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5/2015

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SEEDS Working Paper 5/2015
March 2015
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An analysis of the sensitivity of a dynamic climate-economy CGE model (GDynE) to empirically estimated energy-related elasticity parameters

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Abstract

A dynamic energy-economic CGE model is used to analyse how sensitive simulation results are to alternative values assumed by several types of elasticity of substitution. Substitutability in the energy mix is analysed by taking into account the nest structure of the CGE model in the energy module. Input substitutability in the production function is tested for the relationship between capital and energy in different manufacturing sectors. The simulation exercise reveals that the model produces highly differentiated results when different sets of elasticity parameters are adopted. A reduction in the flexibility of energy substitution possibilities makes abatement efforts more expensive at the general level. Moreover, this restriction generates changes in the distribution of costs associated with abatement efforts across regions. The direct implication derived from this work is that in order to use CGE forecasting models to predict the costs and feasibility of climate policies, they must be integrated with empirically estimated behavioural parameters at the highest possible disaggregation level.

Keywords: sensitivity analysis; CGE model; elasticity of substitution; climate policy

J.E.L. codes: C68; D58; L60; Q47; Q54

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1. Introduction

The impact of climate mitigation policies on economic activity is a longstanding controversial issue still highly debated by the international literature. Given the global scope of climate policies in an open economy, a crucial aspect to carefully account for is the regional distribution of mitigation costs. These concerns justify the assessment of climate change costs by applying several model types which differ in purpose and perspective, such as, for instance, addressing a short or long term time horizon or focusing on a single country or a global analysis of unilateral or coordinated measures.

Computable General Equilibrium (CGE) models are particularly suitable for analysing the effect of low-carbon policies since they can capture differences between regulated and unregulated countries in terms of competitiveness through trade channels, but also through investment dynamics in the long term. However, these models need to be improved and validated with detailed information on behavioural parameters on the technology and energy sides in order to produce more reliable results . As far as CGE models are concerned, this kind of information is mainly represented by elasticity values which regulate the substitution processes in response to changes in relative prices.

In this regard, we analyse the sensitivity of a dynamic version of the GTAP-E model (GDynE) and test different sets of energy-related elasticity parameters.

The rest of the work is structured as follows. Section 2 provides a literature review of the relevance of sensitivity analysis in applied models to validating results and the reasons why detailed behavioural parameters are crucial to the robustness of simulation results. Section 3 illustrates the GDynE model and describes simulation scenarios. Section 4 reports quantitative results and Section 5 outlines the main conclusions.

2. Literature Review

The impact of policies on economic systems can be analysed by taking advantage of different applied models that can assess how the economy will react to any exogenous shock. Examples of shocks are the imposition or cutting of tariffs on imports, export subsidies, trade liberalisation and the impact of price rises on a particular good or changes in supply for strategic resources such as fossil fuels. There are many examples of simulation of economic scenarios through bottom-up, top-down or integrated assessment models, especially in the fields of international trade, agriculture and land use, and climate change policies. Whatever approach is selected, and depending on the issue under investigation, a particular aspect which must be taken into account is the role of the behavioural parameters that regulate the responsiveness of economic agents and, consequently, the effects of the modelled policy scenarios.

In particular, applied general equilibrium (AGE) or CGE models are an analytical representation of the interconnected exchanges that take place between all the economic agents based on observed data. The advantages of this kind of analysis are that they can evaluate direct as well as indirect costs, spillovers and economic trade-off effects in a multi-region and inter-temporal perspective. A CGE model usually includes a detailed database, in the form of Input-Output (IO) matrices or Social Account Matrices (SAMs), and a set of equations linking variables through behavioural parameters (or elasticities). Different elasticity values strongly determine responses to a given shock, but there are often no empirically estimated values for these elasticities. This is a source of large criticism for CGE models. Accordingly, model validation needs accurate estimations of crucial behavioural parameters.

For this purpose, the sensitivity of CGE models has been tested for instance with regard to the elasticity of substitution between goods and the Armington elasticity, which measures the degree of substitution between domestic and imported goods. Hertel *et al*. (2003) investigate how the elasticity of substitution across multiple foreign supply sources influences the economic impacts of free trade agreements. By using econometric estimations for behavioural parameters that are crucial to trade relationships, they conclude that there is great potential for improving the reliability of results when empirically estimated parameters are adopted. Németh *et al*. (2011) estimate Armington elasticities for seven sectors in the GEM-E3 which is a CGE model on the interactions between economy, energy and environment in Europe. They find significant differences in model results due to the different elasticity values between domestic and imported goods as well as between imported goods from different countries, both in the short and long term. More generally, Hillberry and Hummels (2013) state that the elasticity of substitution is one of the most important parameters in modern trade theory since it captures both the own-price elasticity of demand and the cross-price elasticity of demand by measuring how close goods are in the product space.

In climate change models used for policy modelling, there are two main classes of behavioural parameters: i) the elasticity of substitution between energy (E) and other inputs (I) in the production function, hereafter referred to as σ_{EI}; ii) the elasticity between different types of energy sources (inter-fuel substitution). As far as the former is concerned, it directly affects the costs associated with reduction target policies and represents one of the aspects characterising the technology embodied in the model (the others being, for example, the level of capital accumulation and the rate of technical change). It is crucial because changes in energy prices have a direct effect on supply and demand for energy, but also an indirect one on total output and welfare driven by changes in the intensity of other inputs, but mediated through the magnitude of substitutability between inputs in the production function.

These behavioural parameters represent a component of technology information and regulate how the model responds to exogenous policy shocks. The value of σ_{EI}, in particular, is a measure of technological flexibility related to energy use. More precisely, a lower value for such elasticity corresponds, ceteris paribus, to a higher rigidity in the whole economy and, consequently, to higher abatement costs to be sustained for a given climate mitigation policy (Golub, 2013).

Empirical studies analysing elasticity of substitution in the production function generally take into account three or four inputs, thus distinguishing KLE and KLEM models (where K, L, E, M refer to capital, labour, energy and materials, respectively). The functional form usually adopted in a CGE model corresponds to a

Constant Elasticity of Substitution (CES) function. This means that, according to the separability conditions specifically assumed, in order to respect the specific nesting structure adopted by the CGE model, differences in the aggregation of inputs should be carefully detected since they can strongly influence the magnitude of substitution elasticities (Kemfert, 1998). Based on the GDynE structure, in this work we consider elasticity values empirically derived from CES or Translog functions, bearing in mind that the Translog is a second-order Taylor approximation of a CES.

In particular, GDynE is structured as a KLEM model, taking E and K as separable from L and M. Accordingly, the main relation where energy is involved is symmetric substitutability with capital stock. Thus, the value assumed by the elasticity of substitution between energy and capital (σ_{KE}) has a crucial role in shaping abatement costs when low-carbon policies are assessed.

The relevance of values adopted for σ_{KE} in GTAP-related models has been only partially addressed by scientific contributions. Beckman *et al*. (2011) note that values for energy substitution and demand elasticity parameters are too high in the static GTAP-E model and suggest replacing them with more reliable econometrically specified values available in the recent literature.[1]

In many cases, elasticity parameters have proved to be crucial when studying energy policies, especially with regard to carbon leakage effects (Antimiani *et al*., 2013b; Burniaux and Martin, 2012; Kuik and Hofkes, 2010), abatement costs (Antimiani *et al*., 2014; Borghesi, 2011; Nijkamp *et al*., 2005), impact of technological progress (Jacoby *et al*., 2004) and the rebound effect (Broadstock *et al*., 2007).

Nonetheless, an accurate analysis on how sensitive CGE results are to alternative σ_{KE} values is still lacking, especially if the CGE model works in a dynamic framework. When capital dynamics in a recursive approach is shaped, the role of capital, and its substitutability with energy, assumes primary importance. In fact, international capital mobility may expand or reduce the shift in trade patterns and ignoring it could seriously understate or overstate the effects of climate policies (Springer, 2002). With regard to this last point in particular, an econometric estimation of σ_{KE} is of particular interest for climate change analysis in the long term, which means that it allows for international capital mobility. In this context, substitutability between the two primary inputs becomes crucial to understanding the possible consequences of energy-related measures on the amount and distribution of abatement costs and, more generally, on economic competitiveness.

Another important issue is the level of aggregation of the analysis. Alexeeva-Talebi *et al*. (2012), for example, analyse the importance of the heterogeneity of selected energy-intensive and trade-exposed sectors for the implementation of border taxes. The economic impacts for distinguished industries can be highly divergent and a low degree of disaggregation at the sector level produces a biased assessment of carbon-related trade measures. Thus, the value added of sector disaggregation is due to a more differentiated representation of production technologies and international trade relationships. This modelling approach requires an improved

[1] In the same vein, Okagawa and Ban (2008) estimate that the carbon price required to satisfy a given abatement target is overestimated by 44% if standard σ_{KE} values are adopted instead of empirical estimates.

empirical foundation of substitution and trade elasticities at a more detailed sector-based level. This could therefore provide a more precise sector distribution of impacts, re-assess leakage rates and the effectiveness of border adjustments, and quantify the aggregation bias. Caron (2012) estimates the size of this bias to be large, with considerable differences between sectors, both in sign and magnitude, and shows that it is mainly related to within-sector heterogeneity and that it is averaged out at a higher level of aggregation. Lacking precise sector-level elasticity estimates will not account for a crucial source of unobserved heterogeneity.

Following uncertainty in the computation of parameter values, there are several examples of sensitivity analysis performed to identify the sources of output variation that adopt different points of view. As a first more general example, Siddig and Grethe (2014) study the mechanisms driving the transmission of international prices to domestic markets in a CGE approach. They formulate several assumptions on the determinants of price transmissions which include Armington, substitution and Constant Elasticity of Transformation (CET) elasticities. When performing a sensitivity analysis, they consider several values for the elasticity parameters and their results show how different values determine higher or lower price transmissions.

As a second and more interestingly contribution, Lecca *et al*. (2011) investigate the impacts on a CGE model due to different nesting structures, according to different separability assumptions in the KLEM function (EM-KL or EK-L). They also consider the impact of changes in the values of substitution elasticities (in the range 0.2 – 1.2) and perform a sensitivity analysis with regard to GDP and total energy use in production. In particular, in the nesting structure EK-L (which is the closest to the structure adopted in the GDynE used here), the σ_{KE} parameter is particularly relevant and is likely to have a high impact on model results, especially with regard to macroeconomic variables.

At the general level, there are several methods of performing a sensitivity analysis and identifying the sources of output variation for different elasticity values. Local (or limited) sensitivity analysis allows the impact that changing one parameter has on the model's output to be assessed, keeping all others fixed, without taking into account interactions with other parameters. The differential sensitivity analysis (or direct method), one-at-a-time measure and sensitivity index are examples of methods of performing sensitivity on single parameters (Hamby, 1994). Global sensitivity analysis, on the other hand, considers all parameters simultaneously and, accounting for the entire parameter distribution, identifies which combination is more likely to affect output variability and what the effect on output is of changes in the value of parameters. These methods use parameters error analysis or random sampling methods to generate input and output distribution such as the Monte Carlo analysis, the Gaussian Quadrature methods, regression (parametric methods) or variance based approaches (Saltelli *et al*., 2008). In some cases, a preliminary screening procedure is applied to identify the key (and non-influential) elasticities among all the parameters defining the model's result, and then sensitivity analysis is performed only on the most relevant such as the elementary effect (Quillet *et al*., 2013) or the Monte Carlo filtering procedure (Mary *et al*., 2013). While local analysis tests the sensitivity of the model to small variations in parameters, global analysis also accounts for parameter interactions, but can become time consuming and computationally expensive as the number of parameters rises (Cariboni *et al*., 2007).

In our analysis, we are interested in a limited number of behavioural parameters, all of which are included in a narrow area of the model (energy and fuel substitutability). There is a long line of research on the estimation of energy-related parameters and their relevance to a model's results. This leads the current work to focus on the impact that empirically estimated energy-related elasticities have on abatement costs.

3. Model

3.1 Model description

The model we adopt here is a combination of the dynamic version of the GTAP (Global Trade Analysis Project) model (GTAP-Dyn) and the static energy version GTAP-E (Burniaux and Truong, 2002; Hertel, 1997;McDougall and Golub, 2007; Golub, 2013; Ianchovichina and McDougall, 2000).

