General Equilibrium in the Long Run: A Tentative Quantification of the SSP Scenarios

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Preliminary and Incomplete: do not cite

July 13, 2017

Abstract

Elaborating on seminal endeavours to calibrate baselines of global models by the GTAP community, the World Bank, the OECD and IIASA, we combine a fully-fledged macro-econometric growth model (MaGE) with a Computable General Equilibrium Model (MIRAGE) and contribute a quantitative evaluation of the Shared Socioeconomic Pathways popularized by the Intergovernmental Panel on Climate Change. Doing so, we rely on a cross-cutting approach which mixes a theoretically founded macroeconomic framework with a dynamic global and multi-sectoral model, maximizing consistency between them, while relying on experts appraisal to tackle uncertainty around the baseline design.

Key Words: Dynamic baseline, Computable General Equilibrium Model, Shared Socioeconomic Pathways.

JEL Codes: F14, F17, F18, O4, C68.

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Introduction

Computable General Equilibrium (CGE) models are mainly used to conduct policy experiments, with a focus on changes in trade patterns and real income. Accordingly the question asked is: "What if . . . ?". To do so, they rely on theory, parameters and data, and these three issues have been recently addressed extensively in the applied trade literature. As for theory, usual micro-foundations have been challenged along the lines initially proposed by Melitz (2003); this has led to implementations in a CGE framework such as GTAP-HET (Akgul et al., 2016) ; on the data issues, the GTAP initiative has been growing and improving over the past 14 years up to the latest release (Aguiar et al., 2016), the next frontier being data in value added; and finally on parameter estimations, among many others, the seminal contribution of Feenstra et al. (2014) has improved on the elasticity used. "New Quantitative Trade Models" are confronted to similar challenges. Although reduced forms of changes real income are more embracing (Arkolakis et al., 2012) the elasticity of imports with respect to variable trade costs is here again central, and its estimation subject to important challenges (Fontagné et al., 2017b). On the top of these "static" issues, dynamics, both in the static-recursive context or with inter-temporal optimization, is a very important issue for applied economic analysis: this is the issue we will focus on in this chapter.

Indeed, the calibration of dynamics – namely: the dynamic baseline – is instrumental to properly answer the "What if?" question. The importance of this issue has been less emphasized in the literature, although it is an important driver of most models' results. In a sense, the question to be addressed using dynamic CGE models is rather "In the context of . . . , what if . . . ?".

Several approaches of baseline design are usually considered. Extrapolating linear trends is simple but indeed misses any economic rationale; it may lead to major errors in the representation of the potential future for the world economy (proof in e.g. Fouré et al. (2013) about the emergence of the Chinese economy). Alternatively, one can rely on macroeconomic projections: building a theoretically funded framework allows to maintain consistency, but at the cost of less potential details. Finally, relying on experts appraisal as in Dixon and Rimmer (1998), although facing the risk of lack of consistency due to the absence of an encompassing framework, allows to deal with issues and determinants beyond usual economic variables. Of particular interest is the initiative of the Intergovernmental Panel in Climate Change (IPCC): five different stylized baseline scenarios have been built (the Shared Socioeconomic Pathways, SSPs) using a multidisciplinary approach (O'Neill et al., 2017). These scenarios have triggered research on baseline design and allowed for ambitious model comparison such as the AgMIP project (von Lampe et al., 2013; Wiebe et al., 2015).

In this chapter, we build on the two latter approaches and rely on a cross-cutting approach which mixes a theoretically founded macroeconomic framework with a CGE model, maximizing consistency between them, while relying on experts appraisal to tackle uncertainty around the baseline design. To do so we take stock of our previous work on dynamic baselines (Fouré et al., 2013; Fontagné et al., 2013; Fontagné and Fouré, 2013; Fontagné et al., 2017a; Fontagné and Fouré, 2017b) and extend it to the SSPs scenarios.

The remainder of this chapter is organized as follows. Section 1 reviews the relevant determinants shaping the economy in the long run. Section 2 proposes the integrated baseline framework between a macroeconomic framework – the MaGE model – and a CGE model – called MIRAGE-e. Section 3 illustrates this framework by providing a consistent implementation of the five Shared Socioeconomic Pathways (SSP), designed by the Intergovernmental Panel on Climate Change (IPCC), and analyzing the consequences on the analysis of simple climate change policy. Finally, Section 4 concludes.

1 Factors shaping long-run economic trajectories

1.1 Long-term growth trajectories

Solow (1957) seminal attempt to decompose economic growth between factor accumulation (capital and labor) and a residual interpreted as technology improvements, is indeed simplifying (Hogan, 1958; Shaikh, 1974). However, estimating aggregate production functions remains the most workable framework to quantitatively analyze long term trends in economic growth, and by far the most common in the literature. We adopt here a pragmatic approach and address two questions:(i) what are the production factors that shape long-term growth trajectories? and (ii) once factors are identified, what could explain the variations in the residual?

Labor and capital are at the heart of long-term growth analysis (Solow, 1957; Wilson and Purushothaman, 2006; Duval and de la Maisonneuve, 2010), and the stability of their shares in value added explains the success of the aggregate Cobb-Douglas production function. Then, with one of the first attempts at endogeneizing growth, Lucas (1988) introduced human capital instead of labor in the aggregate production function, hence opening the way to explain what actually drives GDP growth in the long run. Finally, natural resources at large, or more specifically primary energy consumption or land, have recently been considered as a part of aggregate production function (van der Werf, 2008; Markandya and Pedroso-Galinato, 2007). Although energy is not properly a production factor – it is rather produced, like capital – it appeared that it behaves as one: its use is common to every sector in the economy, and it can substitute to workforce and capital.

Once the factors are identified, the remaining Solow-like residual represents all the missing determinants of the GDP trajectories. This component may well be the most important: in the Solow framework, it is the only growth component that matters in the long-run. We also know since Wand and Yao (2003) that human capital and the residual growth were contributing more to GDP growth than factor accumulation.

1.2 Trade in the long run

In the very long run, only macroeconomic determinants are at play: accumulation of production factors and technological improvements are only weakly related with trade issues. However, as soon as natural resources are accounted for, the allocation of economic activity between sectors in each country is likely to have important impacts, as it will determine the dependency of each country on fossil resources, or land use.

As exemplified recently by the apparent disconnection of trade and GDP growth at world level, the first interesting stylized fact about the long-run development of trade is that its relation to economic growth is far from being stable. The ten-year average trade-to-income apparent elasticity has ranged in the last 50 years between 1.19 (1980-89) to 2.82 (1990-99)[1]. Assumptions on five key determinants (energy prices, technological progress in the transport sector, tariffs, non-tariff measures and global value chains) can reasonably well reproduce historical trade-to-income apparent elasticity in a CGE framework (Fontagné and Fouré, 2013).

The second important issue to address is to what extent trade growth and trade patterns can be shaped by the combination of determinants of economic growth. In an attempt to implement

[1] Authors calculations based on WTO data.

dynamic baselines in a global trading framework, Fontagné et al. (2017a) show that current trends towards increased regionalization may well be reversed, and that continuing technological progress is likely to have the biggest impact on future economic developments around the globe. Demographics and education were also shown to play a prevalent roles in shaping future trade patterns.

2 Building a consistent general equilibrium baseline: an illustration with the MIRAGE-e model

The methodology developed below is now rather stabilized and has been used repeatedly as a backbone of global simulation exercises in relation with trade policies or climate change mitigation impacts. The first implementation in Fontagné et al. (2013) of macroeconomic projections made publicly available (data and code) were followed by other applications aiming at calibrating a reference scenario for a multi-region, recursive dynamic global CGE model (see e.g. Lemelin and Robichaud (2015)). However, the seminal work in this domain (Van der Mensbrugghe, 2005) departs from our approach as technology is assumed to be trade-driven, while productivity is assumed to be constant in the baseline. All these attempts have hugely benefitted from the support of the community of CGE modellers.[2] The dynamic GTAP model itself (Ianchovichina et al., 2000) has been backed by a well documented baseline quite early Walmsley et al. (2006). The originality of our approach is to have embedded a macroeconomic growth model into a CGE approach, instead of resorting to growth forecasts taken from the literature. It allows to conduct alternative baseline exercises combining consistent shocks to the two frameworks (growth model and CGE). Beyond our approach, with a focus on agriculture results from multiple climate and economic models have been combined to examine the global and regional impacts of climate change on agricultural yields, area, production, consumption, prices and trade (Wiebe et al., 2015). Also for agriculture, a comparison of scenarios combining alternate socioeconomic, climate change, and bioenergy assumptions is performed in von Lampe et al. (2013).

