Calibrating Long-Term Trade Baselines in General Equilibrium

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Abstract

Elaborating on seminal calibrations of baselines of global models by the GTAP community, the World Bank, the OECD and IIASA, we combine a fully-fledged macro-econometric growth model (MaGE) with a Computable General Equilibrium Model (MIRAGE-e) and contribute two baselines for the world economy. Doing so, we rely on a cross-cutting approach which mixes a theoretically founded macroeconomic framework with a dynamic global and multi-sector model, maximizing consistency between them. Migrations, projected by an external model are also taken on board. We show how retroactions between baseline assumptions and macroeconomic fundamentals – such as the current account and labor participation – impact the model outcomes and must therefore be implemented in the macroeconomic projections. Finally, we calibrate the baseline to take stock of the long term trade to income elasticity based on a partial backcasting.

JEL Classification: E23, E27, F02, F17, F47

Key Words: Growth, Macroeconomic Projections, Dynamic Baselines

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INTRODUCTION

Computable General Equilibrium (CGE) models are based on macroeconomic variables, among which Gross Domestic Product (GDP), Total Factor productivity (TFP), labour force, as well as their respective sectoral decompositions, play a crucial role. In addition, how the model is closed and what are the assumptions regarding the dynamics of the current accounts are important elements often disregarded in the related literature. Understanding the properties and the limits of dynamic baselines is worth the effort, although CGEs used to simulate shocks on the world economy focus only on the deviation from the baseline. A key issue, generally disregarded, is whether these models can reproduce the observed international trade to income elasticity.

Indeed, international research centres and organizations (for instance, the International Monetary Fund, IMF) provide short term GDP forecasts. These forecasts, generally based on macro-econometric models, fit well the short term changes in the world economy. However, concerning long-term baselines for the world economy, we lack of a clearly documented, validated, and theoretically funded picture that could drive the long term dynamics of a recursive CGE. This is particularly the case when it comes to having a broad coverage in terms of countries, regions of the world economy and sectors. Against this background, we build on pioneering papers in the field (Burniaux & Château, 2008; Van der Mensbrugghe, 2005, Walmsley 2006) and show how to combine two different modelling frameworks: a growth model nicknamed Macroeconometrics of the Global Economy (MaGE) and the most recent version of the CEPII CGE model, MIRAGE-e.

We depart from the literature in three ways. Firstly, we proceed by combining a macroeconomic model and a CGE. The macroeconomic growth model is providing a detailed projection of GDP and factor accumulation, while sectoral breakdown and results in terms of emissions are provided by a CGE model, the former and the latter both being designed to remain consistent. Secondly, we put the emphasis on a large coverage in terms of countries, combined with a versatile aggregation of sectors and regions, using recursive dynamics. It accordingly departs from the polar choice of having less countries and sectors, but in an inter-temporal macroeconomic framework. Thirdly, we pay attention to the calibration of the CGE in order to obtain a sensible relation of trade (an outcome of the CGE) to income (an outcome of the macroeconomic model and of the CGE) through the relevant elasticity.

MaGE is a theoretical growth model embodying energy, energy efficiency, technical progress, demography and capital accumulation. MIRAGE is a sectoral CGE model of the world economy featuring recursive dynamics. MaGE is a country level model, estimated econometrically, while

MIRAGE is calibrated. Importantly, MIRAGE is calibrated to reproduce the observed trade to income elasticity, using a (partial) backcasting to 1980 (the starting point of MaGE). MaGE is firstly estimated and then used in projection to recollect a long-run growth projection for 147 countries, which is imposed to the baseline of MIRAGE. Based on exogenous variables from MaGE, MIRAGE provides a fully consistent and theoretically funded projection of changes in consumption patterns, resource allocation and sectoral GDP composition, at the regional and country level, for all regions of the world economy.

The time horizon is 2035 though projections are done with a one year step. We account for the 2008-09 global crisis by not relying on post-2008 data for estimation.

MaGE projections rely on a stylized conditional convergence model of economic growth fitting three factors (capital, labour and energy), two types of technological progress (usual total factor productivity versus energy efficiency) and international capital mobility. We also project at the country level saving rates (based on a life cycle hypothesis) and current accounts, while imposing constraints in terms of global balance between saving and investment. The induced GDP, saving, energy efficiency and current account trajectories to 2035 can be imposed to a sectoral CGE model of the world economy, relying on identical assumptions about population, labour force, education, current accounts and energy prices if relevant. The CGE, in turn, is providing a detail representation of factor allocation (across sectors), demand patterns (preferences and budget shares), trade patterns and ultimately location of value added. The exercise is conducted here using MIRAGE but could easily be replicated using other similar CGE models.

Our exercise adopts open-minded assumptions about the evolution of the key drivers of growth, combining large shocks to its main drivers. We also pay attention to the labour market. Regarding labour force and its age structure, we firstly rely on United Nations (UN) and International Labour Organization (ILO) labour projections. One important issue taken into account in MaGE is the female participation in the labour market: it is modelled consistently with an education catch-up, estimated and then projected. Similarly, accumulation of human capital is the main driver of TFP growth and therefore reshapes the world economy. We econometrically estimate and project the educational level of workers, conditional on their age. MIRAGE is fitted with the same projections in terms of population, education and labour force. We finally take on board the impact of migrations and the skill level of migrants, and rely on projections by Docquier and Machado (2017) to calibrate our migration scenarios.[3]

This paper contributes to a recent and growing body of literature on long term prospects for the world economy. Qualitative scenarios combining the two modelling frameworks as a background to a more multidisciplinary approach centred on Europe were developed at the 2050 horizon for the European Commission (EC, 2012). The International Monetary Fund (IMF, 2011) uses a partial equilibrium approach to address the consequences of reductions in exchange rate misalignment with trade patterns in the presence of global value chains and possibly imperfect pass through. World Bank (2007), which is closer to our approach, relies on a multisectoral model of the world economy comparable to MIRAGE, to sketch projections for the world economy at the 2030 horizon. None of these studies use an explicit growth model and the projections are driven by assumptions about TFP imposed on the CGE.

In contrast, Petri and Zhai (2013) rely on Asian Development Bank growth projections using a growth model similar to ours (ADB, 2011). They use this GDP series to derive projections at the 2050 horizon, with a CGE model on which assumptions about TFP, higher food prices, higher energy prices, or protectionism are imposed. Fontagné et al. (2013) propose possible projections to be used as background for environmental studies, and considers the 2100 horizon in order to explore methodological issues associated with the use of long term dynamic baselines in CGE models. Anderson and Strutt (2012) consider the 2030 horizon and build a baseline for the GTAP CGE model by drawing on both ADB (2011) and Fouré et al. (2013). Long-term trade scenarios for the world economy up to 2060 based on a combination of OECD and CEPII macroeconomic projections are modelled in general equilibrium in Château et al. (2014). Interestingly, the latter exercise confirms the important impact of investment in education on trade. Slower educational upgrading in emerging

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[3] Docquier and Machado (2017) provide worldwide projections of population, educational attainment, international migration and income. Their baseline is in line with the 'high-fertility' population prospects of the UN. They rely on a dynamic, stylized model of the world economy accounting for the key interdependencies between demographic and economic variables. They assume in the baseline constant education and migration policies, long-run absolute convergence in total factor productivity between emerging and high-income countries and the absence of economic take-off in Africa.

economies reduce world exports at the 2060 horizon and slow-down the relocation of higher value-added activities into (today) emerging economies.

The rest of the paper is organized as follows. The related literature is presented in Section 1. Section 2 provides a non-technical overview of the methodology. In Section 3, the CGE model used is presented. The macroeconometric model is briefly presented in section 4, jointly with the closure of the CGE. How the agricultural productivity is modelled separately is explained in section 5. In section 6, we obtain two alternative baselines of the world economy on which we apply to illustrative policy experiments, including one experiment featuring a fragmented world and a trade war. The last section concludes.

1. Modelling growth projections and designing scenarios for the world economy

This paper is positioned at the junction between three strands of the applied economic literature: (i) long-term economic growth projections; (ii) dynamic baselines in applied general equilibrium modelling; and (iii) design of medium and long term scenarios for the world economy. The first two are not independent: dynamic baselines rely on the first literature strand (GDP driven baselines), or alternatively provide GDP projections directly based on assumptions about changes in sector-specific TFP (TFP driven baselines). The third stream of literature combines quantitative elements (potentially provided by projections and baselines) with qualitative and sometimes multidisciplinary expertise on the main drivers of economic, social and environmental change. Below, we briefly survey the literatures related to growth projections, dynamic baselines and scenario design. Recall that our ultimate aim is to calibrate a dynamic path of the world economy consistent with a theoretically based macroeconomic growth model, and to use it to derive two alternative baselines for the world economy combining consistently hypotheses imposed to the macroeconomic model and the CGE model. Accordingly, the three strands of the literature will be combined in our exercise.

1.1. Growth projections

Increased interest in long-term economic-related issues, such as environment depletion and energy scarcity, has motivated several growth projection exercises. The business community (Wilson & Purushothaman, 2003; Ward, 2011) and international institutions provided operational frameworks. However, with some exceptions (Duval & de la Maisonneuve, 2010; Johansson et al., 2012; Fouré et al., 2013; Docquier & Machado, 2017), academic work in this area was sparse, leading to a lack of well-documented and economically-grounded projection models. This can be explained by the intrinsic uncertainties surrounding projections and by the focus on featuring multiproduct firm heterogeneity and quality ladders in endogenous growth models (Klette & Kortum, 2004; Akcigit & Kerr, 2018).[4]

Leaving aside endogenous innovation and firm heterogeneity, at least three drivers are common to all empirical studies of economic growth: capital stocks, labour force and TFP. For instance, labour force projections, constant investment rates, and a convergence scenario for TFP are combined in Wilson & Purushothaman (2003). Duval & de la Maisonneuve (2010) identify human capital per worker as a driver, and calibrate conditional convergence scenarios among countries for each of these four determinants. Using a similar framework, Johansson et al. (2012) restrict their analysis to a smaller number of countries, but emphasize the impact of structural and fiscal policies (retirement age, trade regulation, public debt, credit availability). Docquier & Machado (2017) develop a dynamic model of the world economy featuring endogenous income disparities. An important determinant of growth in their model is the migration and investment in human capital.

1.2. Dynamic baselines

Large scale policy simulations generally rely on multisectoral dynamic models of the word economy. CGE is the most commonly used modelling framework. Policies are simulated as shocks and then the deviation of the variables of interest from their reference trajectory is computed. It could be argued that the modeller's interest is in the deviation, not the initial equilibrium. However, considering the medium or long run impact of economic policies, the baseline matters: an economic policy affecting China would have a dramatically different impact on the world economy were China twice as large, which only takes a decade at observed growth rates.

However, since CGE models generally do not describe the intrinsic mechanisms of growth they neither provide a satisfactory representation of efficiency gains, nor plausible trajectories for countries at different levels of development. Accordingly, it is necessary to constrain these models to reproduce a pre-defined GDP growth path *or* a pre-defined TFP path for each country (or region) in the world.

[4] Akcigit (2017) provides an overview of these developments.

This is the aim of dynamic baselines. While many baselines of the first generation focused on the period up to 2020 (e.g. the GTAP model),[5] some exercises extend to 2050 (e.g. for Linkage, a multisectoral model of the world economy similar to MIRAGE – see van der Mensbrugghe, 2006) or even 2100 for environmental studies (Fontagné et al., 2013). Whatever the horizon is, the building blocks of a baseline are similar.

In a first step a trajectory of the world economy is projected, based on robust economic mechanisms. There are two competing approaches here.

The first option is to build a scenario for factor productivity growth in order to recover GDP from the CGE model. The second option is to build a scenario for GDPs such that the CGE model recovers the relevant TFP gains. Recovering GDP from TFP growth assumptions has the advantage that availability of detailed data on demographics or education is not a limiting factor. It also allows different sector specific trajectories to be encompassed without over-constraining the model. The drawback is that this approach is very sensitive to assumptions related to TFP growth and its determinants.[6]

The second option – imposing GDP growth trajectories onto a CGE and recovering the productivity gains – is indeed more data demanding (it is necessary to project growth for every country). Its main advantage is that it enables proper modelling of growth by accounting for conditional convergence and possibly different types of technical progress, in line with the vast literature on macroeconomic growth. Accordingly the second approach is adapted to the modelling of long run growth of economies at different stages of their development. The only crucial assumption in GDP-driven CGEs is the relative dynamism of productivity in broad sectors. Several approaches to this difficult issue have been proposed. The LINKAGE model (Van der Mensbrugghe, 2006-a) adds a sector-specific component to endogenous national TFP, resulting in a constant exogenous agricultural TFP and a 2 percentage points extra productivity in manufacturing compared to services.

A related literature stream specifically tackles environmental issues like the productivity of energy and its impact on CO_2 emissions or the link nexus of natural resources scarcity and prices. Similar to

[5] For instance, the main projections used in the GTAP model and earlier versions of MIRAGE (Decreux and Valin, 2007) were provided by the World Bank (Ianchovichina & McDougall, 2000).

[6] For instance, the EPPA model assumes identical logistic productivity growth for all countries and sectors, and does not implement capital productivity.

environmental baselines, a first approach is to rely on CO_2 emissions (or, equivalently on energy demand) from other institutions and to infer improvements in the carbon intensity of goods (see the PACE model, Böhringer et al., 2009). The second approach consists in developing a scenario for Autonomous Energy Efficiency Improvements – AEEI (see the EPPA model – Paltsev et al., 2005).[7] AEEI scenarios encompass non-price induced, technology-driven productivity changes. An exogenous time trend for energy productivity is imposed. It controls for demand shifts, scaling production sectors' use of energy per unit of output. These AEEI are specific to broad regions of the world economy with two distinct profiles. China and the developed countries face a regularly increasing AEEI while other regions' AEEI decrease up to around 2035 before increasing.

