Probabilistic GHG Emissions Forecasts under Energy Prices Uncertainty

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Abstract.

In this paper we use a multi-country and multi-sector computable general equilibrium (CGE) model to assess the effects of future energy prices uncertainty on global and regional greenhouse gases (GHG) emissions projections by 2015. In the last Annual Energy Outlook of the U.S. Department of Energy (IEA-DOE, 2005), world oil prices are set in an environment where the members of OPEC are assumed to act as the dominant producers, with lower production costs than other supply regions or countries. As explained in the report, the behavior and ability of OPEC member countries to set the price of oil will be influenced by many factors about which there is considerable uncertainty. These factors include the risk of oil supply disruptions, and the forces that will drive world oil demand, such as the rate of economic growth in the developed and developing world and the degree to which oil demand is linked to economic growth. This paper proposes to assess the impact of higher oil prices on GHG emissions. We run two types of simulation. A deterministic scenario in which oil prices are projected to be at \$65 per barrel in 2005, and then rise by 0.6% per year to reach \$74 per barrel in 2015. A stochastic scenario, in which we introduce probability distribution functions for oil prices, and for the indexation of gas prices to oil prices. These PDFs are exogenously set from bottom-up studies and expert thinking. Using a Monte Carlo approach, we obtain probability distribution functions for energy consumption and GHG emissions in the baseline-as-usual scenario by 2015.

keywords:

Oil price, climate change, Kyoto Protocol, general equilibrium modeling.

Contents

1 Introduction

Considering the difficulty of implementing the Kyoto Protocol (e.g. USA and Australia withdrawal) and negotiating a post-Kyoto agreement that would impose commitments for developing countries, one might be tempted to take the current high oil prices as a good news. Indeed, high oil prices will have a beneficial impact on climate change by forcing producers and consumers to change their behaviors. Whatever the future commitments on climate change, greenhouse gases (GHG) emissions might be lower than expected if we are about to enter a new era characterized by the end of cheap oil. As an example, Eberhard Rhein from the European Policy Center, writing in the International Herald Tribune (31 September 2005), said that "*the international community has been laboring for 10 years under the Kyoto Protocol negotiations to agree on a global reduction of energy consumption and carbon dioxide emissions of less than 10 percent by 2012. So the market has achieved within a few months what international bureaucrats - hampered by resistance from key consumer countries like the United States, China, Australia and India - have struggled to obtain in a decade.*" Is this argument valid? What might we really achieve through high oil prices? What are the impacts on GHG emission baselines? Can we count on high oil prices to address the climate change issue and mitigate GHG emissions worldwide? Do we still need to put forward on the building of a post-Kyoto international regime on global climate change? In this paper we use a multi-country and multi-sector computable general equilibrium (CGE) model to assess the effects of future energy prices uncertainty on global and regional greenhouse gases (GHG) emissions projections by 2015.

In section 2, we briefly present the GEMINI-E3 model. In section 3 we present the deterministic scenario. We comment oil price forecasts that are commonly used in CGE model designed for climate change policy analysis. We assess the effects of oil prices on GHG emissions and the economy. In section 4 we present the stochastic scenarios. We present the study used to build the probability distribution functions for oil prices and for indexation of gas price to oil prices. Using a Monte Carlo approach we run 550 simulations and present the probability distribution functions for energy consumption, GHG emissions and welfare effects of the variation of oil prices. The section 5 conclude.

2 The Model

We use a computable general equilibrium (CGE) approach to assess the effects of the present oil price shock on global and regional greenhouse gases (GHG) emissions. We use a dynamic-recursive CGE model, GEMINI-E3. GEMINI-E3 is a multi-country, multi-sector, dynamic General Equilibrium Model incorporating a highly detailed representation of indirect taxation[1]. The version of GEMINI used in this paper is built on a comprehensive energy-economy data set, the GTAP-5 database [17], that expresses a consistent representation of energy markets in physical units as well as a detailed Social Accounting

[1] This version of GEMINI-E3 is formulated as a mixed complementarity problem using GAMS with the PATH solver [15][16].

Matrix (SAM) for a large set of countries or regions and bilateral trade flows. The reference case for the different regions were closely calibrated against projections of CO_2 emissions, energy consumption, GDP, and population, as provided by the Department of Energy [13], the International Energy Agency [18][19], the World Bank and the United Nations.