2.1 Long-term growth trajectories: the MaGE model

In order to implement our baseline exercise, we use the long-run growth projections from the MaGE model (Fouré et al., 2013). These projections are based on a three-factor (capital, labor, energy) production function at national level, for 147 countries. First, we briefly describe the methodology underlying such projections.

The three factors are gathered in a CES function of energy $E_{r,t}$ and a Cobb-Douglas aggregate of capital $K_{r,t}$ and labor $L_{r,t}$:

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

were $A_{r,t}$ and $B_{r,t}$ respectively are the usual TFP – in our case the efficiency of labor and capital combined – and an energy-specific productivity. In line with the literature (see e.g. Mankiw et al., 1992), α is set to 0.3. In turn, the $\sigma = 0.2$ parameter is calibrated, within the range estimated by van der Werf (2008) but also considering that services are not included in these estimations; and

[2] see e.g; the GTAP dedicated webpage: `https://www.gtap.agecon.purdue.edu/models/dynamic/baseline/default.asp`.

the shape of energy productivity must not be reduced to an inverse function of energy price (see Fouré et al., 2013). In addition, GDP, $Y_{r,t}$, where appropriate, is considered net of oil rents to avoid a biased measure of productivity. Oil rents are added separately and are assumed to be pure rents: the volume of production is constant, but its real value (in terms of the GDP deflator) increases with the relative price of oil.

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

In particular, capital accumulation follows a permanent inventory process, where the stock of capital increases each year with investment but also can be depleted. The depletion rate is set in accordance with the MIRAGE model at 6%, whereas investment-to-GDP ratios depend on savings rates through an error-correction Feldstein-Horioka-type relationship. This allows us to relax the common assumption of a closed economy. Savings rates are determined by both the demographic and economic situations in line with life-cycle theory.

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

2.2 GE implementation: the MIRAGE-e model

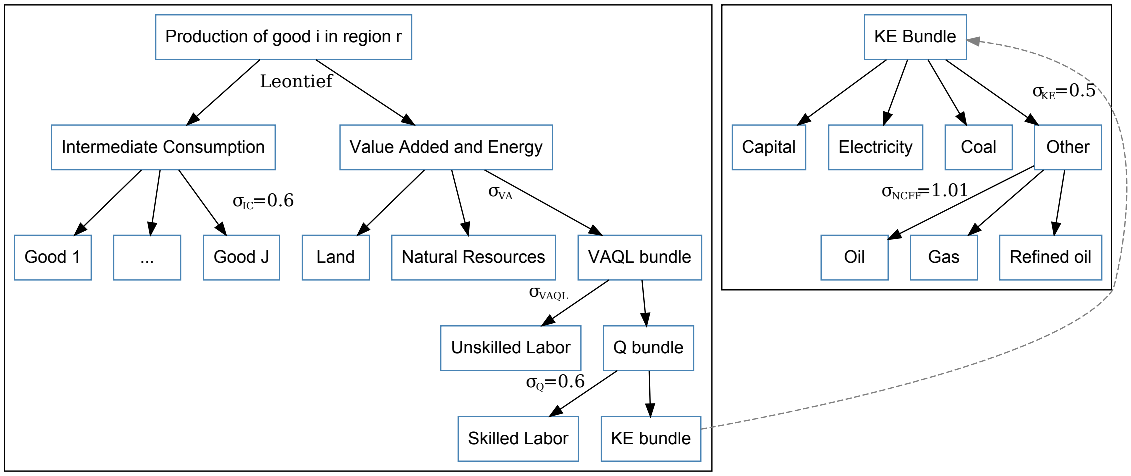
The MIRAGE-e model is a computable general equilibrium model which builds on the initial MIRAGE model (Bchir et al., 2002; Decreux and Valin, 2007). It is extensively documented in Fontagné et al. (2013), so only key issues being discussed in this section.

2.2.1 The MIRAGE-e general framework

Supply On the supply side, each sector in MIRAGE-e is modeled as a representative firm, whose production function is summarized in Figure 1. It combines value-added and intermediate consumption in fixed shares. Value-added is a bundle of imperfectly substitutable primary factors (capital, skilled and unskilled labor, land and natural resources) and energy. Firms' demand for production factors is organized as a CES aggregation of land, natural resources, and a bundle of the remaining factors. This bundle is a nested CES aggregate of unskilled labor and a bundle of the remaining factors, which is composed by skilled labor, and another bundle of capital and energy. Finally, energy is a CES aggregate of energy sources (except for non-electricity energy production sectors, for which the share of each energy input is fixed). Energy consumption of the representative firm comprises five energy goods (electricity, coal, oil, gas and refined petroleum), which are aggregated in a single bundle that mainly substitutes for capital. Substitution elasticities are taken from the literature (Aguiar et al. (2016) for σ_{VAQL}; (Paltsev et al., 2005) and Burniaux and Truong (2002) for energy substitution).

MIRAGE-e assumes full employment of primary factors. Skilled and unskilled labor is perfectly mobile across sectors, but immobile between countries. On the contrary, natural resources are sector specific, while land is only (imperfectly) mobile between agricultural sectors. 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.

Figure 1: Production function of firms in MIRAGE-e



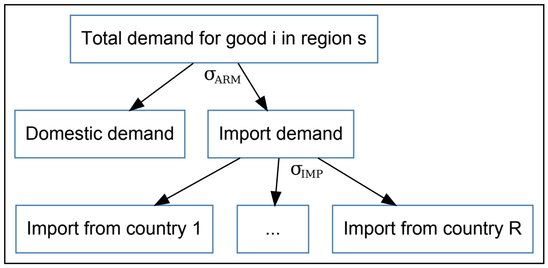
Gross investment is determined by the combination of saving and the current account. Finally, while total investment is saving-driven, its allocation is determined by the rate of return on investment in the various activities. For simplicity, and because we lack reliable data on foreign direct investment at country of origin, host and sectoral levels, international capital flows only appear through the current account imbalances, and have not been explicitly modeled yet.

Consumers On the demand side, a representative consumer from each country/region maximizes instantaneous utility under a budget constraint, her savings being determined by saving rates projected in our first-step exercise. Expenditure is allocated to commodities and services according to a LES-CES (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. This representation of preferences is well suited to our purpose as it is flexible enough to deal with countries at different levels of development. Elasticities and minimal consumption levels are calibrated such that the utility function reproduces at best price and income elasticities from USDA (USDA, 2005).

Trade Within each sector, total demand for each good (final, intermediate and investment) is differentiated by its origin. A nested CES function allows for a particular status for domestic products according to the usual Armington hypothesis (Armington, 1969), as depicted in Figure 2: 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) for σ_{IMP} and a simple rule of the thumb to relate to the (lower) σ_{ARM}.

Issues with energy and CO_2 emission accounting Using CES functional forms with variables in monetary units leads to inconsistencies when trying to retrieve physical quantities. In our case, this matters for energy consumption, production, and trade, and their consequences for CO_2

Figure 2: Demand in MIRAGE-e



emissions.[3] Therefore, in addition to accounting relations in constant dollars, MIRAGE-e integrates a parallel accounting in energy physical quantities (in million tons of oil equivalent, $Mtoe$) allowing CO_2 emissions to be computed (in million tons of carbon dioxide, $MtCO_2$). Since the CES architecture does not maintain coherence in physical quantities, MIRAGE-e introduces energy- and country-specific adjustment coefficients. These two aggregation coefficients allow our basic energy accounting relationships to remain valid. This means that the quantity produced by one country[4], $EY_{e,r,t}$ must equal the demand in this country both local, $ED_{e,r,t}$ and from abroad, $EDEM_{e,r,s,t}$, as in Equation (2) ; and energy consumption (by households, $EC_{e,s,t}$ and firms, $EEIC_{e,j,s,t}$) in one country must equal its local and foreign demand (Equation (3)).

$$EY_{e,r,t} = ED_{e,r,t} + \sum_{s} EDEM_{e,r,s,t} \tag{2}$$

$$EC_{e,s,t} + \sum_{j} EEIC_{e,j,s,t} = ED_{e,s,t} + \sum_{r} EDEM_{e,r,s,t} \tag{3}$$

The corresponding adjustment coefficient, $AgDem_{e,r,t}$ (resp. $AgCons_{e,r,t}$) is re-scaling the country's demand (resp. consumption) such that it matches the physical quantities produced (resp. demanded). In turn, only energy quantity produced is proportional to the volume production Y due to its being above rather than inside the CES. Finally, CO_2 emissions are recovered as proportional to the energy quantities consumed, using energy-, sector- and country-specific factors determined by the data.

