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**Value Added in Motion: Modelling World Trade Patterns
at the 2035 Horizon**

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VALUE ADDED IN MOTION: MODELLING WORLD TRADE PATTERNS AT THE 2035 HORIZONLionel Fontagné¹ & Jean Fouré[‡]

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ABSTRACT

We address in this paper the future geography of production, migration and energy at the world level, and the consequences for the largest European countries. We take scant account of the wide range of possible evolutions of the world economy in terms of technological progress and diffusion, education, demography including migrations and finally energy price and efficiency. Taking a 2035 horizon, we examine how world trade patterns will be shaped by the changing comparative advantages, demand, and capabilities of different regions, and what will be the implications in terms of location of value added at the sector and country level. We combine a convergence model fitting three production factors (capital, labour and energy) and two factor-specific productivities, alongside a dynamic CGE model of the world economy calibrated to reproduce observed elasticity of trade to income. Each scenario involves three steps. First, we project growth at country level based on factor accumulation, demography and migration, educational attainment and efficiency gains, and discuss uncertainties related to our main drivers. Second, we impose this framework on the CGE baseline. Third, we implement trade policy scenarios (tariffs as well as non-tariff measures in goods and services), in order to get factor allocation across sectors from the model as well as demand and trade patterns.

JEL Classification: E23, E27, F02, F17, F47*Key Words:* Growth, Macroeconomic Projections, Dynamic Baselines

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INTRODUCTION²

What will be the geography of production, migration and energy at the world level in two decades? How will changes in economic size and comparative advantages of countries impact the patterns of world trade in the 2030s and the location of value added? There is indeed much uncertainty in such projection. There are two main sources of errors of judgment: projection of the drivers of international trade and location of value added, and the basic unpredictability of some key variables which is irreducible.

Thus, it is firstly essential to rely on a sound representation of economic growth for the largest number of countries, providing projections of their economic size and comparative advantages. The combination of the two ultimately drives the location of value added at the sector level. Regarding GDP projections, is it best to adopt a very detailed model of growth that includes regulations for example, or to focus on the main drivers and treat national idiosyncrasies as unobservable? There is a trade-off between restricting detailed projections to the set of OECD countries plus a handful of emerging economies, and including a much larger set of countries in a more stylized growth model.³ Concerning the drivers of the location of value added a similar set of question arises: one can hardly model a detailed representation of each sector. But modelling the role of factor accumulation and technical progress on the specialization in broad type of activities is doable.

The second prerequisite is to acknowledge the unpredictability of certain key variables. The demographic paths are indeed dependent on assumptions on fertility. But the patterns of the labour force will be driven by other forces as well, like migrations flows and the level of education of migrants. Education convergence may speed up or may be hampered, with sizeable impacts on productivity. The future of international capital mobility is also very uncertain. Productivity convergence may accelerate or decelerate as a result of methods of technology transfer and approaches to firm mobility. Finally, energy prices will vary widely over the next 20 years, as the result of uncertainties surrounding economic growth, geopolitical tensions (e.g. Middle-East) or technological breakthroughs (e.g. shale gas or jumps in energy efficiency). Against this background only a scenario approach may help.

In the following, we provide insights into the future of geography of value added by feeding projected economic growth for a large set of countries into a dynamic sectoral model of the world economy. Our 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) or current accounts, while imposing constraints in terms of global

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³ See Château et al. (2014) for a discussion.

balance between saving and investment. The induced GDP, saving, energy efficiency and current account trajectories to 2035 can be imposed on a sectoral Computable General Equilibrium (CGE) model of the world economy, relying on identical assumptions about population, labour force, education and current accounts. 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.

Our exercise adopts open-minded assumptions about the evolution of the key drivers of growth, combining large shocks to its main drivers. Beyond scenarios on energy prices, our main interest will be on the impact of migrations and the skill level of migrants. When doable, we rely on projection exercises performed in other parts of the ENEL project to calibrate our scenarios. Importantly, our migration scenarios are consistent with Docquier and Machado (2015).

To better assess their effect on the location of value added, we combine these shocks with possible evolutions in trade costs. We consider the situation of a tariff war driving countries beyond the legal World Trade Organization (WTO) framework, to post-Tokyo Round tariff levels. We examine the impact of generalized inspection of shipments, as a response to pandemics or terrorism. Finally we address changes in the barriers to services trade. The aim is not to suggest that any of these scenarios is plausible given current information on the world economy. Instead we want to show how common modelling tools can be combined to characterize the broad range of possible future geography of value added, associated with the presence of high uncertainty.

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 scenarios for the world economy at the 2030 horizon. None of these studies use an explicit growth model and the scenarios 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 scenarios 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 scenarios 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. Using the same horizon but emphasizing the endogenous determinants of migration by skill level, Docquier and Machado (2015) provide worldwide projections of population, educational attainment, international migration and income. Their baseline scenario is in line with the ‘high-fertility’ population prospects of the United Nations. 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 takeoff in Africa. 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 economies reduce world exports at the 2060 horizon and slow-down the relocation of higher value-added activities into (today) emerging economies.

Taking stock of this literature, the contribution of the present paper is twofold. First, it highlights the technical issues and the wide range of uncertainty raised by combining macroeconomic and multisectoral models. To our knowledge, this is the only exercise so far on such a scale, at the 2035 horizon, adopting a methodology of consistent scenario construction for the growth and the CGE models. Incorporating Docquier and Machado (2015) projections of international migrations helps plausibly depicting the future geography of value added with a focus on Europe.

The rest of the paper is organized as follows. Assumptions related to growth projections and our scenarios are presented in Section 1. Section 2 describes the methodology and the scenarios are implemented in the growth model in Section 3. Section 4 summarizes the results of the global and sectoral models of the world economy. 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) economic growth projections; (ii) design of dynamic baselines in applied general equilibrium modelling with a focus on the environment; and (iii) design of medium and long term scenarios for the world economy. The first two are not independent: design of dynamic baselines relies on the first literature strand (GDP driven baselines), or provides 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 building.

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 initiated documentation of the huge shift towards the emerging economies (Wilson and Purushothaman, 2003; Ward, 2011), which was added to by work from international institutions. With some exceptions (Duval and de la Maisonneuve, 2010, Johansson et al., 2012, Fouré et al., 2013, Docquier and Machado, 2015), 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 huge uncertainties surrounding projections that rarely prove accurate and are conditional on changes in the geopolitical context. Nevertheless, long-term investigations are a prerequisite for much downstream analysis, such as provided in this paper to address future patterns of world trade.

This lack of attention contrasts with the importance of economic growth factors in the economic literature. Starting from the standard neo-classical Solow model, mechanisms for production factor accumulation have been identified, for instance, in the demographic determinants of saving (see, for instance, Masson et al., 1998) and capital formation (Feldstein and Horioka, 1980), or in human capital catch-up and productivity improvements (Aghion and Howitt, 1992). Long-term growth projection models build on this vast literature by combining existing analyses.

At least three drivers are common to all empirical studies: capital stocks, labour force and TFP. These factors are taken into account by Wilson and Purushothaman (2003), which combines existing labour force projections, constant investment rates, and a convergence scenario for TFP. Duval and 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 and Machado (2015) 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. What is missing is ageing and its impact on savings, investment and the current account, capital movements and trade. The giant step forward is to integrate in such model covering most countries in the world endogenous migration by education level. Fertility and education decisions are also endogenized. The baseline scenario is compatible with the high fertility scenario of the UN, and we will exploit this compatibility below.

1.2. Dynamic baselines

Large scale policy simulations generally rely on multisectoral dynamic models of the world 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, this would be flawed reasoning if the focus is medium or long run policies: an economic policy affecting China would have a dramatically different impact on the world economy were China twice as large, which will be the case in less than ten years at current growth trends.

Since the model is exploited to determine capital accumulation, energy and primary resources prices, it is necessary to supplement it with world data including demographics. However, since CGE models generally do not describe the intrinsic mechanisms of growth (conditional convergence) they provide neither a satisfactory representation of efficiency gains from combining production factors, nor plausible trajectories for countries at different levels of development. Accordingly, it is necessary to constrain the CGE to reproduce a pre-defined GDP growth path or a pre-defined TFP path for each world country (or region). This is the aim of dynamic baselines.

Many baselines focus on the period up to 2020 (e.g. the GTAP model), but some exercises extend to 2050 (e.g. the Linkage model). Relying on an ambitious approach, Fontagné et al. (2013) tentatively consider the 2100 horizon in order to provide environmental studies with a theoretically consistent baseline of the world economy. Whatever the horizon is, the building blocks of a baseline are the same.

The first step is projection of a general trajectory of world growth, based on simple and robust economic mechanisms. There are two competing approaches to CGE modelling. The first option is to build a scenario for factor productivity growth in order to recover GDP from the CGE model. The second is to build a GDP scenario such that the 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. Moreover, it allows different sector specific trajectories to be encompassed without over-constraining the model. However, this approach is very sensitive to assumptions related to TFP growth and its determinants. For instance, the EPPA model (Paltsev et al., 2005) assumes identical logistic productivity growth for all countries and sectors, and does not implement capital productivity.

The symmetric approach of imposing GDP growth trajectories onto a CGE, and recovering the productivity gains, is more data demanding since it is necessary, first, to project growth for every country. Its main advantage is that it enables proper modelling of growth by taking account of conditional convergence and possibly different types of technical progress, in line with the vast literature on macroeconomic growth. This is a very important advantage if the interest is in long run modelling of different kinds (mature, emerging, developing) of economies. Also, this approach allows greater reliance on the macro projections in the literature. 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 and McDougall, 2000).

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 – labour-only productivity – to endogenous national TFP. This approach results in: (i) a constant exogenous agricultural TFP; and (ii) a constant 2-percentage points difference between industry and services sector productivity (the former being more productive). There is a separate literature on agriculture-specific productivity that draws on Nin et al. (2001). Coelli and Rao (2005) and Ludena et al. (2007) depart from the usual analysis of yields, and start from non-parametric productivity indices based on the use of agricultural inputs. They show that productivity in agriculture is not constant, and that its growth rate is heterogeneous across countries.