The original version of GEMINI is fully described in [7][2]. Updated versions of the model have been recently used to analyze the implementation of economic instruments for GHG emissions in a second-best setting [8], to assess the economic impact of the US withdrawal from the Kyoto Protocol [9], to analyze the behavior of Russia in the Kyoto Protocol [5][6], and to assess the EU-wide carbon emission trading market promoted by the European Commission [23].

Table 1 gives an overall description and the main characteristics of the present version of the model. Beside a comprehensive description of indirect taxation, the specificity of the model is to simulate all relevant markets: markets for commodities (through relative prices), for labor (through wages), for domestic and international savings (through rates of interest and exchange rates). Terms of trade, i.e. transfers of real income between countries resulting from variations of relative prices of imports and exports, and then “real” exchange rates, can then be coped with[3].

3 A deterministic scenario of high oil price

3.1 Oil prices Projections

In the last Annual Energy Outlook of the U.S. Department of Energy [12], world oil prices are set in an environment where the members of OPEC are assumed to act as the dominant producers, with lower production costs than other supply regions or countries. Non-OPEC oil producers are assumed to behave competitively, producing as much oil as they can profitability extract at the market price for oil. As a result, the OPEC member countries will be able effectively to set the price of oil when they can act in concert by varying their aggregate production. Alternatively, OPEC members could target a fixed level of production and let the world market determine the price.

As explained in the report, the behavior and ability of OPEC member countries to set the price of oil will be influenced by many factors about which there is considerable uncertainty. These factors include the forces that will drive world oil demand, such as the rate of economic growth in the developed and developing world and the degree to which oil demand is linked to economic growth. The behavior of each major non-OPEC producer, and changes in technologies that use or find and extract oil, will also be important. Each

[2]for a complete description of the model see our web site and the technical document downloadable at : http://www.gemini-e3.net

[3]The real exchange rate between two countries is the relative price of the numraires chosen in each country (and usually based on a basket of goods representative of GDP). It is not identical to the monetary exchange rate of the currencies of the two countries : in particular, the real exchange rate can evolve between countries belonging to a same monetary union.

Table 1: Dimensions of the GEMINI-E3 Model

Countries or Regions		**Sectors**
Annex B		***Energy***
Germany	DEU	01 Coal
France	FRA	02 Crude Oil
United Kingdom	GBR	03 Natural Gas
Italy	ITA	04 Refined Petroleum
Spain	ESP	05 Electricity
Netherlands	NLD	***Non-Energy***
Belgium	BEL	06 Agriculture
Rest of EU-15	OEU	07 Mineral products
Switzerland	CHE	08 Chemical Rubber Plastic
United States	USA	09 Metal and metal products
Japan	JAP	10 Paper Products Publishing
Eastern Europe[a]	CEA	11 Transport n.e.c.
Canada, Australia, and New Zealand	CAZ	12 Sea Transport
Former Soviet Union	FSU	13 Air Transport
Non-Annex B		14 Other Goods and services
China	CHI	
Brazil	BRA	***Household Sector***
India	IND	
Middle East and Turkey	MID	***Primary Factors***
Asia	ASI	Labor
Latin America and Mexico	LAT	Capital
Rest of World[b]	ROW	Energy
		Fixed factor (sector 01-03)
		Other inputs

[a] Includes Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia.
[b] All countries not included elsewhere (mostly Africa).

of these factors will also be influenced by the market strategy that the OPEC members choose for OPEC in the aggregate or for themselves.

In Figure 1 we present historical oil prices from 1900 to 2005, world oil price scenario from the U.S. Department of Energy published in [12], and the alternative high oil price scenario implemented in GEMINI-E3. These oil price projections have been designed to address the uncertainty about the market behavior of OPEC. They are not intended to span the full range of possible outcomes. The DOEs scenarios are defined as follows:

- DOE-Ref: It corresponds to the reference scenario in [12]. Prices in 2010 are projected to be about $10 per barrel lower than current prices (2004 dollars) as both OPEC and non-OPEC producers add new production capacity over the next 5 years. After 2010, oil prices are projected to rise by about 1.3 percent per year, to around $28 per barrel in 2025.

- DOE-low: It is the low world oil price scenario in [12]. Prices are projected to decline from their high in 2004 to $22 per barrel in 2009 (2004 dollars).