First, this is a top-down model whose main novelty is the introduction of a specific energy module that includes energy data and ad hoc modelling of energy sub-nests in a very detailed multi-region multi-sector model with complex bilateral relationships. Energy demand is explicitly specified and substitution between energy sources appears both in the production and consumption structure. As far as the demand side is concerned, the GTAP-E model separates energy and non-energy composites within a nested-CES function for both private and government consumption (thus admitting substitution between the two groups). Finally, the household demand function is a constant difference in the elasticity (CDE) functional form with substitution elasticity equal to one. The production structure, on the other hand, is characterised by a multistage CES function whose top level includes the value added nest and intermediate inputs. In particular, energy enters the production structure as a good within the energy-capital composite in the value added nest, together with labour and land. At the lower level, the module presents the energy-capital composite and, following the energy commodities line, is separated into electricity and non-electricity groups. The nesting structure continues first dividing the non-electricity sources into coal and non-coal and then dividing the latter into oil, oil products and natural gas. According to this structure, each level is characterised by a different substitution parameter so that the model can distinguish between inter-factor and inter-fuel substitution. This is particularly significant given the importance that these parameters play in determining aggregate output related to changes in energy and fuel prices. In particular, energy-capital substitution affects the impacts of technology on energy efficiency, the level and distribution of carbon emissions and permit prices as well as capital accumulation.

Moreover, the introduction of specific data on carbon dioxide through SAMs allows a detailed representation of CO_2 emissions as consequences of energy consumption at regional level and distinguished from fuel. The model admits the possibility of introducing market-based instruments that can imply changes in the consumption structure such as a carbon tax on CO_2 (with detailed information on the corresponding costs and revenues) and international emission trading among regional blocks.

Given the highlighted characteristics, GDynE is particularly suited for assessing the economic impacts of

CO_2 mitigation policies and offers a detailed representation of the consequences in terms of trade analysis, competitiveness and the distribution of the economic costs of climate change measures. It provides a time path for both CO_2 emissions and global economy and allows the impacts of policies on abatement costs as well as on regional and sector competitiveness to be captured.

The GDynE adopted here uses the last version of the GTAP-Database (GTAP-Database 8.1, updated to 2007), together with the latest version of the additional GTAP-Energy data on CO_2 emissions and the arrays in the standard GTAP-Database 8.1. Some modifications are introduced at the general modelling structure level according to recent contributions to the GDynE modelling approach (Antimiani *et al*., 2013a, 2014). First, updated coefficients have been introduced in order to account for factor productivity growth differentials. In particular, a first coefficient (non-cumulative endowment productivity growth differential) was already introduced in Golub (2013), but only for commodities and regional sets, whereas we also model it for sub-products, endowments and tradables, which represent all the commodities demanded by firms.

Second, we develop a different specification for household saving behaviour in the investment-capital module. In the standard design, a saving rate is given for each region as a fixed proportion of income. Consequently, the net regional foreign position can grow without boundaries, where regions with higher growth rate face an excess in savings and investments and a consequent fall in the rate of return on capital. In the new specification adopted here, the propensity to save is not fixed but the saving rate in each region is endogenously determined as a function of the wealth to income ratio.[2]

3.2 Alternative sets of elasticity of substitution parameters

The first set is given by standard values available from the GTAP Database here named as Case A (first column in Table 1). The second set is derived from an analysis by Koetse *et al.* (2008) on the energy-capital elasticity of substitution values empirically estimated in past contributions (ELFKEN elasticity in GTAP jargon) and by an analysis carried out by Stern (2012) on the inter-fuel elasticity of substitution values (ELFENY, ELFNELY, ELNCOAL in GTAP jargon), synthesised as Case B (second column in Table 1). The third set replicates Case B, where σ_{KE} parameters are sector-specific econometrically estimated values for ten manufacturing sectors provided by Costantini and Paglialunga (2014). The criterion adopted for selecting empirically estimated values is based on the availability of a comparison of different estimation techniques and values. Considering that estimated values for elasticity parameters are strongly volatile, strictly depending on assumptions for the specific empirical strategy, the only way to reduce bias in this sense is the choice of values taken from a careful comparative work. In this sense, values included in Case B derive from two contributions based on a meta-analysis approach (Koetse *et al.,* 2008; Stern, 2012) which allows a large number of different estimated values in past literature to be compared. As far as Case C is concerned, sector-specific σ_{KE} values provided by Costantini

[2] See Appendix A in Golub (2013) for further details.

and Paglialunga (2014) for manufacturing sectors are built as average values from different econometric estimation techniques applied to the same panel dataset and validated by comparing them with already existing values available for selected sectors.

Table 1 - Values of alternative substitution elasticities in energy-related nests

Elasticity	Case A	Case B	Case C
Capital and energy (ELFKEN)			
Food	0.50	0.38	0.45
Textile	0.50	0.38	0.44
Wood	0.50	0.38	0.13
Pulp and paper	0.50	0.38	0.38
Chemicals	0.50	0.38	0.29
Minerals (non-metal)	0.50	0.38	0.44
Basic metals	0.50	0.38	0.24
Machinery eq.	0.50	0.38	0.32
Transport eq.	0.50	0.38	0.28
Other manufacturing	0.50	0.38	0.27
Agric., Electricity, Transport, Services	0.50	0.38	0.38
Coal, Oil, Gas, Oil products	0	0	0
Electricity and non-electricity (ELFENY)	1.00	0.81	0.81
Non-electricity energy sources (ELFNELY)	0.50	0.57	0.57
Non-coal energy sources (ELNCOAL)	1.00	0.41	0.41

3.3 Baseline and policy scenarios

Consistent with existing scenarios, the GDynE in use extends the time horizon to 2050 in order to perform long term analysis of climate change policies in a world-integrated framework. In order to calibrate the baseline, existing scenarios have been compared according to two main criteria defining the scenarios: i) the degree of ambition in terms of stringency of instruments to mitigate climate change; ii) the degree of convergence among countries and regions which represents to what extent countries achieve multilateral agreements.

The baseline scenario corresponds to a Business as Usual (BAU) scenario calibrated with the CO_2 projections provided by alternative international sources.

The World Energy Outlook (WEO) 2013 (IEA, 2013) provides different emission projections according to the state of the art in terms of policy implementation and distinguishes between the Current Policies scenario, the New Policies scenario, and the 450PPM scenario. The Current Policies scenario takes only into account the effects of the policies that had been implemented by mid-2013; the New Policies scenario embodies all policy commitments that have already been adopted as well as those that have been announced and, finally, the 450PPM scenario establishes the goal of limiting the concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO_2 equivalent (ppm CO_2-eq).

The IPCC in the Fifth Assessment Report (IPCC, 2013) describes a set of future emission pathways: the Representative Concentration Pathways (RCPs). They consist of a set of projections on greenhouse gas concentration where radiative forcing by 2100 is an input for climate modelling (van Vuuren *et al*., 2011).[3] The two scenarios we are interested in are the RCP 6.0 that corresponds to a status quo view and the RCP 2.6 which broadly corresponds to a concentration path comparable with the 450PPP scenario.

The projections provided by Global Change Assessment Model (GCAM), which is an integrated assessment tool developed to analyse cost-effective pathways for the transition to a low-carbon economy (Capellán-Pérez *et al*., 2014), include results similar to the WEO 2013 and the IPCC Report. The "Do-nothing" scenario represents low ambition and convergence in climate policies, resulting in CO_2 trends comparable with the Current Policy and RCP 6.0 scenarios. On the opposite, the "Global deal path" scenario represents a path with high ambition and high convergence which corresponds to the 450PPM and RCP 2.6 scenarios.

In this work, we refer to a BAU scenario based on the definition of a Current policies approach where projections for exogenous variables such as GDP, population and labour force are taken from major international organizations. GDP projections are taken from the comparison of the reference case from four main sources: the OECD Long Run Economic Outlook, the GTAP Macro projections, the IIASA projections used for the OECD EnvLink model, and the CEPII macroeconomic projections used in the GINFORS model. Population projections are taken from the UN Statistics (UNDESA). Projections for the labour force are taken from the International Labour Organization (ILO).

In order to calibrate CO_2 emissions in the baseline, we projected macro variables by using the set of elasticity parameters given by Case C. Assuming that econometrically estimated behavioural parameters are more reliable than standard ones, the calibration procedure has been developed on Case C and then applied to Case A and B. This means that we have three baseline scenarios depending on the set of parameters adopted.

The calibration procedure is commonly developed whatever set of parameters is adopted, on the basis of standard steps. First, an autonomous energy efficiency improvement parameter (AEEI) was modelled in the baseline as an exogenously given input augmenting technical change. This is a common parameter in bottom-up energy-technology models (de Beer, 2000). The AEEI is modelled here as an input augmenting technical change with an approximate value corresponding to an increase in energy efficiency per year of 1%. This is an average value within the feasible range indicated by the literature where AEEI estimations vary from 0% to 2% per annum (Grubb *et al*., 1993; IPCC, 2013; Löschel, 2002). Second, projections provided by WEO2013 (IEA, 2013) on fossil fuel availability in terms of reserves are internalised by giving growth constraints to the primary energy commodity supply (coal, oil and natural gas).

Obviously, by applying the same calibration procedure to the same baseline macro projections working on different sets of behavioural parameters, we obtain three baselines that are slightly different in terms of CO_2 pathways. Although this may appear to be a procedure that produces baselines that are not fully comparable, it is

[3] Radiative forcing is a cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter and is defined as the change in the balance between radiation coming into and going out of the atmosphere because of internal changes in the composition of the atmosphere. Thus, positive radiative forcing tends to warm the Earth's surface.

worth mentioning that we need to retain differences in economic behaviours due to different parameters. If different calibration techniques are applied with the aim of achieving exactly the same CO_2 baseline path, we lose the effective mechanisms behind economic relationships, thus invalidating the entire sensitivity analysis.

With regard to the policy scenarios, we simulate the 450PPM scenario for stabilizing concentrations of GHGs to 450 part per million of CO_2 equivalent, helping the global mean temperatures not to exceed 2^{o}C, here considered as an upper bound case with the most challenging (but technically feasible) abatement target developed by international climate models.

In order to ensure that the world will be on track with the 450PPM scenario, we adopt two alternative mitigation policy instruments: a domestic carbon tax (CTAX) and an international emission trading system (IET). In the former, every country or region reduces its own emissions *internally*, and the corresponding carbon tax revenue (CTR) is added to their equivalent variation (EV), resulting in an additional component of domestic welfare, mitigating the costs of abatement efforts.[4]

On the other hand, with international emission trading, all countries can trade allowances to emit and domestic carbon tax levels are all equalised to the permit price. In the IET case we set the same abatement targets as for the CTAX scenario, but the trading option allows the same objective to be reached at lower costs, ensuring a higher level of efficiency. While they are both market-based instruments, the CTAX case represents the upper bound of abatement costs and IET is the cost-effective (or lower bound) option. In the same light of comparability, as previously mentioned, we use the same CO_2 shocks in all three baselines, setting a given quantity of target emissions for each region.

In this case, we assume that all regions participate in international emission trading to achieve the 450PPM goal. This is clearly far from being achieved in the current negotiations. However, an IET where all countries cooperate can be seen as a benchmark in terms of cost effectiveness in achieving abatement targets, while the inclusion of less developed countries in those participating in the carbon market can help analyse the global costs of internationally debated climate change options. The adoption of a global deal allows side effects such as a pollution haven or carbon leakage to be excluded which may complicate or bias the interpretation of the results in terms of sensitivity to alternative elasticity values.

As far as country and sector coverage is concerned, we consider 20 regions and 20 sectors. With regard to the former, we distinguish between Annex I (Canada, European Union, Former Soviet Union, Japan, Korea, Norway, United States, Rest of Annex I) and non-Annex I countries (Brazil, China, India, Indonesia, Mexico, African Energy Exporters, American Energy Exporters, Asian Energy Exporters, Rest of Africa, Rest of America, Rest of Asia and Rest of Europe). The distinction between Annex I and non-Annex I countries derives from the approach adopted by the Kyoto Protocol for defining countries subject to abatement targets (Annex I) and countries excluded (non-Annex I), as the only international binding climate rule in force. In the non-Annex I

[4] In the GDYnE carbon taxation is modelled as a standard lump sum in welfare computation and is built as an ad valorem on energy commodities (thus, when energy efficiency reduces energy prices, the carbon tax level is also lower).

aggregate, we consider single countries (the main emerging economies with strong bargaining positions in the negotiations and eligible to emission cut commitments) as well as aggregates. Finally, considering a geographically-based rule (Africa, America and Asia), we divide both the energy exporter country group and all remaining ones (rest of) into three groups each. It is important to analyse the impact of abatement policies on economies rich in natural resources, but it is also crucial to compare it with the effect on countries in the same area with less resource availability, and across macro regions.