In addition to these efforts to provide the modelling community with dynamic baselines for their policy simulations that rely on CGEs, a related literature stream specifically tackles environmental issues. Two key issues are raised: first the productivity of energy and its impact on CO₂ emissions, and second, natural resources scarcity and its direct link to energy prices. In both cases, assumptions focus on one variable such that the other adjusts.

Similar to environmental baselines, the first approach is to rely on CO₂ emissions from other institutions (or, equivalently, on energy demand), such as in the PACE model (Böhringer et al., 2009). In this case, improvements to the carbon intensity of goods are deduced, although no comprehensive framework for energy consumption is developed. In addition, particular attention has to be given to the coherence between the emissions projections' underlying growth assumptions and the growth model projections because CO₂ emissions depend heavily on economic activity.

The second approach consists of developing a scenario for Autonomous Energy Efficiency Improvements (AEEI) as in the EPPA model. These AEEI encompass non-price induced, technology-driven productivity changes. An exogenous time trend for energy productivity is imposed in order to control for the evolution of demand reduction, which scales production sectors' use of energy per unit of output. These AEEI are specific to broad regions (10 regions in the EPPA) with two distinct profiles. On the one hand, China and the Developed Countries face a regularly increasing AEEI. On the other hand, other countries' AEEI first decrease (up to around 2035) and then increase at different rates. These discrepancies are driven by the empirical observation that energy productivity has regularly increased in countries with well-developed industry and services sectors, and have stagnated or even decreased in industrializing countries. The Linkage model implements a mixed framework, in

which energy demands are imposed to recover productivity changes with the exception of crude oil consumption which is driven by an exogenous productivity scenario.

A problematic issue related to CO₂ 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. Laborde and Valin (2011) point out 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. 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 on the model that production, consumption and trade are coherent in both monetary units and physical quantities.

Finally, the question of natural resource depletion can be approached in two ways. As underlined by Paltsev et al. (2005), long run dynamics of energy prices are captured by natural resources depletion. Therefore, it is possible to model this depletion and deduce the corresponding energy prices, or to do the reverse. The first solution is chosen by the EPPA model, which incorporates resource-specific natural resources use as well as additional recoveries. The second involves exogenously fixing energy prices, as in the ENV-Linkage model (an option also available in EPPA), such that natural resources adjust to match targeted prices. The assumption in ENV-Linkage is to rely on IEA's world price projections up to 2030 and then assume a 1% growth in oil prices.

1.3. Scenario design

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

World Bank (2007) relies on LINKAGE (a multisectoral model of the world economy comparable to MIRAGE, described in van der Mensbrugghe, 2006) to draw scenarios for the world economy at the 2030 horizon. Instead of recovering TFP from the CGE on which GDP and factor accumulation would be imposed, TFP assumptions are imposed on the CGE to obtain GDP. In addition, energy efficiency is assumed to improve exogenously by 1% per year worldwide. Energy efficiency is derived theoretically and projected on a country basis in MaGE, before being introduced in the CGE in our exercise. Finally, international trade costs are assumed to decline by 1% per year, in line with our own pre-experiment aimed at mimicking the historical income elasticity of international trade. This exercise was calibrated on the GTAP-2001 database (we used GTAP-2011 for MIRAGE).

Petri and Zhai (2013) combine Asian Development Bank growth projections at the 2050 horizon (ADB, 2011) with a CGE model in order to develop their scenarios. In addition to a focus on Asia rather than a world-wide perspective, the big difference from our study is not the horizon considered, but the methodology used to design the scenarios. Our approach involves three steps. We first design a

business-as-usual scenario of world growth, and run a pre-experiment in order that our CGE reproduces income trade elasticity observed in the past. Second we construct two scenarios for the growth model, which are then imposed on the CGE in a consistent way. Third, we shock the CGE, completing our two scenarios with evolutions, such as possible changes in transaction costs, that can be tackled only by the CGE. In contrast, Petri and Zhai use a business-as-usual macroeconomic baseline and then proceed to our third step.⁴ This is an important difference since many of the assumptions of our scenarios (e.g. fertility, female participation in the labour market, education catch up) will have cascading effects for growth and trade, channelled through the different mechanisms in the two models.

Anderson and 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) 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 and Zhai) directly in the CGE: they show a drop in TFP and further trade liberalization. Implications for world trade are derived. Two drawbacks to this approach are the combining of different growth models (ADB and MaGE-V1.2), and the implementation of scenarios directly in the CGE rather than using two modelling frameworks. Also, the scenarios can be questioned since further trade liberalization is not necessarily an outcome for the future economy. Anderson and Strutt acknowledge the absence of scenarios for trade costs, transport costs and current account imbalances, all dimensions included in our analysis.

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 Modeling 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), 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 being integrated with the OECD's ENV-Linkages CGE model, following a method similar to ours; to our knowledge, results are not yet available.

⁴ Their simpler approach allows deeper developments in terms of income distribution. While we rely on a representative household and two labor categories (skilled, unskilled), Petri and Zhai supplement their CGE with an income distribution module which allocates total consumption to four income bins.

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 CEPII's MaGE model. 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 CEPII), 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.

2. WHAT WE DO

This paper adopts the GDP-driven CGE approach described above. To proceed, we start with a growth model derived theoretically, estimated, and used to make macroeconomic projections for more than 160 countries – we call this first step the “Macro” step. Projections of savings rate, energy efficiency, current account and GDP are done at the country level, imposing 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). Using this framework, we implement scenarios for the world economy. The second step – labelled as the “Secto” step – consists in calibrating the dynamic trajectory of CGE model (both sectoral TFP and level of natural resources) such that it matches the Macro projections (respectively GDP and energy prices) in coherence with sector-specific constraints, current account constraints and exogenous agricultural productivity. To proceed we use an updated version of MIRAGE⁵ (Fontagné et al., 2013). The CGE provides sector decomposition of growth, factor allocation, country specialization and world trade patterns, these last being our ultimate objective. In this second stage, additional shocks are imposed on the CGE in order to provide the best representation of future allocation of value added across countries and sectors possible. Finally, the CGE is mobilized in a third step – the “Trade policy” step, to build alternative scenarios of the world economy.

Below we describe the growth model (MaGE), the CGE model (MIRAGE), and the design of the scenarios.

2.1. The growth model

Projections of world macroeconomic trends are elaborated with the MaGE model proposed in Fouré et al. (2013).⁶ 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.

Using World Bank, United Nations and International Labour Organization 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

⁵ The version used is nicknamed MIRAGE-e 1.0.2.

⁶ A more detailed description is provided in Appendix D. The version used is MaGE 2.3, corresponding to the projection database EconMap 2.3 available online at http://www.cepii.fr/CEPII/fr/bdd_modele/presentation.asp?id=11.

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.

Behavioural relations are econometrically estimated from this dataset for population, capital accumulation and productivity. Population projections are given by United Nations 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 International Labour Organization, 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 depreciation 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, saving depends 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 dissavings.

Capital-labour and energy productivity follow catch-up behaviour with the best-performing countries. The former is conditional on and fuelled by education level (while spontaneous innovation is triggered by tertiary education, the catch-up process (imitation) depends on secondary education); the latter is follows a U-shape relationship between the level of development – proxied by GDP per capita – and energy productivity: agriculture- and services-oriented economies tend to be more efficient in energy use compared to industrial ones.

All these behavioural estimations provide dynamics for factor accumulation (labour force, capital) and productivity (capital-labour and energy-specific), that we can use in projection. 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. We are therefore able to recover GDP projections.

2.2. The CGE model

We use a new 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). For simplicity, we use the version of the model fitting perfect competition. This version of the model proposes a different modelling of energy use, and introduces modelling of CO₂ emissions (Fontagné et al., 2013).

MIRAGE was adapted to the exercise conducted here.⁷ MIRAGE has a sequential dynamic recursive set-up which is consistent with the output of MaGE: capital accumulation and current account will be driven by the results of the first step of our exercise. Macroeconomic closure consists of having the share of each region in global current accounts imbalances varying yearly according to the projections from MaGE.

On the supply side, in this perfect competition version of MIRAGE, 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.

Growth rates of the fully employed primary factors are set exogenously, based on MaGE projections. Installed capital is assumed to be immobile (sector-specific), while investment is allocated across sectors according to their rates of return. The overall stock of capital evolves by combining 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, and natural resources are sector-specific.

Firms' energy consumption 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 about the extent to which 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 coal or 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 and Truong (2002).⁸ Finally, the value of the energy aggregate is subject to the efficiency improvements projected by the growth model. As stressed above, in CGE models CO₂ 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 CO₂ emissions can be computed in millions of tons of CO₂. Carbon

⁷ The interested reader will find a more complete description of MIRAGE in Appendix E.

⁸ 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).

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 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 comparison of the current account and 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 (FDI) 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-up; this mechanism will be integrated separately when building the scenarios.

Firms' demand for production factors is organized as a CES aggregation of land, natural resources, unskilled labour, and a bundle of the remaining factors. This bundle is a CES aggregate of skilled labour, and another bundle of capital and energy. Finally, energy is an aggregation of energy sources as defined above.

On the demand side, a representative consumer from each region maximizes its intra-temporal utility function under its budget constraint. This agent, which could be a household or government, saves a 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. Thus, it is well suited to our purpose.

Then, within each sector, goods are differentiated by their origin. 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.

Efficiency in the use of primary factors and intermediate inputs is based on the combination of four mechanisms. First, agricultural productivity is projected separately, as detailed in Fontagné et al.

(2013). 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 this long-run baseline, the time span is 24 years, the starting point being 2011.

Feeding the world population and providing the industry with its agro-related primary resources will be continuing challenges in future decades. It is therefore essential to properly assess to what extent technical progress in the agricultural sector will mitigate these problems. 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.). We need to implement a multi-input, non-parametric methodology, such as the Malmquist productivity index, based on productivity distance to a global (moving) frontier (for details, see Fontagné et al., 2013). We use FAO data for agricultural production and inputs. We chose two agricultural outputs (crops and livestock) and, on the basis of their common occurrence across the world, and data availability, five inputs (labour, land, machinery, fertilizers, livestock). Inputs can be allocated either to crops or to livestock, or be shared between these sectors.