Data sources MIRAGE-e mainly relies on the GTAP 9 database (Aguiar et al., 2016). However, along with this base data, the model relies on the HS6 level MAcMap database (Guimbard et al., 2012; Bouët et al., 2008) for tariff data and Minor (2013) (based on the methodology by Hummels and Schaur, 2013) for trade costs associated with delays – modelled by and iceberg trade cost.

2.2.2 Consistent baseline implementation

Factor accumulation Availability of primary factors is determined by macroeconomic projections.

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

[4]In these equations, and in the rest of this paper, the subscript e will be an index for energy goods. In addition, r denotes (where appropriate), the country of origin of a good and s denotes its destination.

- Skilled and unskilled labor grow at exogenous rates, taken from MaGE's projections.
- Capital supply depends on two outputs from macro projections: the savings rate and the current account balances, both of them varying exogenously.
- Natural resources for the mining sector and land for agricultural sectors are set at their 2004 levels: prices adjust demand to this fixed supply.
- Natural resources for fossil fuel production sectors (coal, oil and gas) adjust to match the exogenous price target we impose (International Energy Agency, 2015) according to the energy demand projected by the model.
- Land (for agricultural sectors) expands following an iso-elastic function of real return to Land.

Dynamics in MIRAGE-e is sequentially recursive: the equilibrium is solved successively for each period by adjusting to projected growth in the variables described above. The time span of this long-run baseline is 2011-2100. Over this time period, capital stocks change according to investment decisions based on rates of return to capital at sectoral level and the depreciation rate, which is assumed to be constant and uniform across regions (i.e. $\delta = 6\%$).

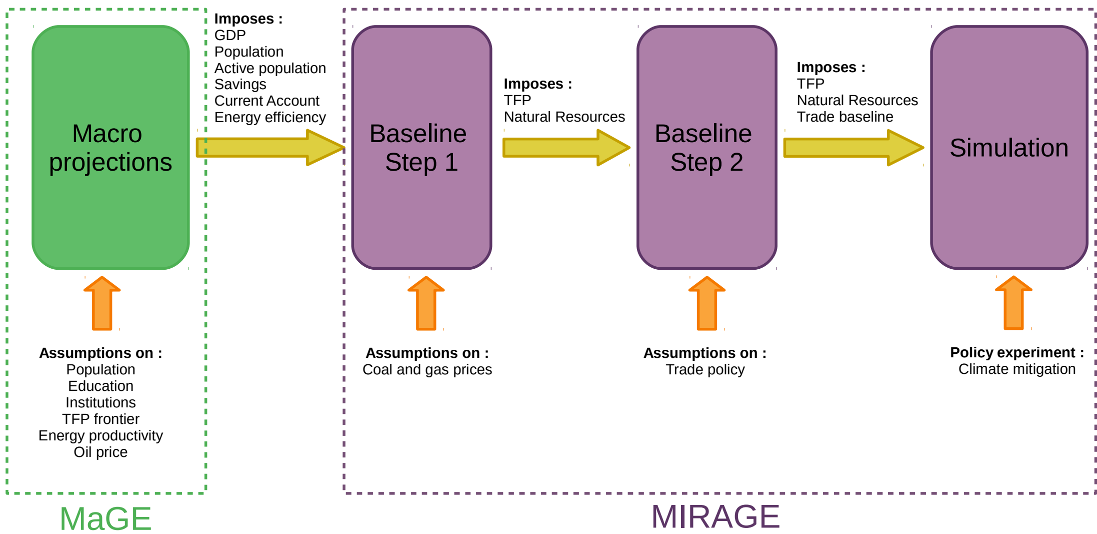
$$K_{j,r,s,t} = K_{j,r,s,t-1}.(1-\delta) + INV_{j,r,s,t} \tag{4}$$

Factor productivity Only three production factors, namely the two forms of labour and capital, are subject to productivity improvement. The level of productivity is also mainly derived from macroeconomic projections in the baseline, but some sector variations are taken into account. Indeed, factor productivity improvements follow the following rules: (i) at the regional level, the average productivity must make GDP growth match the level of the macroeconomic projections ; (ii) agricultural productivity is exogenous, coming from a Data Envelopment Analysis documented in Fontagné et al. (2013) ; and (iii) we follow the methodology by Van der Mensbrugghe (2010), using estimates from Bernard and Jones (1996) and Timmer et al. (2010), by imposing that the productivity in manufacturing is 2 p.p. greater than for services.

Energy productivity Contrary to other components that act as production factors, energy use is subject to its own technological improvements. Energy productivity follows the trajectory coming from the macroeconomic projections. The only exception concerns non-electricity energy production sectors (coal, oil, gas and refined petroleum), in order to avoid creating energy out of nowhere and in line with our "constant energy production technology" assumption.

Macroeconomic closure Finally, the macroeconomic closure of the model is achieved through the imposition of an exogenous current account imbalance. We believe that this imbalance is mainly driven by demographics, through its impact on the savings and investment, and thus the variation in current account follows the variation in the macroeconomic projections (measured as a percentage of world GDP in order to maintain consistency between each regional imbalance). With such a macroeconomic closure, trade imbalances are then exogenous, and the (implicit) real exchange rate adjusts.

Figure 3: Complete articulation of the models and assumptions



2.2.3 Summary of quantification strategy

As a result from our modelling framework, we propose the workflow depicted in Figure 3 to quantify at best any policy in the context of uncertain global conjuncture. This strategy consists in four steps, illustrated in the Figure by the exercise described later in this chapter.

1. Macroeconomic projections: The variables of interest (GDP, population, etc.) are projected with the macroeconomic model.

2. Baseline Step 1: This global projection is broken down at the sectoral level by the CGE model, with as few additional assumptions as possible.

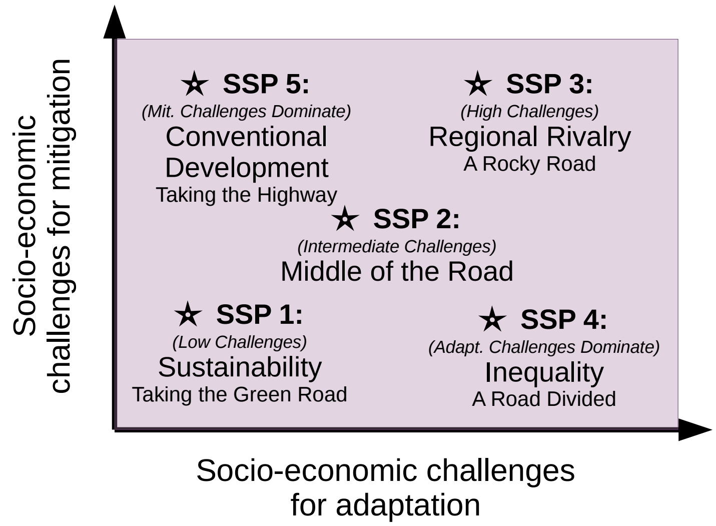
3. Baseline Step 2: Baseline assumptions that go beyond macroeconomics (i.e. sector-specific assumptions that have an impact on GDP growth) are implemented in the CGE model.

4. Simulation: The actual policy experiment to be evaluated is implemented and compared to Baseline Step 2.

3 An application to the quantification of Shared Socio-economic Pathways

Building on an initiative by the Intergovernmental Panel on Climate Change (IPCC), researchers of the climate change field have been conducting since 2010 an interdisciplinary exercise in order to identify the key elements that would impact the potential magnitude and cost of climate change mitigation over the 21st century. The outcome of these working groups has been the elaboration of

Figure 4: Graphical representation of the five SSP scenarios



Source: O'Neill et al. (2017)

five potential scenarios – denominated as Shared Socioeconomic Pathways (SSP) – meant to be a common basis for climate policy analyses.