With regard to sector aggregation, we consider 20 industries with a special focus on the manufacturing industry. Manufacturing sub-sectors are: Food, beverages and tobacco; Textile; Wood; Pulp and paper; Chemicals and petrochemicals; Non-metallic minerals; Basic metals; Machinery equipment; Transport equipment; Other manufacturing industries. The other non-manufacturing sectors are: Agriculture, Transport, Services, and Energy commodities (disaggregated in Coal, Oil, Gas, Oil products and Electricity).

4. Results

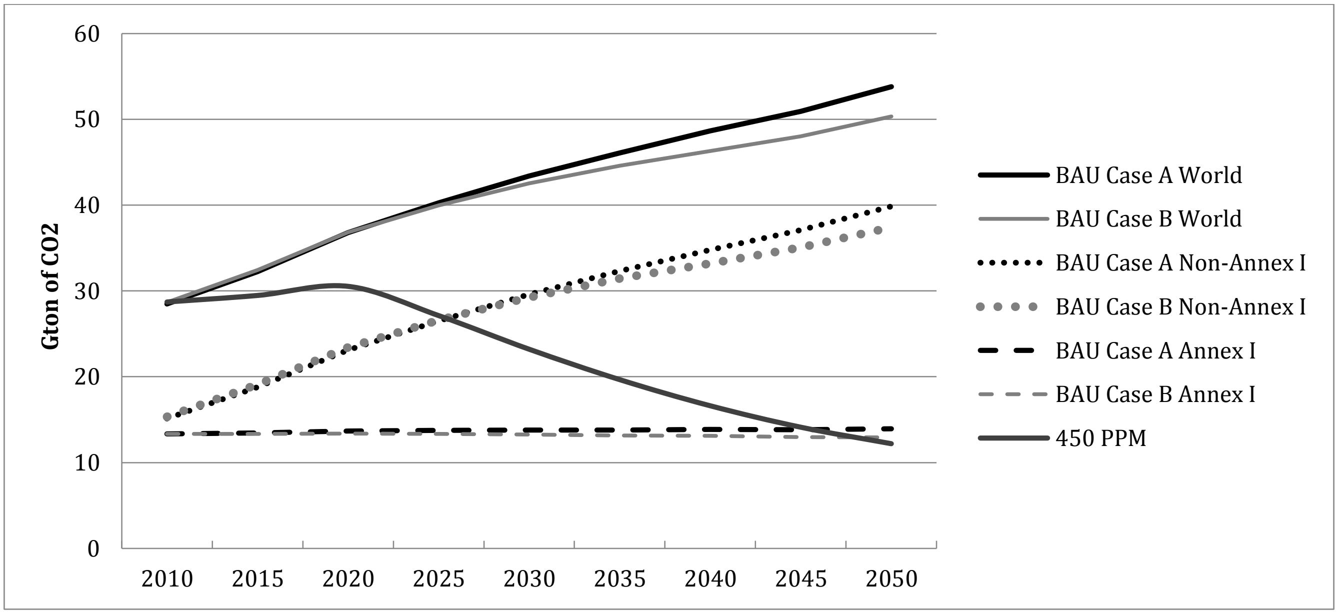
4.1 Comparison between standard and empirically-based elasticity parameters (Case A vs. Case B)

When describing the results, we will do this in two steps: first, we analyse at the aggregated macro level the differences between the model with standard parameters (Case A) and the model with econometrically estimated elasticities from meta analyses presented in Case B. We then focus on the impact of sector-specific σ_{KE} values for the manufacturing industries, looking at the differences between Case B and Case C (Section 4.2).

Figure 1 depicts the trends of CO_2 emission pathways obtained in the two baselines (Case A and Case B), together with the path of global emissions that should be achieved according to the 450 PPM scenario. In both cases, we distinguish between Annex I and non-Annex I countries because, although the parameters assume the same values in all regions, the overall impact is different across countries depending on the internal economic structure. Emissions from baseline A are higher than in case B (there is a gap of 3 Gt CO_2 in 2050), meaning that the introduction of empirically-based behavioural parameters, which are lower than in the standard case, makes the overall system less flexible and the substitution between energy and capital less easy. The gap between Case A and B is mainly due to the difference in emissions from non-Annex I countries. This is partly due to the higher growth rate these regions are characterised by, but is also a clear sign that the parameters sets are country sensitive. In fact, it is also worth noting that, because the elasticities have the same values in all regions and countries, the deviation between case A and B can also be explained by the different impacts that the parameters have on each country given its internal economic structure. In particular, the distinction between Annex I and non-Annex I countries highlights the crucial role played by energy-intensive activities and the fact that changes in inter-fuel and energy-capital elasticities can produce differentiated impacts depending on the internal structure of the country. For example, in the non-Annex I countries, China is responsible for a reduction in CO_2 emissions (in Case B compared with Case A) that is higher than for all the other non-Annex I countries put together.

Moreover, given that the exogenous shock to GDP is the same in both cases (A and B), the differences in energy elasticities generate a different impact on overall regional efficiency and on the consumption of fossil fuels. The endogenously determined factor augmenting technical change is higher in B than in A for all sectors and is particularly high for the fossil fuel sectors.

Figure 1 - CO_2 trends in 450PPM and BAU, Case A vs. Case B



In order to better check for differences derived from alternative behaviours, as a preliminary analysis we control for local sensitivity by distinguishing between the two groups of elasticity, inter-fuel and capital-energy, in order to capture whether one out of the two types of elasticities is more responsible for changes in results. In other words, we test the sensitivity of the model changing only the inter-fuel elasticities (available from Case B), but leaving the energy-capital substitution at the standard level of Case A (we refer to this version as Case A1). Hence, we compare Case A, Case A1 and Case B (Table 2).

In particular, we compare the differences between the CTAX scenarios and their respective BAU. In terms of average carbon tax level, the differences between Case A and Case B are equally explained by the variation in the two types of parameters, meaning that both of them are relevant in explaining differences in abatement costs. Moving on to the differences in terms of GDP and looking at long term variation, we find that the highest losses for non-Annex I and Annex I countries are in Case B and Case A respectively. Interestingly, the associated losses in Case A1 for both regions stand in between these previous cases. This relation is not confirmed only in equivalent variation (EV) given that the welfare losses are higher in Case A1 on a global scale. However, while for non-Annex I countries there are no great differences in the results of the three cases, the main source of change at the world level comes from the introduction of a lower value for the energy-capital elasticity in Annex I. Although the energy-capital parameter assumes the same value in all sectors, it generates impacts of different magnitude among regions, depending on the internal economic structure, and it seems to be highly relevant to the regional distribution of policy impacts. This first result gives rise to the need for further research efforts to be made in finding robust empirical estimations of behavioural parameters at the country level.

Table 2 – Comparison between Cases A, A1 and B applied to CTAX

		2015	2020	2025	2030	2035	2040	2045	2050	Cumulated
		Weighted average Carbon Tax level in CTAX (USD/ton of CO_2)								
Case A	World	11	17	55	109	172	242	362	488	
	Non-Annex I	10	13	40	82	153	232	364	508	
	Annex I	13	23	82	163	211	263	356	438	
Case A1	World	11	17	57	114	182	259	391	530	
	Non-Annex I	10	13	42	86	164	252	398	557	
	Annex I	12	23	85	169	219	275	375	465	
Case B	World	11	17	58	118	191	273	422	570	
	Non-Annex I	11	14	44	92	176	272	439	608	
	Annex I	11	21	84	171	222	277	383	477	
		Differences in GDP between CTAX and BAU (Bln USD)								
Case A	World	-45	-162	-590	-1,563	-3,114	-5,344	-8,417	-12,311	-31,546
	Non-Annex I	-48	-175	-473	-1,055	-2,181	-3,970	-6,583	-10,195	-24,680
	Annex I	3	13	-117	-508	-932	-1,374	-1,834	-2,116	-6,865
Case A1	World	-45	-162	-603	-1,612	-3,245	-5,626	-8,956	-13,230	-33,479
	Non-Annex I	-46	-174	-478	-1,087	-2,298	-4,261	-7,179	-11,245	-26,768
	Annex I	1	11	-125	-526	-947	-1,364	-1,777	-1,985	-6,712
Case B	World	-44	-156	-580	-1,553	-3,140	-5,438	-8,776	-13,172	-32,859
	Non-Annex I	-55	-216	-572	-1,256	-2,600	-4,737	-8,021	-12,673	-30,130
	Annex I	12	60	-8	-296	-540	-700	-755	-499	-2,726
		Differences in EV between CTAX and BAU (Bln USD)								
Case A	World	-117	-193	-1,410	-3,335	-6,000	-9,489	-11,415	-14,930	-46,889
	Non-Annex I	-83	-207	-1,075	-2,328	-4,441	-7,274	-8,772	-11,673	-35,854
	Annex I	-33	14	-335	-1,006	-1,559	-2,215	-2,643	-3,257	-11,035
Case A1	World	-108	-177	-1,414	-3,414	-6,198	-9,919	-12,092	-15,902	-49,225
	Non-Annex I	-77	-199	-1,073	-2,377	-4,594	-7,684	-9,478	-12,741	-38,223
	Annex I	-32	22	-341	-1,037	-1,604	-2,235	-2,614	-3,162	-11,002
Case B	World	-99	-102	-1,249	-2,954	-5,281	-8,212	-9,739	-12,980	-40,616
	Non-Annex I	-78	-206	-1,060	-2,251	-4,311	-7,194	-8,962	-12,449	-36,513
	Annex I	-20	104	-189	-703	-970	-1,017	-777	-531	-4,103

We can now analyse the differences between Case A and Case B considering the effects that different elasticities produce in two alternative policy measures, namely carbon tax and international emissions trading. First, we focus on the average level of domestic carbon tax and the international permit price and notice that in both policy options, the values are higher in Case B than Case A (Table 3). In particular, when referring to the 2050 values, the carbon tax level is 17% higher in B than in A, and there are differences in distribution among regions. Changes in elasticities increase the average carbon tax by almost 20% in non-Annex I countries, whereas in Annex I regions the increase does not even reach half of that value. This aspect can also be highlighted by looking at the differences between regional and world tax level in both cases. In Case A the carbon tax level in Annex I and non-Annex I countries is 10% lower and 4% higher than the global average respectively. Introducing Case B parameters makes these differences even more accentuated (-16% and 7%).

Finally, when comparing domestic carbon tax level and international permit prices, the percentage change at world level remains stable between A and B (-16% and -17%). On the other hand, in Case B the carbon tax in Annex I countries is only 1% higher than the permit price in the IET scenario (7% in Case A), whereas in non-Annex I countries, the corresponding percentage change is 29% (24% in Case A).

Table 3 - Carbon tax level and permit price in 450PPM, Case A vs. Case B (USD/ton CO_2)

		2015	2020	2025	2030	2035	2040	2045	2050
					Weighted average domestic carbon tax (CTAX)				
Case A	World	11	17	55	109	172	242	362	488
	Non-Annex I	10	13	40	82	153	232	364	508
	Annex I	13	23	82	163	211	263	356	438
Case B	World	11	17	58	118	191	273	422	570
	Non-Annex I	11	14	44	92	176	272	439	608
	Annex I	11	21	84	171	222	277	383	477
					International permit price (IET)				
Case A	World	7	11	46	104	170	225	320	410
Case B	World	7	11	48	113	187	249	364	471

In addition to these relative changes, it is worth noting the link between the value of domestic carbon tax (or permit price) and the actual amount of CO_2 emission abated in each 450PPM scenario compared with the BAU case. Considering that the level of emissions in the baseline is higher in Case A and the 450PPM targets are the same irrespective of the elasticity values, although the amount of CO_2 abated in Case B is lower, the costs per ton of emission are higher than in Case A.