Table 1 – Sector and country aggregation in MIRAGE

Regions	Sectors
<i>Developed countries</i>	<i>Primary</i>
France	Crops
Germany	Livestock
Italy	Other Agriculture
Spain	Other Primary
United Kingdom	<i>Energy</i>
Other EU	Coal
USA	Oil
Canada	Gas
Japan	Petroleum and coal products
Australian and New Zealand	Electricity
Korea	<i>Industry</i>
<i>Developing/Emerging countries</i>	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	<i>Services</i>
South Africa	Transport
Mexico	Finance, Insurance and Business services
Rest of Africa	Public administration
Rest of the world	Other services

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) in services, modelled as an iceberg trade cost. 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).

2.3. The dynamic 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 1), 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 1 – 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 1950-2011.

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.

Therefore, using MIRAGE, we develop two baselines in order to encompass elasticity of world trade in goods (and manufacturing goods in particular). The first, ‘Past Trade’ tries to reproduce historical evidence; ‘Pre-experiment’ adjusts the model in order to start with a plausible elasticity for the upcoming decades.

In order to test whether MIRAGE can reproduce historical evidence, we first implement a sensitivity reference case (‘Past Trade’) using different sets of assumptions. The basic case is the standard version of the model with no changes in transaction costs. Tariffs are kept constant. There is no TFP growth in the transport sector beyond what is endogenously determined by the model to match growth projections from MaGE, as referred to above. Energy prices are taken from the central scenario already discussed. We run the model over 24 years and compute the trade to income elasticity.

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: 1.16 (first row in Table 3). This elasticity matches what was observed during the 1980s.

In order to reproduce the higher elasticity observed in the 1950s and 1960s, shown in the middle of panel in Table 3, we integrate a combination of decreasing trade costs, progress in transport technologies, low energy prices and trade liberalization, based on the following assumptions which reproduce the above mentioned determinants of long term income trade elasticity:

- very low energy prices (decreasing by 3% yearly for oil, and no growth for coal and gas, according to the 1980-2007 average from BP historical data);
- 2% additional TFP growth in the transport sector compared to other services (containerization, standards, etc.), in line with estimations of sectoral TFP differentials by Wolff (1999) for the period 1958-1987;
- 38.7% cut in trade costs in the broad sense (time, red-tape, quality of the communications, etc.), own guesstimate: in order to reproduce historical elasticities, a 50% cut in 30 years is needed, corresponding to 38.8% in 24 years;
- 4% annual decrease in tariff rates (corresponding to the evolution of simple average tariffs between 1973 and 2007 in Deardorff and Stern, 1983).

Table 3 – Long-term trade to income elasticity in MIRAGE under alternative assumptions

Baseline	Assumptions on				Elasticity
	Energy prices	TFP boost in transport	Trade cost cut	Tariffs cuts	
Standard	Reference	0%	0%	0%	1.16
Price	Decreasing	-	-	-	1.30
TFP transport	-	2%	-	-	1.20
Trade cost	-	-	38.7%	-	1.36
Tariffs	-	-	-	4% annual	1.36
Past trade	Decreasing	2%	38.7%	4% annual	1.67
Pre-experiment	Reference	2%	17.4%	0%	1.31

Note: All the scenarios are implemented between 2007 and 2035, linearly (trade costs) or at constant growth rate (TFP and decreasing energy price).

Source: Author's calculations.

The elasticity observed in the 1970s can be reproduced only by introducing in the model the observed tariff cuts or alternatively a drop in trade costs. Indeed, the assumption of low energy prices is irrelevant for that period.

The average elasticity over 1950-2013 can only be nearly matched when combining our assumptions on TFP in the transport sector, trade cost reductions and tariff phasing out, under the 'past trade' assumptions.

Finally, what this kind of model cannot reproduce with plausible assumptions, is the trade to income elasticity observed in the 1990s; as already stressed, this period might be unique and it should not be reproduced in the baseline used for projections for future decades.

Regarding our reference scenario, we believe that many of the conditions of the 20th century that lead to such high elasticity of trade to GDP will not be reproduced in upcoming decades, in particular those regarding energy prices. For this reason, we implement a pre-experiment with the following assumptions:

- 2% additional TFP growth in transport sector;
- 17.4% trade cost cuts (half the ‘past trade’ assumption);
- reference energy prices (IEA, 2015);
- no tariff cut.

As the decomposition shows, the boost in TFP for the transport sector and the drop in trade costs have effects of similar magnitude. When combining these assumptions, MIRAGE reproduces a long term elasticity of trade equal to 1.31.

This pattern of MIRAGE, shown in the last row of Table 3, is the new reference on which MIRAGE is calibrated and which we will apply the scenarios described below. Recall the difference between pre-the experiment described here and the scenarios implemented in the next step. Therefore, the trade-to-income elasticity will depart from the above value in the two simulated scenarios, ranging from 0.74 to 1.48 in our two simulations.

2.4. Two scenarios for the world economy

We next illustrate the construction of two contrasting scenarios that will be applied in a consistent way to the growth model – MaGE, and to the CGE of the world economy – MIRAGE. 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 trade costs, technical progress in the transport of merchandise and tariffs imposed on merchandise imports. Finally, two simulations are performed with MIRAGE corresponding to a cooperative world versus a trade war, named “brisk and connected” and “sluggish and fragmented” respectively.

We first present the scenarios in MaGE, followed by their implementation in MIRAGE.

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 changes on a country by country basis, corresponding to anticipated immigration policy changes, and the imposed shock enhances these flows. We were not able to trace UN projected migrations precisely (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 (2015), which are consistent with the "High fertility" scenario of the UN. Docquier and Machado (2015) 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.

In the Sluggish Macro scenario, instead, we address the impact of decelerated convergence in education. In MaGE, 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 time⁹ for this process and increase it by 50% in the Sluggish case. We expect this to reduce technological catch-up and hamper growth.

⁹ 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 – The two scenarios

<i>Reference</i>			
MaGE		Sluggish Macro	Brisk Macro
	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
MIRAGE		Sluggish Secto	Brisk Secto
	Energy prices	High price scenario (IEA)	Low price scenario (IEA)
	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)
<i>Simulation</i>			
MIRAGE		Sluggish & Fragmented	Brisk & Connected
	NTM in services	No change	-25%
	Transaction costs for goods	+50% from developing countries	-50% developing countries
		+20% from developed countries	-20% developed countries
	Tariffs on goods	Trade war (Tokyo round tariffs)	-50% compared to 2010

*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.

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.

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. Such TFP shock corresponds to previously observed episodes. Figure 2 shows that, during the past 30 years, there have been many periods and many countries when TFP growth has slowed or become negative, or alternatively experienced buoyancy. 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. This is a less

cooperative world in which everyone is worse off, but where the richest countries preserve part of their initial advantage.

**Figure 3 – 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.

Another variable of interest is national 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, as depicted in Figure 3 for the MaGE reference case.¹⁰ Here, we assume that countries at different levels of development will benefit evenly from this progression. 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.

¹⁰ At the beginning of projections, almost every country had passed the turning point between efficiency decrease and improvement.

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 4, characterized by a natural rebalancing of the Chinese economy.

Figure 4 – Saving-Investment balance in the reference scenario, 1980-2035 (percentage of GDP)

Source: MaGE, authors' calculation.

The next step is to use the results of these two scenarios imposed on MaGE as inputs for MIRAGE. Accordingly the Sluggish Macro and Brisk Macro scenarios are used in order to design two reference baselines for MIRAGE: Sluggish Secto and Brisk Secto. Recall that the goal of this “Secto” step is to calibrate the dynamic trajectory of MIRAGE such that it is coherent with both MaGE output and sector-specific assumptions; the ultimate target being to impose additional shocks to these two baselines in two simulations, respectively “Brisk & Connected” and “Sluggish & Fragmented”.

But let's start with the two baselines. For each scenario we compute a baseline in MIRAGE, population, total labour force, skill level, saving, energy productivity, agricultural productivity, current account and energy price, and calibrate the sectoral TFP trajectory to match the GDP projections from the ‘Macro’ step. We reproduce global trends in transaction costs consistent with the observed income elasticity of international trade (as already discussed) and recover TFP. Natural resources for fossil

fuel production are calibrated to match the energy price targets provided by the IEA. Our two baselines assume *status quo* for tariffs as well as non-tariff barriers.

The final step consists of implementing trade scenarios in each of the two baselines (tariffs, transaction costs and NTM in services) given the level of TFP and natural resources determined in the previous step. These scenarios are summarized in the bottom panel of Table 4. Fundamentally, we oppose a trade war to a more cooperative outcome. In the ‘Sluggish & Fragmented’ scenario an increase in transaction costs and tariffs is applied to the Sluggish Sector baseline, transaction costs for goods like red tape, various controls at the border etc. are increased too, while regulatory obstacles to trade in services are not reduced. The ‘Brisk & Connected’ scenario starts from the Brisk Sector baseline and describes a more cooperative world where the barriers to trade in goods and services (tariffs and various transaction costs) are reduced compared to their 2011 level.

In the ‘Sluggish & Fragmented’ scenario, we impose on the ‘Sluggish Sector’ baseline a series of shocks reproducing an increase in transaction costs and a tariff war. In the context of a low growth profile and, possibly, geopolitical tensions, countries increase bureaucracy at the border, and systematize container scanning. Developing countries are more affected by this since their exports are perceived as ‘unsafe’ by the advanced economies. This degradation of the world trading environment is progressive: we add a 20% increase in the transaction costs for developed countries’ exports, linearly over the period considered (2014-2035). The increase peaks at 50% for developing countries’ exports. The second dimension to this degradation of the trading environment refers to protectionism. Countries either respect *de jure* WTO commitments and rely almost exclusively on anti-dumping duties and safeguards, or enter in a trade war. Countries go beyond reverting to their bound tariffs, and enter into a scenario in which earlier commitments cease to be respected. To reproduce this outcome, we assume a progressive reversion of the observed tariff liberalization since the Tokyo Round. This is implemented as follows.