A challenging issue related to CO_2 emissions and energy consumption is the limitation inherent to CGE modelling. These two variables are measured in physical quantities, although variables in CGE models traditionally are in dollars at constant prices. The problem is that using Constant Elasticity of Substitution (CES) functional forms for monetary values leads to incoherence in substitutions when commodities are relatively homogenous, as is the case for energy goods (Laborde & Valin, 2011). There are two ways to deal with this issue. One can build a world price matrix for physical quantities of energy goods, such that they account for changes in both value and quantity. A more parsimonious approach is to impose that production, consumption and trade are coherent in both monetary units and physical quantities in the model.

A last challenge is to properly address the question of natural resource depletion, which is shaping the long run dynamics of energy prices (Paltsev et al., 2005). One possibility is to model this depletion and deduce the corresponding energy prices as in the EPPA model. Alternatively, exogenous energy prices can be imposed such that natural resources adjust to match these prices, as in the ENV-Linkage model.[8]

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[7] The Linkage model implements a mixed framework, in which energy demand is imposed to recover productivity changes, with the exception of crude oil consumption which is driven by an exogenous productivity scenario.

[8] Such option is also available in EPPA. ENV-Linkage relies on IEA's world price projections up to 2030 and then assumes a 1% growth in oil prices.

1.3. Scenario design

In what follows, we briefly survey medium term scenarios of the world economy relying on a combination of growth projection, CGE modelling and specific assumptions. These exercises were developed by the World Bank, the OECD, Petri & Zhai (based on Asian Development Bank projections) and Anderson & Strutt (based on Asian development Bank and our own projections).

World Bank (2007) relies on LINKAGE to draw scenarios for the world economy at the 2030 horizon. TFP assumptions are directly imposed on the CGE to obtain GDP, instead of recovering TFP from the CGE on which GDP and factor accumulation would be imposed. In addition, energy efficiency is assumed to improve exogenously by 1% per year worldwide. Finally, international trade costs are assumed to decline by 1% per year. This exercise was calibrated on the GTAP-2001 database.

Petri & Zhai (2013) combine Asian Development Bank growth projections at the 2050 horizon (ADB, 2011) with a CGE model in order to develop scenarios. In addition to a focus on Asia Petri & Zhai use a business-as-usual macroeconomic baseline and then shock the CGE by reducing the transaction costs.[9]

Anderson & Strutt (2012) consider the 2030 horizon and build a baseline for the GTAP CGE model. They combine growth rates for GDP, investment and population from ADB (2011), with our (previous set of) macroeconomic projections for the world economy (Fouré et al., 2013) for those countries not included in the ADB projections. Finally, skilled and unskilled labour growth rate projections are from Chappuis and Walmsley (2011). Historical trends for agricultural land from the Food and Agriculture Organization (FAO), and mineral and energy raw material reserves from British Petroleum (BP, 2010), are extended over the next two decades. TFP growth rates are recovered from the CGE model. Scenarios are implemented (as in Petri & Zhai) directly in the CGE. Implications for world trade are derived.

The OECD uses the ENV-Growth model in order to design climate change scenarios in line with the five Shared Socioeconomic Pathways (SSP) developed by the Integrated Assessment Modelling Consortium (Château et al., 2012). These scenarios are organized around the trade-off between climate change mitigation and adaptation, both translated into demographic (population and education),

[9] This simple approach allows supplementing the CGE with an income distribution module which allocates total consumption to four income bins.

technological (catch-up speed and frontier growth) and natural resources (prices and available resources) related scenarios, and both implemented in the growth model. They clearly identify the drivers of growth as capital accumulation, TFP, labour force (and to a lesser extent human capital and energy), but cannot directly investigate the saving-investment relationship due to the original specifications of the SSPs, nor explicitly deal with uncertainty in labour force participation with trade integration (except via positive externalities on in TFP). These scenarios are integrated in the OECD's ENV-Linkages CGE model, following a method similar to ours; to our knowledge, results are not yet available.

Finally, Château et al. (2015) rely on growth trajectories up to 2060 for 34 OECD economies and 8 non-OECD G20 emerging countries rely on projections from the OECD long-term scenario model – consistently with the long-term OECD Economic Outlook baseline, while projections for another 105 countries are based on MaGE. Although focusing on a limited number of different determinants of growth (structural reforms for the OECD, returns to education, female participation to the labour market and oil rent for MaGE), the two underlying models share a similar representation of conditional convergence based on demography and TFP. Such similarity makes it possible to combine the two sets of projections for some 150 countries. The baseline is then introduced in a CGE which is used to simulate the impact of two stylized trade policies: full regional versus partial multilateral liberalisation.

The take home of this recent literature is that consistency between the growth assumptions and the CGE is to be prioritized. Assumptions made in the scenarios on fertility, female participation in the labour market or educational catch up will have cascading effects for growth and trade, and have to be tackled consistently in the two models. The same applies to migration flows. In the next section, we give a non-technical overview of how to ensure this consistency in the modelling strategy.

2. OVERVIEW OF THE METHOD

This paper adopts the GDP-driven CGE approach described above, meaning that we start with a growth model derived theoretically, estimated, and used in projection for more than 160 countries – we call this first step the "Macro" step. Although projected savings rate, energy efficiency, current accounts and GDPs are country specific, we impose consistency of the projections in terms of saving and investment at the global level. The building blocks of this model are conditional convergence (based *inter alia* on human capital accumulation), energy use and efficiency, demographic transition, and saving behaviour. This first step is performed with the MaGE model (Fouré et al., 2013).

In a second step, we calibrate the dynamic trajectory of CGE model (both sectoral TFP and level of natural resources) such that it matches the baseline macroeconomic projections (respectively GDP and energy prices) in coherence with sector-specific constraints, current account constraints, exogenous agricultural productivity and observed trade to income elasticity ("calibration step"). Importantly, the calibration of the trade to income elasticity of the CGE model is based on historical data and a partial backcasting. To proceed we use an updated version an energy-oriented of MIRAGE, named MIRAGE-e[10] (Fontagné et al., 2013) relying on the GTAP 9.2 database. This CGE provides sector decomposition of growth, factor allocation, country specialization and world trade patterns, these last being our ultimate objective.

In a third step, we implement two scenarios for the world economy in MaGE (coined as "Sluggish Macro" and "Brisk Macro" below) and consistently in MIRAGE providing us with two baselines for the world economy

Below we describe the growth model (MaGE), the CGE model (MIRAGE) and its calibration, and the design of the alternative macroeconomic baselines.

2.1. The growth model

Projections of world macroeconomic trends are elaborated with the MaGE model proposed in Fouré et al. (2013)[11]. Based on a three-factor (capital, labour, energy) and two-productivity (capital-labour and energy-specific) production function, MaGE is a supply-side oriented macroeconomic growth model, defined at country level for 167 countries. It consists of three steps. First, production factor and productivity data are collected for 1980 to 2010. Second, behavioural relations are estimated econometrically for factor accumulation and productivity growth, based on these data. Third, these relations are used to project the world economy.

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[10] The version used is nicknamed MIRAGE-e 1.1.

[11] A more detailed description is provided in Appendix D. The version used is MaGE 2.4, corresponding to the projection database EconMap 2.4 available online at http://www.cepii.fr/CEPII/fr/bdd_modele/presentation.asp?id=11.

Using World Bank, UN and ILO data, we built a dataset of production factors and economic growth for the period 1980-2010. Our theoretical framework consists of a CES production function of energy and a Cobb-Douglas bundle of capital and labour. This theoretical framework allows recovery of energy-specific productivity from the profit-maximization programme of the representative firm, while capital and labour productivity are recovered as a Solow residual. These two different productivities, along with data on GDP and production factors fully describe the world economy in the past (1980 to 2010).

Behavioural relations are econometrically estimated from this dataset for population, capital accumulation and productivity. Population projections are given by UN population projections, split across 5-year age bins and the two genders. For each of age groups, we estimate education and then deduce labour force participation. Educational attainment follows a catch-up process to the leaders in primary, secondary and tertiary education, with region-specific convergence speeds – we distinguish 8 regions in the world, on a geographical basis. While male labour force participation follows the logistic relation determined by the ILO, female participation changes with education level: higher education implies lower participation of the youngest females, while making females of other age groups participate more to the labour force.

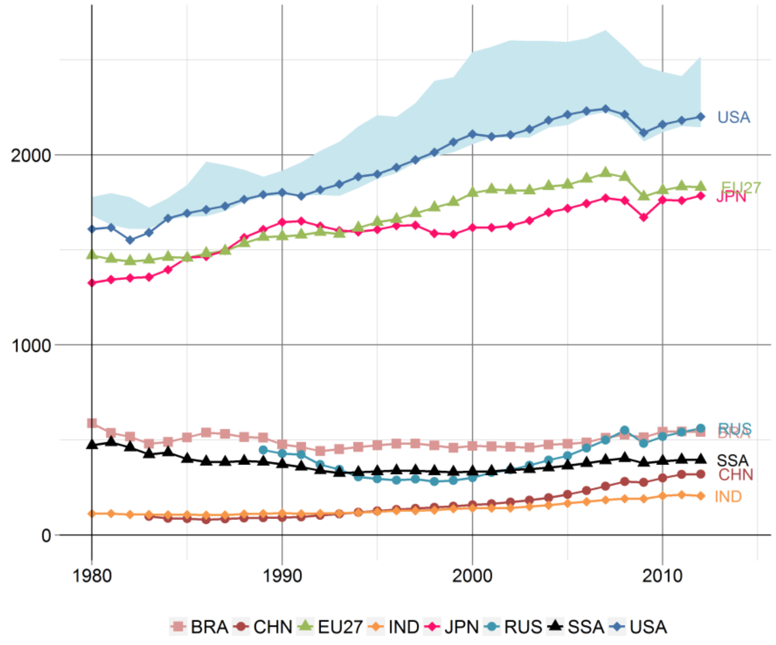
Capital accumulates according to a permanent-inventory process with a constant deprecation rate of 6% per annum. On the one hand, investment depends on saving with a non-unitary error-correction relationship which differentiates long-term correlation between saving and investment and annual adjustments around this trend. Because of the significant differences we found between OECD and non-OECD members, both levels of estimation are conducted separately for the two country groups. On the other hand, savings depend on the age structure of the population, consistent with both the life-cycle hypothesis and economic growth. A younger population or a more dynamic economy will increase national savings, while an ageing population will lead to dissaving.

Capital-labour productivity and energy efficiency are assumed to catch-up with the best-performing countries. While the former process is conditional on and fuelled by the education level,[12] the latter

[12] This corresponds to the stylized fact: while spontaneous innovation is triggered by tertiary education, imitation is favoured by secondary education.

follows a U-shape relationship between the level of development – proxied by GDP per capita – and energy productivity.[13] The observed productivity catch-up is shown in Figure 1.

Figure 2 – Level of TFP and TFP leaders, 1980-2012



Notes: TFP level is corrected for oil rents bias. Leader countries each year are the 5 countries with highest TFP, excluding Luxemburg. These countries include the USA, Belgium, Denmark, France, Ireland, Iceland, the Netherlands, Norway and Sweden, depending on the year considered.
Source: MaGE, authors' calculation.

All these behavioural estimations provide the dynamics of factor accumulation productivity and energy efficiency that will shape the macroeconomic projections. Adding the theoretical link between energy productivity, price and consumption resulting from our profit maximization program, along with exogenous energy prices projected by the IEA, we can fully describe the world economy in projection.

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[13] Agriculture- and services-oriented economies tend to be more energy efficient compared to their industrialization phase.

2.2. The CGE model

We use the most recent version of the multisectoral, multi-regional CGE model MIRAGE (Bchir et al., 2002; Decreux and Valin, 2007), which was developed and has been used extensively to assess trade liberalization and agricultural policy scenarios (e.g., Bouët et al., 2005, 2007). This version of the model, named MIRAGE-e, proposes a different modelling of energy use, and introduces modelling of greenhouse gas emissions. By sake of simplicity, we use the version of the model fitting perfect competition but the model is featuring imperfect competition as well

MIRAGE has a sequential recursive dynamics. This property will be exploited to link the CGE to MaGE: capital accumulation and current accounts from MaGE will be imposed to MIRAGE.[14] Accordingly, the macroeconomic closure is a key assumption to be considered when linking the growth model with the CGE, and our approach is from this point of view an important contribution to the literature. It consists for MIRAGE in having for each region a current account imbalance, measured as a percentage of world GDP, varying yearly according to the projections from MaGE. This has important consequences: the trade balance, exports and imports, and ultimately the sectoral value added in MIRAGE all adjust to a trajectory of the current account made consistent with the behavioural assumptions made in MaGE.[15]

On the supply side (Figure 2), in this perfect competition version of MIRAGE, each sector is modelled as a representative firm, which combines value-added (and energy) and intermediate consumption in fixed shares. Value-added combines imperfectly substitutable factors: land, natural resources and a bundle of unskilled labor and capital and energy combined with skilled labor. The capital-energy bundle ultimately combines capital, electricity, coal, and other energies (oil, gas and refined oil).

