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Joining the CCS club! The economics of CO_2 pipeline projects

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ABSTRACT

This paper examines the conditions for a widespread adoption of Carbon Capture transport and Storage (CCS) by a group of emitters that can be connected to a common CO_2 pipeline. It details a modeling framework aimed at assessing the critical value in the charge for the CO_2 emissions required for each of the emitters to decide to implement capture capabilities. This model can be used to analyze how the tariff structure imposed on the CO_2 pipeline operator modifies the overall cost of CO_2 abatement via CCS. This framework is applied to the case of a real European CO_2 pipeline project. We find that the obligation to use cross-subsidy-free pipeline tariffs has a minor impact on the minimum CO_2 price required to adopt the CCS. In contrast, the obligation to charge non-discriminatory prices can either impede the adoption of CCS or significantly raise that price. Besides which, we compared two alternative regulatory frameworks for CO_2 pipelines: a common European organization as opposed to a collection of national regulations. The results indicate that the institutional scope of that regulation has a limited impact on the adoption of CCS compared to the detailed design of the tariff structure imposed on pipeline operators.

1. Introduction

The current dominance of hydrocarbon fuels in the global primary energy mix is likely to persist in the foreseeable future, suggesting that there will be no sharp decline in carbon dioxide (CO_2) emissions (IEA, 2011). Against this daunting background, geologic Carbon Capture transport and Storage (CCS)[1] represents a technically conceivable option to isolate large volumes of CO_2 from the atmosphere. A widespread deployment of this abatement technology to large industrial CO_2 point sources could reconcile the world's current dependence upon hydrocarbons with the large and rapid reduction of anthropogenic CO_2 emissions required to prevent the effects of global warming (Pacala & Socolow, 2004). However, the large-scale deployment of CCS faces an enduring economic challenge: as CCS scales up from local, small-scale demonstration projects, it becomes contingent upon the construction of a costly CO_2 pipeline infrastructure with national or continental scope (Herzog, 2011).

The purpose of this paper is to contribute to the burgeoning analysis of the economics and regulatory issues of CO_2 pipeline projects. We consider the case of the *ex nihilo* creation of a sizeable CO_2 pipeline system, aimed at gathering the emission streams produced by a given collection of independent industrial plants and transporting them to a storage site. We address two related questions. First, how far would the price of CO_2 emissions have to rise for the CCS technology to be adopted by that collection of emitters? Second, to what extent do the tariff and/or the regulatory structure imposed on the CO_2 pipeline operator modify this *break-even value* for joint CCS adoption?

Over the past decade, a large body of literature has emerged on CCS.[2] Despite the amount of literature, however, little research has

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[1] CCS is a generic name for the combination of technologies applied in three successive stages: (1) the capture which consists of a separation of CO_2 from the emissions stream generated by the use of fossil fuels at industrial plants; (2) the transportation of the captured CO_2 via a dedicated infrastructure to a storage location; and (3) the long-term storage of the CO_2 within a suitable geological formation in a manner that ensures its long-term isolation from the atmosphere (IPCC, 2005).

[2] A tentative and non-exhaustive clustering of these contributions includes: (i) the applications of top-down dynamic models to contrast the relative performances of policy instruments and to check their influence on the adoption of CCS (e.g., Gerlagh & van der Zwaan, 2006); (ii) the detailed bottom-up analyses on the future prospects for CCS (e.g., Kemp & Kasim, 2008; Lohwasser & Madlener, 2012); (iii) the

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considered the spatial nature of this abatement technology (i.e., the fact that sources can be remotely located from geologic sequestration sites imposing the construction of dedicated CO_2 transport systems). This relative lack of consideration can probably be explained by the engineering cost studies that typically highlight the inexpensive nature of CO_2 transportation relative to the other components of the CCS chain (i.e., capture and storage). Nevertheless, CCS experts repeatedly emphasize the importance of carbon transportation issues (Flannery, 2011). According to Herzog (2011), at least two barriers hamper the construction of a sizeable transportation infrastructure. The first is the "chicken and egg problem" faced by CO_2 pipeline project developers: on the one hand, it is not worth building a pipeline system without a critical mass of capture plants to feed CO_2 into it, but on the other hand, emitters are unlikely to invest in a costly capture equipment without being certain that a CO_2 pipeline will be constructed. The second is the lack of clarity in the regulatory regimes (and the tariff policies) governing CO_2 pipelines.

The contribution of this paper is twofold. First, we provide a modeling framework that analyzes the coordination issue at hand with the help of cooperative game-theory techniques. The theoretical basis of our approach stems from a club theory perspective (Buchanan, 1965) and follows the early works of Littlechild (1975) and Sharkey (1982). Accordingly, the CO_2 emitter's decision to install or to not install capture equipment can be viewed as the outcome of a voluntary application to a "CCS club" aimed at aggregating the emissions captured in a given industrial cluster to generate economies of scale in the construction and subsequent operation of a joint CO_2 transportation infrastructure. Our aim is to derive conditions for the large voluntary adoption of CCS, as a function of: (i) the price of CO_2 emissions (set through a tax or a cap-and-trade system), (ii) the CO_2 transportation technology, and (iii) the nature of the tariffs regulation imposed on the pipeline operator.