- DOE-high A: Prices are projected to remain at about $36 per barrel through 2015.

- DOE-high B: Projected prices continue to increase through 2005 to $46 per barrel, fall to $40 in 2010, and rise to $43 per barrel in 2025.

Two oil price scenarios are implemented in GEMINI-E3:

- DOE-2003: The reference scenario defined in [13] is used as the reference oil price scenario in GEMINI-E3.

- GEMINI-high: Oil prices are projected to be at $65 per barrel in 2005, and then rise by 0.6% per year to reach $74 per barrel in 2015 (2004 dollars). Based on expert panel recommendations, we assume an indexation of gas prices to the price of oil at 0.75 (i.e. the price of gas increases by 7.5% when the oil price increases by 10%). Coal prices are endogenously computed by the model.

3.2 Oil Prices Impacts on GHG Emissions

The original baseline scenario of GEMINI-E3 is calibrated on international sources concerning projections of CO_2 emissions, energy consumption, GDP, and population as provided by the U.S. Department of Energy [13] the International Energy Agency [18, 19], the World Bank database, and the United Nations population division, respectively. Non-CO_2 GHG emission projections and MAC curves per region and sector are from the Energy Modeling Forum 21 (Stanford) [11, 24]. As shown in Figure 2, the increase of oil prices is expected to lower GHG emissions worldwide. Global GHG emissions are expected to rise from 10.1 GtC-equivalent in 2005 to 12.2 GtC-equivalent in 2015 in the low oil prices scenario. These

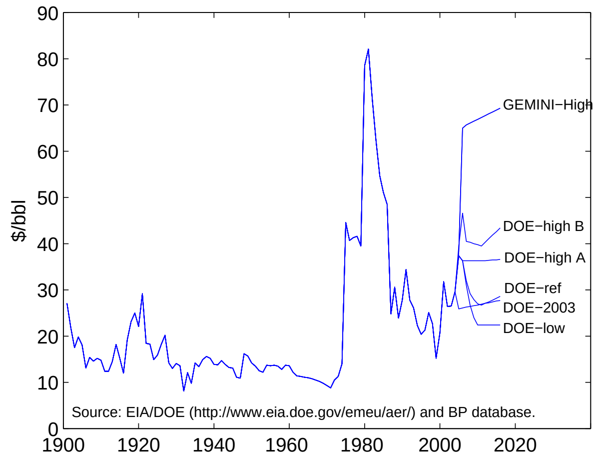

Figure 1: World oil prices, 1900-2015 (2004 dollars per barrel)

emissions are around 10.7 GtC-equivalent in 2015 in the high oil prices scenario. That represents a 12% reduction compared to the original baseline in 2015. This reduction in GHG emissions might be considered as relatively limited as regard to the magnitude of rise in oil and gas prices. Why does this happen?

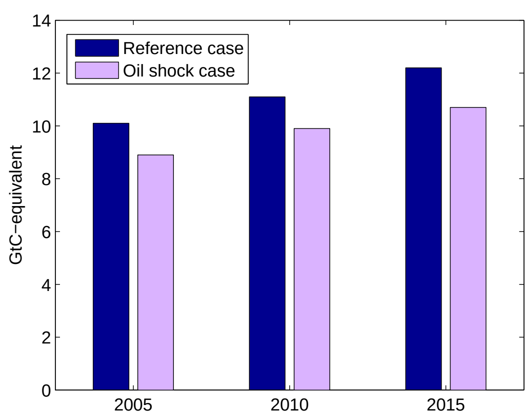

Figure 2: World GHG Emissions in the reference and high oil price scenarios

The main reason for this result is the adverse substitution effect in energy consumption depicted in Figure 3. Indeed, the world GDP shrinks by only 1% in 2015. Because of higher fossil fuel prices, gas and oil consumption are reduced worldwide by 33% and 32% in 2015, respectively. The electricity consumption is also reduced by 9% compared to the original baseline. But these reductions in fossil fuel and electricity consumption are partly compensated by an increase in coal consumption (+20% in 2015). The reduction of global emissions is thus limited by the opportunity to substitute oil and gas by other energy inputs that might have greater carbon content coefficients (i.e. coal). This result illustrates why the substitution of an energy tax for a carbon tax provides a far less efficient policy instrument for achieving the goal of reduced GHG emissions.