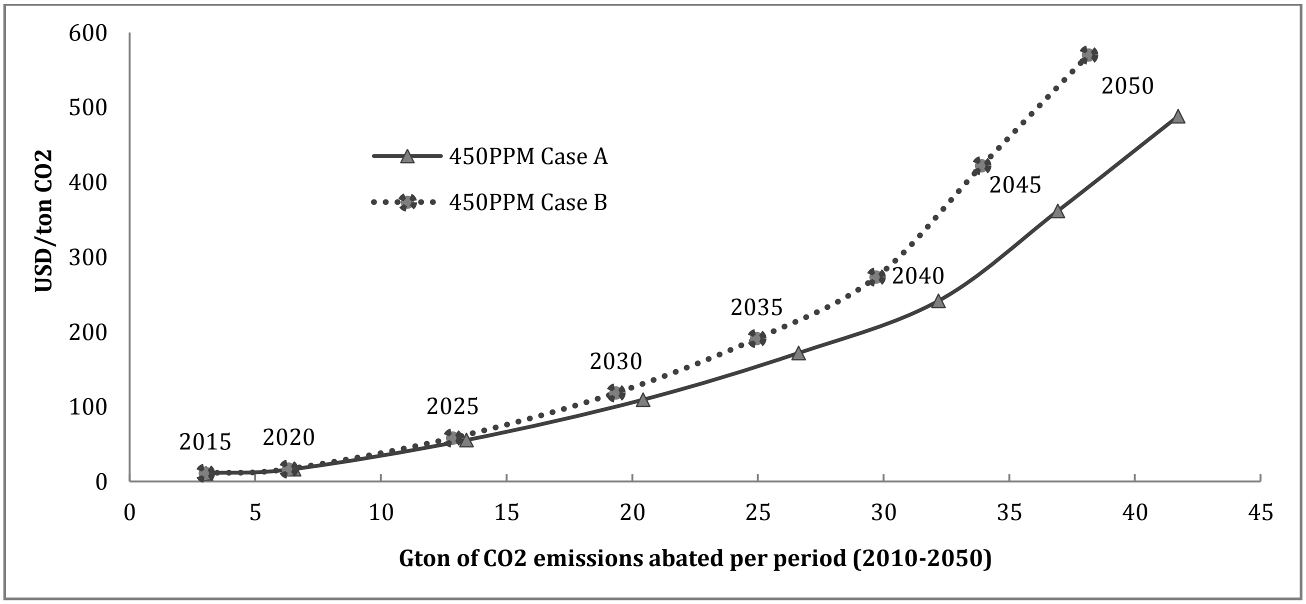
These differences can be explained considering that in Case B, the overall system is less flexible with regard to energy and fuel substitutability which implies that every additional reduction of energy consumption needs to be compensated with a higher amount in capital investment. Thus, the achievement of a particular emission target, irrespective of the emission level, is more expensive given the increased rigidity in Case B, and this is confirmed by the marginal abatement cost (MAC) curves derived from different IET simulations (Figure 2).

The effect of the different elasticity parameters is also coherent with the results from the CTAX case in IET scenarios (see Table 4). The cumulated number of transactions in the emission trading system is higher in B than in A, meaning that the increased rigidity in energy substitution possibilities makes emission reduction within production processes more expensive and thus results in higher access to the permits market in order to ensure compliance with abatement targets. Looking at regional difference in emission trading revenue, countries such as the EU and the USA, which are net permit buyers, and non-Annex I countries such as India and Energy Exporters, which are net permit sellers, have a gain in Case B. On the other hand, there are regions such as Brazil and China that have a deterioration in their emission trading balance with parameters B.

Moreover, by comparing IET and CTAX, we can also look at the differences in terms of the contribution to allocative efficiency of the two policy options together with the differences in EV as a welfare measure (Table

5). As expected, the contribution to allocative efficiency is higher in emission trading, in both Cases A and B,[5] denoting that in a partial equilibrium perspective, IET is the most cost-effective solution among the available mitigation policies. However, considering the general equilibrium effects at the cumulate level, as indicated by the EV differences, only non-Annex I countries have net gains from emission trading policy, whereas at the world level, the negative effect experienced by Annex I countries prevails resulting in a net loss and the gap increases with Case B.

Figure 2 – Marginal Abatement Cost curves at the world level in IET scenario, Case A vs. Case B



Considering only non-Annex I countries, in 2025 and 2030, the contribution to allocative efficiency is higher in the CTAX case, (the differences are negative) and this is due to the increasing stringency in the abatement targets (especially for China and India). Nonetheless, the emission trading is still more cost effective at the global level than the carbon tax measure. Considering the entire time period up to 2050, an emission trading scenario seems to induce a strong restructuring of economic processes that starts immediately until the abatement target becomes binding. On the other hand, in the CTAX case, losses in allocative efficiency due to the reallocation of production factors are lower during the initial periods, but determine higher losses in the long term.

[5] This is also coherent with differences in GDP given that losses in emission trading are lower than in a domestic carbon tax case, in both cases A and B (see Table A.7 in Appendix).

Table 4 – Emission Trading Balance in IET scenario, Case A vs. Case B (Mln USD)

	2015	2020	2025	2030	2035	2040	2045	2050	Cumulated
					Emissions trading balance Case A				
EU	-470	-2,164	-17,266	-53,835	-90,993	-105,654	-120,742	-119,290	-510,414
USA	-54	-451	-12,169	-47,581	-70,219	-65,489	-66,672	-64,161	-326,797
FSU	-16	207	1,924	11,046	32,675	63,421	106,997	140,941	357,195
Other Annex I	-755	-2,978	-16,911	-42,242	-65,941	-73,047	-78,907	-71,848	-352,630
Brazil	-67	-231	-1,864	-4,698	-3,516	2,068	10,955	24,078	26,726
China	2,275	9,256	58,283	134,053	143,988	57,152	-68,341	-219,115	117,552
India	1,062	4,544	29,184	73,806	123,184	159,025	203,418	222,416	816,641
Energy Exporters	-1,072	-4,399	-19,878	-23,054	2,172	53,859	134,739	227,301	369,668
Other non-Annex I	-902	-3,785	-21,304	-47,494	-71,350	-91,335	-121,447	-140,322	-497,938
No. of transactions	3,337	14,008	89,392	218,906	302,019	335,525	456,109	614,737	2,034,031
					Emissions trading balance Case B				
EU	-296	-1,309	-12,753	-45,717	-81,700	-95,825	-111,801	-109,978	-459,379
USA	148	601	-6,940	-39,547	-59,663	-51,313	-48,932	-43,039	-248,686
FSU	-8	165	1,367	11,700	38,457	75,583	132,008	175,362	434,634
Other Annex I	-737	-2,898	-17,346	-43,685	-67,665	-72,251	-76,641	-66,934	-348,157
Brazil	-99	-357	-2,808	-6,944	-6,260	-73	9,701	24,253	17,412
China	2,033	8,125	54,330	127,270	126,709	17,474	-148,689	-347,717	-160,464
India	1,150	4,765	31,518	80,355	134,282	171,765	225,707	249,046	898,589
Energy Exporters	-1,163	-4,823	-22,424	-27,276	-659	57,854	155,537	272,064	429,111
Other non-Annex I	-1,028	-4,270	-24,943	-56,157	-83,502	-103,215	-136,891	-153,058	-563,065
No. of transactions	3,331	13,656	87,215	219,326	299,449	322,677	522,954	720,725	2,189,333

Focusing on emission trading scenarios, in Table 6 we highlight the results and analyse the differences generated by the elasticity changes in Case B compared with Case A in terms of GDP, looking at the deviation between the policy and baseline results. At the world level, GDP losses in IET scenarios compared with the BAU level are quite similar in both Cases A and B. However, there are specular differences across regions, and the introduction of Case B parameters generates higher losses in non-Annex I countries that are compensated by gains in Annex I regions. In fact, while in non-Annex I countries the GDP losses are higher in B and increasingly over time, for Annex I countries results go in the opposite direction. They have GDP gains up to 2030 with Case A, but with Case B the benefits are higher and last up to 2035; from 2040, in both Cases A and B, Annex I countries have GDP losses, even though they are lower in B. Despite the fact that in Case A there is a greater amount of CO_2 emissions to be reduced, the lower overall flexibility in the system associated with parameters B makes the economic impact of the abatement policies greater and also affects the distribution of costs across regions, in this case penalising non-Annex I countries.

However, leaving aside the differences between these two macro regions, the impact of different elasticity values is heterogeneous when also considering single countries. As far as non-Annex I countries are concerned, half of the overall loss is due to the GDP reduction which originated in China and in Case B this effect is even more evident, with an increase in losses in Chinese GDP of 21% in B compared with A, whereas for all other non-Annex I countries the corresponding variation is only 6% (Figure 3).

Table 5 – Comparison in allocative efficiency and EV, Case A vs. Case B (Bln USD)

		2015	2020	2025	2030	2035	2040	2045	2050	Cumulated
					Differences in allocative efficiency between IET and CTAX					
Case A	World	8	20	98	221	171	218	356	532	1,617
	Non-Annex I	4	2	7	30	50	147	317	508	1,064
	Annex I	4	18	91	192	122	70	40	16	553
Case B	World	8	16	83	200	185	264	458	711	1,925
	Non-Annex I	4	2	2	19	81	218	448	703	1,476
	Annex I	3	13	81	182	105	46	10	8	449
					Differences in EV IET and CTAX					
Case A	World	33	-15	227	56	-487	-942	-898	-218	-2,246
	Non-Annex I	13	-78	-60	-384	-573	-370	510	1,732	790
	Annex I	19	63	287	440	86	-573	-1,408	-1,951	-3,036
Case B	World	23	-53	209	52	-496	-970	-907	-32	-2,173
	Non-Annex I	14	-67	-20	-347	-555	-263	842	2,476	2,080
	Annex I	9	14	229	399	60	-707	-1,749	-2,508	-4,253

Table 6 - Differences in GDP between Case A and Case B in IET scenario (Mln USD)

	2015	2020	2025	2030	2035	2040	2045	2050	Cumulated
					Differences in GDP (IET w.r.t. BAU) Case A				
World	-27	-91	-395	-1,212	-2,697	-4,822	-7,609	-10,896	-27,749
Non-Annex I	-42	-166	-541	-1,328	-2,568	-4,215	-6,361	-9,078	-24,299
Annex I	15	75	146	117	-129	-607	-1,249	-1,818	-3,450
					Differences in GDP (IET w.r.t. BAU) Case B				
World	-29	-91	-392	-1,208	-2,706	-4,828	-7,714	-11,196	-28,164
Non-Annex I	-43	-177	-583	-1,455	-2,854	-4,702	-7,210	-10,466	-27,490
Annex I	15	86	191	247	148	-126	-504	-730	-674

Moreover, also within the Annex I regions, differences in GDP losses are quite heterogeneous. The only region that benefits from IET mitigation policy is the EU, which also has an increase in GDP gains in Case B compared to A (Figure 4). On the other hand, both FSU and USA are subject to GDP losses with regard to baseline level but, whereas for the former the introduction of Case B elasticities worsens this loss, USA takes advantage in terms of a lower reduction of GDP with regard to the baseline.

Given that one of the main advantages of Case B is the introduction of econometric based inter-fuel elasticities of substitution, we are now going to analyse the difference in energy mix in terms of world total consumption of energy commodities and highlight the differences between Case A and Case B in emission trading policy.

Considering the structure of the production function, the upper nest describes the substitution between electricity and non-electricity energy sources and the value of the corresponding elasticity parameter (ELFENY) goes from 1 (Case A) to 0.81 (Case B). At the lower aggregation level, coal can be substituted with three other non-electricity fuels (oil, oil products and natural gas) through the non-electricity elasticity of substitution parameters (ELFENELY) which slightly increased from A to B (0.50 and 0.57, respectively). Finally, the non-coal elasticity of substitution (ELFNCOAL), which determine the substitution between oil, oil products and natural gas, drops from the value of 1 in Case A to 0.41 in Case B.