Since the publication of the narratives describing the five SSP scenarios, different teams have contributed by producing quantitative evaluation. Along with the population projections it produces (KC and Lutz, 2017), IIASA also made available the projections exercises conducted by themselves (Crespo Cuaresma, 2017), the OECD (Dellink et al., 2017), and PIK (Leimbach et al., 2017), to which we will compare our results.[5] These three projection exercises rely on the same basic assumption about primary inputs, human capital and TFP, though with different model structures. We contribute to this field by proposing an alternative specification of the SSP scenarios, encompassing more dimensions of the narratives – institutions, energy productivity, heterogenous energy prices, sector-level productivity and trade costs – due to the flexibility of our macroeconomic model MaGE, and our complete integration with a CGE model.

Indeed, the set of tools presented above – the MaGE and MIRAGE-e models – whose aim is to address long-term trade and development issues, is a natural candidate for an evaluation of the SSP scenarios. The present section aims to contribute to the SSP modeling effort by employing these tools, after a short description of the five SSP scenarios taken from Riahi et al. (2017) in Table 1.

3.1 An implementation of the SSP scenarios

We develop several strategies, depending on the issue, in order to best represent our understanding of the SSP narratives and use all the capabilities of our models. The general summary of our assumptions is presented in Table 2.

[5] `https://tntcat.iiasa.ac.at/SspDb/`, consulted May 15, 2017.

Table 1: Summary of SSP narratives

SSP1	Systainability – Taking the Green Road *The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Consumption is oriented toward low material growth and lower resource and energy intensity.*
SSP2	Middle of the Road *The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain.*
SSP3	Regional Rivalry – A Rocky Road *A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Policies shift over time to become increasingly oriented toward national and regional security issues. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized and high in developing countries. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.*
SSP4	Inequality – A Road Divided *Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas.*
SSP5	Conventional Development – Taking the Highway *This world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while global population peaks and declines in the 21st century. Local environmental problems like air pollution are successfully managed. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary.*

Source: Riahi et al. (2017)

Demographics and education Our approach regarding demographics is hybrid, since all the dimensions cannot be directly encompassed using MaGE. Furthermore, other institutions have published detailed demographic scenarios, in particular the IIASA (KC and Lutz, 2017). These IIASA scenarios already include variation in mortality, fertility and migration, whereas MaGE can only deal with some migrations flows. We therefore chose to rely on IIASA projections for population.

Regarding education, two options were available: use IIASA projections or develop scenarios directly in MaGE. On the one hand, MaGE projections would have been more flexible, but on the other hand, IIASA include the impact of education on fertility. We then chose IIASA projections to keep a maximum consistency.

Finally, total population has to be converted into active population. On this matter, MaGE provides the best framework by including variation in female participation to the labor force due to increases in education level.

Institutions The economic literature has studied institutions and their impact for long. For instance, Aron (2000) documents that institutions interfere in the accumulation of all production factors, and in particular by productivity improvements – both regarding innovation and catch-up to the technological frontier – and in capital accumulation. Quite often, as the author suggests, institutions are limited to productivity improvements, neglecting all other aspects. We will try to depart from this common assumption.

Although not explicitly specified, institutions differentials appear in MaGE in two ways. First of all, they are embodied in the fixed effects that are estimated in our econometric relationships (TFP, savings rate, female participation to the labor force and savings-investment relation). Second, institutions also appear in the Feldstein-Horioka relation, because we conduct two separate estimations on two different country groups (OECD countries vs. non-OECD countries). As a consequence, the estimated coefficients embody institutional differences between OECD members and other countries. Scenarios of institutional convergence can then be derived from these two ways.

However, quantifying the magnitude of the impact of institutions on our variables of interest is subject to judgment: to our knowledge the literature has not investigated the quantitative impact of institutions on other variables than TFP. Therefore, productivity improvements due to improvements in institutions efficiency will be derived from estimates from the literature – as described below – while we will have a simple normative definition of efficient institutions regarding other variables (savings rate, female participation and savings-investment relationship).

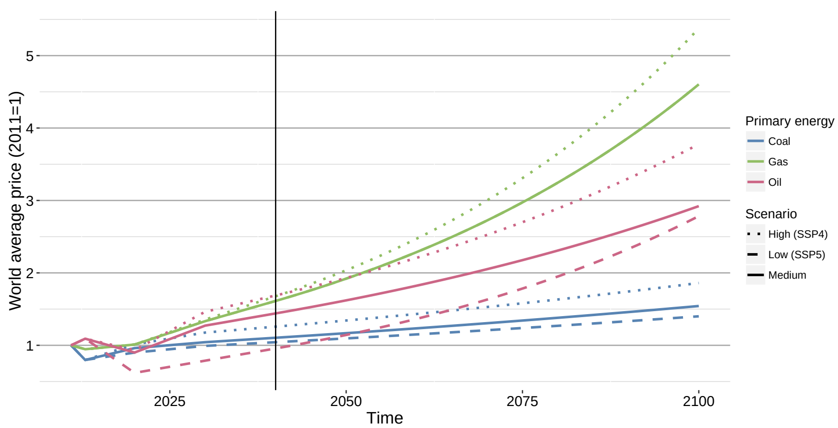
The link between productivity improvements and institutional environment has been quantified by Chanda and Dalgaard (2008). The impact of institutions – measured by the Government Anti-Diversionary Policy (GADP) index – on the level of TFP is tackled using several estimation strategies (Ordinary Least Squares – OLS – and 2-Stage Least Squares – 2SLS – with instrumental variables). Endogeneity issues were finally not convincingly addressed and the results provide only orders of magnitude of the actual impact of institutions on TFP. We convert these results into a range of potential TFP variations – from -30% to +50% – which corresponds to a one-standard-error change in the GADP index.

Regarding other relations that are impacted by institutional convergence, we will arbitrarily consider then institutions in OECD countries are more efficient than in non-OECD countries, and as a consequence, convergence towards more efficient institutions will only impact non-OECD countries, making them converge by 2100 to the average OECD institutions (both the fixed effects and other estimated coefficients converge).

Technology First of all, SSP narratives include scenarios on the technological frontier. This TFP frontier is present in MaGE, and is represented by the TFP level of Ireland and Denmark (these two countries share the leadership over our estimation period). Other countries converge towards the technological frontier conditionally on their education level. In projection, the baseline assumption in MaGE is that the TFP frontier continues to grow at its 1995-2008 average pace (around 1.5% annual growth). The amount of additional TFP for leader countries in SSP scenarios is however not easily determined, so we will consider scenarios where the TFP leader level of TFP growth is +/-50% of the baseline growth rate. The second issue about technology scenarios is energy productivity. We will consider a 50% increase in energy productivity by 2100, or alternatively only a 25% decrease in order to avoid theoretical infeasibility in the growth model when energy prices become greater than energy productivity.

Fossil constraints Fossil constraints in MaGE are materialized by oil price, whose trajectory binds the amount of energy use given the current level of energy-specific productivity. In MIRAGE, we can further differentiate the type of energy, and consider different prices for coal, oil and gas. The central scenario in both models corresponds to the medium projections of the International Energy Agency (IEA), taken from the World Energy Outlook (International Energy Agency, 2015). Accordingly, high and low fossil resource prices scenarios will be derived from their counterparts in IEA projections (resp. "current policies" and "low oil price" scenarios).

Figure 5: Energy prices, 2011=1, 2011-2100



Source: International Energy Agency (2015) and authors' computations.
Vertical line denotes the transition between IEA projections and simple extrapolation.

Sector structure and international trade MaGE does not encompass the sector structure of the economy, but MIRAGE does. The shift in structure (final and intermediate demand) is driven by relative prices and productivity differential. In our central case, agricultural productivity is exogenous (following the projections documented in Fontagné et al. (2013) while we constrain services productivity growth to be 2 percentage points lower than industrial TFP. The national average TFP level is computed given these constraints, plus the need to match MaGE projections in terms of GDP. Accordingly, our scenarios build on this productivity structure.

The choice to implement sector-level scenarios in Step 1 or Step 2 does matter a lot for the results, in particular when dealing with productivity improvement.[6] However, in the SSP narratives, it is not always obvious whether a technological development is more about additional innovation (then, the sectoral scenario goes in Step 2) or about the allocation of innovation (then, it should be implemented in Step 1). In order to choose between the two alternative, we took particular attention to wording in the narratives. On agriculture, O'Neill et al. (2017) mentions "improvements in technology" (SSP1) and "rapid increase in productivity" (SSP5), hence suggesting that technological improvements come in addition to other assumptions. On the contrary, regarding fossil fuel productivity, one read "preferences shift away from fossil fuels" (SSP1), suggesting that it is more a matter of allocation than technological improvements. Finally, on services, the paper reads "the service sector grows relatively quickly" (SSP1), but at the same time the emphasis is on "low growth in material consumption". We therefore retain an implementation in Step 1 (technology is biased towards services).

