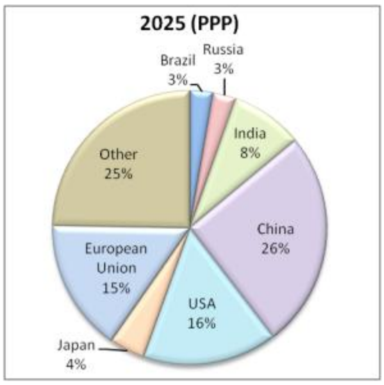
CEPII versus GS, 2025-50, current USD

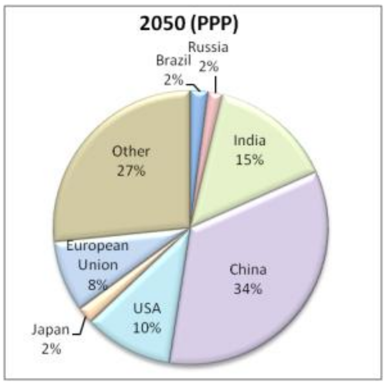


Source: own calculations.

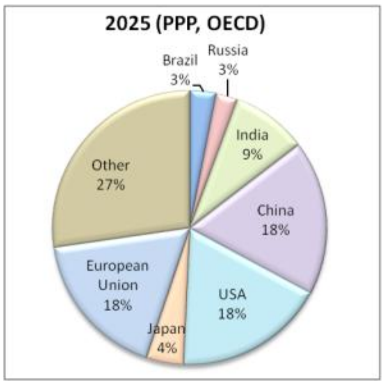
Figure 32 – Share in the world economy, Purchasing Power Parity, CEPII versus OECD

CEPII





OECD



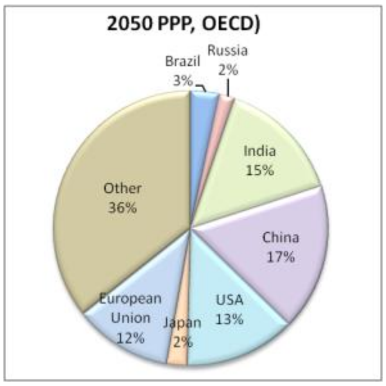


Figure 33 – Share in the world economy, current prices, CEPII versus GS

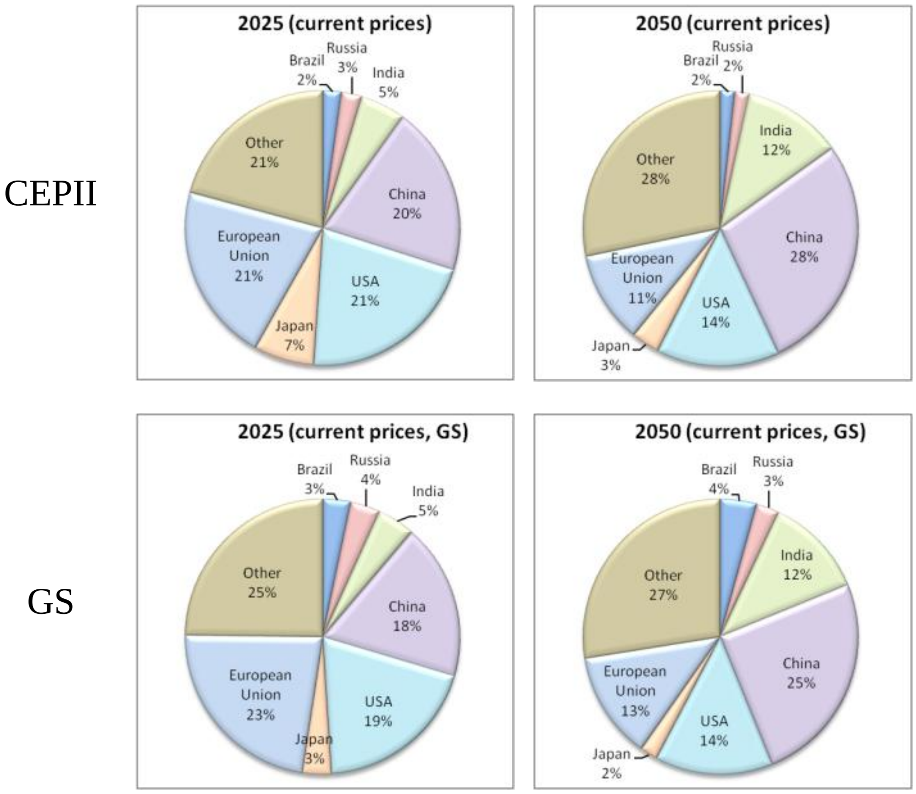
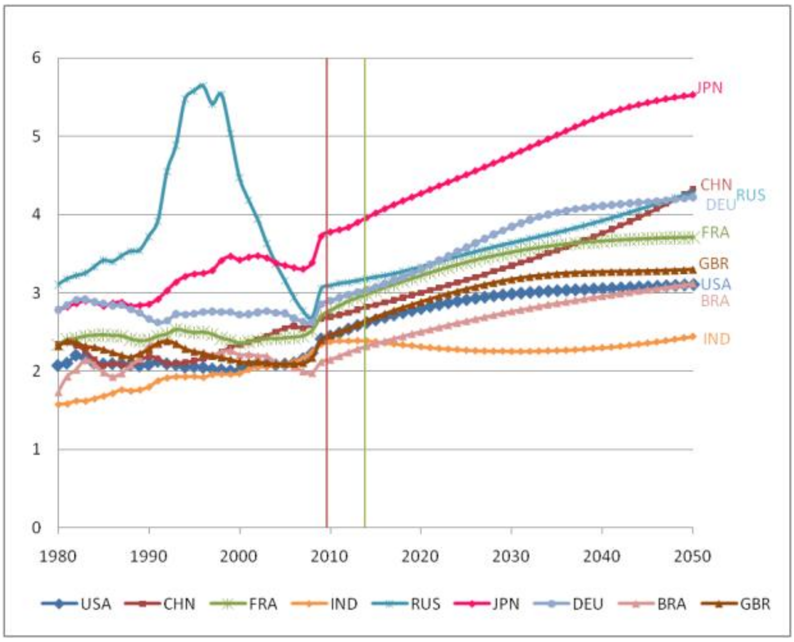


Figure 34 – Capital-GDP ratio in selected countries, 1980-2050, CEPII's projections



Source: own calculations.

CONCLUSION

A theoretically consistent model of world economic growth is especially important for projecting GDP in several countries over a long time period. As is the case with any projections over long time horizons, the work presented in this paper should be considered tentative. However, we have endeavoured to make it as transparent as possible and rely on robust research concerning the determination of savings, investment and TFP growth. Our contribution to theory is that we include energy in the production function and explicitly derive not only TFP, but also energy productivity. We also derive a fully fledged representation of the valuation effects based on the Balassa-Samuelson effects. In our view, we improve on the existing work by including an energy constraint in the projections, accounting for imperfect international capital mobility in the process of capital accumulation, and explicitly measuring the contribution of valuation effects. These changes lead to somewhat different results compared to existing projections. Although the results obtained should be treated with some caution, we believe that they provide useful benchmarks for downstream studies on world commodity demand, international trade, financing capacities, global power, etc. They also provide a fully-transparent and theoretically-grounded benchmark for comparing existing projections and discussing their underlying assumptions. Integrating environmental effects with GDP growth is not addressed in this study, but should remain on the research agenda.

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