When available – i.e. for merchandise trade toward developed countries – we use data from Deardorff and Stern (1983), who provide sector-specific Tokyo Round tariff offers.¹¹ For other countries and sectors, we try to approach post-Tokyo round tariffs by (i) gathering the oldest available information on tariff for primary and manufacturing from the WDI database, (ii) comparing such observed tariffs with the same average in the MACMap HS-6 database for year 2011 and (iii) reverting the tariff decreases since then using the average manufacturing and primary variation applied to MACMap sector-specific tariff. Finally, the resulting “trade war” tariffs are capped at 500%.¹² The corresponding changes in average tariffs are shown in Table 5 for regions and broad sectors concerned. Missing values in this table correspond to values available in Deardorff and Stern (1983). These tariff increases provide a target for 2035, which we implement linearly between 2013 and 2035. Tariffs within Free Trade Areas (FTAs) are assumed not to be subject to a tariff war and are not increased in our scenario. This affects the EU27, EFTA, NAFTA, AU-NZ and USA-AUNZ. We present the outcome of this procedure in Table 6 for selected sectors.

¹¹ Source data is provided in Appendix A.

¹² This capping concerns 246 sector-exporter-importer triplets, corresponding to around 4% of all triplets.

Table 5: Assumptions for the trade war scenario
(Average tariff, earliest data in WDI and GTAP)

Partner	Median year (WDI)	Manufacturing*		Primary	
		MAcMap 2011	Sluggish & Fragmented (WDI)	MAcMap 2011	Sluggish & 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.

The ‘Brisk & Connected’ scenario describes a more cooperative world. Firstly, tariffs on goods are reduced (-50%) compared to their 2011 level. Secondly, benefiting from sustained growth and rapid convergence of emerging countries (increasing income levels and reducing costs of competition), countries address the issue of trade in services. There is a large decrease in the barriers to trade in services (-25%), and transaction costs on goods continue to decrease and decrease faster for developing countries where progress margins are bigger. We assume a 50% decrease in transaction costs for developing countries and a 20% decrease for developed countries.¹³ Regarding the reduction

¹³ Recall that the impact of energy prices on demand for transport is taken into account endogenously in MIRAGE.

in the barriers to trade in services, we start with the ad valorem equivalents computed by Fontagné et al. (2011), modelled here as a trade cost. We then set the target to -50% in 2035, and this phasing out is implemented linearly between 2013 and 2035. The outcome of this exercise is shown in Table 7.

Table 6 – Tariff scenario by importer for selected sectors, ‘Sluggish & Fragmented’ versus MacMap data

	Cars and Trucks		Primary		Coal		Crops		Food	
	MAc Map 2011	Sluggish & Fragmented	MAc Map 2011	Sluggish & Fragmented	MAc Map 2011	Sluggish & Fragmented	MAc Map 2011	Sluggish & Fragmented	MAc Map 2011	Sluggish & Fragmented
Australia & New Zealand	12.8	22.3	0.1	0.3	0.0	0.0	0.6	298.4	1.9	456.3
China	14.2	99.7	0.5	3.7	0.0	0.3	5.5	84.8	11.1	169.6
Japan	0.0	1.5	0.0	0.1	0.0	0.0	10.3	161.3	16.7	339.2
Korea	6.7	29.9	0.8	3.7	0.0	0.0	94.2	274.3	27.7	171.8
ASEAN	15.9	39.5	1.7	4.1	0.4	13.3	11.3	269.5	10.4	297.0
India	18.2	168.7	5.1	47.6	1.6	25.4	27.5	387.3	42.0	429.4
Canada	3.1	1.4	0.1	0.2	0.0	0.0	0.8	76.3	11.4	398.1
USA	0.6	2.1	0.0	0.1	0.0	0.0	2.0	26.2	2.4	29.5
Mexico	7.6	23.7	2.1	6.6	0.0	0.2	5.9	138.7	12.8	283.8
Brazil	17.7	63.4	2.1	7.6	0.0	0.0	6.0	421.2	11.9	462.3
France	2.1	6.5	0.0	0.0	0.0	0.0	1.9	91.5	5.8	216.3
Germany	2.3	6.5	0.0	0.1	0.0	0.0	1.4	80.0	7.2	283.3
Italy	2.3	6.5	0.0	0.2	0.0	0.0	2.2	102.6	8.1	240.8
Spain	2.2	6.5	0.0	0.0	0.0	0.0	2.5	99.6	6.6	208.8
United Kingdom	2.0	6.5	0.0	0.1	0.0	0.0	2.5	112.2	6.8	220.5
Other EU28	2.1	6.5	0.0	0.1	0.0	0.0	1.8	80.7	7.7	253.5
Russia	12.9	11.9	3.4	3.2	1.2	4.1	7.1	24.2	17.3	58.9
Turkey	2.8	12.2	0.3	1.1	0.0	0.0	25.6	473.9	26.6	470.4
Other Middle East	7.5	14.1	2.7	5.1	0.7	3.7	5.8	30.7	13.8	72.4
North Africa	10.5	48.0	2.0	9.4	0.5	6.2	9.9	117.1	26.7	229.5
South Africa	13.8	38.6	0.0	0.1	0.0	0.0	11.6	128.0	6.9	81.6
Sub-Saharan Africa	11.7	15.8	4.8	6.5	0.4	2.8	10.5	81.4	15.2	118.1
Rest of the World	6.7	17.8	1.0	2.6	0.4	6.9	10.3	158.9	12.2	187.4

Note: Simple average. ‘MAcMap 2011’ is the baseline tariff used for ‘Sluggish Sector’ and ‘Brisk Sector’. ‘Sluggish & Fragmented’ is the scenario value.

Source: Authors’ calculations based on MAcMap HS-6 2011, Deardorff and Stern (1983) and WDI.

Finally, the overall three-step method is summarized in Figure 5. We show for each step what is introduced in the models to design our scenarios. In MaGE, we introduce hypotheses on fertility, migrations (from Docquier and Machado, 2015), educational convergence, TFP, energy price from IEA, energy efficiency and international capital mobility. This ends up into a Brisk-macro and Sluggish-macro scenario. MaGE outputs from these two scenarios are introduced in MIRAGE, previously calibrated in a pre-experiment: GDP, population, labour force and skills, savings and current account (hence investment), as well as energy efficiency. Energy prices are set exogenous at that stage. We draw from this, the endogenous trajectories of TFP and the changes in the stocks of natural resources which are consistent with the variables imposed to MIRAGE, in particular energy prices. In a last step, these trajectories of TFP and natural resources are set exogenous in MIRAGE, while GDP and its components (meaning value added by sector) are determined endogenously.

Figure 5 – Design of scenarios in MaGE and MIRAGE

Table 7 – NTM tariff equivalent in services by importer

	Business Services		Public Administration		Transport		Other Services		Food	
	Fontagné et al. (2011)	Brisk & Connected	Fontagné et al. (2011)	Brisk & Connected	Fontagné et al. (2011)	Brisk & Connected	Fontagné et al. (2011)	Brisk & Connected	Fontagné et al. (2011)	Brisk & Connected
Australia & New Zealand	61.4	46.1	75.3	56.4	35.6	26.7	67.1	50.3	8.0	5.1
China	86.2	64.7	96.1	72.1	72.8	54.6	48.7	36.5	5.3	3.6
Japan	60.9	45.6	98.7	74.0	41.3	31.0	37.6	28.2	4.6	3.0
Korea	60.4	45.3	82.2	61.6	20.9	15.7	33.0	24.7	3.7	2.5
ASEAN	42.3	31.8	67.2	50.4	30.9	23.2	32.0	24.0	7.6	5.2
India	60.6	45.4	116.6	87.5	46.9	35.2	65.8	49.3	17.8	12.1
Canada	50.5	37.9	77.8	58.3	39.5	29.6	57.4	43.0	7.5	4.8
USA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	3.4
Mexico	143.0	107.2	92.3	69.2	63.7	47.7	99.8	74.9	9.6	6.1
Brazil	81.1	60.8	74.3	55.7	53.2	39.9	85.8	64.4	12.1	7.8
France	45.7	34.3	72.8	54.6	26.6	19.9	43.1	32.3	6.8	4.2
Germany	23.6	17.7	54.7	41.0	13.3	10.0	20.0	15.0	5.7	3.6
Italy	40.2	30.2	62.9	47.2	30.2	22.7	33.4	25.0	6.6	4.2
Spain	32.9	24.7	84.0	63.0	35.8	26.9	46.1	34.6	6.0	3.8
United Kingdom	25.9	19.4	46.6	35.0	19.5	14.7	38.4	28.8	6.5	4.1
Other EU28	31.2	23.4	70.7	53.0	32.1	24.1	44.9	33.7	6.1	4.0
Russia	51.1	38.3	62.9	47.2	38.5	28.9	42.7	32.0	8.6	5.6
Turkey	107.7	80.8	82.0	61.5	74.8	56.1	99.8	74.8	7.3	4.9
Other Middle East	41.1	30.8	51.0	38.2	35.6	26.7	26.9	20.2	9.4	6.2
North Africa	42.3	31.7	32.2	24.2	33.5	25.1	33.3	25.0	7.9	5.0
South Africa	83.3	62.5	72.3	54.2	39.0	29.3	47.7	35.8	15.0	9.8
Sub-Saharan Africa	41.1	30.8	42.2	31.6	29.5	22.1	36.2	27.1	17.5	11.7
Rest of the World	44.2	33.1	61.6	46.2	29.7	22.3	49.3	36.9	9.9	6.0

Note: Simple average.

Source: Authors' calculations based on Fontagné et al. (2011).

3. IMPLEMENTING THE SCENARIOS IN MAGE

We start by considering the impact of alternative assumptions regarding the variables of interest, shocked one at a time. We then consider the combination of differentiated shocks in the two scenarios.

3.1. Demography and migration

The demographic scenarios were defined as low fertility for all countries in the Sluggish Macro scenario, versus high fertility in all countries in the Brisk Macro scenario. The Brisk Macro scenario adds migrations from the reference scenario of Docquier and Machado (2015). We decompose here these two set of assumptions. In Table 9 we consider the impact of assumptions on fertility. Table 10, 11 and 12 consider the impact of migrations only. The Sluggish and Brisk Macro scenarios are accordingly the combination of the two sets of assumptions.

The shock is rather symmetrical across the high and low fertility scenarios, as shown in Table 9. Population changes in the two scenarios range between +/- 5% and +/- 8%. These changes are not huge, meaning that the population scenario in the baseline will very much drive changes in the labour force in the different regions of the world and countries, which is an important determinant of the distribution of value added and changes in comparative advantages.