Figure 3 – Differences in Non-Annex I GDP between IET and BAU, Case A vs. Case B (Bln USD)

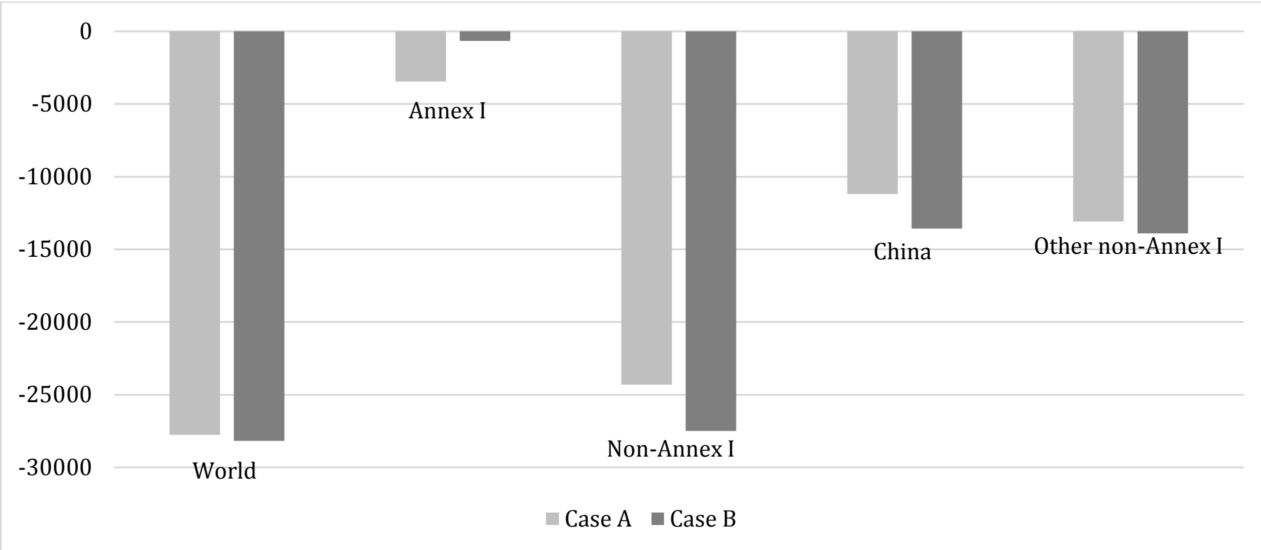
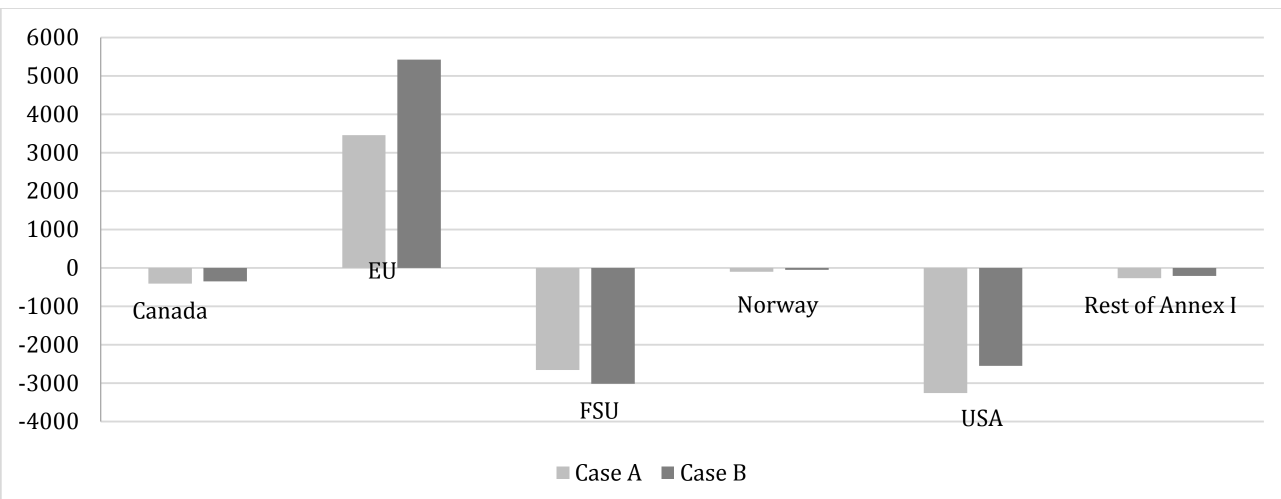


Figure 4 - Differences in Annex I GDP between IET and BAU, Case A vs. Case B (Bln USD)



When introducing less flexible elasticity parameters (Case B), we impose even more stringent boundaries on the model. Therefore, there are differences in the percentage change between 2010 and 2050 in the baselines where the increase (decrease) in energy consumption with Case B is lower (higher) than in Case A (see Table 7). These variations determine changes in regional and sectoral energy demands also in the IET scenario. In particular, the increase in electricity consumption is lower with Case B than with standard parameters (Case A) at the world level, and the effect is particularly evident for non-Annex I countries.

Table 7 – Changes in fuel mix between 2010 and 2050 (Case A vs. Case B)

		Coal	Oil	Natural gas	Oil	Electricity	Total
BAU Case A	World	58%	-16%	57%	115%	181%	75%
	Annex I	-42%	-47%	0%	31%	39%	-1%
	Non-Annex I	107%	21%	137%	217%	361%	153%
IET Case A	World	-79%	-66%	-70%	-21%	93%	-36%
	Annex I	-90%	-76%	-80%	-47%	-20%	-62%
	Non-Annex I	-74%	-53%	-55%	11%	237%	-9%
BAU Case B	World	39%	-19%	50%	107%	155%	63%
	Annex I	-52%	-50%	-6%	24%	28%	-8%
	Non-Annex I	84%	18%	130%	207%	315%	136%
IET Case B	World	-79%	-67%	-68%	-24%	71%	-40%
	Annex I	-90%	-78%	-79%	-52%	-26%	-65%
	Non-Annex I	-73%	-54%	-53%	11%	193%	-14%

Indeed, when looking at the shares of each fuel in the energy mix, we compare the differences (percentage change) of the emission trading scenarios with regard to the baseline in both Cases A and B (see Table 8). Given the abatement constraints and the fact that electricity is the only non-emitting source, its share increases between the baseline and policy scenario, but in B at a lower rate than in A. The increase is more evident in non-Annex I countries than in Annex I, as Table A.8 in the Appendix shows. With regard to the nesting structure, at the lower nest coal is the most carbon-intensive source and, given the abatement target, is substituted by other non-coal energy sources. At the lowest level, we reduce the substitution elasticity from a value of 1 to 0.41, making the system much less flexible than in standard parameters (Case A). We note an increase in the consumption of oil, driven by an increasing demand for oil products, which is mainly due to a growing demand especially in non-Annex I countries (see Table A.7), whereas for natural gas there is a (residual) lower demand (although it is the less carbon-intensive energy source).

Table 8 – Differences in fuel mix shares between IET and BAU, Case A vs. Case B

	2015	2020	2025	2030	2035	2040	2045	2050
	Difference in shares of the energy mix IET w.r.t. BAU Case A							
Coal	-12%	-22%	-38%	-50%	-56%	-60%	-62%	-64%
Oil	5%	9%	19%	26%	27%	23%	17%	10%
Natural Gas	1%	0%	-6%	-16%	-24%	-33%	-41%	-48%
Oil Products	5%	9%	18%	24%	23%	16%	9%	0%
Electricity	3%	6%	12%	20%	32%	50%	68%	87%
	Difference in shares of the energy mix IET w.r.t. BAU Case B							
Coal	-12%	-21%	-37%	-48%	-54%	-56%	-58%	-58%
Oil	5%	9%	18%	25%	25%	20%	15%	9%
Natural Gas	1%	1%	-5%	-13%	-21%	-29%	-36%	-43%
Oil Products	4%	9%	17%	22%	21%	14%	7%	0%
Electricity	3%	6%	11%	19%	30%	47%	63%	81%

4.2 Comparison in model results between economy-wide and sector-specific elasticity parameters

We now focus on the differences in model results when introducing sector-specific values for σ_{KE} (comparing Case B with Case C). Climate change mitigation policies induce a reduction in energy consumption. The costs of achieving a reduction in energy intensity are strongly influenced by the flexibility of each sector in substituting energy with other inputs. Therefore, by using specific σ_{KE} values, the distribution of mitigation costs may vary substantially across different sectors.

First, we report in Table A.9 in the Appendix the carbon intensity of manufacturing sectors which are those where σ_{KE}values have changed from B to C. In particular, we specify the 2010 carbon intensity (which is common to every scenarios) together with the 2050 level, and distinguish between Case B and Case C, as well as between IET and BAU scenarios.

Results from BAU show that the most carbon-intensive sectors are the Non-metallic minerals, Basic metals, Chemicals and Paper industries, but also have the most significant differences between the two regions considered in this analysis (Annex I and non-Annex I). Given that the abatement targets are the same in both Cases B and C, results from policy scenarios are more homogeneous and we can focus on the specific differences induced by the different elasticity sets by looking at the percentage changes between the results from IET and BAU scenarios in 2050. In this case, at the world level the reduction in carbon intensity with Case C values is higher (lower) for all sectors where σ_{KE} has increased (decreased) compared with Case B. The greatest reductions in carbon intensity are in the Food and Textile sectors, with a quite homogeneous difference across regions. On the other hand, there are significant positive changes in the Wood and Other manufacturing sectors, mainly for Annex I countries, and in the Basic metals sector, especially in non-Annex I regions.

It is worth mentioning that in the Paper sector, whose σ_{KE} has the same value in B and C, we note a negative difference for non-Annex I countries and at the world level, while in the Annex I region, the difference is almost zero. Moreover, it is interesting to look at changes in Chemicals sector: there is a negative change in Annex I region (-0.17) and a positive one for non-Annex I countries (1.16), resulting in a positive variation at the world aggregate level. In this case, it is clear how differences in flexibility in energy use may generate different impacts depending on the internal economic structure. In fact, if we look at the whole manufacturing sector, in Annex I countries we found a negative change (-0.45) whereas the same relation in non-Annex I countries highlights a positive difference (0.43). This leads to the fact that, although the changes in parameters are the same for all countries, there are regional differences and the reduction in carbon intensity has been relatively greater for Annex I economies with Case C, while the opposite holds for non-Annex I countries. Thus, at the aggregate level, in the sectors where the σ_{KE} parameters in C are higher than in B (meaning greater technological flexibility), the carbon intensity is always lower than in corresponding sectors with Case B. However, at a more disaggregated regional level, an increase in substitutability is not necessarily linked to a reduction in carbon intensity and a different distribution of abatement costs occurs.

Table 9 shows the differences in output compared with the differences in the σ_{KE}value as a ratio between the percentage change in CO_2 intensity between Case C and B (at 2050 for IET scenario) and the percentage change in σ_{KE}. As a first general remark, at the world level, in each sector where σ_{KE} has increased in Case C w.r.t. Case B, the relative CO_2 intensity is lower, while the same conclusion does not hold for sectors where elasticity has decreased. This means that changes in carbon intensity are not predictable with regard to changes in elasticity values, since sector-specific production structure induces different reactivity to behavioural parameters.

As a second result, it is worth mentioning that there are significant differences in region-specific results. Given the same differences in parameter values, the impact on CO_2 intensity is always positive (higher in C than in B) in Annex I countries and negative in non-Annex I ones.

The sector-specific σ_{KE} values generate changes in the level of the domestic manufacturing output differentiated by regions. In this case, we look at the baseline results because the changes between Case B and Case C already influence the value of the sectoral output in the BAU scenarios and explain most of the differences in the policy cases.

Figures 5 and 6 represent the differences between the values of output (Case C vs. Case B) in BAU for Annex I and non-Annex I regions, respectively. It is worth noting that in the long term the variations for Annex I countries are lower in magnitude (and begin only after 2030) than those in the other group. Moreover, there are interesting differences concerning which sectors have increased (or decreased) the production level in the two regions.

Table 9 – Differences in carbon intensity w.r.t. changes in σ_{KE}, Case C vs. Case B

	(1) % change CO_2 intensity (Emission trading			(2) % change	(1) / (2)		
	World	Annex I	Non-Annex I		World	Annex I	Non-Annex I
Food	-1.44	3.83	-3.52	18.4	-0.08	0.21	-0.19
Textile	-1.35	3.05	-2.53	15.8	-0.09	0.19	-0.16
Non-metallic minerals	-3.53	0.72	-4.24	15.8	-0.22	0.05	-0.27
Wood	-0.85	-15.01	11.32	-65.8	0.01	0.23	-0.17
Paper	-0.09	0.00	-0.14	0.0			
Chemicals	-0.59	-6.10	1.83	-23.7	0.03	0.26	-0.08
Basic metals	4.00	-2.72	4.69	-36.8	-0.11	0.07	-0.13
Transport eq.	2.67	-5.87	4.33	-26.3	-0.10	0.22	-0.16
Machinery eq.	2.81	-3.69	3.27	-15.8	-0.18	0.23	-0.21
Other manuf.	2.33	-0.97	2.79	-28.9	-0.08	0.03	-0.10

When introducing sector-specific elasticities, in Annex I countries the two sectors showing the highest increase are Machinery equipment and Transport equipment. On the other hand, in the non-Annex I region, the two sectors showing the most significant increases in the value of output (Case C w.r.t. Case B) are Basic metals and Chemical industries, which are also characterised by the greatest differences in the percentage change in prices (Table 10). Furthermore, for both country groups, the same sectors have also the highest percentage change in the IET scenario w.r.t. Case B (Table A.10 in Appendix). These results are coherent with development patterns where non-Annex I countries modify their economic structures promoting energy-intensive industries, while in more advanced regions there is an increase in more technology-reliant industrial activities.

