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Optimal timing of carbon capture policies under learning-by-doing

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ABSTRACT

Using a standard Hotelling model of resource exploitation, we determine the optimal energy consumption paths from three options: dirty coal, which is non-renewable and carbon-emitting; clean coal, which is also non-renewable but carbon-free thanks to carbon capture and storage (CCS); and solar energy, which is renewable and carbon-free. We assume that the atmospheric carbon stock cannot exceed an exogenously given ceiling. Taking into account learning-by-doing in CCS technology, we show the following results: (i) clean coal exploitation cannot begin before the outset of the carbon constrained phase and must stop strictly before the end of this phase; (ii) the energy price path can evolve non-monotonically over time; and (iii) when the solar cost is low enough, an unusual energy consumption sequence along with solar energy is interrupted for some time and replacement by clean coal may exist.

Introduction

A large body of evidence has demonstrated the potential of carbon capture and storage (CCS) in mitigating CO_2 emissions, especially from concentrated sources (e.g., the power generation sector). Given that fossil fuels supply over 85% of all primary energy needs, CCS appears as the only technology that can substantially reduce CO_2 emissions while allowing fossil fuels to meet the world's expanding energy demand (Herzog, 2011). According to Hamilton et al. (2009), the mitigation cost for the capture and compression of emissions from gas power plants is about \$52/tCO_2. Adding transport and storage costs ranging from \$5 to \$15/tCO_2, a carbon price of about \$60–65/tCO_2 is needed to make these plants competitive. However, these costs exhibit a high variance. Rubin et al. (2012) report added capital and operating costs of CCS with respect to non-CCS conventional thermic plants within a range of 60–80% for SPC plants and 30–50% for IGCC plants.[1]

Considering this cost evidence, it is widely acknowledged that the actual deployment of CCS in the medium term depends heavily on the implementation of effective GHG emissions mitigation policies. IEA (2008) reports the need to begin by deploying CCS around 2025 and to expand the use of this technology up to a 20% share of carbon emissions' abatement by 2050 to meet the 450 ppm stabilization scenario. According to the technico-economic literature (Van den et al., 2009),

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[1] SPC: Super critical pulverized coal plants; IGCC: Integrated gasification combined cycle plants.

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this would require a carbon price of about \$100/tCO_2 for NGCC plants[2] and \$40/tCO_2 for IGCC plants, based on current state-of-the-art technology.

The uncertainty regarding the effective prospects of world climate change policies surely explains why after an enthusiastic period in the middle of the previous decade, CCS optimism has since been seriously tempered by a lack of effective development of the technology. Carbon capture technology is still in its infancy, with approximately 20 plants in operation (Thronicker and Lange, 2015). Given this context, the potential of learning about CCS technology has attracted a growing interest. The promoters of CCS have long advocated that, although more costly, the technology could benefit from a large potential of cost reduction thanks to learning-by-doing.

Learning-by-doing postulates a progressive reduction of the production costs in the cumulative production capacity. In the engineering literature, the so-called learning rate refers to the percentage cost reduction that could result from doubling the production capacity. Van den et al. (2009) report learning rates for CCS varying between 5% and 18% for capital costs and between 0 and 30% for operating and maintenance costs regarding the main types of thermic plants. Such a huge variance reflects the complexity of the learning assessment exercise. Cost reduction is typically achieved through more energy efficient plants, better management of other pollution mitigation devices (e.g., SO_2 emission control) and dedicated progresses for CCS operation at the plant level. Moreover, learning about energy efficiency can also benefit non-CCS plants. If such technological spillovers could help with the deployment of CCS, they may also benefit production modes that are both more competitive and more polluting. Finally, all existing cost figures have been computed with respect to the highly efficient installations located in North America or Western Europe. Most coal-fired plants installed today in emerging countries, such as China or India, use cheaper techniques. However, the potential difficulty of applying CCS technologies designed for efficient Western plants to these low cost plants remains an open issue (Sheng et al., 2012).

There are four main economic drivers affecting CCS deployment. The first driver is the implementation of environmental policies targeting carbon concentration stabilization objectives throughout the current century. The second is the world's evolving demand for energy. The third driver is the change in the supply of fossil fuels and its resulting impact on the CCS economic potential. Finally, the fourth main economic driver affecting deployment is the competition between CCS and other carbon-free options from renewable sources, such as solar, wind or biomass. Within this context, the pros and cons of CCS can be summarized as follows: on the positive side, CCS allows for the use of fossil fuel, a relatively abundant and cheap energy source, without contributing to global warming. Furthermore, as a clean technological alternative to conventional fossil energy, it increases the social efficiency of the energy production system, thus lowering the social cost of carbon. Conversely, some proposed negative aspects are that the deployment of CCS is highly dependent on the availability of safe, convenient storage facilities and the avoidance of leakage risks to local populations and natural environments. Another concern is that relatively cheap CCS can also delay the development of clean renewable alternatives and/or hinder R&D in other energy production techniques (e.g., hydrogen).

Accounting for all of these issues, the objectives of this paper are two-fold. First, we want to assess the relative strengths of these pros and cons using a stylized economic model that incorporates the previously mentioned drivers. Second, we want to describe the effects of learning-by-doing as it pertains to the optimal timing of CCS use, the dynamics of the relative competitiveness in carbon sequestration compared to other clean energy sources, and its impact on the social cost of carbon pollution under a global atmospheric carbon concentration stabilization objective.

The main drivers affecting the economic potential of CCS are highly interconnected. In the literature, these linkages are taken into account in two ways. Many authors use integrated assessment models to evaluate the role of CCS (McFarland et al., 2003; Edenhofer et al., 2005; Gerlagh and van der Zwaan, 2006; Grimaud et al., 2011). These models underline the high sensitivity of this option concerning critical technological pitfalls and climate policy variables. However, in most cases, CCS is unlikely to become profitable until the second half of the century. Other authors pursue a more analytical route by introducing CCS in theoretical models of climate change. Lafforgue et al. (2008a,b) illustrate optimal CCS policies by using a model of energy substitution, explicitly taking into account the scarcity of sequestration sites. In a recent contribution, Grimaud and Rouge (2014) examine the CCS deployment problem using an endogenous growth model.

The issue of learning-by-doing has also attracted a great deal of attention concerning the 'induced technical change' debate. Following Goulder and Mathai (2000), it is recognized that learning about clean technologies can have ambiguous effects on the timing of the energy transition toward a carbon-free economy. According to Manne and Richels (2004) or Gerlagh (2006), such ambiguous features remain for CCS; learning should be expected to play a role in reducing the cost of carbon sequestration and thus the opportunity cost of carbon pollution. However, learning-by-doing influences not only the deployment of new techniques but also the production of energy and thus the energy price dynamics. This point is examined by Chakravorty et al. (2012) with learning-by-doing in clean renewable energy technologies. They show that learning generally induces price fluctuations over the course of the energy transition from polluting fossil fuels toward clean energy. Our own modeling framework is similar to this work but with a main difference: benefiting from learning-by-doing in CCS requires the burning of fossil fuels and thus forces us to confront their increasing scarcity. These two effects work in opposition of one another: the learning effect, which decreases with cumulative experience, and the scarcity effect, which increases according to the depletion of fossil resources. As the learning effect initially should override the scarcity effect and then becomes dominated by the latter, the average cost of the combined process, which consists of burning coal while

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[2] NGCC: natural gas combined cycle power plants.