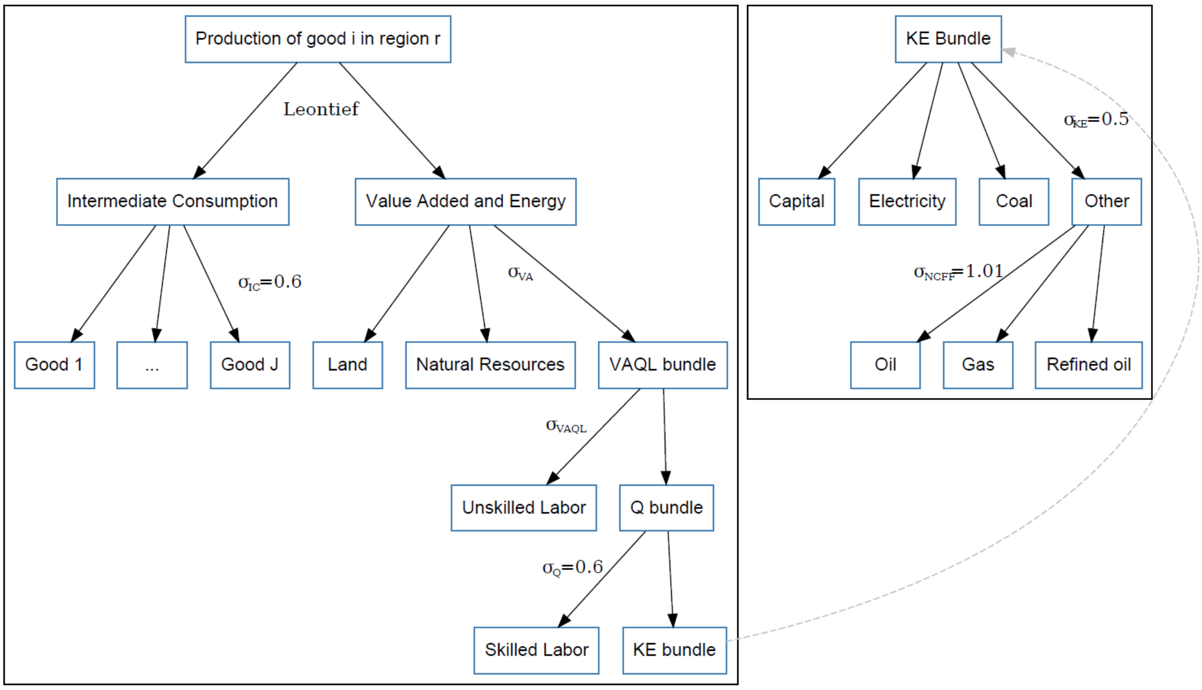
Growth rates of the fully employed primary factors are set exogenously, based on UN population and MaGE projections (MaGE informs on the labour force, its education and on capital formation). Installed capital is assumed to be immobile (sector-specific), while gross investment is allocated across sectors according to their rates of return. We detail below how the overall stock of capital

[14] We also impose energy efficiency from MAGE. Finally, notice that MaGE and MIRAGE have indeed a series of exogenous variables in common, mainly demographic ones.

[15] Contrary to most previous attemps in this direction, the current account trajectories projected by MaGE are not necessarily converging to zero, as the macroeconomic littérature as shown (see the Feldstein-Horioka puzzle).

evolves by combining gross investment and a constant depreciation rate of capital. Skilled and unskilled labour is perfectly mobile across sectors, while land is assumed to be imperfectly mobile between agricultural sectors. Natural resources are sector-specific.

Figure 2 The supply-side of MIRAGE-e



In each sector, energy consumption by the representative firm comprises five energy goods (electricity, coal, oil, gas and refined petroleum), which are aggregated in a single bundle that mainly substitutes for capital. There is no consensus in the literature to what extent capital and energy are substitutable. It can vary according to the vintage of capital (e.g. from 0.12 to 1 in the GREEN model), or be fixed between 0.5 (GTAP-E model) and 0.8 (PACE model). Since energy consumption is very sensitive to this elasticity of substitution, its calibration is vitally important. We choose to reproduce stylized energy consumption trends as in International Energy Agency projections to 2025 (IEA, 2011), which leads us to calibrate this elasticity as in GTAP-E.

The architecture of the energy bundle defines three levels of substitution. Energy used can be delivered by electricity or fossil fuels. Fossil fuels can be i) coal or ii) oil, gas or refined oil. Thus, oil, gas and refined oil are more inter-substitutable than with coal and, finally, electricity. Values of the elasticities of substitutions were chosen in line with the literature: electricity-fossil fuel substitution is based on Paltsev et al. (2005), the other two elasticities are from Burniaux & Truong (2002).[16] Finally, the value of the energy aggregate is subject to the efficiency gains projected by the growth model. As stressed above, in CGE models CO_2 emissions and energy consumption in physical quantities compared to variables measured in dollars at constant prices present a challenge. In practice, using CES functional forms with variables in monetary units leads to inconsistencies when trying to retrieve physical quantities. In addition to the accounting relations in constant dollars, MIRAGE integrates a parallel accounting in energy physical quantities (in million tons of oil-equivalent) based on the use of two country- and energy-specific endogenous adjustment coefficients, such that CO_2 emissions can be computed in millions of tons of CO_2. Carbon dioxide emissions are recovered as proportional to energy consumption in quantity, using energy-, sector- and country-specific parameters calibrated on the data.

Production factors in MIRAGE are evolving, in yearly steps, as follows. Population and participation in the labour market evolve in each country (or region of the world economy) according to the demographics used in MaGE. This determines the labour force as well as its skill composition (skilled, unskilled). Non-fossil-fuel primary resources and land are considered at their 2011 level: prices adjust demand to this fixed supply. Instead of modelling the fossil energy sectors, we rely on the more specialized modelling of the International Energy Agency (IEA, 2015), which provides us with projections for coal, oil and gas prices up to 2040. Given demand, natural resources availability adjusts accordingly in MIRAGE. Capital is accumulated according to the usual permanent inventory assumption. Capital usage is fixed (we use a 6% depletion rate), while gross investment is determined by the combination of saving (the saving rate from MaGE applied to the national income) and the difference between the current account and the domestic absorption. Finally, while total investment is saving-driven, its allocation is determined by the rate of return on investment in the various activities. For simplicity, and because we lack reliable data on Foreign Direct Investment at country of origin, host and sectoral level, we allow capital flows between regions only through the channel of current account imbalances. We are aware that FDI is channelling technology transfer and productivity catch-

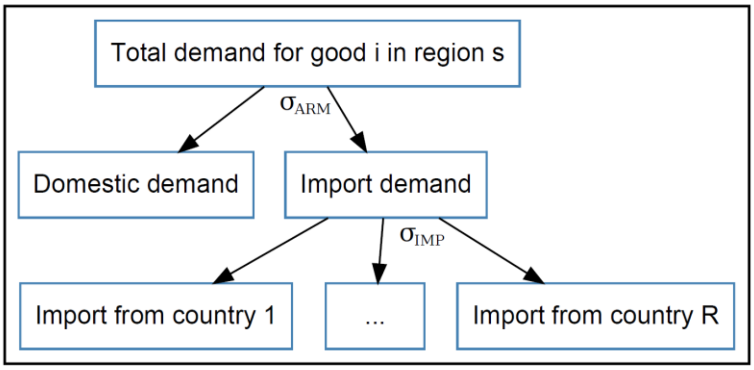
[16] In order to avoid unrealistic results, we assume 'constant energy technology' in non-electricity energy production sectors (coal, oil, gas, petroleum, coal products): it is impossible to produce crude oil from coal, or refined petroleum from gas and electricity. In these sectors, substitutions between energy sources are not allowed (Leontief formulation).

up, not only financial capital; this mechanism will be integrated separately when building the scenarios.

On the demand side, a representative consumer from each region maximizes her intra-temporal utility function under her budget constraint. This agent, which gathers both households and governments, saves part of its income. This behaviour is determined by the saving rate projected by the growth model on the basis of combining individual countries' demographic profiles with a life-cycle hypothesis. Expenditure is allocated to commodities and services according to a LES-CES (Linear Expenditure System – Constant Elasticity of Substitution) function. This assumption means that, above a minimum consumption at sectoral level, consumption choices between sectors are according to a CES. This assumption is a tractable representation of the preferences in countries at different levels of development.

Then, within each sector, goods are differentiated by their origin (Figure 3). A nested CES function allows for a particular status for domestic products according to the usual Armington hypothesis (Armington, 1969). We use elasticities provided by the GTAP 9 database (Global Trade Analysis Project) and estimated by Hertel et al. (2007). Total demand is built from final consumption, intermediate consumption and investment in capital goods.

Figure 3: The two-level Armington in MIRAGE-e



Efficiency in the use of primary factors and energy is based on the combination of four mechanisms. First, agricultural productivity is projected separately. Whereas data on labour-force in agriculture are available, there are no aggregated data on capital in agriculture, although there are some disaggregated data (machinery, land, etc.). Using FAO data for agricultural production and inputs,we implement a multi-input, non-parametric methodology for estimating the Malmquist productivity index, based on productivity distance to a global (moving) frontier. We consider two agricultural outputs (crops and livestock) and five inputs (labour, land, machinery, fertilizers, livestock). Second, energy efficiency computed by MaGE is imposed on MIRAGE (it enters the capital-energy bundle). Third, a 2 percentage point growth difference between TFP in manufactures and services is assumed (as in van den Mensbrugghe, 2006). Fourth, given the agricultural productivity and the relation between productivity in goods and services, MIRAGE is able to recover endogenously country specific TFP from the exogenous GDP (from MaGE) and production factors. While this TFP is recovered from the pre-experiment, it is set as exogenous in the simulations of the scenarios, as explained later.

Dynamics in MIRAGE is implemented in a sequentially recursive approach. That is, the equilibrium can be solved successively for each period by adjusting to the growth in the projected variables described above. For the current exercise, the time span is 24 years, the starting point being 2011.

Table 1 – Sector and country aggregation in MIRAGE

Regions	Sectors
Developed countries	***Primary***
France	Crops
Germany	Livestock
Italy	Other Agriculture
Spain	Other Primary
United Kingtom	***Energy***
Other EU	Coal
USA	Oil
Canada	Gas
Japan	Petroleum and coal products
Australian and New Zealand	Electricity
Korea	***Industry***
Developing/Emerging countries	Food
Brazil	Textile
Russia	Metals
India	Cars and Trucks
China	Transport equipment
Association of Southeast Asian Nations	Electronic devices
Turkey	Machinery
Other Middle-East	Other Manufacturing
North Africa	***Services***
South Africa	Transport
Mexico	Finance, Insurance and Business services
Rest of Africa	Public administration
Rest of the world	Other services

Note: We present here the aggregation used for the calibration and computation of the two baselines. However, for computational reasons, the backcasting exercise is resorting on a more aggregated approach, as detailed below.

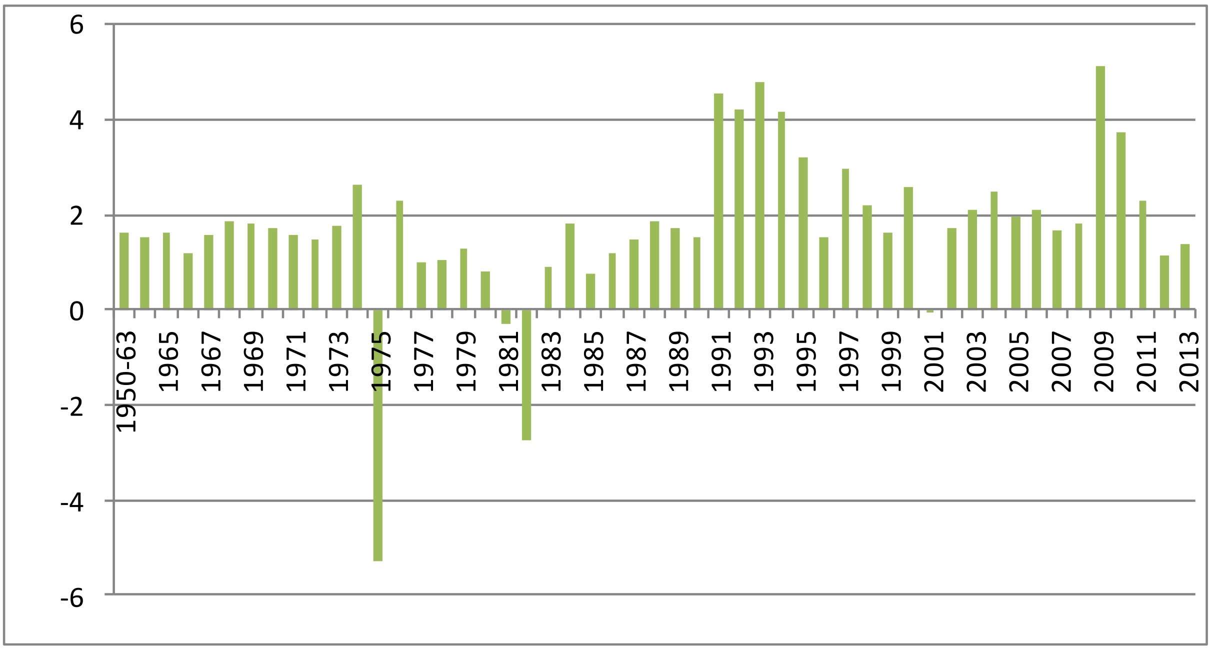
MIRAGE was calibrated on the GTAP dataset version 9, with 2011 as base year. Our data aggregation isolates all energy sectors and combines other sectors into main representative sectors in agriculture, manufacturing and services. For the regional aggregation, we retained the main developed (e.g. EU, Japan and the US) and emerging (e.g. Brazil, Russia, China) economies, aggregated with the rest of the world on a geographical basis (see Table 1). We include tariff data for year 2011 from the MAcMap HS-6 CEPII-ITC database (Guimbard et al., 2012), aggregated using the reference-group method. We also include international transaction costs and non-tariff measures (NTM), modelled as an iceberg trade cost for services, and split between tariff-equivalent, export-tax-equivalent and iceberg trade cost for goods, following Disdier et al. (2015). Data to calibrate trade costs associated with time use a database provided by Minor (2013), which adopts the methodology in Hummels and Schaur (2013); NTM in services are *ad-valorem* equivalents taken from Fontagné et al. (2011) and NTM in goods are provided by Kee et al. (2009).