Figure 5 – Differences in output in BAU for Annex I countries, Case C vs. Case B

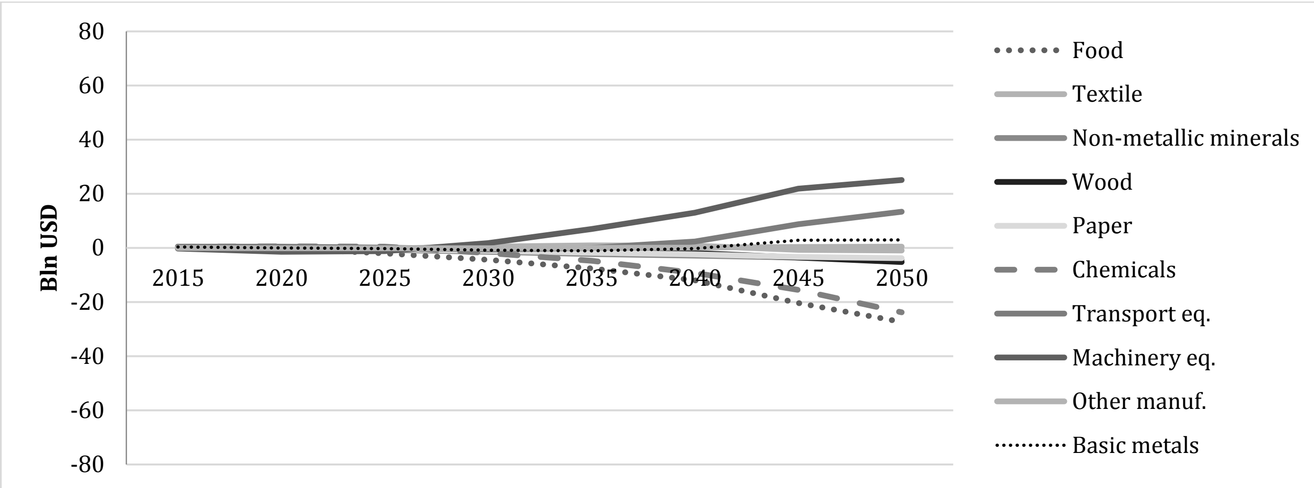


Figure 6 – Differences in output in BAU for non-Annex I countries, Case C vs. Case B

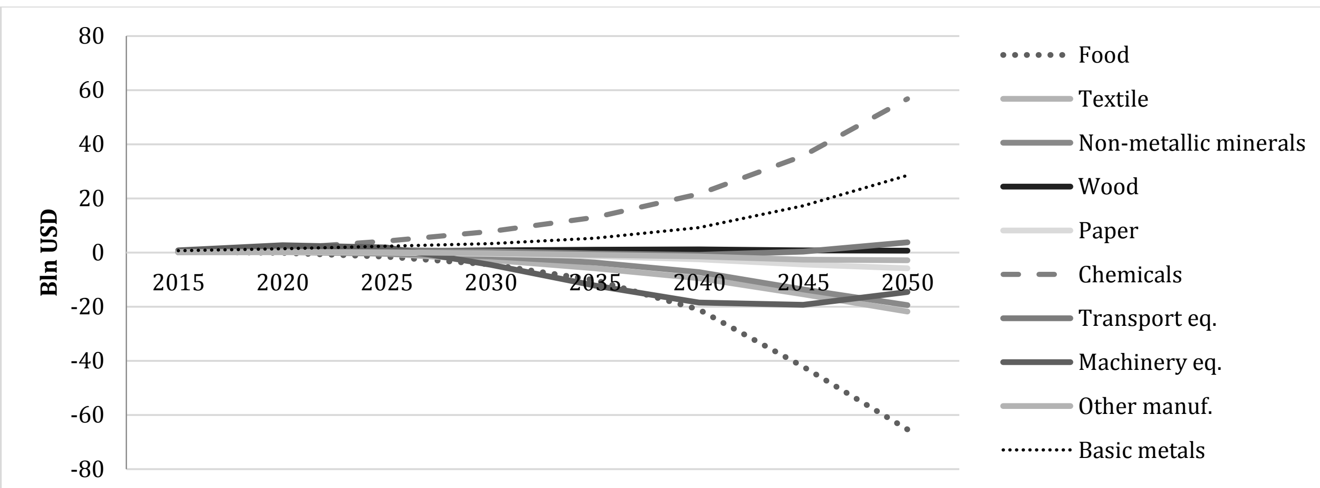


Table 10 – Differences in price changes in BAU, Case C vs. Case B (2050)

	Case B (% change)*		Case C (% change)*		Diff. Case C – Case B	
	Annex I	Non-Annex I	Annex I	Non-Annex I	Annex I	Non-Annex I
Food	9.89	8.44	9.84	8.37	-0.05	-0.07
Textile	3.10	4.13	3.07	4.09	-0.02	-0.04
Non-metallic minerals	-0.02	1.45	-0.08	1.39	-0.06	-0.06
Wood	7.37	7.96	7.41	7.94	0.04	-0.02
Paper	2.90	1.74	2.93	1.74	0.03	0.00
Basic metals	-4.17	-0.53	-3.99	-0.42	0.19	0.11
Chemicals	-2.94	-2.93	-2.74	-2.75	0.20	0.18
Transport eq.	0.90	-0.41	0.94	-0.34	0.04	0.07
Machinery eq.	0.89	-0.43	0.93	-0.38	0.04	0.05
Other manuf.	3.42	1.58	3.46	1.65	0.05	0.07

*Note: * The % changes are expressed in relation to the 2045 level.*

Furthermore, when considering a mitigation policy scenario such as IET, there is still high variability between the two macro-regions especially in the selected sectors shown in Figure 7 (Basic metals and Chemical industries, but also less energy-intensive ones). In non-Annex I countries, the two sectors whose values of output have the most relevant increase (Case C vs. Case B), are still Basic metals and Chemicals. On the other hand, the only two sectors where the Annex I region experiences an increase in the output value are Machinery and Transport equipment. Chemicals, Basic metals and Machinery equipment are also sectors where the changes in elasticity parameters (Case C vs. Case B) produce the greatest variation in terms of carbon intensity between non-Annex I and Annex I countries with regard to the global result.

It is also worth mentioning that the results in terms of value of export (Figure 8) for energy-intensive sectors, especially Chemicals and Basic metals, are reasonably in line with those on output, whereas there are greater differences for the other sectors due to trade dynamics.

Figure 7 – Differences in output in IET (cumulated 2010-2050), Case C vs. Case B

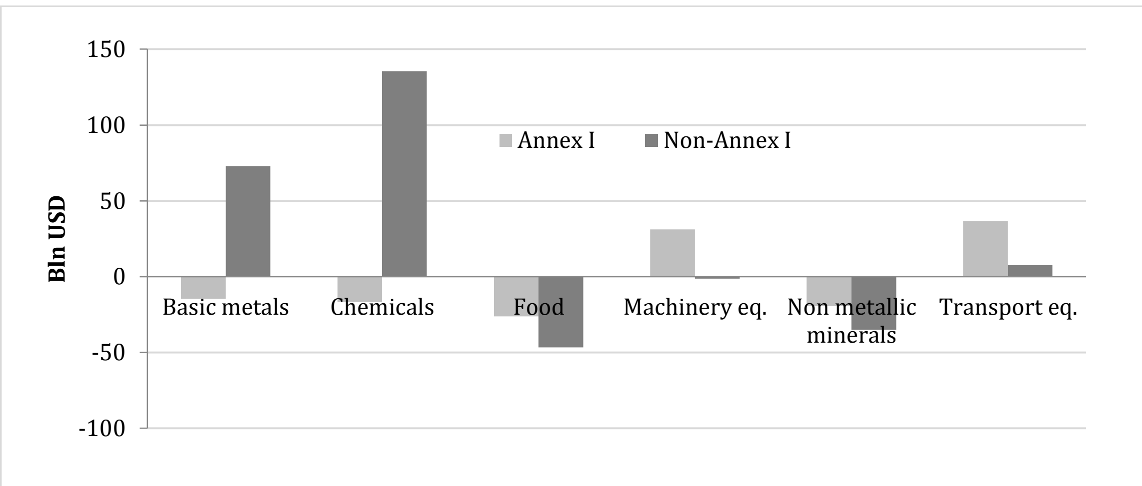
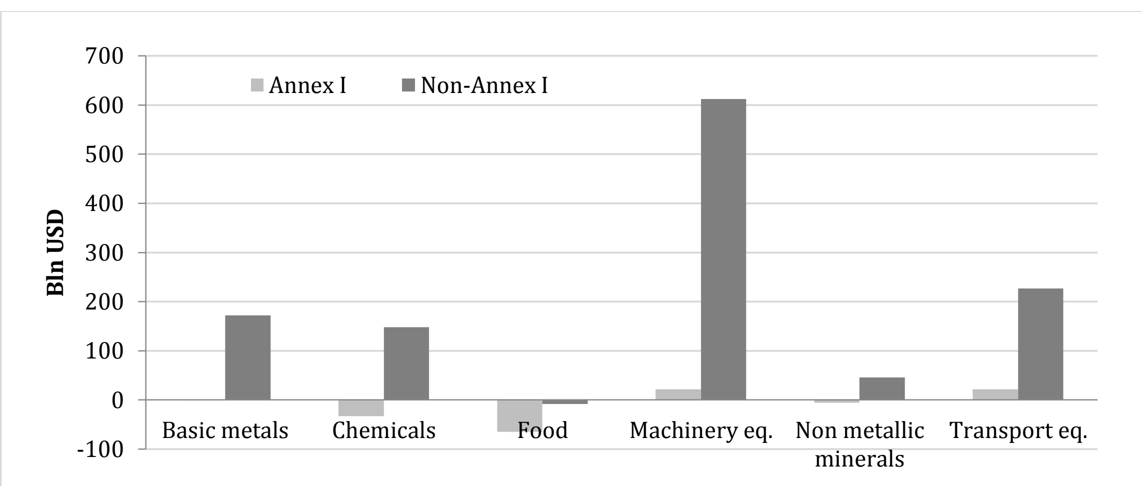


Figure 8 – Differences in export flows in IET (cumulated 2010-2050),Case C vs. Case B



5. Conclusion

The aim of this work was to analyse the sensitivity of the energy version of the GDynE, a dynamic CGE model that specifically accounts for economic and energy data, where we introduced sector-specific and econometrically estimated values for the elasticity of substitution between capital and energy and between fuels. Although this type of model is notably appropriate for addressing the economic impacts of climate mitigation policies, it also needs detailed, reliable information on technology, energy and emissions linkages in order to improve and validate results. We focused on two classes of behavioural parameters: the elasticity of substitution between energy and capital and between different types of energy sources (inter-fuel substitution).

We considered three different sets of elasticity parameters: Case A, including standard values available from the GTAP Database; Case B, including elasticity parameters derived from empirically estimated values elaborated by a meta-analysis approach; Case C, including the same values adopted for Case B where σ_{KE} parameters are sector-specific econometrically estimated values.

We made comparisons between baselines and two alternative mitigation policies, a domestic carbon tax and an international emission trading system, and allowed the target of limiting the concentration of GHGs in the atmosphere to around 450 PPM of CO_2 equivalent by 2050 to be reached.

When analysing the sensitivity of the model, we accounted for the impacts of changes in substitution elasticities on abatement costs, the distribution of the effects among countries and sectors and the cost effectiveness of the different policy measures.

