A Dynamic Path to a Low Carbon Economy

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Achieving the climate objectives set out in the Paris Agreement requires a transition to low-carbon energy and, more generally, the structural transformation of our economies. Studying these changes therefore requires first of all a detailed long-term trajectory of the economies. It is then on the basis of such a reference that the impacts of climate policies, and more generally of any long-term public policy, on the structure of economies can be studied through a counterfactual approach. Then, the question is "How will the implementation of the commitments made in the NDCs transform the EU economies?" To answer this question, we proceed in two steps. First, we construct a long-term trajectory for the global economy up to 2050. Second, we analyse in detail the impacts of a transition to a more sustainable, less greenhouse gas (GHG) intensive economy, in line with the commitments made in the Paris Agreement.

The long-term trajectory is constructed on the basis of the macroeconomic projections of the MaGE model (**?**). This three-factor model (labor, capital and energy) details the working population by education level, age group and gender. It represents a dual process of international convergence of technological levels and energy efficiency. It includes a life cycle determining the level of savings according to the demographic pyramid and a Feldstein-Horioka mechanism determining the international mobility of capital. It consistently projects, for a sample of 170 countries, the GDP, the savings rate, the current account, and the energy efficiency up to 2050. In the following, we use the latest projections, based on up-to-date estimates (2017 is the most recent year available in the data), available in the recently released Econmap 3.1 database (**?**).

These projections are the basis for the long-term trajectory of a dynamic general equilibrium model featuring Global Value Chains and Emissions of GHG. To proceed, we use the MIRAGE-VA model, developed at CEPII. It is a global, dynamic, multi-sectoral and multi-regional model, featuring a detailed representation of energy use. Specifically, as it is standard in energy-oriented models, energy is not considered as an intermediate consumption but directly substitutes with capital in the production function. In addition, energy is subject to independent productivity improvements, specifically calibrated. GHG emissions due to both energy use (carbon dioxide) and production processes (carbon dioxide, methane, nitrous oxide

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and fluorinated gases) are explicitly reported. The model also accounts for trade policies, based on highly disaggregated databases of the equivalents of tariff and non tariff protection, as well as climate policies, in particular cap and trade mechanisms. The model embeds an improved representation of value chains that, coupled to the results on emissions, allows to discuss in details the impacts on GHG leakage through international trade and on GHG footprints.

To build the reference scenario in line with the projections by MaGE 3.1, MIRAGE integrates the current account targets, the investment and savings rates, the participation rates and skills and the GDP trajectories as projected by MaGE. It uses the same series as MaGE for the exogenous variables, i.e.demography from the UN central scenario as well as the international energy prices form the IEA. A first simulation is carried out to reconcile the two models, in which the TFP is considered as an endogenous variable. More precisely, the endogenous variable is the TFP in the manufacturing sector conditional on the agricultural TFP (exogenous) and on a constant difference in TFP between manufacturing and services. Once the TFP trajectory is solved, in the counterfactual simulations, the TFP becomes exogenous again, imposed on MIRAGE, the GDP becoming endogenous.

The long-term trajectory thus constructed, without any policy shocks with respect to the base year of the GTAP 10.1 MRIO (2014), is of interest in itself. It details the state of the world economy to 2050 based on the projections made with Mage. These projections answer the following question: "Given what we know about the functional relationships between observables, what should be the economic trajectory of the different countries, all other things being equal, when their demographics, their education effort, and the price of energy vary at different rates over time?" MIRAGE enriches the information present in the Econmap 3.1 database with sectoral information (trajectories of each sector relative to the others within each economy), with information on GHG emissions, at the sectoral and regional level and information concerning future trade patterns.

The second step of our work is to compare this long-term trajectory with a counterfactual scenario in which the EU and countries actually engaged in abatting their emissions meet their commitments under the Paris Agreement. It would indeed be excessively pessimistic to consider that only the EU is in a position to implement ambitious climate policies, but it would also be particularly optimistic to consider that all the countries that have made commitments under the Paris Agreement will meet them. Nevertheless, this is an important question, as it determines the cost that each country has to bear, given a given climate ambition, as well as, of course, the overall level of emissions. The assumption we make is that only countries that have established a national carbon price in 2020 have proved they are committed. We then consider the most up-to-date version of the commitments made under the Paris Agreement, i.e. the updates to the NDCs made at COP26, which took place in November 2021. We translate all the considered commitments, whether formulated in absolute or in intensity terms or formulated with respect to a business as usual reference, in a relative reduction with respect to 2014, the base year in our simulations. We then apply this reduction linearly from 2014 to the horizon retained in NDCs. If this horizon occurs before 2040, which is the case for the majority of the commitments considered, we keep the commitment unchanged until 2040. Technically speaking, the commitments translate in a yearly cap on GHG emissions, imposed to each committed region of our regional aggregation, and the model then endogenously adjusts the level of a tax on GHGs to meet this target. In other words, we consider here that countries fulfill their commitments based on a cap-and-trade system, while they are actually free to choose the policy instruments they prefer. Lastly as far ar the implementation of climate policies is concerned, the EU carbon market deserves a special consideration. The EU put in place the European Trading Scheme in 2005. In order to reach the target of -55% of economy-wide emissions by 2030 set in the EU new NDCs, we consider two carbon taxes in the EU: one specific to the ETS, and one that applies to all other sectors and to final consumers. The cap imposed to the emissions of the sectors covered by the ETS is the one proposed by the Commission in July 2021, i.e. 61% in 2030 with respect to 2005. The level of the tax supported by sectors not covered by the ETS and on households is set to achieve the Paris target, conditional on the reductions undertaken in the ETS sectors. Unless otherwise specified, emission data are taken from the GTAP-E database and the satellite data on non-CO_2 emissions provided by GTAP.

The paper provides detailed results about the following outcomes: (i) the level of the carbon taxation required to meet the targets as set in the most recent NDCs, (ii) the size of the demand and investment displacement towards the sectors that emit less, (iii) the change in the energy mix required to achieve the target emission reductions, (iv) the size and direction of leakages caused by the presence of large free riders and (v) a quantification of the changes in comparative advantages across countries and the resulting impacts on trade.