2.3. The baseline calibration

A difficulty related to large scale CGE models is whether the main stylized facts of world trade can be reproduced easily using this framework. Similar to the well-documented magnified reaction of world trade to booms and busts in the world economy (see Figure 4), the exercise is hopeless. CGE represent long term equilibrium, and cannot reproduce short term adjustments.

More importantly, we want our CGE to reproduce the medium term income elasticity of trade present in historical data. Table 2 shows trade income elasticity for different sub-periods.

Figure 4 – World trade-to-income elasticity of trade (goods)



Source: Authors' calculation. WTO data 1950-2013.

Table 2 – World trade to income elasticity (goods), for different sub-periods

1950-59	1960-69	1970-79	1980-89	1990-99	2000-13	1950-2013
1.62	1.54	1.31	1.19	2.82	1.74	1.64

Source: Authors calculation. WTO data.

The 1990s have been documented as conveying an increase in this elasticity (Freund, 2009, partly because value chains have been fragmented globally and partly because the contributors to world economic growth chose export-oriented growth (e.g. China). We can hardly assume that the phenomenon will continue with the same intensity in the forthcoming two decades because there is a physical limit to product fragmentation and because complexity costs are increasing while the opportunities for exploiting new comparative advantages are most exhausted.

In a much longer perspective, trade in goods since 1950 has increased faster than industrial or agricultural production, and even more than GDP. Long-term elasticity with respect to GDP was 1.46 over the period 1950-1989, before the rapid growth in world trade during the 1990s. This half-century experience is of the order of magnitude that a model like MIRAGE should aim to reproduce. This elasticity mirrors increases in world trade that have several determinants:

- Energy prices (and especially the oil price) have been decreasing since the 1970s;
- Technological progress has occurred in the transport sector;
- Tariffs have decreased over time;
- Some non-tariff measures have been phased out;
- Global value chains have been fragmented, leading to increased discrepancy between trade measured in gross terms, and GDP measured as value added terms.

We need to calibrate the baseline of MIRAGE-e to make it consistent with the observed trade to income elasticity. We start with a backcasting exercise. This is only a partial backcasting as we do not have Social Accounting Matrices (SAMs) back to 1980 (the starting date of MaGE), and even with the available SAMs (2011, 2007, 2004), we will not seek a perfect match. Building a meaningful trade baseline would imply forcing the model to perfectly match past SAMs. This would imply calibrating a large amount of parameters, and we would we have no intuition about how these parameters could change in the coming decades. Against this background, our approach is to maximize the consistency between the backcasting and the baseline exercises. More precisely, the CGE model will, over the past decades, follow the same determinants as those of baseline exercise, namely GDP, population, labour force by skill level, energy prices, saving rates and current accounts. We will still take advantage of the feature of the current version of GTAP, which provides a SAM for 2004, and this information will allow us to investigate how capital is allocated in backcasting. As investment and sectoral capital allocation drive the recursive dynamics of the model, this choice is consistent with the overall exercise.

We firstly need to invert the usual mechanism driving the recursive dynamics of the model, illustrated in equation 1:

$$K_{i,r,t} = K_{i,r,t-1}(1-\delta) + INV_{i,r,t}$$

Instead of having the current capital stock $K_{r,t}$ endogenous and the previous one $K_{i,r,t-1}$exogenous, we take the current one as exogenous and compute the previous one. We do so using a yearly step back to 2004 and observe the divergence in allocation of capital between MIRAGE's computation and the actual SAMs of 2004. The two diverge because the rigidities in the allocation of capital are not necessarily properly calibrated in MRAGE (in projection we generally assume that half of the adjustment of the sectoral capital stock is performed in four years). A central piece of the process is the elasticity of the gross investment to the sectoral difference between the return to capital (relative to the price of capital) and the depletion rate of capital.

In the backcasting exercise, this speed of adjustment is too rapid and we have overshooting: capital quickly disappears in certain sectors. As we need a stickier adjustment process, we optimize this speed of adjustment in order to minimize the deviation between computation and actual data and obtain an elasticity of 4.6 (instead of 40 in the projections). So doing, the allocation of capital in 2004 can be made consistent in the MIRAGE and in the actual SAM for this year. However, in order to have a proper historical perspective, we need to backcast as far as we can, and in our case up to the year where MaGE data initiates: 1980. Our optimized elasticity is again too large and we needed to reduce it. We took an arbitrary value of 1 (there is still sectoral adjustment of the capital stock, but much slower). There is almost no difference in the quality of the fit between 1 and 6 for this elasticity, and the computational problem is fixed. The entire backcasting exercise is finally performed using this value.

In order to test whether MIRAGE can reproduce historical evidence, we now implement our backcasting using different sets of assumptions. The basic case is the standard version of the model with no changes in transaction costs (in the iceberg), no change in tariffs and an endogenous energy price (with no significant variation), and a TFP in the transportation sector that is identical to all other services. Since we have historical information about these determinants, we will implement them in the backcasting exercise one at a time, and then altogether, with the objective to fit observed trade elasticities. Tariffs will be adjusted to their historical values (2004-11 tariff cuts from the MAcMap database, implemented linearly, similarly for tariff cuts since 1990 as reported in WDI[17], and backward extrapolation to 1980). Energy prices will be exogenous at historical values, also implemented linearly to prevent excess volatility in yearly data. TFP growth in the transport sector will go beyond what is endogenously determined by the model to match growth projections from MaGE, with an addition 2% growth yearly compared to other services, as suggested by the DEA estimates of Cheon et al (2010) for 98 world ports over the period 1991-2004 (2.418%). We run the model over 1980-2011 and compute the trade to income elasticity for each of the three decades.

Results reported in Table 3 show that the trade-to-income elasticity embodied in MIRAGE is low, as usual for any model of this type: using historical data for tariffs and energy prices combined with a 2% cut in transport costs (with no change in the iceberg cost) we obtain an elasticity between 1.13 and 1.21 depending on the decades (first row in Table 3). This elasticity matches what was observed during the 1980s (1.19).

In order to reproduce the higher elasticity observed in the 1990s and 2000s, we calibrate the iceberg trade cost. According to this calibration, trade costs were cut by 0.68% annually in the 2000's, 2,22% in the 1990's, and increased by a modest 0.16% yearly in the 80's.

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[17] We retain the oldest data available in WDI which, depending on the country, can vary from 1988 to 1996 (except for the Middle-east region, 2000).

Table 3 –Trade to income elasticity in MIRAGE under alternative assumptions and by sub-period (1980-2011)

Assumptions				Trade to GDP elasticity		
Energy prices	Tariffs	TFP transport	Iceberg	80's	90's	2000's
Endog.	Const.	0	0	0.80	0.89	1.03
Hist.	Const.	0	0	1.14	0.97	0.80
Endog.	Hist.	0	0	0.89	1.01	1.28
Endog.	Const.	2%	0	0.84	0.94	1.08
Hist.	Hist.	2%	0	1.21	1.17	1.13
Hist.	Hist.	2%	Adj.	1.19	2.82	1.74
			Data:	**1.19**	**2.82**	**1.74**

Source: Author's calculations.

2.4. Two baselines and two scenarios for the world economy

We now illustrate the construction of two contrasted baselines for the world economy combining in a consistent way the growth model – MaGE and the global and sectoral CGE – MIRAGE. Let us recall that this joint implementation of the two models and its implication for the macroeconomic closure of the CGE is a contribution to the literature.

We firstly define two macroeconomic trajectories for the world economy at the 2035 horizon with MaGE (resp. "Sluggish Macro" and "Brisk Macro"). These two trajectories are then used to calibrate two dynamic trajectories with MIRAGE (resp. "Sluggish Secto" and "Brisk Secto"), combining MaGE outputs with hypotheses concerning energy prices, transaction costs, technical progress in the transport of goods and tariffs.

For the Sluggish Macro and Brisk Macro scenarios, we assume changes in demography, migrations, education attainment, technical progress, energy price and productivity and finally capital mobility.

The first variable to experience a shock is demography. We start from the UN's low and high fertility scenarios applied to all countries. The low case is expected to have a negative impact on growth, although not necessarily on income per capita.

The second variable of interest is migration. Some migration flows are indeed embedded in the UN's demographic projections. These correspond to the 'normal migration assumption' where net migration is generally kept constant, at least for our time horizon. The UN introduces conservative changes on a country by country basis, corresponding to anticipated immigration policy changes. We were not able to trace UN projected migrations by sex, age group or education level. Therefore, the initial migrants in UN projections, who are present in all scenarios, are assumed to resemble the local inhabitants. This is our reference case for migrations, applied to the “Sluggish Macro” scenario. In contrast, our “Brisk Macro” scenario includes – in addition to initial UN migrations – migrations from Docquier and Machado (2017), which are consistent with the “High fertility” scenario of the UN. Docquier and Machado (2017) provide their baseline migration projections measured as the stock of migrants by skill level – high skill or low skill, corresponding to tertiary-educated migrants and others – for people aged 25 and more, using a time-step of 25 years. Given that MaGE needs population and skill level by gender and age group on a yearly basis, we need to convert these stocks of migrants into a variation (net outwards migration) by skill level, expressed in percentage of initial local population, on a yearly basis (the number of annual migrants is constant for each 25-year period). In turns, these net migration rates are applied uniformly for each gender and age group over 25, leading to changes in the national education level as well as in the origin country.

Concerning educational attainment, we address the impact of a decelerated convergence in education in the Sluggish Macro scenario. In MaGE, the catch up to the education frontier plays an important role because it drives convergence in TFP. The productivity frontier is not constant because the leading country (which can change over time) is continuously improving its education level. For each region of the world, we estimated in MaGE the structural speed of convergence to the education frontier. We consider the half-life time[18] for this process and increase it by 50% in the Sluggish case. We expect this to reduce technological catch-up and hamper growth.

[18] Half-life time is defined as the time necessary to reduce by half the distance to the education frontier, assuming a constant frontier.

Table 4 –Assumptions for the two baselines

		Sluggish Macro	Brisk Macro
MaGE	Demography	Low fertility for all countries	High fertility in all countries
	Migrations	Reference case	Docquier (baseline)
	Education convergence	+50% half-life time	Reference case + Migration from Docquier
	Differentiated TFP	-50% TFP growth rate for low and mid income countries, -25% for high-income.	Reference case
	Oil price	High price scenario (IEA)	Low price scenario (IEA)
	Energy productivity	+25% targeted in 2050	Reference case
	Capital mobility	Convergence to I=S targeted in 2050, in each region	Reference case
		Sluggish Secto	Brisk Secto
MIRAGE	Transaction costs*	25% cut	25% cut
	Transport TFP*	2% annual growth	2% annual growth
	Tariffs	No change (w.r.t. 2011)	No change (w.r.t.2011)

[*]As discussed in the text, these two trends were introduced in a pre-experiment in order to reproduce long-term income elasticity of world trade.

The fourth variable of interest is technical progress. As already explained, TFP is endogenous in MaGE. It is determined by a catching up process in which distance to the technology frontier and education drive convergence. We keep the reference pace of technical progress in the Brisk Macro scenario, while reducing it in the Sluggish Macro scenario. In the Sluggish case, a deteriorating economic environment, lower trade and FDI flows and possibly less collaborative technical programs will lead to reduced TFP convergence in Low and middle-income countries, but less technical progress in developed countries as well, although to a lesser extent. TFP shocks of similar magnitude have been observed in the past. Figure 2 above shows that, during the past 30 years, there have been several periods where TFP growth has slowed or become negative or alternatively experienced buoyancy for certain countries. The most notable include the transition of Russia after the fall of the USSR, and Japan during the 1990s. Our scenarios try to consider the impact of similar prolonged phases that are not captured by econometric estimation. The Sluggish case reflects 'hard times' with limited TFP gains in the North (just three-quarter of the gains projected in the reference scenario), lower levels of technology transfer and tensions over intellectual property rights among this group of countries. As a result, TFP gains are even more reduced (-50%) in the group of catching-up countries.

Another variable of interest is countries' energy efficiency. Technological breakthroughs could have a major impact on energy efficiency, since sectoral transition to less energy-intensive activities is endogenous, monitored by the conditionality of catching-up in energy productivity to GDP per capita.[19] Here, we assume that countries at different levels of development will benefit evenly from this progress. In the Sluggish case, technical progress in response to high energy prices occurs in the high income countries, and is passed on to the middle- and low-income ones. Efficiency gains in energy accordingly are shared worldwide (we assume a 25% increase with respect to the reference scenario). In the Brisk case efficiency gains are absent because low energy prices are a strong incentive to rely on the existing technology.