First, the two types of parameters are both responsible for the variation in results and the different distribution of impacts. A reduction in the flexibility of energy substitution possibilities makes abatement efforts more expensive. In fact, considering both policy measures, the level of carbon tax and permit price is higher for Case B w.r.t. Case A and the upward shift of the MAC curves confirms that, irrespective of the emissions level, the increased rigidity makes the achievement of abatement targets more expensive. The limited possibilities to increase energy consumption, especially for non-Annex I countries, and the consequent changes in fuel mix, justify the greater losses in terms of GDP.

Second, restrictions in substitution possibilities in the energy nests generate changes in the distribution of costs associated with the abatement efforts with regard to the two aggregate regional groups. This finding is confirmed by all the economic impacts analysed such as differences in GDP, allocative efficiency, and welfare levels. With regard to GDP, a restriction in flexibility generates opposite differences across the two regional groups and the higher losses in non-Annex I countries are compensated for by gains in the Annex I regions. Within each group there are also different responses to the same changes in elasticities, as in the case of China and the European Union.

Third, when accounting for the elasticity of substitution between energy and capital differentiated by sector, the model is again sensitive to the introduced changes both considering the climate and economic dimensions. Changes in elasticities have large impacts in terms of distributive effects, given that there are significant differences in carbon intensity and the value of production across sectors and regions. Even if the sector-specific elasticities assume the same values in all countries, the effects between Annex I and non-Annex I regions are rather different. In fact, changes in flexibility in energy use generate different regional impacts and the internal economic structure can intensify the differences induced by the sectoral parameters.

Two main implications follow from this analysis. First, when considering the allocation of abatement targets between different sectors within a country, heterogeneity in the technological flexibilities should also be taken into consideration. Second, it is worth noting that further improvements to this type of model are highly recommended in order to increase the reliability of simulation results. In particular, given the regional differences in reacting to common sector-specific elasticity values, there is a need to empirically estimate all energy-related behavioural parameters at the specific sector and country level with the highest disaggregation compatible with data availability.

Acknowledgements

Financial support from the European Union D.G. Research with Grant Agreement number 283002 to the research project "Environmental Macro Indicators of Innovation" (EMInInn), the Roma Tre University-INEA-ENEA Consortium, and from the Italian Ministry of Education, University and Research (Scientific Research Program of National Relevance 2010 on "Climate change in the Mediterranean area: scenarios, economic impacts, mitigation policies and technological innovation") is gratefully acknowledged. The usual disclaimer applies.

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Appendix

Table A.1 - List of GDYnE countries

GTAP code	Code	Country	GTAP code	Code	Country	GTAP code	Code	Country
BRA	bra	Brazil	EU27	mlt	Malta	RAM	gtm	Guatemala
CAN	can	Canada	EU27	nld	Netherlands	RAM	hnd	Honduras
CHN	chn	China	EU27	pol	Poland	RAM	nic	Nicaragua
CHN	hkg	Hong Kong	EU27	prt	Portugal	RAM	pan	Panama
EExAf	xcf	Central Africa	EU27	rou	Romania	RAM	pry	Paraguay
EExAf	egy	Egypt	EU27	svk	Slovakia	RAM	per	Peru
EExAf	nga	Nigeria	EU27	svn	Slovenia	RAM	xca	Rest of Central America
EExAf	xnf	Rest of North Africa	EU27	esp	Spain	RAM	xna	Rest of North America
EExAf	zaf	South Africa	EU27	swe	Sweden	RAM	xsm	Rest of South America
EExAf	xac	South Central Africa	EU27	gbr	United Kingdom	RAM	ury	Uruguay
EExAm	arg	Argentina	FSU	blr	Belarus	RAS	arm	Armenia
EExAm	bol	Bolivia	FSU	rus	Russian Federation	RAS	bgd	Bangladesh
EExAm	col	Colombia	IDN	idn	Indonesia	RAS	bhr	Bharain
EExAm	ecu	Ecuador	IND	ind	India	RAS	khm	Cambodia
EExAm	ven	Venezuela	JPN	jpn	Japan	RAS	kgz	Kyrgyztan
EExAs	aze	Azerbaijan	KOR	kor	Korea	RAS	lao	Lao People's Democratic Rep.
EExAs	irn	Iran Islamic Republic of	MEX	mex	Mexico	RAS	mng	Mongolia
EExAs	kaz	Kazakhstan	NOR	nor	Norway	RAS	npl	Nepal
EExAs	kwt	Kuwait	RAF	bwa	Botswana	RAS	xea	Rest of East Asia
EExAs	mys	Malaysia	RAF	cmr	Cameroon	RAS	xoc	Rest of Oceania
EExAs	omn	Oman	RAF	civ	Cote d'Ivoire	RAS	xsa	Rest of South Asia
EExAs	qat	Qatar	RAF	eth	Ethiopia	RAS	xse	Rest of Southeast Asia
EExAs	xsu	Rest of Former Soviet Union	RAF	gha	Ghana	RAS	sgp	Singapore
EExAs	xws	Rest of Western Asia	RAF	ken	Kenya	RAS	lka	Sri Lanka
EExAs	sau	Saudi Arabia	RAF	mdg	Madagascar	RAS	twn	Taiwan
EExAs	are	United Arab Emirates	RAF	mwi	Malawi	RAS	pak	Pakistan
EU27	aut	Austria	RAF	mus	Mauritius	RAS	phl	Philippines
EU27	bel	Belgium	RAF	moz	Mozambique	RAS	tha	Thailand
EU27	bgr	Bulgaria	RAF	nam	Namibia	RAS	vnm	Vietnam
EU27	cyp	Cyprus	RAF	xec	Rest of Eastern Africa	REU	alb	Albania
EU27	cze	Czech Republic	RAF	xsc	Rest of South African Custom	REU	hrv	Croatia
EU27	dnk	Denmark	RAF	xwf	Rest of Western Africa	REU	geo	Georgia
EU27	est	Estonia	RAF	sen	Senegal	REU	xee	Rest of Eastern Europe
EU27	fin	Finland	RAF	tza	Tanzania	REU	xef	Rest of EFTA
EU27	fra	France	RAF	uga	Uganda	REU	xer	Rest of Europe
EU27	deu	Germany	RAF	zmb	Zambia	REU	xtw	Rest of the World
EU27	grc	Greece	RAF	zwe	Zimbabwe	REU	tur	Turkey
EU27	hun	Hungary	RAF	mar	Morocco	REU	ukr	Ukraine
EU27	irl	Ireland	RAF	tun	Tunisia	ROECD	aus	Australia
EU27	ita	Italy	RAM	xcb	Caribbean	ROECD	isr	Israel
EU27	lva	Latvia	RAM	chl	Chile	ROECD	nzl	New Zealand
EU27	ltu	Lithuania	RAM	cri	Costa Rica	ROECD	che	Switzerland
EU27	lux	Luxembourg	RAM	slv	El Salvador	USA	usa	United States of America

Table A.2 - List of GDYnE Regions

GTAP code	Description
CAN	Canada
EU27	European Union
FSU	Former Soviet Union
JPN	Japan
KOR	Korea
NOR	Norway
USA	United States
ROECD	Rest of OECD
BRA	Brazil
CHN	China
IND	India
IDN	Indonesia
MEX	Mexico
EExAf	African Energy Exporters
EExAm	American Energy Exporters
EExAs	Asian Energy Exporters
RAF	Rest of Africa
RAM	Rest of America
RAS	Rest of Asia
REU	Rest of Europe

Table A.3 - List of GDYnE commodities and aggregates

Sector	Code	Products	Sector	Code	Products
agri	pdr	paddy rice	wood	lum	wood products
agri	wht	wheat	paper	ppp	paper products, publishing
agri	gro	cereal grains nec	oil_pcts	p_c	petroleum, coal products
agri	v_f	vegetables, fruit, nuts	chem	crp	chemical, rubber, plastic products
agri	osd	oil seeds	nometal	nmm	mineral products nec
agri	c_b	sugar cane, sugar beet	basicmet	i_s	ferrous metals
agri	pfb	plant-based fibers	basicmet	nfm	metals nec
agri	ocr	crops nec	basicmet	fmp	metal products
agri	ctl	bovine cattle, sheep and goats, horses	transeqp	mvh	motor vehicles and parts
agri	oap	animal products nec	transeqp	otn	transport equipment nec
agri	rmk	raw milk	macheqp	ele	electronic equipment
agri	wol	wool, silk-worm cocoons	macheqp	ome	machinery and equipment nec
agri	frs	forestry	oth_man_ind	omf	manufactures nec
agri	fsh	fishing	electricity	ely	electricity
Coal	coa	coal	gas	gdt	gas manufacture, distribution
Oil	oil	oil	services	wtr	water
Gas	gas	gas	services	cns	construction
nometal	omn	minerals nec	services	trd	trade
food	cmt	bovine cattle, sheep and goat meat products	transport	otp	transport nec
food	omt	meat products	wat_transp	wtp	water transport
food	vol	vegetable oils and fats	air_transp	atp	air transport
food	mil	dairy products	services	cmn	communication
food	pcr	processed rice	services	ofi	financial Oth_Ind_sericesnec
food	sgr	sugar	services	isr	insurance
oth_man_ind	ofd	Oth_Ind_ser products nec	services	obs	business and other services nec
food	b_t	beverages and tobacco products	services	ros	recreational and other services
textile	tex	textiles	services	osg	public admin. and defence, education, health
textile	wap	wearing apparel	services	dwe	ownership of dwellings
textile	lea	leather products			

Table A.4 - List of GDYnE aggregates

Sector	Full description
agri	Agriculture
food	Food
coal	Coal
oil	Oil
gas	Gas
oil_pcts	Petroleum, coal products
electricity	Electricity
text	Textile
nometal	Non-metallic mineral products
wood	Wood
paper	Pulp and paper
chem	Chemical and petrochemical
basicmet	Basic metal
transeqp	Transport equipment
macheqp	Machinery and equipment
oth_man_ind	Other manufacturing industries
transport	Transport
wat_transp	Water Transport
air_transp	Air Transport
services	Services

Table A.5 - Baseline GDP Projections to 2050 (Billion constant USD)

	2010	2015	2020	2025	2030	2035	2040	2045	2050	Growth p.a.
Canada	1,424	1,668	1,893	2,092	2,286	2,493	2,707	2,924	3,145	2.1%
European Union	16,489	18,302	20,051	21,451	22,627	23,714	24,823	25,943	27,080	1.3%
Former Soviet Union	1,344	1,589	1,858	2,105	2,346	2,580	2,782	2,937	3,065	2.2%
Japan	4,186	4,575	4,895	5,173	5,379	5,500	5,546	5,592	5,641	0.8%
Korea	1,100	1,316	1,474	1,595	1,686	1,759	1,817	1,863	1,896	1.4%
Norway	393	427	472	522	572	621	672	728	786	1.8%
United States	13,947	15,868	17,779	19,633	21,548	23,565	25,656	27,799	29,986	2.0%
Rest of OECD	1,646	1,861	2,071	2,267	2,459	2,660	2,872	3,099	3,330	1.8%
Brazil	1,474	1,753	2,077	2,421	2,775	3,137	3,500	3,863	4,223	2.8%
China	4,687	7,157	10,602	15,128	20,630	26,893	33,517	40,130	46,321	6.8%
India	1,482	2,091	2,925	4,068	5,591	7,558	9,996	12,872	16,119	7.0%
Indonesia	498	648	848	1,104	1,421	1,802	2,250	2,769	3,361	5.4%
Mexico	995	1,233	1,478	1,733	1,985	2,219	2,432	2,636	2,830	2.8%
African Energy Exp.	889	1,117	1,408	1,785	2,273	2,902	3,702	4,722	6,039	5.4%
American Energy Exp.	801	942	1,126	1,326	1,542	1,772	2,014	2,266	2,525	3.1%
Asian Energy Exp.	1,723	2,092	2,529	3,026	3,559	4,125	4,708	5,297	5,898	3.3%
Rest of Africa	571	733	953	1239	1627	2102	2692	3400	4271	5.7%
Rest of America	753	912	1,087	1,278	1,489	1,750	2,049	2,380	2,746	3.5%
Rest of Asia	1528	1932	2457	3112	3924	4927	6151	7631	9394	5.1%
Rest of Europe	962	1,152	1,379	1,612	1,842	2,063	2,269	2,459	2,638	2.7%
World	56,893	67,366	79,362	92,669	107,560	124,142	142,154	161,311	181,294	3.1%
Non-Annex I	16,364	21,760	28,869	37,832	48,658	61,250	75,279	90,427	106,366	5.3%
Developed	40,529	45,606	50,493	54,836	58,902	62,892	66,875	70,884	74,928	1.6%