As for scenarios, a more (resp. less) productive agriculture will correspond to a 0.2% additional (resp. less) annual productivity growth, corresponding roughly to the average productivity growth in crops sector. In addition, productivity growth in services will be 1 p.p. greater when necessary (the gap between manufacturing and services is narrowed by half). The same magnitude (+/-1 p.p. growth) is retained for the fossil fuel production sectors.

Finally, international trade is influenced by tariffs and other transaction costs faced by exporters, as well as by energy prices through transport, as documented in Fontagné and Fouré (2013). We focus on the two first determinants, since energy prices scenarios are derived separately, taking the assumptions elaborated in Fontagné and Fouré (2013). Namely, we consider (i) a world trade war by 2100 resulting in a return to post-Kennedy round tariffs (in 1967)[7] ; or (ii) a global liberalization resulting in a 50% decrease in tariffs plus 20% decrease in transaction costs. Both assumptions naturally happen in Step 2, because they are likely to influence GDP growth by a channel not present in Step 1.

Summary Table 3 summarizes the assumptions made to represent at best the five SSP narrative scenarios.

[6] For instance, simulations not present in this paper showed that implementing services productivity improvement in Step 2 instead of Step 1 could reverse the ordering of SSP 1 and SSP 5 scenarios in terms of world GDP.

[7] When available, we retain tariffs from Deardorff and Stern (1983), and otherwise we use simple order of magnitudes assuming the reversal of previous changes. An increase by 24% in primary sectors' tariffs is assumed, as well as an increase by 25% in manufacturing plus an increase in transaction costs by 20%

Table 2: MaGE-MIRAGE implementation of the SSP scenarios

Topic	SSP1 Sustainability	SSP2 Middle of the road	SSP3 Fragmentation	SSP4 Inequality	SSP5 Conventional	Model concerned
Population			Provided by IIASA			MaGE
Education			Provided by IIASA			MaGE
Institutions	Convergenc of fixed effects	–	-30% TFP	OECD:+50% TFP ; Other: -30%	+50% TFP ; convergence of fixed effects	MaGE
TFP frontier	+50% growth	–	-50% growth	+50% growth	+50% growth	MaGE
Energy productivity	+50%	–	-25%	–	-25%	MaGE
Fossil resource prices	–	–	–	High	Low	MaGE & MIRAGE (Step 1)
Agricultural productivity	–	–	-0.2% growth	OECD: +0.2% growth	+0.2% growth	MIRAGE (Step 2)
Services productivity	+1 p.p. growth (wrt. manuf.)	–	–	–	–	MIRAGE (Step 1)
Fossil productivity	-1 p.p. growth (wrt. manuf.)	–	–	–	+1 p.p. growth (wrt. manuf.)	MIRAGE (Step 1)
Tariffs	–	-50% (agr.)	Return to post-Tokyo round	–	-100%	MIRAGE (Step 2)
Transaction costs	–	–	+20%	–	-20%	MIRAGE (Step 2)

3.2 Illustration with a simple climate change mitigation policy

3.2.1 Data and aggregation

MIRAGE-e was calibrated on the GTAP dataset version 9.2, with 2011 as a base year. As shown in Table 1, our data aggregation singles out all energy industries and combines other industries into main representative sub-sectors within the agriculture, manufacturing and services aggregates.[8] For the regional aggregation, we retain a simple geographic disaggregation.

Table 3: Sector and country aggregation

Regions	Sectors
Oceania	**Primary**
Asia	Vegetal Agriculture
North America	Animal Agriculture
Latin America	Other Primary
Europe	Coal
West Asia	Oil
Middle-east and North Africa (MENA)	Gas
Sub-saharan Africa (SSA)	**Secondary**
	Unskilled manufacturing
	Skilled manufacturing
	Petroleum and coal products
	Tertiary
	Electricity
	Finance, Insurance and business services
	Transportation
	Other Services

In order to compare the five baselines so designed, we implement a simple climate change policy experiment. On the one hand, the current level of commitment on such policies is summarized in the Paris Agreement signed in 2015 at the COP21. However, the time horizon for commitments is at best 2030, hence uncertainty across the whole 21^{st} century cannot be addressed with such emission reduction targets. The order of magnitude of the Paris Agreement pledges is that, by 2030, the increase in GHG emissions shall be limited to around 35 percent compared to 2011 emissions level (Fontagné and Fouré, 2017a). On the other hand, the IPCC 5^{th} Assessment Report (Pachauri et al., 2014) can be used to obtain order of magnitude at horizon 2100. Among the emissions scenarios considered in the report (Representative Concentration Pathways, or RCPs), the most stringent emissions reduction objectives – including those that are likely to satisfy the ambition of the Paris Agreement to maintain global warming below 2°C – cannot be considered in our exercise because they imply null or negative GHG emissions in 2100. Indeed, in our simple GE framework, mainly

[8] The distinction between skilled and unskilled manufacturing is based on the GTAP database version 8.1, because more recent versions lost the differential in skill intensity. Skilled manufacturing are then the sectors with a share of skilled labor force in the USA greater than the median.

constituted by CES functional forms, this would imply negative or null economic activity due to the lack of technological breakthrough or carbon sinks. We therefore concentrate on less ambitious scenarios, namely RCP6.0, that are only "likely" to limit global warming by 4°C. These RCP6.0 scenarios result on average in a limitation of global GHG emissions to an increase by around 30% in 2100 compared to 2011.

In our simulations, we implement a global carbon market with the objective to limit the increase in CO_2 emissions to 30% by 2100 – or, put differently, make the assumption that the world will implement a carbon tax high enough to achieve this goal.

3.2.2 The five SSP baselines

Baseline economic growth Figure 6 shows our results on average GDP growth (2011-2100) in all scenarios, but for the moment we will focus on the baseline steps 1 and 2 (resp. blue and green bars).

Our projected GDP growth rates range from 1.3 to 3.3 % at the world level, ranking SSP scenarios in a consistent way, from SSP3 being the less economically favourable case to a very dynamic world economy in SSP5. In addition, our results show that very contrasted trade policy scenarios in SSP 3 and 5 (respectively a return to post-Tokyo round tariffs and a full tariff liberalization with NTM reductions) only lead to sizeable but moderate differences in overall economic activity. This conclusion is consistent with the trade policy analysis literature, where trade liberalization only lead to slight increases in GDP.

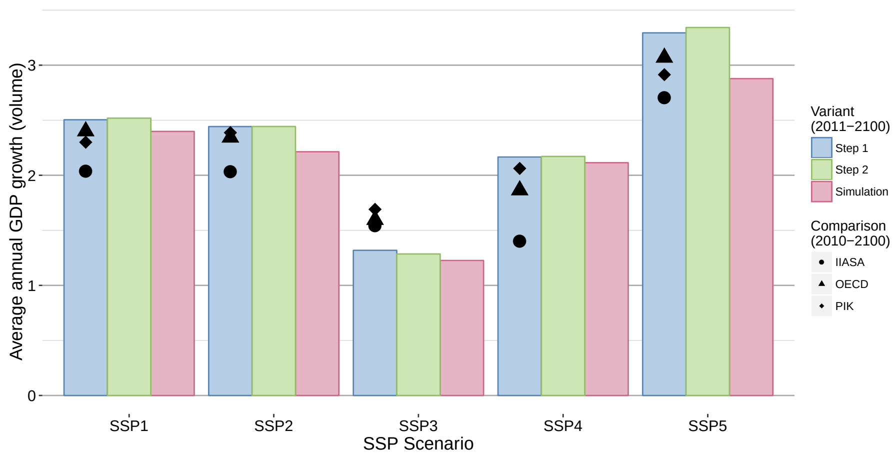
Regarding the way we compare alternative SSP evaluations (Crespo Cuaresma, 2017; Dellink et al., 2017; Leimbach et al., 2017), two issues are worth mentioning. First, from a methodological point of view, other SSP evaluations are only comparable to our Step 1 (i.e. without trade policy). On this regard, our estimations are in the same order of magnitude, but more contrasted, especially regarding SSP3 and SSP5. This difference is not that surprising, as the three cited modelling teams have harmonized their interpretation of the SSP storylines, and therefore present the same scenarios with only a difference in the underlying models. On the contrary, we built an independent interpretation of the SSP storylines consistent with our model. By doing so, we ended up with specific quantification of TFP shocks – the most important driver of baseline growth – based on econometric estimations, and even go beyond TFP scenarios by including other determinants in both the macroeconomic growth model and the CGE.