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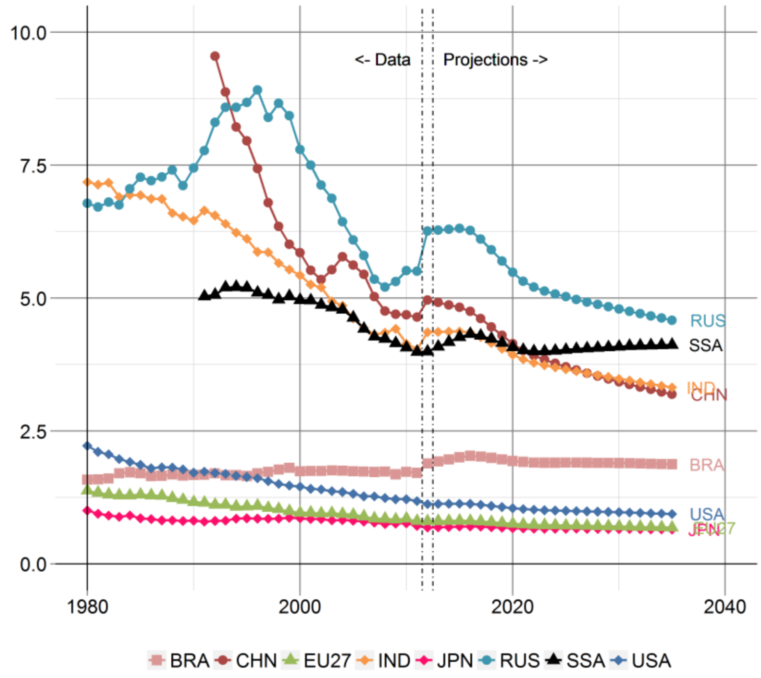
19 At the beginning of projections, almost every country had passed the turning point between efficiency decrease and improvement.

Figure 5 – Energy intensity of the GDP in the reference scenario of MaGE, 1980-2035 (barrel of oil per 1,000 2005 USD of GDP)



Source: MaGE, authors' calculation.

Finally, capital mobility is an important determinant of growth since it shapes the difference between national saving and investment. Increased capital mobility should allow better allocation of capital worldwide and, thus, enhance growth overall. Said otherwise, in the Sluggish case, there is 'financial de-globalization', meaning that countries return progressively to financial autarky by 2035.

Notice that assumptions about demographic profiles and capital mobility will modify the dynamics of the saving-investment balance depicted in Figure 6, characterized by a natural rebalancing of the Chinese economy.

While our two baselines assume *status quo* for tariffs as well as non-tariff barriers, we will shock the model twice with alternative assumptions on tariffs, transaction costs and TFP in transport. A first policy experiment aims at capturing trade patterns in a future "fragmented" world. Transaction costs are assumed to increase by 50% linearly up to 2035 when imported from developing countries. This corresponds to a tightening of standards, controls and certification procedures. The increase is only

20% for imports from developed countries, less targeted by these measures. This comes hand-in-hand with a trade war whereby tariffs are progressively set to their Tokyo round level for all goods.

The extreme opposite policy experiment is a "connected" world whereby transaction costs are reduced by 50% (20%) for imports from developing (developed) countries. Tariffs are further reduced by 50% compared to their 2011 level and NTMs in services are reduced by 25% at the 2035 horizon.

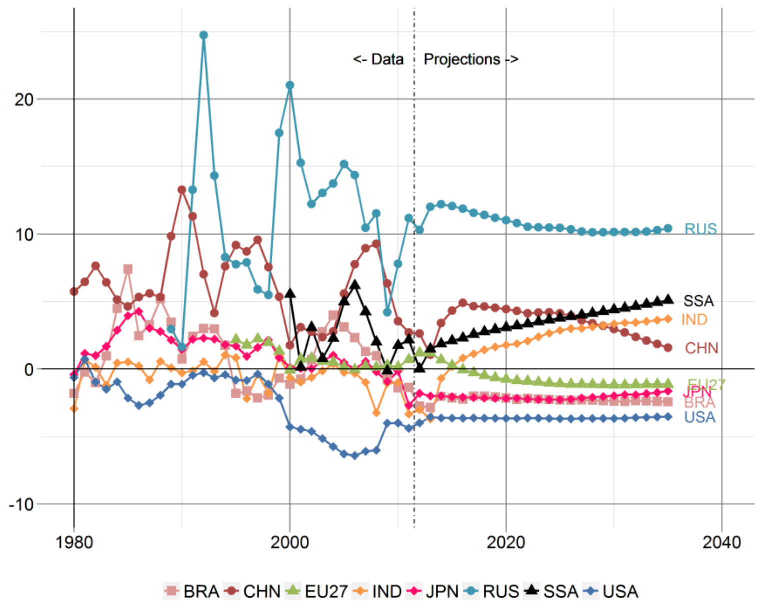
When implemented in MIRAGE these two policy experiments will be nicknamed "fragmented" and "connected".

Table 5 – Two contrasted policy experiments

		Fragmented	Connected
MIRAGE	NTM in services	No change (w.r.t 2011)	-25% in 2035
	Transaction cost in goods	+50% from developing countries, +20% from developed countries	-50% from developing countries, -20% from developed countries
	Tariffs on goods	Trade war* (Tokyo round tariffs)	-50% compared to 2011

* *Data for the trade war are detailed in appendix A.*

Figure 6 – Saving-Investment balance in the reference scenario, 1980-2035 (percentage of GDP)



Source: MaGE, authors' calculation.

3. THE MIRAGE-E MODEL

We use a new version of the multi-sectoral and multi-regional CGE model MIRAGE. MIRAGE has a sequential dynamic recursive set-up which is used to evaluate a long-term path for the world economy, and we focus on perfect competition. The MIRAGE-e version of the model relies on a different modelling of energy use, hence the extension of its nickname. The macroeconomic closure consists in imposing the share of each region in global current accounts imbalances, which varies yearly according to the projections from MaGE.

3.1. Representative firms

In the perfect competition version of MIRAGE we assume that each sector is modelled as a representative firm, which combines value-added and intermediate consumption in fixed shares. Value-added is a bundle of imperfectly substitutable primary factors (capital, skilled and unskilled labour, land and natural resources) and energy.

All primary factors endowments of countries are supposed to be fully employed and their growth rates are set exogenously from MaGE's projections. Installed capital stock is assumed to be immobile (sector-specific), while investment, which represents the long run adjusting possibilities of a capital market, is allocated across sectors (perfect mobility) according to their rate of return to capital. Skilled labour is perfectly mobile across sectors, while unskilled labour and land are imperfectly mobile, the former between the agricultural sector and others and the latter between agricultural sectors. Finally, natural resources are sector-specific.

Energy consumption of the five energy goods (Electricity, Coal, Oil, Gas and Refined petroleum) by firms are aggregated in a single bundle by firm which mainly substitutes with capital. The extent to which capital and energy are substitutable, or alternatively value-added and energy depending on the chosen nesting, is not subject to consensus among CGE literature. Estimations, for instance by van der Werf (2008), suggest that the elasticity of substitution between capital and energy heavily depends on the sector and country considered, but were never conducted, at least to our knowledge, on recent data nor in service sectors.

In CGE, the elasticity of substitution between capital and energy can vary according to the vintage of capital (for instance from 0.12 to 1 in the GREEN model), or be fixed between 0.4 (EPPA model) and 0.8 (PACE model).[20] We found out that energy consumption was very sensitive to the capital-energy elasticity of substitution. Calibrating this elasticity like GTAP-E provides an energy consumption in our reference scenario that is in line with International Energy Agency projections to 2025 (IEA, 2015). We therefore stick to the GTAP-e value, i.e. $\sigma_{KE} = 0.5$. The architecture of the energy bundle defines three levels of substitutions and is depicted in Figure 1 as well as its position in MIRAGE's production function. Oil, gas and refined oil are more inter-substitutable than with coal and finally with electricity. Values of the elasticities of substitutions are determined according to the literature. Whereas electricity-fossil fuels substitution comes from Paltsev et al (2005), the two other elasticities come from Burn & Truong (2002).

However, in order to avoid unrealistic results, we made the assumption of "constant energy technology" in non-electricity energy production sectors (coal, oil, gas, petroleum and coal products) such that it is impossible to produce crude oil from coal or refined petroleum from gas and electricity. For these sectors, substitutions between energy sources are not allowed (Leontief formulation).

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[20]The respective reference documents of the two models are Paltsev et al (2005) and Böhringer (2009).

The value of energy aggregate of sector j in country r, $ETOT_{j,r,t}$, is subject to productivity improvements, $EE_{j,r,t}$ based on the growth model, as shown in Equation (1). These productivity improvements are introduced at the capital - energy bundle level, $KE_{j,r,t}$.

$$ETOT_{j,r,t} = a_E EE_{j,r,t} KE_{j,r,t} \left(\frac{PKE_{j,r,t}}{PE_{j,r,t}} \right)^{\sigma_{KE}} \quad (1)$$

In Fouré et al. (2012), energy productivity has a different definition than its equivalent in MIRAGE. The former does not include TFP and the latter does not include the share coefficient. By trickling-down the effect of MIRAGE's sectoral TFP, $TFP_{r,t} TFPJ_{j,r,t}$, onto the capital-energy bundle CES function, we can make the analogy between the two expressions and deduce the value of energy productivity in MIRAGE, $EE_{j,r,t}$, given the MaGE energy productivity, $B_{r,t}$ and an initial value normalized to 1.

$$EE_{j,r,t} = \left(\frac{B_{r,t}}{TFP_{r,t} TFPJ_{j,r,t}} \right)^{\sigma_{KE}-1} = \frac{EProd_{r,t}}{\left(TFP_{r,t} TFPJ_{j,r,t} \right)^{\sigma_{KE}-1}} \quad (2)$$

For non-electricity energy production sectors, we also set energy productivity constant in order to match our ``constant energy technology'' assumption, in line with the substitutions between energies in these sectors.

3.2. Representative consumer

The demand side is modeled through a representative consumer from each region that maximizes its intratemporal utility function under its budget constraint. This unique agent, which includes households and government, saves a part of his income and the rest is spent on commodities according to a LES-CES *(Linear Expenditure System - Constant Elasticity of Substitution)* function. Regional propensity to save changes yearly in the dynamic baseline according to MaGE's projections. Above a minimum consumption proportion at sectoral level, consumption choices between sectors are done according to a constant elasticity of substitution. Then, within each sector, a nested CES allows for a particular status for domestic products, together with a product differentiation according to their geographical sources ("Armington hypothesis"), using the GTAP Armington elasticities estimated in Hertel (2007). Even though the most complete version of Mirage allows for product differentiation across varieties, we decided to keep simple demand trees in agriculture, raw energies and electronic devices to work with a tractable model.

Total demand is built from final consumption, intermediate consumption and investment in capital goods. The former and the latter follow the same rules as described above.

3.3. Energy and CO_2 emissions accounting

Using CES functional forms with variables in monetary units leads to inconsistencies when trying to retrieve physical quantities. In our case, this matters for energy consumption, production and trade, as well as their consequences on CO_2 emissions.[21]

Therefore, in addition to the accounting relations in constant dollars, MIRAGE-e integrates a parallel accounting in energy physical quantities (in million tons of oil equivalent, $Mtoe$) such that the CO_2 emissions could be computed (in million tons of carbon dioxide, $MtCO_2$). Since the Constant Elasticity of Substitution architecture does not maintain the coherence in physical quantities, MIRAGE-e introduces two energy- and country-specific adjustment coefficients. These two aggregation coefficients allow us to maintain basic energy accounting relationships valid.

Namely, the produced quantity by one country[22], $EY_{e,r,t}$ must equal the demand addressed to this country both locally, $ED_{e,r,t}$ and from abroad, $EDEM_{e,r,s,t}$, as in Equation (3) ; and the consumption of energy (by households, $EC_{e,s,t}$ and firms, $EEIC_{e,j,s,t}$) in one country must equal its local and foreign demand (Equation (4)).

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[21] Preliminary simulations of MIRAGE-e showed that there could be a gap of more than 20% between energy consumed and energy demanded by a country if proportionality was assumed between monetary and physical values.

[22] In these equations, as well as in the remainder of this paper, the subscript e will be an index for energy goods. In addition, r denotes a country that is, when appropriate, the origin of a good and s its destination.

$$EY_{e,r,t} = ED_{e,r,t} + \sum_s EDEM_{e,r,s,t} \quad (3)$$

$$EC_{e,s,t} + \sum_j EEIC_{e,j,s,t} = ED_{e,s,t} + \sum_r EDEM_{e,r,s,t} \quad (4)$$

The corresponding adjustment coefficient, $AgDem_{e,r,t}$ (resp. $AgCons_{e,r,t}$) rescales the demand addressed to (resp. the consumption of) the country such that it matches the produced (resp. demanded) physical quantities. In turn, only energy quantity production is proportional to the volume production Y due to its being on the top of a CES rather than inside. The epsilons in Equations (5) to (9) are constant conversion coefficients calibrated from the energy quantity data and allow to link energy quantities with corresponding volumes of demand for local good, $D_{e,r,t}$, bilateral demand, $DEM_{e,r,t}$, local final consumption, $C_{e,s,t}$ and local intermediate consumption, $EIC_{e,j,s,t}$.

$$EY_{e,r,t} = \varepsilon^{Y}_{e,r} Y_{e,r,t} \quad (5)$$

$$ED_{e,r,t} = \varepsilon^{D}_{e,r} AgDem_{e,r,t} D_{e,r,t} \quad (6)$$

$$EDEM_{e,r,s,t} = \varepsilon^{DEM}_{e,r,s} AgDem_{e,r,t} DEM_{e,r,s,t} \quad (7)$$

$$EC_{e,s,t} = \varepsilon^{C}_{e,s} AgCons_{e,s,t} C_{e,s,t} \quad (8)$$

$$EEIC_{e,j,s,t} = \varepsilon^{EIC}_{e,j,s} AgCons_{e,s,t} EIC_{e,j,s,t} \quad (9)$$

CO_2 emissions are finally recovered as being proportional to the energy quantities consumption, using energy-, sector- and country-specific factors determined by the data.