Second, we consider an application of the proposed framework to the case of the construction of a trunkline system collecting the CO_2 captured by 14 industrial facilities located in northwest France and Belgium, and transporting it to the Netherlands.[3] Our findings confirm that spatial pricing issues significantly narrow the possibility of constructing a pipeline tariff structure: any kind of uniform postage stamp tariff impedes the adoption of CCS, whereas geographical price discrimination is more effective. Our findings reveal that CCS adoption is easier to achieve in case of a smaller project that solely considers the 12 largest emitters. Our modeling framework can also be used to compare two alternative organizations for the regulation of CO_2 pipelines: a regulation designed at the EU-level and a collection of national-based regulations. Our findings indicate that an integrated European regulation is preferable to ease the deployment of that carbon removal technology. Yet, the choice of the institutional scope of the pipeline regulation (national vs. European) seems quantitatively less important for the adoption of CCS than the detailed decisions related to the tariff structure imposed on pipeline operators.

Our framework should prove useful in evaluating the cost effectiveness of CO_2 abatement via CCS. A series of widely quoted studies have attempted to estimate the cost effectiveness of carbon abatement by means of CCS technologies (IPCC, 2005; McKinsey, 2008; MIT, 2007). Apart from the accounting controversies pointed out in İşlegen and Reichelstein (2011), all these studies typically make reference to average cost concepts. However, accounting-only approaches neglect the coordination issues associated with the joint adoption of CCS by a group of heterogeneous emitters. Because of this omission, average cost figures can underestimate the real break-even value. The empirical results reported in this paper document the magnitude of this underestimation and indicate that the difference can be substantial and varying depending on the emitters' heterogeneity and the tariff system used.

The paper is organized as follows. Section 2 justifies our approach. Section 3 presents a cooperative game theoretic model of the adoption of pipeline transport of CO_2. In Section 4, this framework is used to derive a numerical methodology aimed at evaluating the break-even value for joint CCS adoption. Then, Section 5 details an application of this methodology to the case of a real European project. Finally, the last section offers a summary and some concluding remarks. For the sake of clarity, all the mathematical proofs are presented in Appendix A.

2. CO_2 pipeline systems as a club good

In this section, we justify our approach by detailing the main economic features of a pipeline-based CO_2 transportation service. In Section 2.1, we highlight the presence of very marked economies of scale. Section 2.2 reviews the recent models proposed to determine the deployment of a CO_2 pipeline system and argues that the decision to construct a CCS infrastructure resembles the decision to create a "club." Lastly, Section 2.3 introduces the tools needed to analyze club goods and the organizational structures to be analyzed.

2.1. Economies of scale in CO_2 pipeline systems

Recently, a series of engineering analyses have been conducted to model the economics of simple point-to-point pipeline systems capable of transporting a given steady flow rate of CO_2 across a given distance (e.g., McCoy & Rubin, 2008; McCoy, 2009). These studies detail an exhaustive, engineering-based, representation of the CO_2 pipeline technology[4] and put that representation to work to determine the cost-minimizing design of a given CO_2 pipeline infrastructure (the pipeline diameter; the size of the compression equipment installed along the pipeline).

From a conceptual perspective, these studies bear a strong analogy with the engineering economic methodology used in the natural gas industry. As far as natural gas pipelines are concerned, a prolific literature, stemming from Chenery's (1949) seminal contribution, has combined engineering and economics to guide both investment and operational decisions.[5] Using that analogy,[6] one may describe the CO_2 pipeline technology as an engineering production function that

application of differential game models to analyze the strategic behavior of countries that consider reducing their emissions through CCS while facing transboundary CO_2 pollution (Bertinelli et al., 2014); (iv) the investment analyses applying the real-option approach to value CCS projects (e.g., Heydari et al., 2012); (v) the contributions aimed at determining an optimal R&D policy for the CCS technology (Baker & Solak, 2011; Eckhause, 2011; Eckhause & Herold, 2014) and (vi) studies aimed at identifying the tax incentives required for new power plants to be willing to adopt carbon capture technology immediately (Comello & Reichelstein, 2014).

[3] To be precise, this project assumes the construction of a trunkline system aimed at collecting the CO_2 captured by 14 small to large-sized industrial facilities located in both Le Havre (France) and Antwerp (Belgium), and transporting it to the Rotterdam area (Netherlands), where it can be stored in depleted oil fields in the North Sea. This sizeable project could represent one of the first attempts to build a transnational CO_2 pipeline system in Continental Europe.

[4] A comprehensive presentation of these engineering considerations is beyond the scope of this paper. These studies typically include: (i) a flow equation that describes the frictional loss of energy through the pipe (i.e., the pressure drop) as a function of the fluid's properties (e.g., flow-rate, pressure, temperature) and engineering parameters (e.g., the pipeline length, its diameter, an empirically determined friction coefficient); (ii) the mechanical constraints related to the pipeline's maximum operating pressure; and (iii) the equation governing the power required to pump the CO_2.

[5] For example: (i) the analytical studies conducted on simple point-to-point natural gas infrastructures (André & Bonnans, 2011; Massol, 2011), and (ii) the numerous applications of mathematical programming to model meshed networks (e.g., De Wolf & Smeers, 1996; André et al., 2009).

[6] There exists some technological differences between natural gas and CO_2 pipelines systems as methane is typically piped in a gaseous state whereas CO_2 is piped in a supercritical state (McCoy & Rubin, 2008). Nevertheless, these differences are not sufficient to denounce the validity of this analogy.