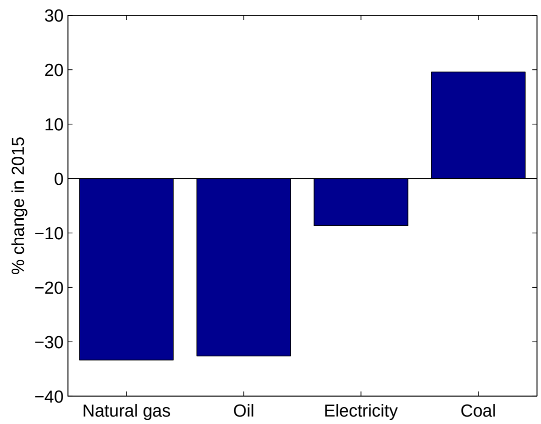

Figure 3: World energy consumption (% change from the reference scenario in 2015)

Figure 4 presents the oil price impacts on CO_2 emissions in the different economic sectors. Globally, the rise of oil prices is projected to have a strong impact on the emissions of the transportation sector and the chemical industry. In contrast, CO_2 emissions are expected to increase in the electricity sector as a result of fuel mix changes. Indeed, in a baseline scenario without any climate change policy, the electricity sector reacts to higher fuel prices by shifting from oil and gas to coal. Since the electricity sector has probably the lower carbon abatement costs, emission reductions are far from the one that would result from an efficient climate policy that would equalize marginal abatement costs across sectors.

In Figure 5, it is shown that the effects of high oil prices on GHG emissions may greatly vary from one country to another[4]. According to GEMINI-E3, GHG emissions might be reduced by around 20% in the Former Soviet Union, the Middle East and Latin America in 2015 as a consequence of higher oil prices. In the meantime, they would decline by around -19% in Europe and -13% in the United States, and increase by more than 2% in China. The insight of Figure 5 is clear: An increase in oil prices is likely to be beneficial for the climate but the respective contributions of the different regions would largely differ, depending on adjustments and substitutions opportunities within the different economies.

A key factor in this analysis is the assumption about the relationship between the oil market and other energy markets. It is assumed that gas prices remain highly indexed on

[4]CANZ, CEA, and FSU are for Canada+New zealand+Australia, Central European Associates, and the Former Soviet Union, respectively.

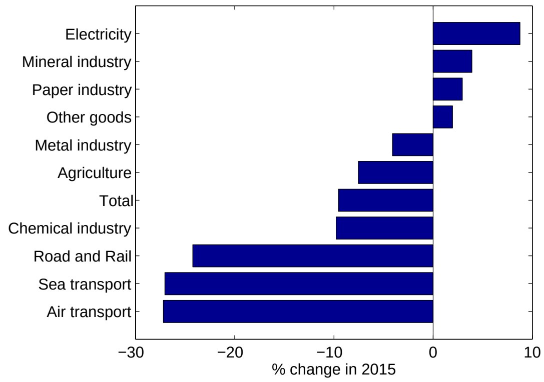

Figure 4: CO_2 Emissions by sector (% change from the reference scenario in 2015)

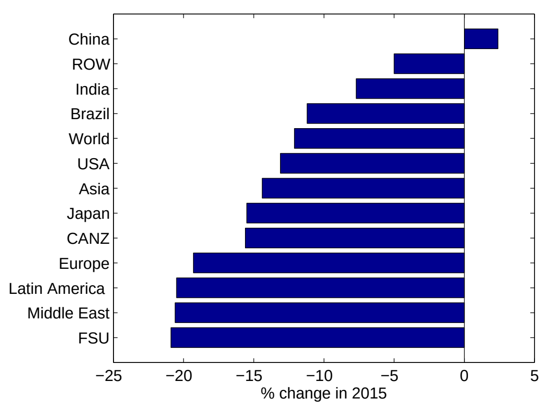

Figure 5: GHG Emissions by region (% change from the reference scenario in 2015)

oil prices during the whole period of time. However, some decoupling between oil and gas prices might be expected in the long run. We performed sensitivity analysis to examine the effect of indexation parameters on world energy consumption and GHG emissions. In this experiment, we do not impose any oil/gas price indexation but let the model computes gas prices endogenously. In that case, gas prices raise on average by less than 10% by 2015. Thus gas consumption increases by 13% while coal consumption is also improved by 12%. Oil and electricity consumptions decrease by around 35% and 4%, respectively. As a result, the reduction of world GHG emissions is only 6% in 2015 compared to 12% in the high indexation scenario. This "counterintuitive" result comes from the fact that the consumption of fossil fuels is higher than in the high oil/gas price indexation scenario. The decoupling between oil and gas prices would thus have a negative effect on global GHG emissions if oil prices were to remain high.