Table 9 – Differentiated population scenarios: impact of fertility, 2035 (million people)

	Reference	Low fertility	High fertility
United States of America	373	-6.2%	+6.2%
Japan	118	-5.6%	+5.7%
European Union	510	-6.1%	+6.1%
Brazil	227	-8.0%	+8.3%
Russian Federation	130	-7.2%	+7.2%
India	1525	-7.6%	+7.7%
China	1449	-7.4%	+7.5%
Latin America	499	-7.8%	+7.9%
Middle east and North Africa	588	-7.8%	+7.8%
Sub-saharian Africa	1517	-6.4%	+6.5%
Rest of Asia	1250	-7.9%	+8.0%
Rest of the World	244	-7.1%	+7.1%
Total world	8430	-7.2%	+7.3%

Source: MaGE, authors' calculation.

The next step for demography is to introduce migrations from Docquier and Machado (2015), beyond the conservative migration flows included in the UN's demographic projections, in the Brisk scenario only. The results for population are presented in Table 10. We indeed observe that migrations impact populations in source and destination countries symmetrically with a null impact at the world level.

Table 10 – Total population in the presence of additional migrations, 2035 (million people)

	Reference	High migrations
United States of America	373	+3.8%
Japan	118	+0.2%
European Union	510	+3.2%
Brazil	227	-0.1%
Russian Federation	130	+5.2%
India	1525	+1.6%
China	1449	+0.1%
Latin America	499	-2.2%
Middle east and North Africa	588	-1.8%
Sub-saharian Africa	1517	-0.3%
Rest of Asia	1250	-2.6%
Rest of the World	244	-1.0%
Total world	8430	+0.0%

Source: MaGE, authors' calculation.

As already noted, when migrants leave their origin country, their initial level of education remains unchanged by assumption. Given the numbers considered, migrants will have a significant impact on the share of the population at each education level. Table 11 shows the outcome of our assumptions related to education attainment at secondary and tertiary levels. Education increases in main origin countries because of the age group aggregation: only people over 25 can migrate, while education is increasing, leading to age bins 15-19 and 20-24 being the most educated. Not surprisingly, origin countries have (on average) less human capital than destination countries and, therefore, immigrants tend to reduce education levels in developed countries.

Table 11 – Secondary and tertiary education, 2035 (percentage of working-age population)

	Secondary		Tertiary	
	Reference	High migrations	Reference	High migrations
United States of America	99	-5.5	66	-3.7
Japan	97	-0.3	66	-0.2
European Union	93	-4.5	36	-1.8

Brazil	71	+0.1	18	+0.0
Russian Federation	99	-6.0	64	-3.9
India	66	-1.5	15	-0.4
China	86	-0.1	14	-0.0
Latin America	74	+2.4	26	+0.8
Middle east and North Africa	70	+1.8	25	+0.7
Sub-saharian Africa	43	+0.3	5	+0.0
Rest of Asia	62	+2.4	18	+0.7
Rest of the World	91	+0.4	42	+0.2
Total world	71	-0.0	21	-0.0

Source: MaGE, authors' calculation.

The last direct consequence of the migration considered is for saving rates due to the distortion of the age structure (in both the origin and destination countries), which is the main determinant of saving in our life-cycle framework. Saving also determines investment capacity for a given level of international financial flows. Table 12 shows how the migrations scenarios (marginally) affect investment and savings.

Table 12 – Investment and saving rates, 2035 (percentage GDP)

	Investment		Savings	
	Reference	High migrations	Reference	High migrations
United States of America	18	+0.06	14	+0.12
Japan	25	-0.05	23	-0.07
European Union	21	+0.04	19	+0.12
Brazil	20	-0.01	17	-0.02
Russian Federation	24	+0.06	35	+0.37
India	24	+0.02	28	+0.14
China	37	-0.01	38	-0.01
Latin America	22	-0.05	22	-0.10
Middle east and North Africa	23	-0.07	26	-0.10
Sub-saharian Africa	20	-0.02	25	+0.05
Rest of Asia	27	+0.04	29	-0.04
Rest of the World	24	+0.03	24	+0.08
Total world	24	-0.08	24	-0.08

Source: MaGE, authors' calculation.

We made the assumption that the age structure of the population of migrants is mirroring the one of their origin country. Accordingly, the arrival of younger age groups in ageing countries such as EU countries and the USA, tends to increase these countries saving rates (+0.12% of GDP). However, this is accompanied by a fall in saving rates in origin countries due to the departure of working-age population (but not younger people). At the global level, the saving loss is greater than the saving increase (-0.08% of world GDP). Thus, the global investment envelope decreases while the share of EU, Russia and USA in this envelope increases and investment reduces in all other countries (but India).

3.2. Human capital accumulation

In addition to demography, we need to investigate shocks to investment in human capital. Education catch-up over the past 50 years has been very diverse across regions and has been one of the main drivers of differences in per-capita income performance across countries. For estimation purposes, we estimate catch-up speed according to geographical regions. However, average speed does not encompass the diversity of situations depicted in Figure 6.

Shocks to MaGE try to frame educational convergence and represent lower and upper bounds of catch-up using a standard catch-up measure: half-life time. Half-life time is the time it takes for a country to reduce its difference with the education leader by half, assuming a constant education frontier.

Figure 6 – Share of tertiary educated population in selected Asian countries, 1980-2010

Key: KOR = Korea, SGP = Singapore, THA = Thailand,
 LAO = Laos, CHN = China, KHM = Cambodia

Source: Barro and Lee (2013).

The increase in education levels observed for the emerging countries is shown in Figure 8, as the evolution in educational attainment in some Asian countries over the period 1980-2010. The pattern differs across countries. The achievements observed for Korea and Singapore fuelled productivity gains and helped to elevate income levels in those countries. By contrast, China remains at low levels, and its comparative advantage is mainly in low value added segments and low value added products.

In the Brisk scenario, there is no change in the educational convergence and the only changes in the skill structure of the population are driven by migrations. In contrast, as shown in Table 13, we assume that catch up is decelerated in the Sluggish Macro scenario (50% increase in the half-life of convergence). Not surprisingly, this assumption reduces the educational attainment in countries far from the frontier. A more subtle mechanism deserves an explanation: educational convergence is observed almost everywhere. The reason is our catching up process, by educational level and age bin, meaning that ultimately most countries, including the US for instance are somehow converging (in that case on Korea for certain age bins and skills).

Table 13 – Secondary and Tertiary education, 2035 (% of population)

	Secondary		Tertiary	
	Reference	Low education	Reference	Low education
United States of America	99	-0.2	66	-3.2
Japan	97	-0.3	66	-2.1
European Union	93	-1.4	36	-4.6
Brazil	71	-3.4	18	-4.3
Russian Federation	99	-0.2	64	-3.1
India	66	-4.1	15	-3.3
China	86	-1.5	14	-2.1
Latin America	74	-3.6	26	-4.6
Middle east and North Africa	70	-3.6	25	-4.3
Sub-saharian Africa	43	-4.6	5	-1.2
Rest of Asia	62	-4.5	18	-2.5
Rest of the World	91	-1.5	42	-4.8
Total world	71	-3.1	21	-2.8

Source: MaGE, authors' calculation.

3.3. Energy price and technical progress in energy use

The next shock we consider is to energy. First, energy prices are set after IEA scenarios (Figure 7)¹⁴. It induces substitution between energy and the capital-labour bundle. Second, energy productivity is also shocked in the Sluggish case (+25% productivity). Table 15 shows how these phenomena impact energy efficiency. The reference scenario is shown in column 1, where values are energy intensity expressed as barrels of oil equivalent (boe) per US\$1,000 of GDP in 2035. Energy productivity can be observed independently, but does not include possible substitution for labour and capital. Thus, we present the results as energy intensity of GDP (E/Y). In general, lower productivity leads to higher energy intensity.

Columns 2 and 3 in Table 15 show changes in energy intensity, measured in the same units, after a change in energy prices. We observe first that the world economy is much more energy efficient under the high price scenario. For oil producing countries, this effect is reinforced by the oil rent boosting growth and facilitating convergence in energy efficiency. The biggest gains are expected for SSA, and

¹⁴ Energy scenarios and their implications are detailed in a companion paper: Fontagné L., Fouré J. and Santoni G. (2015), Value added in motion: alternative scenarios for energy prices.

Russia. Japan, Europe and the US are expected to achieve lower efficiency gains in this respect, although in Japan and Europe, from very low initial energy intensity in Japan and Europe.

Figure 7 – Observed oil price and IEA scenarios 1980-2035 (constant 2011 USD)

Source: International Energy Agency (2010-2035) and Energy Information Administration (1980-2010).

Energy use is determined by the energy price and induced adjustment of economies towards less intensive technologies in the case of high energy prices. Beyond this ‘economic’ adjustment, we need to consider an autonomous strand of technical progress in the energy domain. Major technological breakthrough or societal changes may occur in the next two decades, leading to a dramatic increase in the energy efficiency of our economies. Such changes are not embedded in existing data and therefore are not included in our econometric estimations. They can be introduced in the projections as exogenous shocks.

Results for energy intensity are shown in Table 15 along with the impacts of energy price scenarios. As in the previous case, columns 4 and 5 of Table 15 show the results of our assumptions about the energy price on energy use efficiency, measured in boe per US\$1,000 of GDP. Although in this case, the impact on countries differs, the world average order of magnitude is the same as for the scenarios for energy price.

Regarding technological progress (here: energy productivity only), we assume in the Sluggish scenario a 25% increase (compared to our reference scenario) in energy efficiency for all countries at the 2035 horizon.

Table 15 – Energy intensity, 2035 (barrel per \$1,000 of GDP)

	Reference (1)	Impact of energy price		Impact of techno. progr.
		High energy price (2)	Low energy price (3)	High techno. progr. (4)
United States of America	0.94	-0.03	+0.05	-0.10
Japan	0.65	-0.02	+0.03	-0.07
European Union	0.68	-0.02	+0.03	-0.07
Brazil	1.87	-0.06	+0.10	-0.19
Russian Federation	4.58	-0.19	+0.33	-0.46
India	3.32	-0.09	+0.17	-0.34
China	3.19	-0.09	+0.16	-0.33
Latin America	1.55	-0.06	+0.10	-0.15
Middle east and North Africa	1.80	-0.10	+0.17	-0.17
Sub-saharian Africa	4.12	-0.22	+0.34	-0.37
Rest of Asia	2.46	-0.09	+0.16	-0.24
Rest of the World	1.34	-0.06	+0.10	-0.12
Total world	1.76	-0.07	+0.12	-0.17

Source: MaGE, authors' calculation.

