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A STOCHASTIC DYNAMIC GAME OF THE 2050 EUROPEAN ENERGY ROAMAP WITH CCS UNCERTAINTIES

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Overview

Climate policy is one of the corner stones of European Union (EU) policy. In 2011, the European Commission has defined a roadmap to low carbon economy in 2050 in which the Commission reconfirmed the EU objective of reducing European greenhouse gases (GHG) emissions by 80-95% in 2050 compared to 1990 levels. In this paper, we propose a meta-game approach to assess a fair and robust burden sharing agreement to be negotiated by European nations to meet European GHG abatement objectives. The meta-game is used to define a Nash equilibrium that would lead to a balanced set of welfare losses among European countries. The strategies are the supply of emission quotas on a European emissions trading system and the payoffs are the net gains obtained from the emissions. The paper also tries to determine the role of the Carbon Capture and Storage (CCS) options to meet the EU CO_2 target. Indeed CCS is often cited as a valuable technology to abate CO_2 emissions, but its development is still surrounded by uncertainties. We integrate these uncertainties directly in the model through a stochastic framework.

Method

We formulate a non-cooperative game with coupled constraint that describes the 28 European member states where the strategic decisions are the supply of emission rights on an international carbon market. We assume a competitive market for emissions permits, which clears at each period. The allocation of EU emissions budget by member states is defined on several alternative rules. The solution of the game is a normalized equilibrium in a game with a coupled constraint where each player minimizes a discounted welfare cost. The manifold of normalized equilibria corresponds to the set of Nash equilibria in the games obtained by distributing the global emission budget to the different countries participating in the agreement. One may then look for the allocation that would lead to an equilibrium solution which is "balanced", i.e. which tends to equalize the relative welfare losses for all countries.
The uncertainties on the CCS cost and potential are integrated in the model through a event tree and the game is alternatively solved under deterministic assumptions and within a stochastic framework.
The model is calibrated using a statistical emulation of the computable general equilibrium model called GEMINI-E3. The statistical emulation uses a space filling experimental design of 200 runs evaluating different possible European abatement policies.

Results

First we solve the game without CCS and we test three alternative rules to allocate the EU CO_2 budget between member states based on historical emissions, population and GDP. While the total EU discounted welfare costs are very similar for the three rules (i.e. 1.2% of total discounted EU consumption) with a CO_2 price of 1100 $ per ton of CO_2 in 2050, the three allocations appear to be unfair among countries with very contrasted individual contributions. We then compute a *balanced equilibrium* corresponding to a fair equilibrium solution where the maximum welfare loss among the 28 member states is minimized..
For the stochastic analysis, we define an event tree with 3 "equiprobable" scenarios of CCS development from 2030 (i.e. optimistic, medium and pessimistic) each one characterized by a cost (i.e. 55, 110 and 160$/t$CO_2$, respectively) and a potential of CO_2 that is expected to be sequestered in 2050 (i.e. 100%, 50% and 25% of emissions from gas and coal power plants).
The results on deterministic games show that CCS development scenarios may have significant impacts on EU climate policy. For example, assuming medium assumptions on CCS, the total EU welfare loss and the CO_2 price in 2050 are reduced by a factor 2 with 11 Gt of CO_2 sequestered. We also observe that countries have incentive to delay their abatements to the period 2030-2050 to exploit cheaper CCS opportunities. When running the stochastic game,

countries must anticipate very early uncertainty on CCS development to reduced their risk and thus increase their abatements in 2020. For the stochastic equilibrium computed on a balanced rule, the total EU welfare costs are equal to 0.52% in average for all countries and more precisely to 0.12%, 0.55% and 0.90% on the optimistic, medium and pessimistic scenarios, respectively. The CO_2 price are respectively equal to 400, 760 and 900 \$/tCO2 in 2050. The EU CO_2 budget is be shared with the following allocations: 15% for UK, 14% for Germany, 13% for France, 12% for Italy, 9% for Spain, 6% for Poland, 5% for Greece, etc.

Conclusion

In this paper we propose a stochastic meta-game approach based on statistical emulation of a comprehensive general economic equilibrium model to numerically simulate the burden sharing of the European roadmap to a low carbon economy. First, we show that, assuming a global budget for EU emissions, the permits allocated to EU countries are the key variables of any agreement. We define an equilibrium that equalizes the welfare loss of the climate policy where the total EU discounted welfare loss is equal to 1.2% of total discounted EU consumption. Then we consider the uncertainties associated to the deployment of the CCS to define a stochastic dynamic game. We show that this technology could reduce significantly EU policy costs with total welfare losses ranged between 0.12% to 0.9%.

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