3.3 Macroeconomic Impacts of High Oil Prices

There is an extensive theoretical and empirical literature on the macroeconomic effects of oil price shocks ([20]). [21] developed aggregated simulations models to assess the magnitude of effect on the economy. They found that a 1 percent reduction in oil usage reduces gross output by a percentage amount corresponding to the cost share of oil. This share of oil in input is though to be no larger than 4 percent; with a unit elasticity of substitution between oil and value added, a 10 percent increase in oil prices, for example, will result in a less than 0.5 percent reduction in gross output. If the elasticity of substitution is less than 1, the drop in gross output is even smaller. [3] identifies a number of mechanisms that might provide a causal link from oil prices to recessions, inflation, and economic growth. Oil prices shocks have a stagflationary effect on the macroeconomy of an oil importing country ([22]): they slow down the rate of growth (and may even reduce the level of output i.e. cause a recession) and they lead to an increase in the price level and potentially an increase in the inflation rate. An oil price hike acts like a tax on consumption; for a net oil importer like Europe or the United States, the benefits of the tax go to major oil producers rather than the oil-importing government. According to [22], the size of the output growth/level effect and inflation rate/price level effect of an oil shock depend on many factors: the size of the shock, both in terms of the percentage increase in oil prices and the real price, the shocks persistence, the dependency of the economy on oil and energy, the policy response of monetary and fiscal authorities.

In CGE models like GEMINI-E3, welfare effects of a drastic change in oil prices can be assessed through the indirect utility function that may distinguish (i) the "imported costs" due to the change in the prices –or the quantities– of foreign trade (the "terms of trade" effect) and (ii) the "domestic cost" interpreted as the indirect change in revenue arising from the change in price. As an example, CGE approaches used in climate change economics have shown that the deadweight losses of climate policies under the Kyoto Protocol may be partly outweighed by positive terms of trade effects in energy-importing regions ([10], [1]). In the high oil price scenario, one should expect a high cost for oil-importing regions due to the combination of deadweight costs and losses from a terms of trade deterioration.

[2] show that the increased volatility in the terms of trade since Bretton Woods is largely due to the increased volatility in the relative price of oil rather than the increased volatility of nominal or real exchange rates.

In Figure 6 we present the welfare effects of the increase in oil prices obtained from GEMINI-E3. In this scenario, we do not take into account the possibility of fiscal or monetary policy response to high oil prices. Globally, high oil prices have the effect of reducing the welfare by around 2% in 2015 compared to the original baseline scenario. As shown on the graph, high oil prices impose a significant welfare cost in oil-dependant regions like India, Asia or Europe (-6%, -5%, -4%, respectively). At the opposite, oil-exporting countries –in particular the Middle East (+10%), the ROW (mainly Africa, +6%) and the Former Soviet Union (+4%)– would of course gain a lot from an appreciation of oil prices.

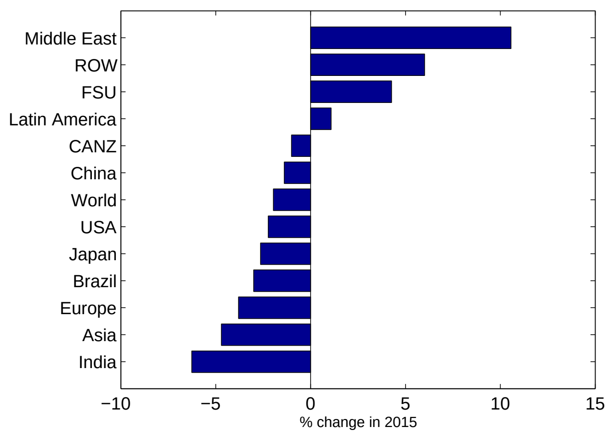

Figure 6: Welfare effects by region (% change from the reference scenario in 2015)