3.4. Total factor productivity

Technological progress in the various regions of the world is an important driver of changes in comparative advantages, specialization of countries and hence the distribution of the sectoral value added worldwide. Technological progress is assumed here to vary depending on the scenario. These changes can be driven by national autonomous technological developments or international transfers of technology. In the Sluggish scenario we consider a 50% drop in TFP growth rates for low- and middle-income countries compared to our baseline scenario, and a 25% drop for high-income countries. In the Brisk scenario, we keep the reference trajectory of TFP for each country. The impact on TFP growth in the Sluggish case is shown in Table 16. For countries catching up otherwise, especially China, the change is really substantial, as the TFP growth rate is roughly divided by two.

Table 16 – Average annual TFP growth rate, 2012-2035

	TFP growth	
	Reference	Low TFP
United States of America	0.89	-0.22
Japan	1.44	-0.34
European Union	1.27	-0.27
Brazil	1.25	-0.59
Russian Federation	3.68	-1.69
India	3.01	-1.38
China	4.49	-2.01
Latin America	1.32	-0.61
Middle east and North Africa	1.21	-0.60
Sub-saharian Africa	2.20	-0.98
Rest of Asia	2.12	-0.41
Rest of the World	1.51	-0.24
Total world	1.48	-0.14

Source: MaGE, authors' calculation.

3.5. International capital mobility

The last factor of production is capital. Capital is depreciating at a constant rate in our growth model, consistent with the specification used in MIRAGE. In considering gross investment, we need to take account of two drivers. First, savings are driven by demography (as already discussed) and per capita income. Second, the difference between domestic savings and domestic investment is driven by the international mobility of capital to which we apply a shock. In the Sluggish case, countries are returning to capital autarky linearly with a 2050 target year. Low mobility has a positive impact for current account surplus countries (India, Russia or China) as shown in Table 17.

Table 17 – Average investment rate, 2012-2035 (percentage of GDP)

	Investment	
	Reference	Low capital mobility
United States of America	18	-2.91
Japan	25	-1.07
European Union	21	-0.48
Brazil	20	-2.08
Russian Federation	24	+9.20
India	24	+3.33
China	37	+1.57
Latin America	22	+0.40
Middle east and North Africa	23	+4.58
Sub-saharian Africa	20	+6.23
Rest of Asia	27	+2.62
Rest of the World	24	+0.98
Total world	24	+0.65

Source: MaGE, authors' calculation.

3.6. Combining the different assumptions of the two scenarios in MaGE

So far we have examined the impact of introducing one assumption at a time in MaGE. We now introduce jointly all the assumptions in the two scenarios simulated. Table 18 shows the results for GDP growth which take account of all the relations and feed-backs among the variables in the MaGE model.

In the first panel in Table 18, column (1) presents annual growth rates for the regions included in MIRAGE and columns (2) and (3) show the difference between each scenario and the reference case. China shows a 6.5% average growth rate to 2035 under the reference case. This is the highest figure among regions considered. The Brisk scenario corresponds to almost no variation in GDP growth and -2.8 percentage points corresponds to the Sluggish scenario. For all countries, the Sluggish scenario is definitively a very adverse outcome and there is no symmetry in the magnitude compared with the Brisk scenario. For Europe, the Sluggish scenario is driving the region as a whole in the vicinity of 1% annual growth, with all the expected associated economic imbalances. In the second panel, column (4) shows GDP levels at 2005 US\$ exchange rates and prices. Columns (5) and (6) indicate the percentage deviations from the 2035 level. We observe that the scenarios combining different assumptions show stark contrasts. World GDP is 21% lower (2.6% higher) in the Sluggish (Brisk) scenario, compared to the reference case.

Table 18 – GDP projections under the Brisk and Sluggish Macro scenarios

	GDP growth			GDP in 2035			Share of world GDP		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Reference	Sluggish	Brisk	Reference	Sluggish	Brisk	Reference	Sluggish	Brisk
United States of America	1.85	-0.53	+0.23	20621	-11.29	+5.42	20.2	+2.42	+0.56
Japan	1.56	-0.54	+0.05	6721	-11.62	+1.23	6.6	+0.76	-0.09
European Union	1.63	-0.56	+0.24	21235	-11.92	+5.69	20.8	+2.33	+0.63
Brazil	2.58	-0.96	+0.05	2041	-19.53	+1.10	2.0	+0.03	-0.03
Russian Federation	3.94	-1.65	+0.19	2387	-30.75	+4.38	2.3	-0.29	+0.04
India	5.58	-2.01	+0.00	4774	-35.76	+0.07	4.7	-0.88	-0.11
China	6.48	-2.81	-0.03	19145	-45.89	-0.55	18.7	-5.94	-0.57
Latin America	2.94	-0.71	-0.01	4644	-14.69	-0.19	4.5	+0.35	-0.12
Middle east and North Africa	2.84	-0.38	+0.06	4883	-8.18	+1.31	4.8	+0.76	-0.06
Sub-saharian Africa	4.94	-1.38	+0.02	2705	-26.18	+0.50	2.6	-0.18	-0.05
Rest of Asia	3.70	-0.96	-0.10	6733	-19.32	-2.16	6.6	+0.12	-0.30
Rest of the World	2.80	-0.68	+0.20	6321	-14.07	+4.47	6.2	+0.52	+0.11
Total world	2.90	-1.04	+0.11	102210	-20.79	+2.58	100.0		
Total Developed	1.89	-0.55	+0.20	58156	-11.62	+4.68	56.9	+6.58	+1.16
Total Developing	4.74	-1.80	-0.01	44054	-32.88	-0.18	43.1	-6.58	-1.16

Note: Column (4) is in 2005 US\$ billions. Columns (1), (5), (6) and (7) are percentages and columns (2), (3), (8), (9) are percentage points.

Source: Authors calculations.

GDP trajectories are plotted in Figure 8 and also show large contrasts. The continuous line corresponds to the ‘Sluggish Macro’ scenario for each country. Figure 8 confirms that the range of outcomes for GDP is very large for developing countries, compared to the developed ones. The highest in the range is China which matches the US GDP in 2035 in the Brisk scenario. Similarly, India catches up with the Japanese GDP at the same horizon in the Brisk scenario.

Figure 8 – GDP in the ‘Brisk Macro’ and ‘Sluggish Macro’ scenarios, 2007-2035 (2007 US\$ billion)

Note: continuous line is ‘Sluggish Macro’; dotted line is ‘Brisk Macro’.

Note: constant dollars of 2007 (instead of 2005) used here are units of MIRAGE .

Source: MaGE, authors’ calculation.

Due to the intrinsic link between all the factors that receive shocks in our scenarios, it is not possible to determine precisely the relative impact of each shock. However, we can observe the impact of individual variables on GDP in 2035. Results are shown in Figure 9.

The individual shocks (coloured bars in Figure 9) allow us to visualize that TFP is the main contributor to GDP changes in our Sluggish scenario. Although they are considered one at a time, demography, education and energy productivity seem to have relatively more marginal impacts, with the exception of Russia. On the Brisk side, migrations are indeed the key driver of changes. The reader will take care of the different units in the two panels of the figure however. The largest impact of inward migration is around 4.5% of GDP.

If we compare this outcome with the outcome if all the variables suffer shocks simultaneously (black crosses in Figure 9), orders of magnitude are maintained compared to the sum of individual variable shocks, for all developing countries notwithstanding the feedbacks in the model (e.g. education fuels TFP; energy productivity inflates the benefits of a low energy price; and demography drives saving and investment in addition to capital mobility).

Taking stock of these changes at the macroeconomic level under our different sets of assumptions, our objective in the next section is to discuss the implications for world trade patterns and distribution of sectoral value added.

Figure 9 – Contributions from scenarios on individual variables to GDP level, 2035.

Source: MaGE, authors' calculation.

4. CONTRASTING WORLD TRADE PATTERNS AT THE 2035 HORIZON

We now present the results of the two scenarios ('Sluggish & Fragmented' and 'Brisk & Connected') simulated in MIRAGE, provided that MIRAGE simply replicates in Sluggish Secto and Brisk Secto the Sluggish Macro and Brisk Macro scenarios discussed above, although with a sectoral decomposition of the value added. We now add the shocks on transaction costs and tariffs for goods and NTM in services, as described in Table 6, to obtain the 'Sluggish & Fragmented' and 'Brisk & Connected' scenarios.

4.1. World trade patterns

World trade patterns are fundamentally shaped by gravity-like determinants. We expect the volume of world exports to be determined by changes in GDP, comparative advantage, and trade costs.

The overall result is depicted in Figure 10, where we compare the "Brisk", "Brisk & Connected", "Sluggish" and "Sluggish & Fragmented" scenarios in MIRAGE. Scenarios with no trade policy assumptions ("Brisk" and "Sluggish") are indicated by plain line rectangles, while the two scenarios including trade policies ("Brisk & Connected" and "Sluggish & Fragmented") are simply coloured. Under the 'Brisk & Connected' scenario, developing economies will have buoyant exports of goods, growing at a rate close to 6% annually (4.5% in the 'Brisk Secto' scenario with no further trade liberalization). This figure is even larger for services. This contrasts with the 'Sluggish & Fragmented' scenario where GDP grows much slower, especially for the developing countries, and where trade costs (tariffs and transaction costs) are increasing. The Sluggish scenarios are particularly penalizing for goods, especially the 'Sluggish & Fragmented': goods have to be transported and are subject to tariff wars, while services are only subject to regulations, which are assumed to be constant in the Sluggish scenario. Finally, developing countries' exports are strongly affected by the combination of transaction costs, tariff and growth assumptions in the Sluggish scenario.

