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Carbon capture and storage and transboundary pollution: A differential game approach ☆

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ABSTRACT

We study the strategic behavior of two countries facing transboundary CO_2 pollution under a differential game setting. In our model, the reduction of CO_2 concentration occurs through the carbon capture and storage process, rather than through the adoption of cleaner technologies. Furthermore, we first provide the explicit short-run dynamics for this dynamic game with symmetric open-loop and a special Markovian Nash strategy. Then, we compare these strategies at the games' steady states and along some balanced growth paths. Our results show that if the initial level of CO_2 is relatively high, state dependent emissions reductions can lead to higher overall environmental quality, hence, feedback strategy leads to less social waste.

1. Introduction

According to the International Energy Agency (2011), energy related CO_2 emissions have increased by 5.9 percent in 2010, with no perspective of a slowdown in the coming decade. Although 75% of this increase has been driven by emerging economies such as China or India, energy consumption in developed countries remains at high and increasing levels. The largest share of this increase in energy demand is absorbed by new coal, gas, and oil fired power plants, oil sands and more recently unconventional gas sources.[2]

As a consequence, non-renewable energies will be used over a longer period, but they need to be used more efficiently. Unfortunately, improvements in energy use can only be applied progressively, as they often entail a switch in technology and ensuing adoption costs. Conversely, capture technologies, which do not require a change in production technology, could be more rapidly applied at a large scale, mainly for two reasons: (i) their only requirement is to fit coal-fired power plants with capture technologies; and (ii) capture technologies can be implemented on large energy supply sites at lower cost than current low emissions technologies.[3]

Carbon capture and storage (CCS) has been at the forefront lately, as it encompasses a broad set of technologies, and it essentially consists in capturing CO_2 emissions from large point sources and storing it in geological formations.[4] In the recent past CCS has raised increasing interest among scientists and policy makers. In 2007 for instance, CCS was accepted as a climate change mitigation possibility within the Kyoto Protocol, on top of national regulations (see IEA, 2010). However, the implementation of large scale transboundary policies remains largely an unaddressed issue, dealt at the national or regional level so far. This is notably true for the development of large scale CCS demonstration sites. International cooperation on CCS regulation seems unavoidable, given the international nature of climate change. In the coming years, CCS will therefore certainly be part of a mix of solutions to mitigate climate change, as it permits non-negligible reductions of CO_2 emissions.

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[2] Unconventional gas sources refers to gas which has not been exploited to its full extent, essentially unprofitable. These gas sources include: (i) deep natural gas, trapped in very deep deposits underground, (ii) tight natural gas, stuck in tight formations, trapped in impermeable rocks or non-porous sandstone formations, and (iii) shale gas, caught in shale rock formations, deep underground. See Smith (1980) for more details about unconventional gas sources.

[3] The International Energy Agency (2010) noted that carbon capture and storage is fundamental in a least-cost carbon abatement mix. If carbon capture and storage (CCS) technologies are not implemented, the overall costs to limit to 2^0C global mean temperature would rise by 70%. Furthermore, this figure could be even larger if CCS is used at a larger scale because it will further reduce its costs. Biello (2009) mentions that the present CO_2 capturing cost is about \$50 to \$90 per metric ton, and costs could potentially be reduced to \$20 by scaling up the process.

[4] The storage technology is not new and has been in use mainly in oil fields and nature gas extracting wells. More details on key projects on http://www.globalccsinstitute.com/ccs/key-projects.

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In the present paper, we use a dynamic framework to analyze the strategic behavior of countries when pollution is borderless and mitigation policies are nationally financed. This framework corresponds to the CCS case nowadays. Our framework focuses on non-renewable resources, *i.e.* we do neither consider the possibility of adopting technologies based on renewable resources nor energy saving technological progress. This is consistent with the view that CO_2 emissions due to the usage of non-renewable resources will still be an important issue in the future.

Furthermore, the transboundary nature of pollution is of tremendous importance when dealing with CO_2 emissions. A number of contributions have tackled this issue: Copeland and Taylor (1994, 1995) study the relationship between trade and transboundary pollution. In their 1994 contribution, they note that "…free trade increases world pollution…" and propose a number of policies regarding global pollution in their subsequent 1995 paper. Building on these results, Hatzipanayotou, Lahiri, and Michael (2002, 2005) offer complementary abatement policies, while Alemdar and Ozyildirim (2002) study the relationship among transboundary pollution, knowledge spillovers and growth in a North–South model. However, these studies ignore the possibility of having recourse to CCS, and only analyze long term issues. In the present work, we take these aspects into account. Our contribution also differs in this regard to Kalkuhl, Edenhofer, and Lessmann (2012), who explicitly model the CCS mechanism and provide some comparison elements between CCS and pure renewable energy policies. Nevertheless, their setting is based on one country model without any strategic interactions nor international competition.