Second, the introduction of a second SSP baseline step (including trade policies) further widen the contrast between our projected baseline GDP growth and other projections, though the difference is of second order.

CO_2 emissions On CO_2 emissions, our results are even more contrasted, ranging from an 190 (SSP 4) to 1100 % (SSP 5) increase in emissions level. However, this quantification may not be considered more than a simple illustration of potential applications for our SSP baselines. Indeed, the MIRAGE-e model is not well fitted to deal with such long-run emissions: renewable energies are not explicit, hence constrained at their 2011 share ; emission factors for fossil fuels are constant ; and no carbon sink is considered either. As a result, if we compare to alternative quantifications, e.g. from (Pachauri et al., 2014), our figures are much higher.

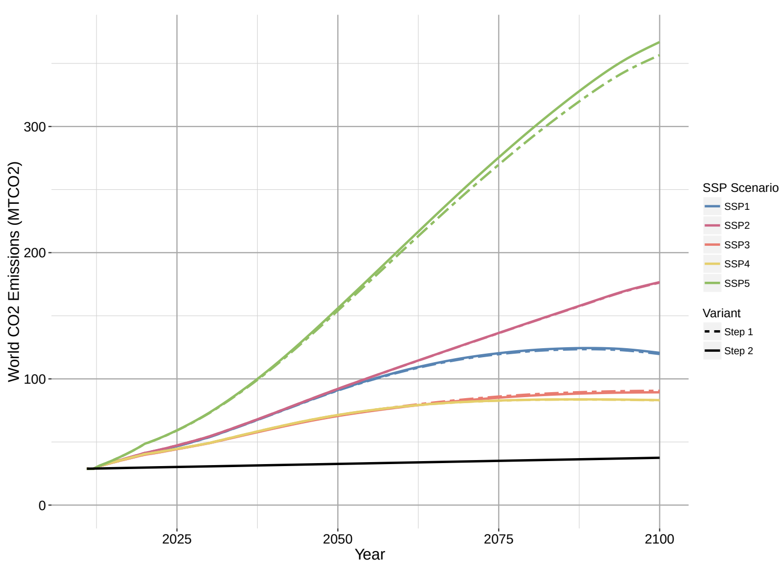
However, these emissions results are worth considering, as Figure 7 show that only a very ambitious trade liberalization in SSP5 could have a sizeable impact on global emissions, both through increased economic activity and increased demand for international transportation.

Figure 6: World GDP growth rate (volume) under all scenarios



Source: Authors' calculations. Comparison is made with (Crespo Cuaresma, 2017) for IIASA, (Dellink et al., 2017) for OECD and (Leimbach et al., 2017) for PIK.

Figure 7: World CO_2 emissions under all scenarios



Note: The black line denotes the emission reduction objective considered in Step 3 (Simulation).

Table 4: Average trade to income elasticity in Step 2 (2011-2100)

Step / Variant	SSP 1	SSP 2	SSP 3	SSP 4	SSP 5
Step 2	1.05	1.10	1.04	1.07	1.14
Simulation	1.00	1.03	1.06	1.03	0.99

Trade patterns At the world level, the average annual growth rate of trade, measured as export volume, follow the shape discussed above on GDP, although of course the effects of trade policies in Step 2 are magnified. The resulting trade-to-income elasticities, presented in Table 4, range from 1.04 (SSP3) to 1.14 (SSP5), way below trade elasticities observed in the past as emphasized in (Fontagné and Fouré, 2013). However this result is not surprising as SSP 3 and 5 include trade policies. By contrast, in other scenarios, trade elasticities also vary significantly, suggesting that SSP narratives impact significantly trade patterns, through composition effects (the change in relative size of countries in the different SSPs, along with their difference in involvement in global value chains lead to heterogeneity in trade response).

In addition to the impacts of SSP narratives on overall trade *volume*, the *allocation* of both exports and imports between regions is even more impacted, as shown in Figure 8.[9] Although all regions are impacted, the most astonishing result concerns current two largest trade blocks, Europe and Asia. Although as importers their relative size remain roughly constant across scenarios, Asia as an exporter can either become comparable to Europe in the best economic conjecture (SSP 5) or completely outperform Europe in case of a gloomy conjecture (SSP 3). Interestingly, the share of Sub-Saharan Africa in world trade is likely to increase a lot in all scenarios (though more as an exporter than as a importer), even outperforming North America in the best conjecture (SSP 5).

3.2.3 Mitigation cost

Finally, the illustration would not be complete without a tentative quantification of a climate change policy, keeping in mind the limitations mentioned above.

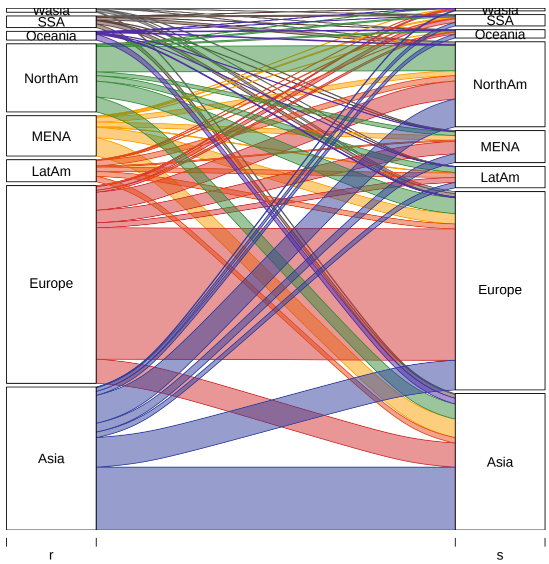
Mitigation costs in terms of GDP are also presented in Figure 6. Unsurprisingly, the GDP cost of climate change mitigation increases with "challenges for mitigation" in the narratives, the most challenging world being the one with the most favourable economic conjecture (SSP 5). In addition, Table 4 shows that for this scenario, the impact on world trade is even larger and could lead to a trade elasticity slightly below 1. In any other case, trade is more sensitive to climate mitigation than GDP, always leading to lower trade elasticities.

When it comes to the allocation of trade, the effects of climate change mitigation can be spectacular as shown in Figure 9: in all cases, mitigation efforts play at the advantage of more energy-efficient developed countries. In particular, in all scenarios but SSP 3, a global mitigation effort would restore Europe to its current status of largest trade block. Conversely, less CO_2-efficient countries as in Asia on average always loose market shares from a world mitigation effort. These very contrasted results have however to be nuanced, because potential climate actions, such as the Nationally Determined Contributions as decided in the Paris Agreement, are very likely to be differentiated between regions in order to recognize the right of developing countries to rely on fossil energy as developed countries did over the past two centuries.

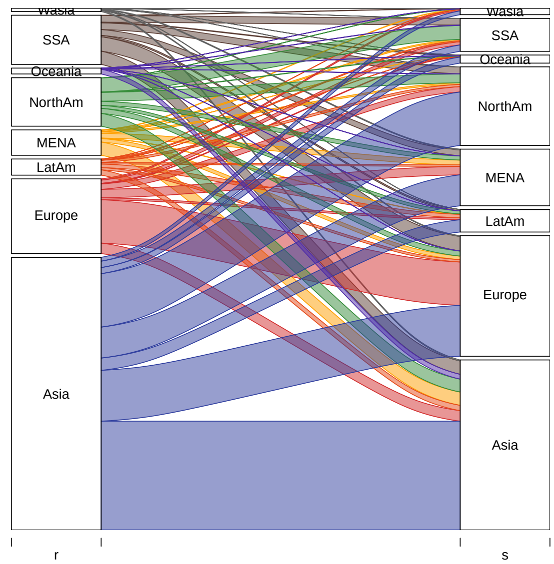
[9]Figure 8 only presents the more contrasted SSP scenarios. Full results are available in Appendix A

Figure 8: World bilateral trade flows in 2011 and 2100 (volume at 2011 FOB price), selected SSP scenarios