The annual growth rates for GDP and exports of goods and services shown in Figure 10, suggest that trade to income elasticity will differ across the two scenarios and the two regions of the world economy. Table 19 presents the computed trade elasticity. In the 'Brisk & Connected' scenario, the elasticity is 1.48 at the world level. This is low compared to historical levels, and particularly compared to the 1990s, the decade when many global value chains were established: elasticity in the 1990s was 2.8. In our projection, we return to the values observed in the 1960s. Under all circumstances, the elasticity is higher for the developed economies which will increase trade with a faster growing developing world. Under the 'Sluggish & Fragmented' scenario, we have (slow) growth and no trade in the developing world (elasticity 0.74), while trade and income follow the path of the developed economies.

Table 19 – Trade to income elasticity (goods), 2012-2035

	Brisk & Connected	Sluggish & Fragmented
Developed	1.76	1.61
Developing	1.24	0.24
World	1.48	0.74

Note: elasticity computed on the exports.

Source: MIRAGE, author's calculation

Figure 10 – GDP (volume) and exports (volume, incl. intra) growth rates, 2012-2035

Note: average annual growth rates (percentages). Developing countries' trade in services grows annually by 4.5% in the 'Brisk Secto' scenario, compared to 5.5% in the 'Brisk & Connected' scenario.

Source: MIRAGE, authors' calculation.

Although our trade scenarios have only a marginal effect on GDP (GDP is endogenous indeed in MIRAGE in the simulations) compared to the determinants of growth in MaGE, they tend to reshape trade patterns profoundly over the next 20 years.

4.2. Intra-regional trade

Trade patterns are also affected by the share of intra-regional trade in world trade. As a result of the gravity forces shaping world trade, we expect South-South trade to grow faster. However, growth in South-South trade may not necessarily be driven by the presence of FTAs because the current levels of

market integration currently agreed for the South are too low to have a significant impact. This contrasts with integrated regions such as the EU and, to a lesser extent, NAFTA. Thus, in the ‘Sluggish & Fragmented’ scenario, we observe that the EU and NAFTA manage to maintain their initial share of world trade at the 2035 horizon, or even to increase it. The fact that tariffs within FTAs are supposed not to be subject to tariff wars in the ‘Sluggish & Fragmented’ scenario also contributes to this result.

Figure 11 – Share of intra-regional FTAs exports in world trade (volume, incl. Intra)

Note: The size of each pie is proportional with one another.

Source: MIRAGE, authors' calculation.

In contrast, in the ‘Brisk & Connected’ scenario, most trade growth occurs in developing economies, shifting the centre of gravity of international trade to the South. World trade will almost triple in volume, EU exports will increase by 70% “only”, and the EU’s share dramatically decreases. A similar pattern is observed for NAFTA (with a 90% increase in exports). FTAs in the South do not deliver since the share of ASEAN is kept constant in all scenarios. This reduction in the share of regional trade in world trade in the Brisk scenario, could be reversed were ambitious and new FTAs (e.g. those under negotiation for the Pacific and to a lesser extent the Transatlantic levels) to be signed. We do not model such outcomes.

4.3. Regional specialization

Alternative growth paths for the world economy will be conducive to different country export specialization. In the ‘Brisk & Connected’ and ‘Sluggish & Fragmented’ scenarios considered here, accumulation of human as well as physical capital will be different, TFP will differ strongly and finally migration will also impact the overall picture. This will shape countries’ comparative advantages. A good illustration of this mechanism is provided by China’s specialization, shown in

Figure 12. The ‘Brisk & Connected’ scenario will maintain China’s specialization in the electronic sector and further increase its specialization in Machinery as opposed to textiles. In the ‘Sluggish & Fragmented’ scenario, with less physical and human capital per worker, China will maintain its specialization in textiles and increase specialization in other manufacturing, while progressively losing ground in electronics. These results suggest that countries’ specialization is not completely pre-determined if one considers seriously the wide range of possible outcomes for medium term growth.

Figure 12 – Share of sectors in China total export (volume)

Notes: Solid lines correspond to ‘Brisk Secto’ (left) and ‘Sluggish Secto’ (right) scenarios; dotted lines correspond respectively to ‘Brisk & Connected’ and ‘Sluggish & Fragmented’.

Source: MIRAGE, authors’ calculation.

Figure 12 shows the patterns for the different baselines. In the Sluggish scenarios, almost all the shift in Chinese exports to textiles away from electronics is due to shocks to trade costs. These patterns occurs because these sectors represent China’s most important exports, and because reverting to post-Tokyo Round tariffs would lead to a multiplication of tariffs on electronics of between 1.1 and 123 (for Canada), and a factor of 10 for the USA and 20 for Australia and New Zealand. In contrast, for the textile sectors it is lower than 5.3. This supports the claim that, except for the huge sectoral differentiation provided by trade policy shocks, the main determinants of national specialization in a CGE are baseline assumptions.

These widely contrasting scenarios for country specialization have a profound impact on the shape of world production in several sectors. Figure 13 depicts the effects for the automotive sector. We observe that Chinese production of cars rapidly overtakes European production in the Brisk scenario, but at a slow pace in the Sluggish scenario. This pattern applies also to comparison between China and the US in this sector. In all the scenarios, the Japanese car industry is overtaken by China. Again, with the exception of electronics (see Figure 14), in the trade war scenario, countries’ market shares are determined mainly by the baseline, rather than the trade policies we implemented.

Figure 13 – Regional shares in world car and truck production (volume)

Notes: Solid lines correspond to 'Brisk Secto' (left) and 'Sluggish Secto' (right) scenarios; dotted lines correspond respectively to 'Brisk & Connected' and 'Sluggish & Fragmented'.

Source: MIRAGE, authors' calculation.

4.4. Value added patterns

Ultimately, this exercise provides information on the sectoral distribution of value added at the sector and country level. Value added differs from production due to the import content of exports and the related development of global value chains.

Not surprisingly the share of Europe in the world value added is expected to decline, mainly as a result of the development and catching up of emerging countries. More interestingly, this reduction will be uneven across broad sectors and scenarios. In the manufacturing sector, the value added records a 3.9 percentage point decrease in the 'Brisk & Connected' scenario, while only recording a 2.4 p.p. contraction in the 'Sluggish & Fragmented' scenario, due to developing economies performing relatively worse than developed countries. On the contrary, in the Services sectors, the contraction is greater (-6.8 p.p.) but symmetric in both scenarios. It is however interesting to note that in any case value-added more than doubles between 2011 and 2035.

The second result of about individual EU Member states. Several patterns seem to emerge: the share of Germany, Italy and France in the European manufacturing value added is expected to shrink in both scenarios, while remaining more or less unchanged in Spain or even increasing in the United Kingdom. This evolution is compensated by a 13.4 percentage point increase in the share of the manufacturing value added of Other EU28 members, suggesting relocation of German, Italian or French industries to the New Member states. Regional value chains could therefore be much more fractioned than they are today, Germany being the big player in Europe. Notice that it does not mean a

reduction in absolute terms of the German value added in manufacturing (it actually records an increase under both scenarios), but most of the growth in the manufacturing value added takes place outside the German boundaries. This pattern is emphasized with the sector-specialization of Germany, oriented towards Machinery and Cars & Trucks (see Figure 14) and hence suffering from the increasing competition of China, while Other EU28 and United-Kingdom manufactures tend to specialize in Metals.

Regarding sector specialization of countries, it is interesting to note that the patterns are much contrasted inside the European Union. While the balance between manufacturing and services in richer countries (France, Germany, Italy, and United-Kingdom) remain more or less stable, Other EU 28 countries record a significant increase in the share of services, converging gradually to the 80% observed in the most developed countries.

Table 20 – Value-added in the EU (volume): Total value-added, share in the world and distribution inside EU, 2013 and 2035

		Primary			Manufacturing			Services		
			Sluggish & Fragmented (2035)	Brisk & Connected (2035)		Sluggish & Fragmented (2035)	Brisk & Connected (2035)		Sluggish & Fragmented (2035)	Brisk & Connected (2035)
		2011			2011			2011		
European Union	Total (billion 2007 USD)	188	460	543	1236	3005	3155	4975	13310	15389
	Share in the world (%)	5.6	5.8	6.0	22.3	19.9	18.4	27.2	20.4	20.4
Shares in the EU (%)	France	9.1	10.1	11.5	15.1	10.1	11.5	15.1	16.9	16.7
	Germany	10.4	12.7	12.6	20.5	12.7	12.6	20.5	16.6	16.4
	Italy	7.6	9.6	10.4	15.0	9.6	10.4	15.0	8.7	9.1
	Spain	6.9	8.8	8.1	8.8	8.8	8.1	8.8	8.3	8.2
	United Kingdom	24.3	17.7	16.9	12.8	17.7	16.9	12.8	18.7	18.7
	Other EU28	41.8	41.2	40.6	27.8	41.2	40.6	27.8	30.8	31.0
Shares in national economy (%)	France	1.8	1.7	2.0	17.9	17.0	15.7	80.2	81.3	82.3
	Germany	1.5	2.1	2.1	17.7	19.4	18.8	80.8	78.5	79.0
	Italy	1.5	2.9	3.1	19.2	21.9	20.7	79.3	75.2	76.2
	Spain	2.4	3.0	2.9	17.4	14.7	13.3	80.2	82.3	83.8
	United Kingdom	5.9	2.7	2.7	12.0	15.1	13.7	82.2	82.2	83.6
	Other EU28	4.0	3.6	3.7	24.6	18.8	16.9	71.4	77.6	79.4

Source: *MIRAGE*, authors' calculations.

Figure 14 – Manufacturing value-added in the EU (volume): Share by sectors in selected countries, 2013 and 2035

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 investigated the determinants of past economic growth and international trade developments in order to build sound baseline assumptions. We implemented contrasting scenarios encompassing a wide range of potentialities. The combination of MaGE, a growth model, with MIRAGE a dynamic multisectoral CGE model of the world economy proved fruitful. Finally we introduced in this exercise migrations drawn from Docquier and Machado (2015).

Our results point to the need for careful building of baseline scenarios when evaluating policies in dynamic general equilibrium, given that the magnitude of the changes in world trade patterns when baselines differ is at least as large as when trade policy shocks are imposed. Due to the huge uncertainty surrounding future paths for the global economy, our work highlights the important role of key assumptions in their modelling.

Finally, our contrasted scenarios point to a continuation of the reorganisation of value chains in Europe, mostly detrimental to Germany and Italy, although the absolute value of the manufacturing value added in Germany should not decrease.