4. THE CLOSURE OF MIRAGE

In order to implement our baseline exercise, we use the long-run growth projections from the MaGE model (Fouré et al., 2012). These projections are based on a three-factor (namely capital, labour and energy) production function at the national level for 147 countries. We first briefly describe the methodology underlying such projections.

4.1. The production function

These three factors are gathered in a Constant Elasticity of Substitution (CES) function of energy $E_{r,t}$ and a Cobb-Douglas aggregate of capital $K_{r,t}$ and labour $L_{r,t}$:

$$Y_{r,t} = \left[\left(A_{r,t} K_{r,t}^{\alpha} L_{r,t}^{1-\alpha} \right)^{\frac{\sigma-1}{\sigma}} + \left(B_{r,t} E_{r,t} \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \qquad (10)$$

were $A_{r,t}$ and $B_{r,t}$ are respectively the usual Total Factor Productivity (TFP), which in this case is the efficiency of the combination of labour and capital, and an energy-specific productivity. In line with the literature (see e.g. Mankiw et al., 1992), α is set to 0.3. In turn, the $\sigma = 0.136$ parameter is calibrated based on the MIRAGE structure, using a pre-experiment simulation. In addition, GDP, $Y_{r,t}$ is considered net of oil rents, when appropriate, to avoid a biased measure of productivity. Oil rents are added separately and are assumed to be pure rents: the volume of production is constant, but its real value (in terms of the GDP deflator) increases with the relative price of oil.

This model is fitted with UN population projections as well as econometric estimations for capital accumulation, education, female participation to the labour force and the two technical progresses. The energy consumption factor is not directly projected, it is recovered from the firms' optimization program.

In particular, capital accumulation follows a permanent inventory process, where the stock of capital increases each year with investment but also depreciates. The depletion rate is set, in accordance with the MIRAGE model, to 6%, whereas investment to GDP ratios depend on the savings rates by an error-correction, Feldstein-Horioka-type relationship. Such relationship enables to depart from the common assumption of closed economy. The savings rates are determined by both the demographic and economic situation, in coherence with the life-cycle theory.

The two productivity measures follow catch-up processes. Whereas TFP growth is fuelled by education level, energy productivity growth is tempered by the level of GDP per capita such that it mimics the impact of sectoral changes on the productivity of energy during a country's development process.

4.2. Closure and dynamic set-up

Thanks to MaGE's projections, the dynamic baseline of MIRAGE has many original features regarding savings, GDPs, active population, energy efficiency changes and current account balances, all at the regional level. This set of projections has been also completed with oil, gas and coal world prices projections from the Annual Energy Outlook (IEA, 2011).[23]

Dynamics in this model is implemented as a sequentially recursive approach. That is, the equilibrium can be solved successively for each period by adjusting to the growth in the projected variables described above. For this long-run baseline, the time span is 96 years, the starting point being 2004. During this period of time, capital stocks change according to investment decisions based on rates of return to capital at the sectoral level and the depreciation rate, which is assumed constant and uniform across regions (i.e. $\delta = 6\%$).

$$K_{j,r,s,t} = K_{j,r,s,t-1}.(1-\delta) + INV_{j,r,s,t} \qquad (11)$$

Skilled and unskilled labour supplies from each region, $\overline{H}_{r,t}$ and $\overline{L}_{r,t}$ resp., are also yearly updated according to the population growth rates by MaGE. $g^{H}_{r,t}$ is the growth rate of active population having achieved at least a tertiary level diploma and $g^{L}_{r,t}$ is the growth rate of the rest of active population. It is a crude approximation, since GTAP definition of skilled population is based on occupation rather than on diploma, nevertheless it is available.

$$\overline{L}_{r,t} = \left(1+g^{L}_{r,t}\right)\overline{L}_{r,t-1} \qquad (12)$$

$$\overline{H}_{r,t} = \left(1+g^{H}_{r,t}\right)\overline{H}_{r,t-1} \qquad (13)$$

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[23]The latter and MaGE outputs have been converted into growth rates to be implemented in the dynamics from MIRAGE in order to keep our initial year fully coherent with GTAP database.

Total population also increases exogenously under the dynamic baseline by inducing growth through the final demand.

Growth rates for regional GDP are also set exogenously according to MaGE projections and thus, the TFP is endogenously determined. Sectoral factor productivity, calculated by large sectors (i.e. Agriculture, Manufactures and Services) also intervenes in this dynamic baseline. Factor productivity in Agriculture is differentiated between Livestock and Crops sectors, and are calibrated according to our estimates from Section 4. Factor productivity in Manufactures and Services are endogenous variables, which are affected by regional GDP (through the TFP) and Agricultural factor productivities. Factor productivity growth in Manufactures is higher than in Services (for instance, Δg_j^{TFP} is greater than 0 for Manufactures and null for Services as in Equation 15), following the ENVISAGE model methodology Van der Werf (2008). The gap between services and manufacture is calibrated to a 2 p.p. growth differential, according to two estimates by Bernard & Jones (1996) and Timmer et al. (2010), respectively held on the 1970-1989 and 1980-2005 periods among developed countries.

$$GDP_{r,t} = \left(1 + g_{r,t}^{GDP}\right) GDP_{r,t-1} \quad (14)$$

$$TFPJ_{j,r,t} . TFP_{r,t} = TFPAgri_{j,r,t} \; if \quad j \in Agri \quad (15)$$

$$TFPJ_{j,r,t} . TFP_{r,t} = \left(1 + \Delta g_j^{TFP}\right) TFPJ_{j,r,t-1} TFP_{r,t} \; if \quad j \notin Agri \quad (16)$$

where $TFP_{r,t}$ is the variable that adjusts to match GDP target and $TFPAgri_{j,r,t}$ corresponds to projected agricultural (crops and livestocks) factor productivities.

Energy productivity, $EProd_{j,r,t}$ also increases exogenously during the baseline according to MaGE's projections on regional energy efficiency. It directly affects the energy demand per unit of output by sectors such as described above.

$$EProd_{j,r,t} = EProd_{j,r,t-1} . \left(1 + g_{r,t}^{B}\right)^{\sigma^{KE} - 1} \quad if \quad j \notin Energy \quad (17)$$

World prices of primary fossil energies (i.e. oil, coal and gas) are also assumed to be exogenous during the new dynamic baseline. They yearly increase according to the World Energy Outlook projections (IEA, 2011) up to 2035, keeping a constant growth rate afterwards, leading to adjustments of the corresponding stock of natural resources.

$$PWORLD_{e,t} = \left(1 + g_{e,t}^{P}\right) PWORLD_{e,t-1} \quad if \quad e \in \{coal, oil, gas\} \qquad (18)$$

where $g_{e,t}^{P}$ is the growth rate of energy prices. Each fossil energy price has its own projections.

Such as in the original version of MIRAGE, regional investment is savings-driven and is allocated across sectors according to the capital rate of return. Even if it provides the possibility to work with foreign direct investment Decr07a, in this version we remain simple, allowing capital flows between regions only through the channel of current account imbalances.

The new dynamic set-up in MIRAGE particularly affect macroeconomic closures. The current account is driven by MaGE projections and updates yearly. By sake of consistency, the savings rate are also taken from MaGE, thus determined by demography, life cycle and purchasing power. Savings rates grow at the exogenous growth rate $g_{r,t}^{SAV}$ and current account are incremented by the sold deviation $\Delta SOLD_{r,t}$. Current account variations are not represented by a growth rate because of its capability of changing its sign across time.

$$SAV_{r,t} = \left(1 + g_{r,t}^{SAV}\right) SAV_{r,t-1} \qquad (19)$$

$$SOLD_{r,t} = SOLD_{r,2004} + \Delta SOLD_{r,t} \qquad (20)$$

Equation 21 show the current account definition, $SOLD_{r,t}$, as the difference between all sectoral investments, $INV_{j,r,t}$ and national savings, $SAV_{r,t}$, as well as its implementation as a share of world GDP, $WGDP_t$.

$$SAV_{r,t}.REV_{r,t} = WGDP_t.SOLD_{r,t} + \sum_j P_t^{INVTOT}.INV_{j,r,t} \qquad (21)$$

5. Modelling TFP in Agriculture

Although we have already developed a methodology to compute and project TFP on the long run for national economies, two reasons lead us to consider agriculture apart. First, technical progress in agriculture seems to be lower than national TFP growth, and should therefore be studied further. Second, the definition of production factors in agricultural sectors is trickier at the macroeconomic level.

Whereas data on labour-force in agriculture is available, no aggregated data on capital in agriculture seems to be available, on the contrary to disaggregated data (machinery, land, etc.). We therefore need to implement a multi-input, non-parametric methodology such as the Malmquist productivity index, based on productivity distance to a global frontier.

5.1. Data Envelopment Analysis (DEA)

Malmquist indices are designed to represent productivity growth rates both at a national or sectoral level. Computing such indices needs a two step approach. The ground concept from which Malmquist indeces are built are distance measures. These distances represent of the gap between the production of a country and the potential production it could have achieved if it had used its inputs at the best available technology. The first step is then to compute such distances measures. The underlying logic of the method, detailed in Appendix, is to build a peace-wise linear surface of the best performing countries to identify the technological frontier, starting from production and production factors data, and to measure the distance between each country's productivity and such a frontier.

Once these distances are known, the second step is to combine them in order to build a Malmquist index $M^{t,t+1}$ for each year and country, representing productivity growth rates. Instead of detailing the formulation in distances, Fare (1997) rely on the following decomposition.

$$M^{t,t+1} = \Delta EFF^{t,t+1}.\Delta TECH^{t,t+1} \qquad (22)$$

These two components have different meanings. The first one, $\Delta EFF^{t,t+1}$, is called efficiency change and represents the growth rate of the distance to the technological frontier. The second term, $\Delta TECH^{t,t+1}$, is a technical change term and represents the contribution of the country to the evolution of the technological frontier.

Such an index has some interesting properties. $M^{t,t+1} \geq 1$ if there have been progresses in TFP between year t and $t+1$ and $M^{t,t+1} \leq 1$ if technological regress has occurred. Furthermore, improvements (resp. deterioration) of $\Delta EFF^{t,t+1}$ or $\Delta TECH^{t,t+1}$ are equivalent to their value being greater (resp. lower) than 1.

5.2. Data

We use data from the Food and Agriculture Organization (FAO) on agricultural production and inputs, for the 1961-2009 period. We choose two outputs for agriculture (gross production of crops and livestock) and five different inputs, due to their commonness across the world and their data-availability.[24] Inputs can be allocated to crops or livestock, or be shared between these two sectors.

First, labour force (non-allocatable) is described by economically active population in agriculture, although data for 1961-1979 needs to be recovered from agricultural population by assuming a constant activity rate. Land input (non-allocatable) includes arable land and permanent crops. Machinery is measured as the total of agricultural tractors in use, though gaps are filled with agricultural tractors series. This input is allocated to crops production, as well as fertilizers, whose consumption is measured in nutriments. The series between 1961 and 2001 being available in weight units only, we convert to nutriments assuming a constant nutriment content of the three selected fertilizers: nitrogen, phosphate and potash. Finally, livestock input (allocated to the livestock sector only) is computed using Livestock Units (LU) equivalents, using the number of heads for buffaloes, camels, cattle, pigs, sheep, goats, chickens, ducks and turkeys. This data is aggregated following Lude (2007), as detailed in Appendix.

Several adjustments were needed to have a fully operational dataset. First, we had to deal with countries that changed their borders over the period (Belgium-Luxembourg in 2000, Czechoslovakia in 1993, Ethiopia PDR in 1993, USSR in 1992, Yugoslavia in 1992 and Serbia-Montenegro in 2006). For these countries, we took the share of different members for the first disaggregated year available, and for previous years we split the aggregated data between the countries. Second, we aggregated the

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[24] We are well aware of the roughness of some assumptions here that are due to the fact that our DEA method does not suffer gaps.

data for 9 broad regions (see Appendix). These regions' productivity will be computed among all independent countries, and their values will be used for estimations.

6. THE TWO BASELINES AND THE TWO POLICY EXPERIMENTS

We now combine all the assumptions in the two baselines: “Brix” and “Sluggish” is now the output of MIRAGE.