Our framework partly relies on Dockner and Van Long (1993, 2000)'s model of a two-player dynamic game of international pollution control and transboundary pollution which characterizes cooperative and non-cooperative strategies of a government maximizing the discounted stream of benefits of the representative consumer. Special attention is paid to the existence, multiplicity and properties of stationary steady states via Hamilton–Jacobi–Bellman equations. We however depart from previous work in several ways. First, we provide the short-run dynamics via a transitory dynamic analysis using Pontryagin Maximum Principle. The short run is crucial in the case of CCS since its implementation requires to complement existing technologies in the short run. Second, we present two alternative non-cooperative scenarios characterized by open-loop strategies and one scenario using a special type of Markovian strategies. In the absence of supranational institutions enforcing environmental regulations, our scenarios describe some alternatives available to policy makers, the multilateral negotiations involved and the optimal strategies. Notice that optimal strategies are adaptable in time and depend on the state of pollution. Further details about the strategic choices and their implications are provided in Section 4.1.

Further, we can describe analytically the short run dynamics. Adoption of new, more environmental friendly technologies is lengthy and involves considerable inertia due to high fixed costs of present technologies. This is not so much the case for CCS technologies, more readily applicable, and to which we refer to in the present paper. In terms of the modeling strategy, we suppose that pollution is predetermined and that agents decide the amount of emissions to reduce. As a corollary, pollution reduction does not imply a direct reduction of output in the production process. Following Aghion and Howitt (1998), we introduce a potential rate of regeneration in the equation for environmental quality. In the existing literature, most studies ignore the possibility that different countries may be endowed with different capacities to absorb pollution. We believe it is of considerable importance since the self-regeneration capacity of nature acts as a pollution sink.

Countries with open-loop strategies commit once and for all to a trajectory of reduction of emissions.[5] Open-loop strategies are used in situations in which it is difficult or too costly to check commitments. We find a unique equilibrium solution to the dynamic system, which is interior under certain assumptions. Furthermore, weakly restricting the parameter set, we prove the existence of a balanced growth path where pollution and efforts displayed to absorb emissions grow at the same rate as the emissions. Contrary to most of the previous findings, and in line with Wirl (1994), we prove that Markovian strategies are not always socially less desirable. Indeed, allowing countries to revise their effort to reduce emissions every period leads to lower overall levels of pollution, provided levels of pollution are sufficiently high.

The paper is organized as follows: in Section 2, we briefly introduce the basics of CCS economics, and possible challenges for future multilateral rounds of negotiations. The model is unfolded in Section 3. Section 4 displays the different strategy choices, and explains the theoretical results; in Sections 5 we compare the outcomes from different strategies. Section 6 concludes.

2. Carbon capture and storage: the economics, policies and regulations

[6]The tremendous growth performance of a number of economies and the ensuing energy famine thereof has led to a situation where new coal-fired power plants open every week worldwide, most of which are located in China and in a number of other emerging economies. Furthermore, coal plays also a significant role in countries like Poland or Germany, notably to progressively compensate for the reduction of nuclear energy. All these facts indicate that increases in energy supply will not come from zero-emission sources in the medium run. In this regard, CCS appears as a transition technology for the coming decades, as these technologies build on traditional energy supply technologies.

Whenever fossil fuel is burned, it generates CO_2, which is usually emitted in the atmosphere, contributing to climate change. CCS refers to a set of technologies meant at capturing, compressing, transporting and storing CO_2 emissions permanently. Despite its advantages, CCS technologies have not been massively adopted since they remain relatively costly: estimates show that fitting a power plant with additional CCS technology might increase its cost by about 50 per cent for the installation of the capture equipment.[7]

On top of the capture process itself, the transport and storage systems have to be built and operated, increasing the running costs further (Heal & Tarui, 2008). Inferring the cost structure on CCS is not straightforward, as the returns to scale depend on the interlink of costs of capture, transport and storage, each of which highlights potential economies of scale at given emissions levels (Bielicki, 2008).

From a legal point of view, there have been a number of steps undertaken to foster CCS regulation at national and international levels. Probably the most noticeable advance has been the integration of CCS as a climate change mitigation instrument within the Kyoto Protocol in 2007, although so far, no agreement has been found regarding their inclusion of CCS in the Clean Development Mechanism.[8] A further issue facing CCS regulation is the classification of CO_2 emissions as industrial by-product or as waste product.

[5] More about strategies choice and related literature are presented in the next Section.

[6] This section relies on Intergovernmental panel on climate Change (2007) and Massachusetts Institute of Technology (2007).

[7] See, for example, the Global CCS Institute report (2011).

[8] The Clean development Mechanism allows developed countries to invest in the reduction of emissions in less developed countries, earning this way certified emissions reduction credits.