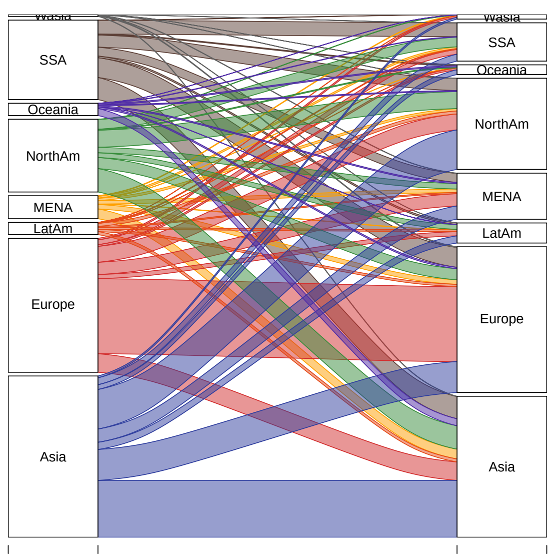
(a) 2011



(b) 2100, SSP3 (step 2)



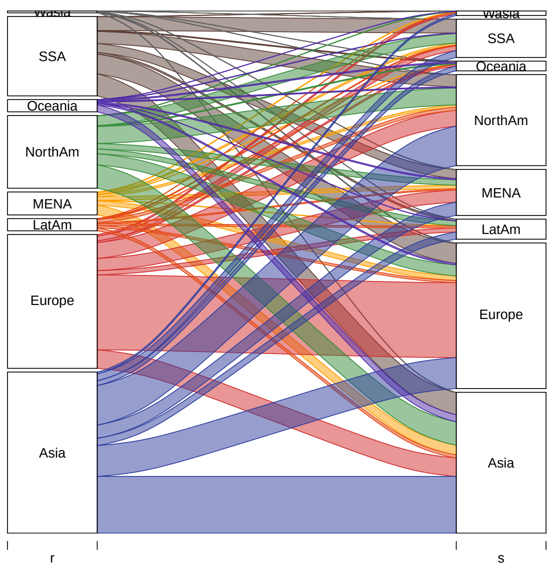
(c) 2100, SSP5 (step 2)



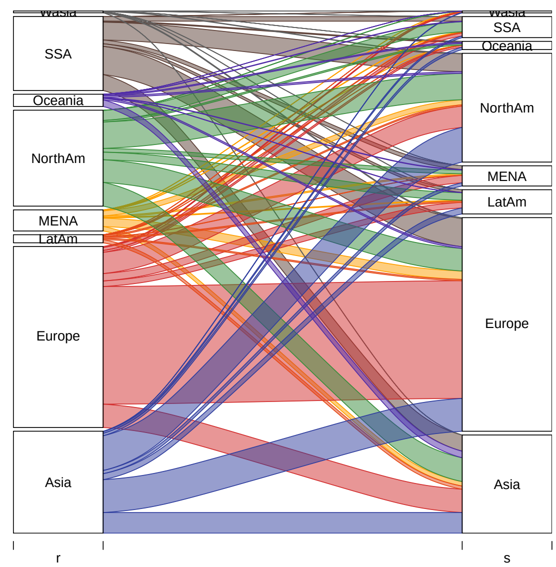
Source: Authors' calculations. All SSP scenarios are depiced in Appendix A.

Figure 9: World bilateral trade flows in 2100 with and without climage change mitigation, selected SSP scenarios

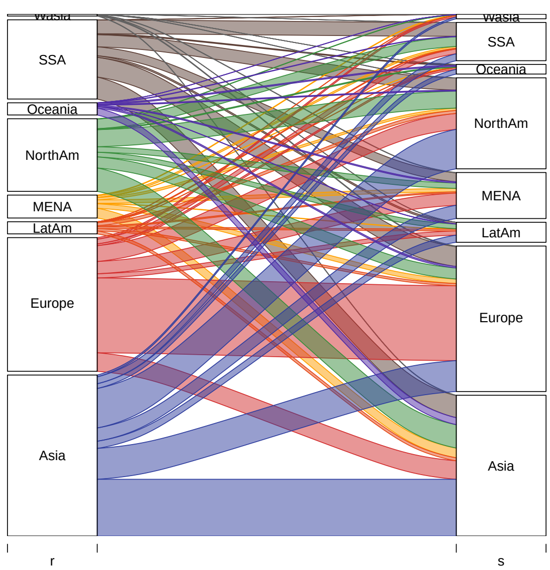
(a) SSP2 – Step 2



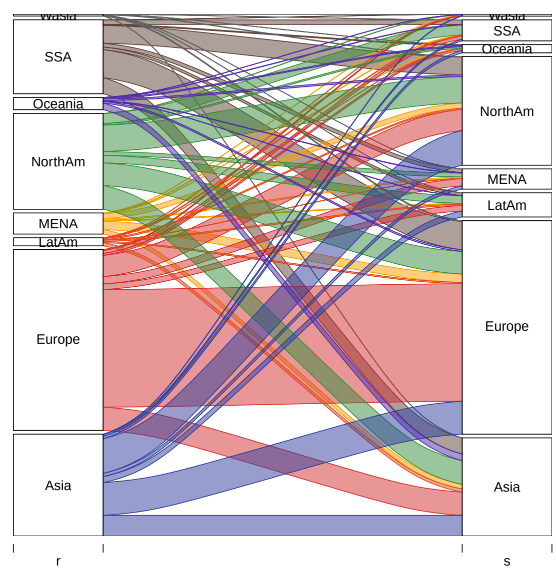
(b) SSP2 – Simulation



(c) SSP5 – Step 2



(d) SSP5 - Simulation



4 Concluding remarks

We proposed in this chapter a sound, theoretically founded baseline of the world economy consistent with the SSP baseline methodology, along with an quantitative illustration. Although the quantification is not of paramount importance *per se*, due to model limitations, several mechanisms drawn from our results are informative for future modelling works. First, trade policies play only a limited role in both trade patterns and mitigation costs as compared to underlying macroeconomic long term determinants: trade patterns are way more impacted by macroeconomic determinants of growth and climate change mitigation policies. These findings calls for a deepening of the kind of approaches presented here.

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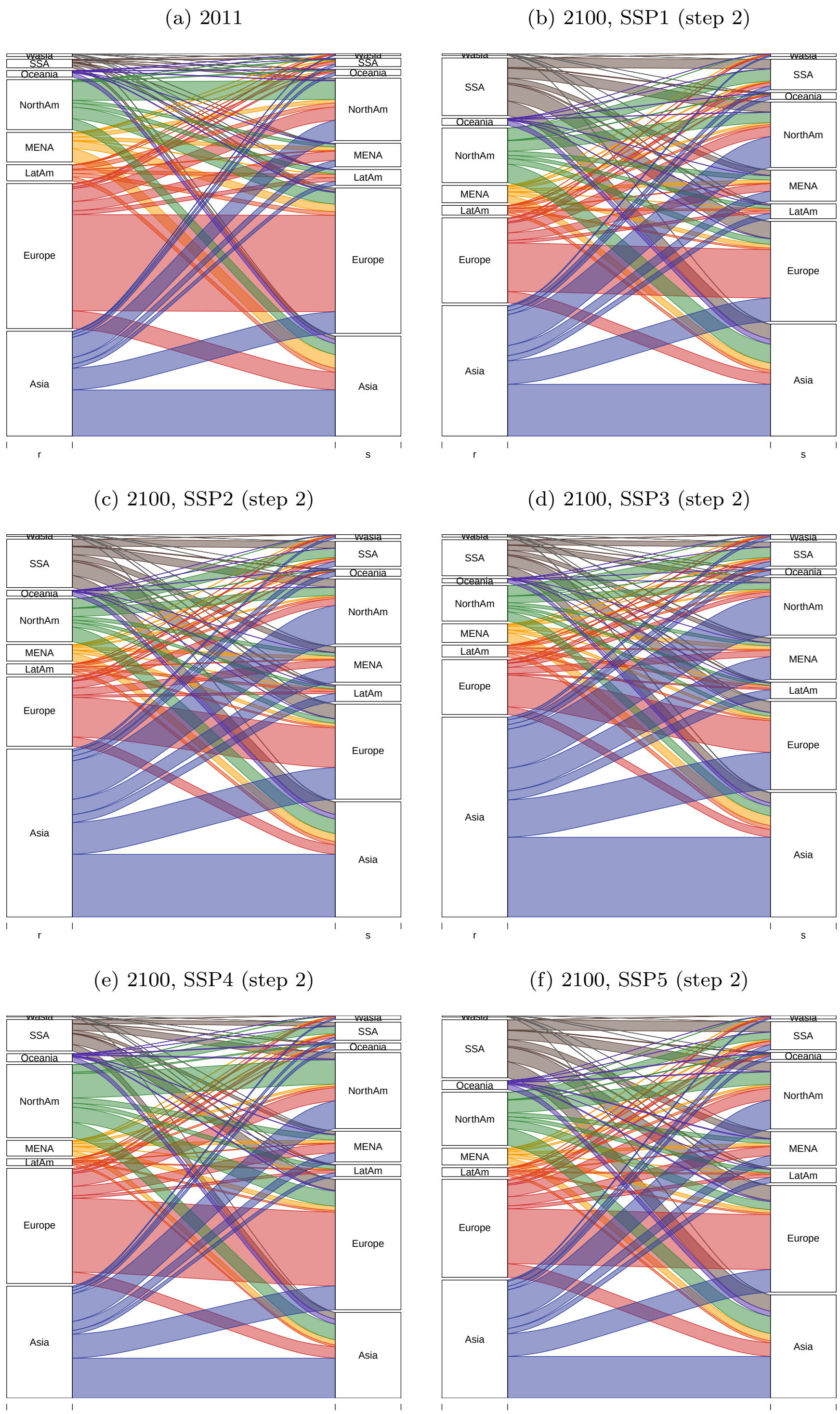
A Additional figures