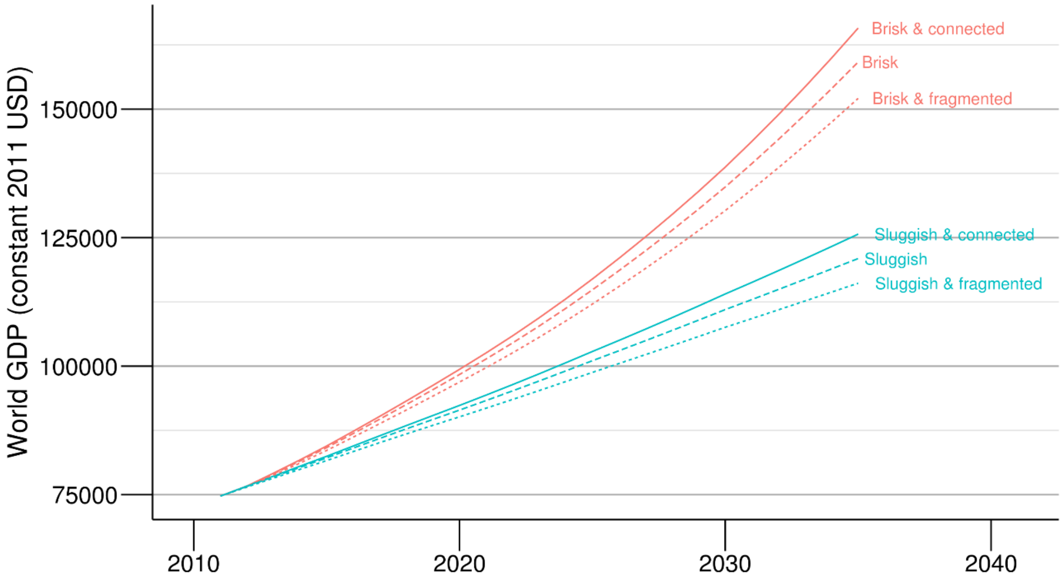
Figure 6 shows the results for the world GDP up to 2035, an endogenous variable of MIRAGE in the baseline (“Brisk” and “Sluggish”) and policy experiment (“Brisk and connected“,“Brisk and fragmented“ , versus “Sluggish and connected” and “Sluggish and fragmented”). It takes account of all the relations and feed-backs among the variables in the MaGE and MIRAGE models.

Beyond the expected divergent trajectories of GDP driven by the set of assumptions of the two baselines, the interesting outcome is that macroeconomic determinants are the main explanation of differences in the outcome. This confirms the importance of well designing the dynamic baselines of the model before conducting any policy experiment.

Finally, we can now compute how the trade to income elasticity should evolve in our two baselines and in our two policy experiments, recalling that MIRAGE is now calibrated to reproduce the past (but not the 1990s).

The range of elasticities obtained at world level is 0.87 (under the “Sluggish and fragmented” policy experiment) and 1.53 (under the “Sluggish and connected” scenario).

Figure 6 World GDP in MIRAGE under 4 sets of assumptions (2011-35, at constant US $ of 2011)



Source: MaGE, authors' calculation.

Table 5: Trade to income elasticity in MIRAGE under different assumptions (2011-35)

	Sluggish	Sluggish & fragmented	Sluggish & connected	Brisk	Brisk & Connected	Brisk & fragmented
Developed	1.57	1.38	1.80	1.33	1.49	1.20
Developing	1.04	0.61	1.32	1.10	1.27	0.85
World	1.24	0.87	1.53	1.21	1.40	0.98

Source: Author's calculation using MIRAGE-e

7. CONCLUSION

This paper has developed a comprehensive methodological framework for projecting world trade patterns and the sectoral distribution of value-added at a medium-run horizon, based on scenarios for the world economy. We calibrated the CGE to reproduce observed international to income elasticities. We implemented contrasting scenarios encompassing a wide range of potentialities. The combination of a growth model with a dynamic multisectoral CGE model of the world economy proved fruitful. We also introduced in this exercise migrations drawn from Docquier and Machado (2017). Two baselines of the world economy were obtained, and two policy experiments were conducted, one being a trade war bringing back the world economy to the post-Tokyo Round situation in terms of tariffs.

Our results point to the need for careful building of baseline scenarios when evaluating policies in dynamic general equilibrium. The magnitude of the changes in world trade patterns when baselines differ much larger than when trade policy shocks are imposed.

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9. APPENDIX

APPENDIX A: TRADE WAR DATA

Table A1 – Post-Tokyo round tariffs by sector

Table II. Post-Kennedy Round Base Rate Tariffs on Industrial Products by Sector in the Major Industrialized Countries (Percent; Weighted by Own-Country Imports, Excluding Petroleum)

	ALA⁺	ATA	BLX	CND⁺	DEN	FIN	FR	GFR	IRE	IT	JPN⁺	NL	NZ	NOR	SWD	SWZ	UK	US	ALL
Textiles	21.5	18.7	9.5	18.9	12.1	24.1	9.8	10.3	10.7	7.5	3.3	11.8	14.2	16.2	10.9	8.2	9.2	14.4	10.7
Wearing Apparel	61.8	36.3	16.7	25.4	16.4	37.2	16.7	16.8	16.4	16.6	13.8	16.8	58.7	22.8	14.4	15.5	16.9	27.8	20.7
Leather Prod	25.7	9.1	4.1	8.2	3.6	12.6	3.3	5.1	5.4	1.7	3.0	5.2	15.3	6.6	4.8	2.8	2.8	5.6	4.5
Wood Products	13.6	4.8	3.2	5.8	4.4	0.5	3.3	3.9	3.2	1.0	0.3	3.6	11.7	2.0	0.9	5.0	4.0	3.6	2.7
Paper, Pap Prod	7.1	15.9	9.3	11.8	10.8	8.0	7.6	7.1	10.9	3.7	2.1	8.4	20.9	2.9	3.0	6.6	6.6	0.5	5.8
Print & Publ	1.8	2.4	2.4	5.7	4.4	1.8	3.4	3.3	2.4	2.7	0.2	3.5	1.1	4.3	0.2	0.9	3.3	1.1	2.9
Chemicals	5.8	8.1	11.6	7.9	11.9	3.1	10.9	11.6	10.7	11.8	6.2	11.9	10.0	8.1	6.3	1.1	11.4	3.8	9.4
Rubber Products	13.8	14.6	6.2	12.2	6.7	13.9	5.2	5.7	5.6	4.0	1.5	6.1	9.5	7.3	6.5	2.0	4.0	3.6	5.8
Nonmet Min Prod	11.6	8.9	5.2	9.5	6.7	3.8	7.0	5.4	6.0	3.3	0.6	4.4	13.8	2.8	3.1	3.5	3.2	9.1	5.8
Glass, Gl Prod	15.2	17.5	9.9	11.3	9.7	25.4	9.8	10.2	9.5	9.6	7.5	9.3	15.4	10.5	9.3	4.5	10.4	10.7	10.5
Nonfer Metals	5.3	4.5	1.9	2.0	8.1	1.2	3.1	2.3	8.0	2.2	1.1	4.3	9.3	1.1	0.9	4.3	2.0	1.2	2.0
Metal Products	24.1	19.3	7.7	14.1	7.9	9.6	7.8	8.0	7.7	8.0	6.9	7.8	29.7	6.3	5.3	3.8	8.0	7.5	9.0
Nonelec Mach	14.2	10.8	6.4	6.1	6.4	8.7	6.4	6.6	6.1	6.5	9.1	6.4	28.1	8.8	4.9	1.5	6.4	5.0	6.7
Elec Machinery	21.6	18.7	9.6	12.9	9.3	11.0*	9.8	10.2	9.5	9.9	7.4	10.0	21.0	8.6	7.0	2.0	10.0	6.6	9.6
Transp Equip	22.1	24.5	11.1	2.4	8.5	6.0*	10.3	9.9	12.0	10.7	6.0	10.9	27.6	3.5	8.2	6.7	9.3	3.3	7.7
Misc Manufact	13.0	13.7	5.2	8.8	10.0	18.1	9.6	9.1	11.2	9.4	6.0	8.7	20.5	8.9	6.1	1.5	4.9	7.8	7.8
All Industries	17.0	15.4	8.2	7.3	9.0	9.6	8.3	8.7	9.4	7.3	3.9	9.2	18.9	6.9	6.4	3.9	7.3	6.5	7.8

* Estimated from incomplete data.
+ Prevailing rates, which include unilateral reductions in post-Kennedy round tariff rates.
Source: based on data supplied by Office of U.S. Trade Representative.

Source: Deardorff and Stern (1983).

For countries not present in Table A1, we retain the oldest tariff data from WDI, for primary and manufacturing sectors. This is summarized in Table A2:

Table A2: Assumptions for the trade war scenario when missing data (Average tariff, earliest data in WDI and GTAP)

Partner	Median year (WDI)	Manufacturing*		Primary	
		MAcMap 2011	Fragmented (WDI)	MAcMap 2011	Fragmented (WDI)
Australia & New Zealand	1991.5			0.01	37.86
Rest of the World	1996	3.25	8.65	0.70	10.70
China	1992	5.20	36.41	0.91	13.96
Japan	1988			0.15	4.82
Korea	1988	3.77	16.91	1.31	8.15
ASEAN	1990.5	4.97	12.35	0.43	13.05
India	1990	8.21	76.28	1.76	27.13

Canada	1989			0.10	9.53
USA	1989			0.18	2.42
Mexico	1991	4.20	13.03	0.33	8.25
Brazil	1989	10.58	37.96	0.10	19.01
Other EU28	1988			0.06	2.78
France	1988			0.06	2.73
Germany	1988			0.05	2.73
Italy	1988			0.05	2.73
Spain	1988			0.06	2.73
United Kingdom	1988			0.06	2.73
Russia	1993	8.14	7.52	1.18	4.01
Other Middle East	2000	5.00	9.39	1.44	7.55
Turkey	1993	1.23	5.37	0.12	7.90
North Africa	1993	6.63	30.24	1.25	14.77
Sub-Saharan Africa	1996	9.28	12.56	1.69	13.18
South Africa	1988	4.80	13.42	0.37	4.30

Reminder: Tokyo round 1973-1979; Uruguay round 1986-1993.
* For manufacturing in the majority of developed countries (left blank in this table), data from Deardorff & Stern (1983) is used instead.
Source: MAcMap HS-6 2011, WDI, authors calculations.

APPENDIX B: COUNTRY CLASSIFICATION

Table B1 – Country list, codes, income classes and region

code	name	Inc. class	zone
AFG	Afghanistan	L	MENA
AGO	Angola	M	SSA
ALB	Albania	M	ROW
ANT	Netherlands Antilles	H	SAM
ARE	United Arab Emirates	H	MENA
ARG	Argentina	M	SAM
ARM	Armenia	M	ROW
AUS	Australia	H	ROW
AUT	Austria	H	EU27
AZE	Azerbaijan	M	MENA
BDI	Burundi	L	SSA
BEL	Belgium	H	EU27
BEN	Benin	L	SSA
BFA	Burkina Faso	L	SSA
BGD	Bangladesh	L	ROAS
BGR	Bulgaria	M	EU27
BHR	Bahrain	H	MENA
BHS	Bahamas, The	H	SAM
BIH	Bosnia and Herzegovina	M	ROW
BLR	Belarus	M	ROW
BLZ	Belize	M	SAM
BMU	Bermuda	H	ROW
BOL	Bolivia	M	SAM
BRA	Brazil	M	BRA
BRB	Barbados	H	SAM
BRN	Brunei Darussalam	H	ROAS
BTN	Bhutan	M	ROAS
BWA	Botswana	M	SSA
CAF	Central African Republic	L	SSA
CAN	Canada	H	ROW
CHE	Switzerland	H	ROW
CHL	Chile	M	SAM
CHN	China	M	CHN
CIV	Cote d'Ivoire	M	SSA
CMR	Cameroon	M	SSA
COG	Congo, Rep.	L	SSA
COL	Colombia	M	SAM
COM	Comoros	L	SSA
CPV	Cape Verde	M	SSA

CRI	Costa Rica	M	SAM
CUB	Cuba	M	SAM
CYP	Cyprus	H	EU27
CZE	Czech Republic	H	EU27
DEU	Germany	H	EU27
DJI	Djibouti	M	SSA
DNK	Denmark	H	EU27
DOM	Dominican Republic	M	SAM
DZA	Algeria	M	MENA
ECU	Ecuador	M	SAM
EGY	Egypt, Arab Rep.	M	MENA
ERI	Eritrea	L	SSA
code	name	Inc. class	zone
ESP	Spain	H	EU27
EST	Estonia	H	EU27
ETH	Ethiopia	L	SSA
FIN	Finland	H	EU27
FJI	Fiji	M	ROW
FRA	France	H	EU27
GAB	Gabon	M	SSA
GBR	United Kingdom	H	EU27
GEO	Georgia	M	ROW
GHA	Ghana	L	SSA
GIN	Guinea	L	SSA
GMB	Gambia, The	L	SSA
GNB	Guinea-Bissau	L	SSA
GNQ	Equatorial Guinea	H	SSA
GRC	Greece	H	EU27
GRL	Greenland	H	ROW
GTM	Guatemala	M	SAM
GUM	Guam	H	ROW
GUY	Guyana	M	SAM
HKG	Hong Kong, China	H	ROAS
HND	Honduras	M	SAM
HRV	Croatia	H	EU27
HTI	Haiti	L	SAM
HUN	Hungary	H	EU27
IDN	Indonesia	M	ROAS
IND	India	M	IND
IRL	Ireland	H	EU27
IRN	Iran, Islamic Rep.	M	MENA
IRQ	Iraq	M	MENA
ISL	Iceland	H	ROW
ISR	Israel	H	MENA
ITA	Italy	H	EU27
JAM	Jamaica	M	SAM
JOR	Jordan	M	MENA
JPN	Japan	H	JPN
KAZ	Kazakhstan	M	ROW
KEN	Kenya	L	SSA
KGZ	Kyrgyz Republic	L	ROAS
KHM	Cambodia	L	ROAS
KOR	Korea, Rep.	H	ROAS
KWT	Kuwait	H	MENA

