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Uncertain long-run emissions targets, CO_2 price and global energy transition: A general equilibrium approach

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ABSTRACT

The persistent uncertainty about mid-century CO_2 emissions targets is likely to affect not only the technological choices that energy-producing firms will make in the future but also their current investment decisions. We illustrate this effect on CO_2 price and global energy transition within a MERGE-type general-equilibrium model framework, by considering simple stochastic CO_2 policy scenarios. In these scenarios, economic agents know that credible long-run CO_2 emissions targets will be set in 2020, with two possible outcomes: either a "hard cap" or a "soft cap". Each scenario is characterized by the relative probabilities of both possible caps. We derive consistent stochastic trajectories—with two branches after 2020—for prices and quantities of energy commodities and CO_2 emissions permits. The impact of uncertain long-run CO_2 emissions targets on prices and technological trajectories is discussed. In addition, a simple marginal approach allows us to analyze the Hotelling rule with risk premia observed for certain scenarios.

1. Introduction

This paper shows how the current uncertainty about the 2020–2050 CO_2 emissions targets may affect CO_2 and energy prices as well as technological choices in the energy sector.

To assess the cost of reducing GHG emissions, applied general-equilibrium models linking aggregated descriptions of economies and detailed energy sectors together[2] have been developed. Some of them, for instance MERGE (Manne et al., 1995), GEMINI (Bernard and Vielle, 2003), IGSM (Sokolov et al., 2005) and WITCH (Bosetti et al., 2006), have been used by IPCC (2007) and USCCSP (2007) to evaluate climate change policies. So far, the issue of agents' behavior under uncertainty has been addressed in these models through sensitivity analysis (Löschel and Otto, 2009; Magné et al., 2010), Monte-Carlo simulation (Kypreos, 2006) and stochastic formulations where agents hedge themselves against some probabilistic outcomes. This last approach was first introduced by Manne and Richels (1992) and Manne and Olsen (1996) who studied the effect of a low-probability climate catastrophe on agent's behavior. More recently,[3] Bosetti and Tavoni (2009) investigate the impact of uncertain energy-related R&D activities and Loulou et al. (2009) derive different EMF 22 radiative forcing scenarios by assuming an uncertain sensitivity of climate to emissions.

In this paper, we use a stochastic approach to illustrate how the persistent uncertainty about the 2050 CO_2 emissions caps impacts prices and technological choices in the energy sector.[4] These energy prices are especially useful to understand agents' behavior and assess the relevance of our model's results.

In a deterministic model, the agents plan their actions with a perfect knowledge of the future, and the efficient (or clean) technologies expand at the optimal rate in the economy. In our model, until 2020, the agents have to invest before knowing the full sequence of emissions caps imposed to regional economies, by trading off the gain in postponing the adoption of efficient but expensive technologies against the risk of being tied to some detrimental technological choice once the actual emissions caps are set.

The model we use is a modified stochastic version of the MERGE model.[5] For the sake of illustration, here uncertainty only involves two political outcomes, with, at the end of 2020, the setting of either a "hard-cap" policy or a "soft-cap" policy for

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[1] This author has been financially supported by GDF-Suez.
[2] The so-called "top-down/bottom-up" models.
[3] See also the survey by Labriet et al. (2009).
[4] The energy sector represents 76% of total direct CO_2 emissions in 2005 (IEA, 2008b).
[5] See Manne et al. (1995) for a presentation of the MERGE model.

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energy-related CO_2 emissions. Each policy defines series of regional quotas which are linearly decreasing until 2050 and constant after this date. Until 2050 the hard-cap and soft-cap quotas are respectively consistent with the IPCC (2007)'s 450 and 550 ppm atmospheric-GHG-concentration scenarios. However, over the model's whole horizon, the hard-cap and soft-cap policies are less stringent than the two IPCC's scenarios since complying with these scenarios would involve post-2050 emissions reductions (IPCC, 2007; IEA, 2008b).

In our model, all agents (i.e., firms and households) are forward looking, in the sense that firms (households) always act so as to maximize their expected present value (expected sum of discounted utilities) under rational expectations. In other words, in each date firms base their current decisions on consistent subsequent prices of inputs and outputs (or, in the case of decisions made until 2020, consistent subsequent prices in each possible outcome), i.e., prices that precisely result from the decisions currently made.

Firstly, our approach makes possible an explicit modelling of agents behavior in the presence of long-run CO_2 policy uncertainty. Secondly, it yields stochastic scenarios of energy prices—for CO_2, oil, gas, power—with two possible sequences for post-2020 prices, that are consistent with the stochastic political scenario under consideration. Note that the unique pre-2020 sequence and the two possible post-2020 sequences obtained for the price of a given energy commodity may broadly differ from the two deterministic sequences of prices that would be determined by successively considering each CO_2 target as certain from the beginning (i.e., 2005 in our model). In addition, as illustrated later, a stochastic price scenario is not necessarily bounded by the corresponding two deterministic sequences of prices. This shows the interest of a stochastic-scenario-based approach for studying the energy transition when long-run CO_2 emissions targets are uncertain.