Figure A.10: World bilateral trade flows in 2011 and 2100, all SSP scenarios



(a) 2011

(b) 2100, SSP1 (step 2)

(c) 2100, SSP2 (step 2)

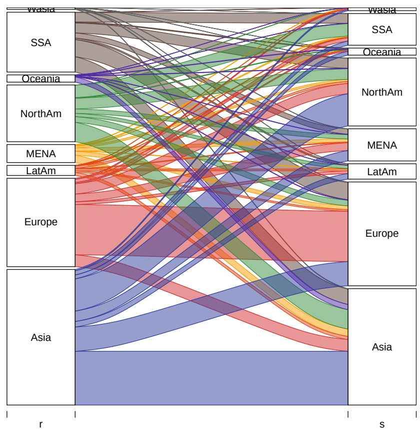
(d) 2100, SSP3 (step 2)

(e) 2100, SSP4 (step 2)

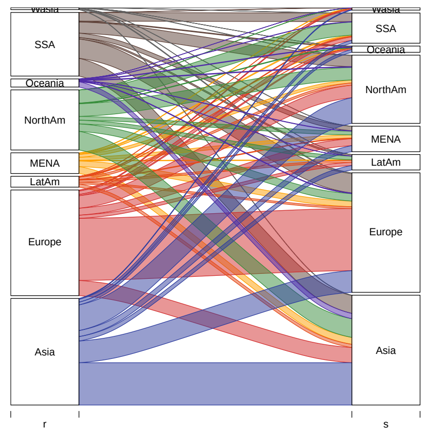
(f) 2100, SSP5 (step 2)

Figure A.11: World bilateral trade flows in 2100, SSP 1 to 3 and mitigation scenarios

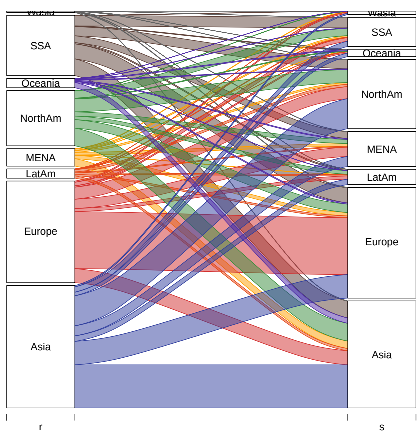
(a) 2100, SSP1 (step 2)



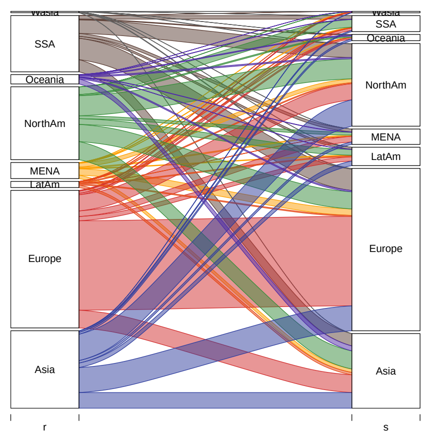
(b) 2100, SSP1 (Simulation)



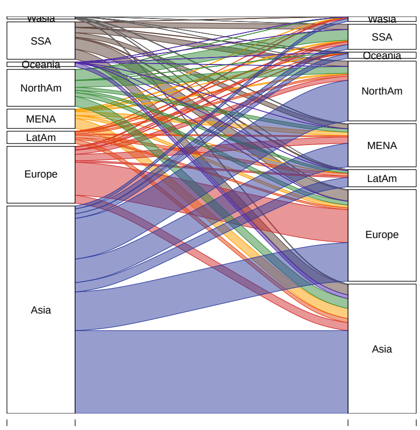
(c) 2100, SSP2 (step 2)



(d) 2100, SSP2 (Simulation)



(e) 2100, SSP3 (step 2)



(f) 2100, SSP3 (Simulation)

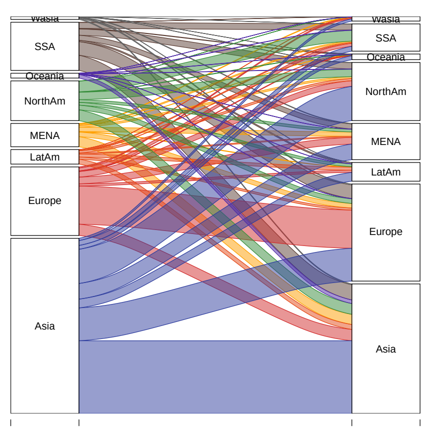
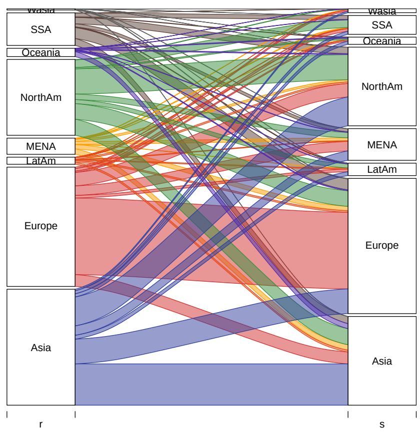
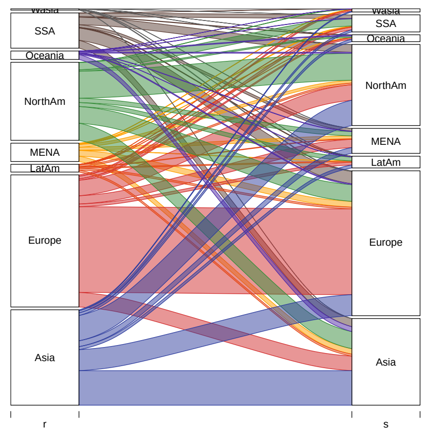


Figure A.12: World bilateral trade flows in 2100, SSP 4 and 5 and mitigation scenarios

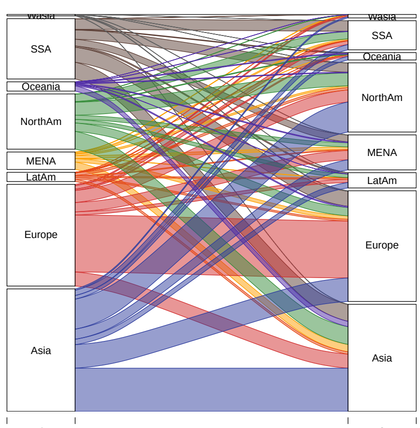
(a) 2100, SSP4 (step 2)



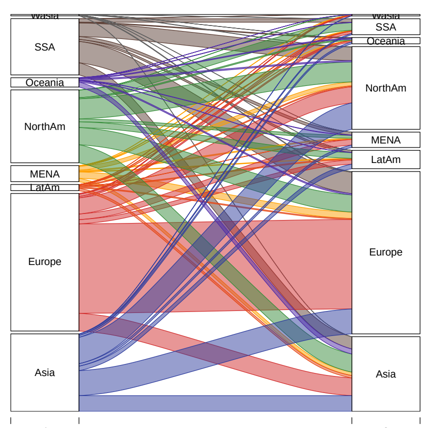
(b) 2100, SSP4 (Simulation)



(c) 2100, SSP5 (step 2)



(d) 2100, SSP5 (Simulation)



B MIRAGE-e equations

To be added