LAO	Lao PDR	L	ROAS
LBN	Lebanon	M	MENA
LBR	Liberia	L	SSA
LBY	Libya	M	MENA
LCA	St. Lucia	M	SAM
LKA	Sri Lanka	M	ROAS
LSO	Lesotho	M	SSA
LTU	Lithuania	M	EU27
LUX	Luxembourg	H	EU27
LVA	Latvia	M	EU27
code	name	Inc. class	zone
MAC	Macao, China	H	ROAS
MAR	Morocco	M	MENA
MDA	Moldova	M	ROW
MDG	Madagascar	L	SSA
MDV	Maldives	M	ROW
MEX	Mexico	M	SAM
MKD	Macedonia, FYR	M	ROW
MLI	Mali	L	SSA
MLT	Malta	H	EU27
MMR	Myanmar	L	ROAS
MNE	Montenegro	M	ROW
MNG	Mongolia	M	ROAS
MOZ	Mozambique	L	SSA
MRT	Mauritania	L	SSA
MUS	Mauritius	M	SSA
MWI	Malawi	L	SSA
MYS	Malaysia	M	ROAS
NAM	Namibia	M	SSA
NER	Niger	L	SSA
NGA	Nigeria	M	SSA
NIC	Nicaragua	M	SAM
NLD	Netherlands	H	EU27
NOR	Norway	H	ROW
NPL	Nepal	L	ROAS
NZL	New Zealand	H	ROW
OMN	Oman	H	MENA
PAK	Pakistan	M	ROAS
PAN	Panama	M	SAM
PER	Peru	M	SAM
PHL	Philippines	M	ROAS
PNG	Papua New Guinea	M	ROW
POL	Poland	M	EU27
PRI	Puerto Rico	H	SAM
PRK	Korea, Dem. Rep.	L	ROAS
PRT	Portugal	H	EU27
PRY	Paraguay	M	SAM
PYF	French Polynesia	H	ROW
QAT	Qatar	H	MENA
ROM	Romania	M	EU27
RUS	Russian Federation	M	RUS
RWA	Rwanda	L	SSA
SAU	Saudi Arabia	H	MENA
SDN	Sudan	M	SSA

code	name	Inc. class	zone
SEN	Senegal	L	SSA
SGP	Singapore	H	ROAS
SLB	Solomon Islands	M	ROW
SLE	Sierra Leone	L	SSA
SLV	El Salvador	M	SAM
SOM	Somalia	L	SSA
SPM	Saint Pierre and Miquelon	M	ROW
SRB	Serbia	M	ROW
STP	Sao Tome and Principe	M	SSA
SUR	Suriname	M	SAM
SVK	Slovak Republic	H	EU27
SVN	Slovenia	H	ROW
SWE	Sweden	H	EU27
SWZ	Swaziland	M	SSA
SYR	Syrian Arab Republic	M	MENA
TCD	Chad	L	SSA
TGO	Togo	L	SSA
THA	Thailand	M	ROAS
TJK	Tajikistan	L	ROW
TKM	Turkmenistan	M	ROW
TMP	Timor-Leste	M	ROW
TON	Tonga	M	ROW
TTO	Trinidad and Tobago	H	SAM
TUN	Tunisia	M	MENA
TUR	Turkey	M	MENA
TZA	Tanzania	L	SSA
UGA	Uganda	L	SSA
UKR	Ukraine	M	ROW

code	name	Inc. class	zone
URY	Uruguay	M	SAM
USA	United States	H	USA
UZB	Uzbekistan	L	ROW
VCT	St. Vincent and the Grenadines	M	SAM
VEN	Venezuela, RB	M	SAM
VIR	Virgin Islands (U.S.)	H	SAM
VNM	Vietnam	L	ROAS
VUT	Vanuatu	M	ROW
WBG	West Bank and Gaza	M	MENA
WSM	Samoa	M	ROW
YEM	Yemen, Rep.	L	MENA
ZAF	South Africa	M	SSA
ZAR	Congo, Dem. Rep.	L	SSA
ZMB	Zambia	L	SSA
ZWE	Zimbabwe	L	SSA

Table B2 – Labels for zones and income groups:

Label	Zone	Developed / Developing
EU	European Union	All developed
MENA	Middle-East and North Africa	All developing
SSA	Sub-Saharan Africa	All developing
USA	United States of America	Developed
JPN	Japan	Developed
CHN	China	Developing
IND	India	Developing
BRA	Brazil	Developing
RUS	Russian Federation	Developing
ROAS	Rest of Asia	All developing exc. Hong-Kong, Korea Singapore
SAM	Latin America	All developing exc. Chile, Argentina
ROW	Rest of the World	All developing excepted Switzerland, New Zealand, Iceland, Norway, Australia and Canada
H	High income (WB)	
M	Medium income (WB)	
L	Low income (WB)	

APPENDIX D: MAGE SHORT DESCRIPTION

Our macroeconomic projections, used in the first two steps of our methodology rely on the MaGE model.[25] This appendix shortly describes the model's underlying assumptions, while a full documentation can be found in Fouré et al. (2012,2013).

The model consists of three steps. First, production factor and productivity data are collected for 1980 to 2010. Second, behavioural relations are estimated econometrically for factor accumulation and productivity growth, based on these data. Third, these relations are used to project the world economy.

Production function

MaGE relies on the following theoretical framework:

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

With $Y_{i,t}$ being the GDP in volume, $K_{i,t}$ the stock of capital (in constant dollars), $L_{i,t}$ the labor force (active population) and $E_{i,t}$ the energy consumption measured as total primary energy consumption. Capital-Labor productivity – that we will also call TFP by analogy with the standard Cobb-Douglas model – is labeled $A_{i,t}$, while energy-specific productivity is $B_{i,t}$. This production function is parameterized by two parameters, $\alpha = 0.3$ determining the relative shares of capital and labor in their aggregated bundle, and $\sigma = 0.2$ defining the authorized substitutions between energy and the capital-labour bundle.

GDP is measured in constant dollars, net of oil rents – oil rents tend to alter productivity levels and are therefore treated apart.

[25] Version 2.3, available online at http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=13. The central scenario of MaGE corresponds to the EconMap 2.3 database, available online at http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=11.

Describing past data

While capital, labor and energy consumption are available in the database we use, TFP and energy productivity are dependent on the production function. Energy productivity $B_{i,t}$ is recovered theoretically using a simple perfect-competition profit-maximization program. The first order conditions lead to:

$$B_{i,t} = {p_E}_t^{\frac{\sigma}{\sigma-1}} \left(\frac{E_{i,t}}{Y_{i,t}}\right)^{\frac{1}{\sigma-1}}$$

With p_E corresponding to the energy price, that we proxy by oil price. The only missing parameter is then the capital-labor productivity $A_{i,t}$ and we are able to recover it as the residual:

$$A_{i,t} = \frac{Y_{i,t}}{{K_{i,t}}^{\alpha}{L_{i,t}}^{1-\alpha}} \left[1 - \left(\frac{B_{i,t}}{{p_E}_t}\right)^{\sigma-1}\right]^{\frac{\sigma}{\sigma-1}}$$

Estimations

Once the database in built for 1980-2010, we estimated behavioral relationships in order to have a consistent framework for capital, labor and energy, as well as their respective productivity levels. We describe here briefly the different estimations.

Savings rate

We follow Masson et al. (1998) life-cycle hypothesis by making savings rate dependent on the age structure of the population – measured after Higgins (1998) by polynomials – and the GDP per capita. The resulting relation is the following:

$$\left(\frac{S}{Y}\right)_{i,t} = \alpha_i + \beta_1 \frac{y_{i,t-1}}{y_{US,t-1}} + +\beta_3 g_{i,t-1} + \sum_{k=1}^{3} \eta_k \, d_{i,t}^{k}. g_{i,t-1} + \varepsilon_{i,t}$$

With$y_{i,t}$ being GDP per capita, $g_{i,t}$ its growth rate, and $d_{i,t}^{k}$ the polynomial forms à la Higgins (1998).

Investment rate

Both investment rates and savings rate are not stationary series. As a consequence, we follow Herwartz and Xu (2009) by solving the so-called Feldstein-Horioka paradox using an Error Correction Model.

$$\begin{cases} \left(\frac{I}{Y}\right)_{i,t} = \alpha_i + \beta_i \left(\frac{S}{Y}\right)_{i,t} + u_{i,t} \\ \Delta\left(\frac{I}{Y}\right)_{i,t} = a_i + \theta_i \left(\left(\frac{I}{Y}\right)_{i,t-1} - \hat{\alpha}_i - \hat{\beta}\left(\frac{S}{Y}\right)_{i,t}\right) + b\,\Delta\left(\frac{S}{Y}\right)_{i,t} + \varepsilon_{i,t} \end{cases}$$

Given the important heterogeneity of estimation results, we conduct the estimation using the Engle and Grander two-step method separately on OECD and non-OECD countries.

Education

For education attainment, we rely on a standard catch-up model for two age groups (15-19 and 20-24) and three education levels (primary, secondary and tertiary). People aged 25 and more are assumed to keep their initial education level. The relation is the following:

$$ln\left(\frac{h^l_{a,i,t}}{h^l_{a,i,t-1}}\right) = \lambda^l_r ln\left(\frac{h^{l*}_{a,t-1}}{h^l_{a,t-1}}\right) + \epsilon_{i,t}$$

Where $h^l_{a,i,t}$ is the proportion of the age-group a in country i having a level of education of at least l ($l = 1, 2, 3$) in year t and $h^{l*}_{a,t}$ is the corresponding leader level of schooling. The estimated convergence speed λ^l_r is specific to one of the 8 regions we distinguish.

The leader level $h^{l*}_{a,t}$ is determined as the envelope of all countries. Several countries can appear as the leader level at least for one age group during a sub-period. The main primary education leaders are Austria, Japan, France and Switzerland. The main secondary education leaders are the United States, Australia, Norway and New Zealand. The main tertiary education leaders are the United States, Australia, New Zealand and the Russian Federation.

Female participation

Unlike for men, the participation of females to the labour force is very unequal across countries. As noted for instance by Bloom et al. (2009), female participation is highly dependent on fertility, education and urbanization. We adapt their framework to our own by specifying:

$$ln\left(\frac{l^F_{a,i,t}}{1-l^F_{a,i,t}}\right) = \sigma_{a,i} + \beta^2_a h^2_{a,i,t} + \beta^3_a h^3_{a,i,t}$$

Where ${l^F}_{a,i,t}$ is the participation rate of females of age *a* in country *i* at time *t*. Like in the previous subsection, $h^2_{a,i,t}$ is the proportion of age-group *a* (of both genders) in year *t* that has at least a secondary diploma, $h^3_{a,i,t}$ is the proportion holding a tertiary diploma.

TFP growth

For TFP growth, we rely on Vandenbussche et al. (2006). In this papers, TFP growth is explained by a pure catch-up effect, a pure (tertiary) education effect, and an interaction term between education and catch up. Adapted to our framework, this reads:

$$\Delta \ln(A_{i,t}) = \alpha_{0,r} + \alpha_1 a_{i,t-1} + \alpha_2 h^3_{i,t-1} + \alpha_3 a_{i,t-1}(h^2_{i,t-1} - h^3_{i,t-1}) + \epsilon_{j,t}$$

where $A_{i,t}$ denotes the TFP of country *i* in year *t*, $a_{i,t-1} = \ln\left(\frac{A_{i,t-1}}{A^*_{t-1}}\right)$ represents the distance to the TFP frontier A^* in year *t*-1, $h^3_{j,t-1}$ is the proportion of the working-age population with a tertiary diploma, $h^2_{j,t-1} - h^3_{j,t-1}$ is the proportion of the working-age population with a secondary diploma but no tertiary diploma.

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:

$$\Delta \ln B_{i,t} = \beta_i^0 + \beta^1 \ln \frac{B_{i,t-1}}{B_{t-1}^*} + \beta^2 \ln \frac{y_{i,t-1}}{y_{i,t-1}^*} + \beta^3 \ln \frac{y_{i,t-1}}{y_{i,t-1}^*} \times \delta_{i,t-1}^L + \beta^4 \ln \frac{y_{i,t-1}}{y_{i,t-1}^*} \times \delta_{i,t-1}^M + \epsilon_{i,t}$$

Using dummied for low- and middle-income countries (respectively $\delta_{i,t}^L, \delta_{i,t}^M$) and the energy productivity leader level B_t^*. The U-shaped relationship comes from the estimation results, where β^3 is significantly negative and β^4 is not significatively different from 0. Countries are split between income levels using the thresholds provided by the World Bank, leading to potential changes across time.

Projections

Using the behavioral relationships described above, we are almost able to fully project the world economy. We add a few additional assumptions.

First, in order to avoid the problem of non-significance of fixed effects, our projections are based on differences from a "reference period" between 1995 and 2008.

Second, we use oil prices projections from IEA (WEO 2012) to proxy energy price, and rely on the following equation for projections, this equation resulting from the representative firm's maximization program:

$$Y_{i,t} = A_{i,t} K_{i,t}^{\alpha} L_{i,t}^{1-\alpha} \left[1 - \left(\frac{B_{i,t}}{p_{E_t}} \right)^{\sigma-1} \right]^{\frac{\sigma}{1-\sigma}}$$

Finally, in order to circumvent the n[th] country problem (with *n* countries in the world, there are only *n*-1 independent savings-investment imbalances), we rescale investment rate every year such that world total investment equals world total savings.