Section 2 presents the stochastic CO_2-emissions policy scenarios under consideration and motivates our approach. The structure, calibration and computation of our stochastic general equilibrium model are discussed in Section 3. The simulation results are studied in Section 4, with an emphasis on the impact of uncertainty on prices and technology trajectories. The last section concludes.

2. A stochastic-scenario approach for long-run emissions targets

The forthcoming energy transition, that will result from the technological choice made by the economic agents, will crucially depend on CO_2 emission targets. If current negotiations can set credible regional emissions targets on the short and intermediate runs, uncertainty on long-run targets (i.e., up to the middle of the century and beyond) is likely to persist. In addition, economic agents are likely to consider these long-run emissions targets as credible only once they have been transposed into regional energy policies (since, meanwhile, any long-run commitment might be offset by possible political, economic or environmental shocks, Frankel, 2009). In our model, we therefore assume that the agents have currently an incomplete information. They know the emissions targets set until 2020 but they consider that credible mid-century emissions targets will be set in 2020 only.

Therefore, until 2020 they face an uncertainty which impacts not only their future but also their current technological choices and investments. For example, the uncertainty on long-term emissions targets can lead the firms to delay costly investment in clean technologies, although this might cause very high CO_2 emissions costs if restrictive emissions targets are finally set. Indeed this effect is not taken into account in a deterministic model where agents plan their actions with a perfect knowledge of the future and clean technologies expand at the optimal rates in the economy.

Since our primary goal is to illustrate the effect of uncertain long-run CO_2 emissions targets on CO_2 price and energy transition, we consider here a simple stochastic scenario, in the sense that agents are aware that either a hard-cap or a soft-cap target will be set for mid-century energy-related CO_2 emissions. As earlier explained, agents consider that the political choice between the hard and soft caps will be definitely made in a credible way in year 2020. To better illustrate the effect of uncertainty, different assumptions about the relative probabilities of these two possible caps are considered.

More precisely, in our model, the CO_2 emissions targets are enforced through a cap-and-trade mechanism. There are two successive series of linearly decreasing emissions caps. These series are reported in Table 1. For every OECD region, the first series, which spans from 2010 to 2020, sets an emission cap for every period. These caps decrease linearly so as to converge towards the 2020 emissions target. For each OECD or non-OECD region, the second series of emissions caps concern the post-2020 periods. The caps linearly decrease from 2020 to 2050, so as to reach either the hard-cap or the soft-cap emission stabilization level in 2050, and after remain constant.

The OECD countries commit themselves to known reduction levels of energy-related CO_2 emissions for 2020. The European Union agrees on a reduction of 20% with respect to 1990. North America (USA, Canada and Mexico) agrees to reduce emissions by 17% with respect to 2005 (IHT, 2009). The Pacific OECD countries (Japan, South Korea, Australia and New Zealand) are assumed to commit themselves to the same target as North America. Until 2020, the emissions of the non-OECD countries are not limited.

The climate negotiations for the period 2025–2050 are assumed to be finalized in 2020, and to yield at that date either the hard-cap or the soft-cap climate agreement. Therefore, until 2020, households and firms ignore which one of these two caps will be set. In the hard-cap outcome, every OECD region has to cut emissions in 2050 by a factor 4 with respect to 2005. Every non-OECD region commits to a 27% emission reduction by 2050 with respect to 2005. Globally, these commitments correspond to a halving of energy-related CO_2 emissions by 2050 with respect to 2005.

If the soft cap is set, every OECD region has to cut emissions in 2050 by a factor 3 with respect to 2005. Every non-OECD region commits to increase its emissions in 2050 by no more than 14% with respect to 2005. The soft cap corresponds to a 25% decrease in global emissions in 2050 with respect to 2005.

Until 2050 the emissions corresponding to the hard and soft caps are respectively consistent with the 450 and 550 ppm scenarios proposed by IEA (2008b) on the basis of IPCC (2007). However, when considering the model's whole horizon, the hard and soft caps are less constraining than the 450 and 550 ppm scenarios since here, after 2050, emissions are only assumed to be stabilized.

Unused emissions permits can be banked (ensuring intertemporal efficiency) from 2010 on for OECD regions and from 2025 on for non-OECD regions. From 2060 on, banked permits can no longer be used. Inter-regional trade of emissions permits (i.e., a global CO_2 emission permits market that ensures spatial efficiency) occurs only after 2020.

In the stochastic CO_2 policy scenarios considered here, the two possible post-2020 series of caps represent two distinct states of the world, as illustrated in plain line on the left-side of Fig. 1. As in Manne and Olsen (1996), we can oppose a "Learn then Act" model (where the scenario is deterministic) to an "Act then Learn" model