4 Stochastic scenarios of high oil price

4.1 Probability distribution function for oil prices

There is a large uncertainty on the evolution of the oil price even in the short run. In a recent work done by the Energy Modeling Forum [4], Beccue and Huntington have developed a risk assessment framework in order to determine the likelihood of oil disruption over the next ten years. They exclude domestic (i.e. US) and weather-related oil disruptions and focus the effort specifically upon geopolitical, military and terrorist causes for disruptions overseas. They utilize expert judgment to detail the overall probability of a major oil disruption. Their final results of risk assessment convey a range of insights across the three dimensions of magnitude, likelihood, and length of a disruption and the main conclusions are the following :

- The probability of a net (of offsets) disruption of 2 MMBD (million barrels per day) or more lasting at least 1 month is approximately 80%;
- The probability of a net (of offsets) disruption of 2 MMBD or more lasting at least 6 months is approximately 70%;
- The probability of a net (of offsets) disruption of 2 MMBD or more lasting at least 18 months is approximately 35%;
- The chance of a 3 MMBD net disruption or more lasting at least 1 month is 65%; the chance of 5 MMBD or more is about 50%.

Finally they estimate the probabilities of the three oil prices scenario considered in the International Energy Outlook done by the Energy Information Administration [14]. The table 2 gives the three oil production scenarios and the probabilities associated.The high, reference, and low price scenarios were assigned probabilities of 50%, 35% and 15% respectively.

On the basis of this probability distribution we adjust a lognormal distribution function. The figure 7 gives the probability distribution function estimated.

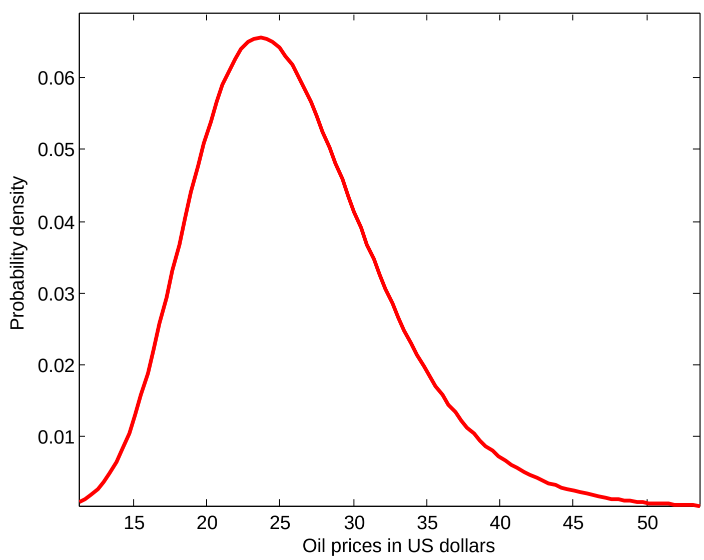

Figure 7: Probability Distribution Function for oil price

Table 2: Oil production scenarios

	High Price	Reference	Low Price
Oil Capacity			
Iran	3,9%	4,2%	4,5%
Irak	3,2%	3,9%	4,4%
Kuwait	2,6%	3,3%	3,6%
Saudi Arabia	10,4%	13,9%	16,7%
Total Persian Gulf	**23,80%**	**29,30%**	**33,40%**
Nigeria	2,4%	2,7%	3,0%
Venezuela	3,6%	3,9%	4,3%
Total other OPEC	11,3%	12,4%	12,9%
Total OPEC	**35,1%**	**41,7%**	**46,3%**
Former Soviet Union	15,4%	13,9%	12,8%
United States	11,0%	10,0%	9,1%
Total Industrialized	**28,4%**	**26,1%**	**23,9%**
Total Non-OPEC	**64,9%**	**58,3%**	**53,7%**
Total World	**100,0%**	**100,0%**	**100,0%**
Levels			
Capacity (MMB/Day)	90	95,1	100,6
Price (2002$/B)	33,28	24,18	16,99
Probability	50%	35%	15%

Source [4]

4.2 Probability distribution function for the indexation of gas prices to the prices of oil

Concerning the indexation of gas prices to the prices of oil, we assume that the indexation is based on an uniform function on the interval [0.5,1]. The mean of this function (0.75) is equal to the indexation value taken into account in the deterministic scenario. For coal prices we suppose that they are endogenously computed by the model as it was done in the deterministic case.

4.3 Energy prices uncertainty impacts on GHG Emissions

4.4 Welfare impacts of Energy prices uncertainty

5 Conclusion

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