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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).

APPENDIX B: COUNTRY CLASSIFICATION

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

code	name	Inc. class	zone	code	name	Inc. class	zone
AFG	Afghanistan	L	MENA	ESP	Spain	H	EU27
AGO	Angola	M	SSA	EST	Estonia	H	EU27
ALB	Albania	M	ROW	ETH	Ethiopia	L	SSA
ANT	Netherlands Antilles	H	SAM	FIN	Finland	H	EU27
ARE	United Arab Emirates	H	MENA	FJI	Fiji	M	ROW
ARG	Argentina	M	SAM	FRA	France	H	EU27
ARM	Armenia	M	ROW	GAB	Gabon	M	SSA
AUS	Australia	H	ROW	GBR	United Kingdom	H	EU27
AUT	Austria	H	EU27	GEO	Georgia	M	ROW
AZE	Azerbaijan	M	MENA	GHA	Ghana	L	SSA
BDI	Burundi	L	SSA	GIN	Guinea	L	SSA
BEL	Belgium	H	EU27	GMB	Gambia, The	L	SSA
BEN	Benin	L	SSA	GNB	Guinea-Bissau	L	SSA
BFA	Burkina Faso	L	SSA	GNQ	Equatorial Guinea	H	SSA
BGD	Bangladesh	L	ROAS	GRC	Greece	H	EU27
BGR	Bulgaria	M	EU27	GRL	Greenland	H	ROW
BHR	Bahrain	H	MENA	GTM	Guatemala	M	SAM
BHS	Bahamas, The	H	SAM	GUM	Guam	H	ROW
BIH	Bosnia and Herzegovina	M	ROW	GUY	Guyana	M	SAM
BLR	Belarus	M	ROW	HKG	Hong Kong, China	H	ROAS
BLZ	Belize	M	SAM	HND	Honduras	M	SAM
BMU	Bermuda	H	ROW	HRV	Croatia	H	EU27
BOL	Bolivia	M	SAM	HTI	Haiti	L	SAM
BRA	Brazil	M	BRA	HUN	Hungary	H	EU27
BRB	Barbados	H	SAM	IDN	Indonesia	M	ROAS
BRN	Brunei Darussalam	H	ROAS	IND	India	M	IND
BTN	Bhutan	M	ROAS	IRL	Ireland	H	EU27
BWA	Botswana	M	SSA	IRN	Iran, Islamic Rep.	M	MENA
CAF	Central African Republic	L	SSA	IRQ	Iraq	M	MENA
CAN	Canada	H	ROW	ISL	Iceland	H	ROW
CHE	Switzerland	H	ROW	ISR	Israel	H	MENA
CHL	Chile	M	SAM	ITA	Italy	H	EU27
CHN	China	M	CHN	JAM	Jamaica	M	SAM
CIV	Cote d'Ivoire	M	SSA	JOR	Jordan	M	MENA
CMR	Cameroon	M	SSA	JPN	Japan	H	JPN
COG	Congo, Rep.	L	SSA	KAZ	Kazakhstan	M	ROW
COL	Colombia	M	SAM	KEN	Kenya	L	SSA
COM	Comoros	L	SSA	KGZ	Kyrgyz Republic	L	ROAS
CPV	Cape Verde	M	SSA	KHM	Cambodia	L	ROAS
CRI	Costa Rica	M	SAM	KOR	Korea, Rep.	H	ROAS
CUB	Cuba	M	SAM	KWT	Kuwait	H	MENA
CYP	Cyprus	H	EU27	LAO	Lao PDR	L	ROAS
CZE	Czech Republic	H	EU27	LBN	Lebanon	M	MENA
DEU	Germany	H	EU27	LBR	Liberia	L	SSA
DJI	Djibouti	M	SSA	LBY	Libya	M	MENA
DNK	Denmark	H	EU27	LCA	St. Lucia	M	SAM
DOM	Dominican Republic	M	SAM	LKA	Sri Lanka	M	ROAS
DZA	Algeria	M	MENA	LSO	Lesotho	M	SSA
ECU	Ecuador	M	SAM	LTU	Lithuania	M	EU27
EGY	Egypt, Arab Rep.	M	MENA	LUX	Luxembourg	H	EU27
ERI	Eritrea	L	SSA	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
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 C: ADDITIONAL RESULTS

Figure C1 – Share of sectors in total export (volume) by region, ‘Brisk & Connected’ vs. ‘Sluggish & Fragmented’

Notes: Continuous lines correspond to the ‘Brisk & Connected’ scenarios and dotted lines to ‘Sluggish & Fragmented’.

Figure C2 – Regional shares in world production (volume) by sector, ‘Brisk & Connected’ vs. ‘Sluggish & Fragmented’

Notes: Continuous lines correspond to the 'Brisk & Connected' scenarios and dotted lines to 'Sluggish & Fragmented'.

APPENDIX D: MAGE SHORT DESCRIPTION

Our macroeconomic projections, used in the first two steps of our methodology rely on the MaGE model.¹⁵ 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.

D.1 Production function

MaGE relies on the following theoretical framework:

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

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.

D.2 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:

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

¹⁵ 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.

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:

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

D.3 Estimations

Once the database is 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:

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

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 Granger 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:

$$\ln\left(\frac{h_{a,i,t}^l}{h_{a,i,t-1}^l}\right) = \lambda_r^l \ln\left(\frac{h_{a,t-1}^{l*}}{h_{a,t-1}^l}\right) + \epsilon_{i,t}$$

Where $h_{a,i,t}^l$ 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 $h_{a,t}^{l*}$ is the corresponding leader level of schooling. The estimated convergence speed λ_r^l is specific to one of the 8 regions we distinguish.

The leader level $h_{a,t}^{l*}$ 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:

$$\ln\left(\frac{l_{a,i,t}^F}{1 - l_{a,i,t}^F}\right) = \sigma_{a,i} + \beta_a^2 h_{a,i,t}^2 + \beta_a^3 h_{a,i,t}^3$$

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

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

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 $t-1$, $h_{j,t-1}^3$ is the proportion of the working-age population with a tertiary

diploma, $h_{j,t-1}^2 - h_{j,t-1}^3$ 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 significantly different from 0. Countries are split between income levels using the thresholds provided by the World Bank, leading to potential changes across time.

D.4 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:

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

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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.

D.5 References

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APPENDIX E: MIRAGE SHORT DESCRIPTION

As a complement to the short description given in the main text, the main elements of the MIRAGE model's structure are sketched below. The latest version of the MIRAGE model, used here, is documented in Fontagné et al. (2013), the original model being fully described in Bchir et al. (2002) and Decreux and Valin (2007).¹⁶

Supply Side

On the supply side, each sector in MIRAGE is modeled as a representative firm, which combines value-added and intermediate consumption in fixed shares. Value-added is a CES bundle of imperfectly substitutable primary factors (capital, skilled and unskilled labor, land and natural resources). Firms' demand for production factors is organized as a CES aggregation of land, natural resources, unskilled labor, and a bundle of the remaining factors. This bundle is a nested CES aggregate of skilled labor and capital (that are considered as relatively more complementary).

MIRAGE assumes full employment of primary factors. Population, participation in the labor market and human capital evolve in each country (or region of the world economy) according to the demographics embedded in the macro projections. This determines the labor force as well as its skill composition (skilled/unskilled). Skilled and unskilled labor is perfectly mobile across sectors, but immobile between countries. Natural resources are sector specific, while land is mobile between agricultural sectors. Natural resources for the mining sector and total land for agricultural sectors are set at their 2007 levels: prices adjust demand to this fixed supply. Natural resources for primary fossil fuel production sectors are calibrated in the baseline exercise to match exogenous price targets that are imposed (from the International Energy Agency, 2012) for coal, oil and gas.

Installed capital is assumed to be immobile (sector-specific), while investments are allocated across sectors according to their rates of return. The overall stock of capital evolves by combining capital formation and a constant depreciation rate of capital of 6% that is the same as in the long-term growth models. Gross investment is determined by the combination of savings (the savings rate from the growth model, applied to the national income) and the current account. Finally, while total investment is savings-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 levels, international capital flows only appear through the current account imbalances, and are not explicitly modeled.

Demand Side

On the demand side, a representative consumer from each country/region maximizes instantaneous utility under a budget constraint and saves a part of its income, determined by saving rates projected in our first-step exercise. Expenditure is allocated to commodities and services according to a LES-CES

¹⁶ This version is nicknamed MIRAGE-e 1.0. The model is also documented in an interactive wiki-based website. See <http://www.mirage-model.eu>.

(Linear Expenditure System – Constant Elasticity of Substitution) function. This implies that, above a minimum consumption of goods produced by each sector, consumption choices among goods produced by different sectors are made according to a CES function. This representation of preferences is well suited to our purpose as it is flexible enough to deal with countries at different levels of development.

Within each sector, goods are differentiated by their origin. A nested CES function allows for a particular status for domestic products according to the usual Armington hypothesis (Armington, 1969): consumers' and firms' choices are biased towards domestic production, and therefore domestic and foreign goods are imperfectly substitutable, using a CES specification. We use Armington elasticities provided by the GTAP 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.

Dynamics

Dynamics in MIRAGE are of two kinds: the total factor productivity (TFP) is calibrated in a baseline exercise, while production factors dynamics are set exogenously. Both are built in MIRAGE using macroeconomic projections from the MaGE model documented in Fouré (2013).

TFP is based on the combination of three mechanisms. First, agricultural productivity is projected separately, as detailed in Fontagné et al. (2013). Second, a 2 percentage point growth difference between TFP in manufactures and services is assumed (as in van den Mensbrugghe, 2005). Third, the aggregate country-level TFP is calibrated in the baseline exercise in order to match both production factors and GDP projections from the aggregate growth model, given the exogenous agricultural productivity and the productivity gap between manufacturing and services.

Dynamics in MIRAGE is implemented in a sequentially recursive way. That is, the equilibrium can be solved successively for each period, given the exogenous trajectory for sector-specific TFP calibrated as describe above, as well as the accumulation of production factors – savings, current accounts, active population and skill level – and an exogenous energy-specific productivity coming from the growth model. Simulations extend up to 2035. Finally, MIRAGE is calibrated on the GTAP dataset version 8.1, with 2007 as a base year.