Table A.6 - Baseline CO_2 Projections to 2050 (Gt CO_2)

	2010	2015	2020	2025	2030	2035	2040	2045	2050	% Change 2010-2050
Canada	0.53	0.58	0.65	0.66	0.66	0.66	0.67	0.68	0.70	30.2%
European Union	3.67	3.52	3.31	3.20	3.12	3.01	2.95	2.86	2.83	-22.7%
Former Soviet Union	1.62	1.70	1.75	1.84	1.89	1.96	2.05	2.06	2.09	28.9%
Japan	1.11	1.11	1.10	1.09	1.08	1.05	1.04	1.02	1.01	-8.7%
Korea	0.48	0.51	0.56	0.57	0.56	0.53	0.51	0.50	0.50	4.1%
Norway	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	8.4%
United States	5.36	5.33	5.31	5.29	5.29	5.27	5.27	5.22	5.19	-3.3%
Rest of OECD	0.51	0.54	0.62	0.61	0.59	0.57	0.55	0.53	0.53	2.9%
Brazil	0.35	0.39	0.47	0.52	0.56	0.61	0.65	0.71	0.81	130.9%
China	7.19	9.42	11.58	12.80	13.76	14.33	14.42	14.51	14.78	105.6%
India	1.59	1.93	2.37	3.03	3.62	4.21	4.77	5.28	5.75	261.7%
Indonesia	0.41	0.48	0.54	0.60	0.69	0.75	0.79	0.86	0.95	133.4%
Mexico	0.41	0.41	0.45	0.45	0.45	0.46	0.46	0.47	0.47	15.9%
African Energy Exp.	0.70	0.84	1.04	1.18	1.27	1.39	1.50	1.61	1.76	151.0%
American Energy Exp.	0.41	0.49	0.59	0.67	0.75	0.82	0.88	0.93	0.99	139.9%
Asian Energy Exp.	2.06	2.49	3.07	3.49	3.82	4.13	4.43	4.82	5.28	156.5%
Rest of Africa	0.19	0.20	0.25	0.30	0.36	0.41	0.49	0.58	0.75	300.3%
Rest of America	0.29	0.31	0.38	0.44	0.50	0.50	0.48	0.49	0.52	80.8%
Rest of Asia	1.14	1.45	1.92	2.23	2.49	2.72	3.06	3.44	3.88	240.1%
Rest of Europe	0.63	0.70	0.82	0.87	0.89	0.92	0.96	1.01	1.09	74.0%
World	28.71	32.48	36.84	39.90	42.39	44.38	46.00	47.67	49.95	74.0%
Non-Annex I	15.36	19.13	23.47	26.56	29.14	31.24	32.90	34.72	37.04	141.1%
Developed	13.35	13.35	13.37	13.34	13.25	13.14	13.10	12.95	12.91	-3.3%

Table A.7 – Differences in GDP between IET and CTAX Scenarios, Case A vs. Case B (Mln USD)

	2015	2020	2025	2030	2035	2040	2045	2050
				Differences in GDP in CTAX scenario				
Case A	-45 403	-161 627	-590 205	-1 562 514	-3 113 651	-5 344 093	-8 416 859	-12 310 735
Case B	-43 765	-155 856	-580 107	-1 552 657	-3 140 162	-5 437 626	-8 776 404	-13 171 580
				Differences in GDP in IET scenario				
Case A	-27 041	-91 241	-394 669	-1 211 828	-2 696 710	-4 822 242	-7 609 288	-10 895 958
Case B	-28 631	-91 171	-391 991	-1 207 987	-2 705 902	-4 828 187	-7 713 837	-11 196 250

Table A.8 - Differences in fuels mix in IET w.r.t. BAU, Case A vs. Case B (%)

	2015	2020	2025	2030	2035	2040	2045	2050	Cumulated
	Difference in fuels shares in the energy mix IET w.r.t. BAU (Case A)								
	Annex I countries								
Coal	-9%	-17%	-33%	-45%	-49%	-51%	-52%	-53%	-18%
Oil	2%	4%	10%	15%	17%	17%	16%	16%	13%
Natural gas	-1%	-2%	-8%	-17%	-26%	-34%	-41%	-48%	-12%
Oil products	2%	4%	9%	13%	13%	11%	8%	5%	3%
Electricity	1%	2%	5%	9%	16%	26%	37%	50%	7%
	Non-Annex I countries								
Coal	-12%	-21%	-37%	-49%	-55%	-60%	-63%	-65%	-33%
Oil	7%	13%	25%	34%	32%	25%	17%	7%	26%
Natural gas	2%	1%	-7%	-17%	-26%	-34%	-41%	-47%	-15%
Oil products	7%	13%	25%	31%	28%	18%	8%	-3%	10%
Electricity	4%	8%	17%	27%	42%	63%	83%	103%	30%

	2015	2020	2025	2030	2035	2040	2045	2050	Cumulated
	Difference in fuels shares in the energy mix IET w.r.t. BAU (Case B)								
	Annex I countries								
Coal	-9%	-17%	-34%	-44%	-48%	-48%	-48%	-48%	-16%
Oil	2%	4%	9%	13%	14%	14%	13%	12%	12%
Natural gas	0%	-1%	-5%	-13%	-21%	-28%	-35%	-42%	-10%
Oil products	2%	4%	8%	11%	10%	7%	4%	0%	1%
Electricity	1%	2%	5%	10%	17%	27%	39%	51%	7%
	Non-Annex I countries								
Coal	-12%	-20%	-36%	-47%	-53%	-56%	-58%	-60%	-31%
Oil	7%	13%	25%	32%	31%	23%	16%	6%	24%
Natural gas	2%	1%	-7%	-15%	-23%	-30%	-38%	-44%	-14%
Oil products	7%	12%	24%	29%	27%	17%	9%	-1%	9%
Electricity	4%	8%	16%	25%	38%	57%	75%	93%	26%

Table A.9 – Carbon intensity (Ton/Mln USD, *10,000)

	2010			2050 BAU PAR B			2050 ET PAR B			2050 BAU PAR C			2050 ET PAR C		
	World	Annex I	Non-Annex I	World	Annex I	Non-Annex I	World	Annex I	Non-Annex I	World	Annex I	Non-Annex I	World	Annex I	Non-Annex I
Food	0.62	0.42	0.97	0.13	0.09	0.15	0.04	0.03	0.04	0.14	0.10	0.16	0.04	0.03	0.04
Textile	0.54	0.29	0.74	0.21	0.15	0.23	0.04	0.04	0.04	0.23	0.16	0.25	0.04	0.04	0.04
Non-met. min.	6.65	3.30	10.05	3.98	1.59	4.58	0.53	0.36	0.57	4.18	1.69	4.81	0.51	0.36	0.55
Wood	0.36	0.26	0.61	0.12	0.09	0.14	0.02	0.03	0.02	0.09	0.06	0.11	0.02	0.02	0.02
Paper	1.18	0.80	2.61	0.67	0.33	0.99	0.10	0.08	0.12	0.67	0.33	0.99	0.10	0.08	0.12
Chemical	1.73	1.03	3.09	1.26	0.77	1.54	0.34	0.26	0.40	1.21	0.72	1.49	0.34	0.25	0.40
Basic metals	3.38	1.77	5.39	2.40	0.99	2.64	0.47	0.26	0.51	2.21	0.90	2.43	0.49	0.25	0.53
Transport eq.	0.25	0.13	0.64	0.26	0.07	0.36	0.04	0.02	0.06	0.23	0.06	0.32	0.04	0.02	0.06
Machinery eq.	0.21	0.11	0.40	0.20	0.06	0.22	0.04	0.01	0.05	0.19	0.05	0.21	0.04	0.01	0.05
Other manuf.	0.55	0.16	1.10	0.44	0.09	0.54	0.06	0.03	0.07	0.41	0.08	0.50	0.06	0.03	0.07
Tot. Manuf.	1.20	0.61	2.32	0.72	0.30	0.89	0.15	0.09	0.17	0.71	0.29	0.88	0.15	0.09	0.17
Total	1.50	0.94	2.89	0.60	0.30	0.80	0.21	0.14	0.26	0.59	0.30	0.79	0.15	0.10	0.20

% change 2050 ETS vs. BAU	Case B				Case C				*diff. C-B*			
	World	Annex I	Non-Annex I	ELFKEN	World	Annex I	Non-Annex I	ELFKEN	Diff. ELFKEN	Diff. World	Diff. Annex I	Diff. Non-Annex I
Food	-70%	-67%	-71%	0.38	-73%	-70%	-74%	0.45	0.07	-2.78	-2.88	-2.84
Textile	-81%	-76%	-82%	0.38	-83%	-77%	-84%	0.44	0.06	-1.53	-1.52	-1.53
Non-met. Min.	-87%	-77%	-87%	0.38	-88%	-79%	-89%	0.44	0.06	-1.06	-1.24	-1.07
Wood	-80%	-69%	-84%	0.38	-72%	-57%	-77%	0.13	-0.25	7.84	11.81	7.43
Paper	-85%	-77%	-88%	0.38	-85%	-77%	-88%	0.38	0	-0.03	0.00	-0.04
Chemical	-73%	-66%	-74%	0.38	-72%	-66%	-73%	0.29	-0.09	0.74	-0.17	1.16
Basic metals	-81%	-74%	-81%	0.38	-78%	-72%	-78%	0.24	-0.14	2.53	1.82	2.64
Transport eq.	-84%	-76%	-84%	0.38	-81%	-73%	-81%	0.28	-0.1	2.32	2.26	2.52
Machinery eq.	-80%	-76%	-80%	0.38	-78%	-75%	-78%	0.32	-0.06	1.78	1.06	1.90
Other manuf.	-87%	-64%	-88%	0.38	-85%	-59%	-86%	0.27	-0.11	1.35	5.89	1.28
Tot. manuf.	-80%	-70%	-81%		-80%	-70%	-81%			0.31	-0.45	0.43
Total	-65%	-55%	-67%		-74%	-68%	-75%			-9.20	-12.99	-8.12

Table A.10 – Differences in output between IET scenarios, Case C vs. Case B (%)

	2015	2020	2025	2030	2035	2040	2045	2050
				Annex I countries				
Food	0.00	0.00	-0.04	-0.06	-0.06	-0.06	-0.08	-0.08
Textile	-0.02	-0.05	-0.04	0.00	0.03	0.06	0.10	0.06
Non-metallic minerals	0.00	-0.02	-0.06	-0.11	-0.17	-0.24	-0.27	-0.28
Wood	0.00	0.00	0.00	-0.01	0.01	0.03	0.03	0.05
Paper	0.01	0.00	-0.02	-0.03	-0.02	0.00	0.01	0.05
Basic metals	0.02	0.01	0.00	-0.05	-0.14	-0.26	-0.28	-0.10
Chemical	0.01	0.02	0.03	0.00	-0.03	-0.07	-0.12	-0.12
Transport eq.	0.01	0.02	0.01	0.02	0.04	0.08	0.13	*0.21*
Machinery eq.	0.00	-0.03	-0.03	-0.01	0.02	0.09	0.23	*0.26*
Other manuf.	-0.02	-0.03	-0.02	-0.02	0.01	0.05	0.12	0.17
				Non-Annex I countries				
Food	0.01	0.00	-0.03	-0.05	-0.05	-0.07	-0.10	-0.14
Textile	0.03	0.04	0.00	-0.04	-0.05	-0.04	-0.05	-0.02
Non-metallic minerals	0.01	0.00	-0.03	-0.06	-0.09	-0.12	-0.14	-0.20
Wood	0.02	0.03	0.05	0.06	0.05	0.04	0.04	0.03
Paper	0.02	0.03	0.00	-0.02	-0.02	-0.02	-0.01	0.00
Basic metals	0.04	0.07	0.08	0.11	0.17	0.24	0.25	*0.26*
Chemical	0.04	0.07	0.14	0.22	0.29	0.37	0.45	*0.55*
Transport eq.	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.03
Machinery eq.	0.03	0.07	0.04	0.00	-0.01	-0.02	-0.02	0.00
Other manuf.	0.03	0.05	0.03	0.01	0.01	0.01	0.00	0.02