Overlapping Policies and Clean Technology Adoption under Endogenous Uncertainty

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1 Extended Abstract

Market-based environmental policy instruments, such as taxes and pollution permits, are widely advocated as effective means to solve pollution-related externalities. They have been shown to be superior to command-and-control regulation in several respects, providing stronger incentives to promote abatement technologies (Jung, Krutilla and Boyd 1996), and being more effective in reducing emissions (Fowlie, Holland and Mansur, 2012). At the same time, however, it is well known that different market-based instruments might exhibit dissimilar performances (see, for instance, Kempe and Soete 1990, Requate 2005 and Perino and Requate 2012).

The recent resurgence of interest on the linkages among technology adoption, instruments choice and uncertainty is primarily motivated by the unsatisfactory performances of cap-and-trade schemes in some of their most relevant applications. The best example in this respect is surely the European Emissions Trading Scheme (ETS), the cap-and-trade scheme launched in 2005 to promote a cost-effective reduction of emissions in the EU. Since its inception, the carbon price has in fact, on several occasions, dipped below the level required to promote emissions abatement and to provide innovation incentives (EC 2010). The undergoing reform (the so called Market Stability Reserve - MSR) implies moving from a "pure" market mechanism towards a hybrid between a cap-and-trade and a carbon tax mechanism (Kollenberg and Taschini, 2015). In addition, in Europe, most countries complement the ETS with support schemes for renewable electricity generation (mainly in the form of feed-in tariffs or green certificates);

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this has received significant criticism: several authors argued that negative ETS - renewable energy policies interactions hinder the cost effectiveness of attaining overall environmental objectives[1].

We take a fresh approach towards uncertainty, explicitly modeling the impact of firms' technological choice (i.e., adoption or non-adoption of a low-carbon technology) on the effects of uncertainty on expected profits. Our model shows that technological choice affects the incidence of uncertainty on expected profits and, therefore, it can have a significant impact on the desirability of an "overlapping" of a price or a quantity based instrument with policy tools affecting uncertainty on the revenues or costs side (such as a feed in tariff).

More specifically, we consider a simple setting, in which two risk neutral firms initially share the same carbon intensive technology. Firms are subject to environmental regulation, and choose whether or not to adopt a low-carbon technology under uncertainty, which takes the form of shocks on the revenue as well as on the cost side affecting each firm. While revenue shocks are modeled as economy-wide shocks and are assumed to be perfectly correlated across firms regardless of their technological choice, the correlation of the cost shocks is a function of the firms' adoption pattern. If the two firms share the same technology, then they are subject to perfectly correlated cost shocks. If, instead, their technology differs, the correlation of their cost shocks turns out to be weaker. In this setting, both the level of uncertainty and the degree of correlation across the shocks faced by the firms are in turn affected by their own technological choice, and firms incorporate this consideration into their adoption decision.

As the impact of shocks correlation on the firms' profits (and, as a result, on the adoption choices) is shown to depend on the type and combinations of environmental and energy policies under scrutiny, we first compare each firm's expected profits in the two cases of adoption and of non adoption of the low-carbon technology, under price based regulation and under a cap-and-trade system; the two instruments are then complemented with energy related tools. In such a way, we pin down firms' adoption decisions, and derive the incentives to adopt low-carbon technologies induced by each (combination of) regulatory mechanism(s).

Our article relates to the strand of literature which analyzes the incentives for technology adoption under various pollution control approaches (Milliman and Prince 1989, Denicolò 1999, Requate 2005). In particular, Requate and Unold (2003) - henceforth R&U - compare carbon tax and cap-and-trade under perfect competition in the regulated sector and no uncertainty. They find that, with initially symmetric firms, taxes tend to induce symmetric adoption, while permits may determine asymmetric adoption. Their result may be interpreted by observing that, under cap-and-trade, each firm deciding to adopt triggers a decline in the demand for permits, and, as a result, of the permits price; this reduces the net benefits from additional adoption. On the contrary, a carbon tax is fixed regardless of the level of adoption; therefore, all of the firms face

[1] The overlap may only be justified on the ground of technology adoption considerations and the related market and policy failures (Lehmann and Gawel, 2013). For an overview of some recent relevant contributions, see Requate (2015).

the same net benefit from adoption, independently of the other firms' adoption strategies. While our results bear some analogies with those in R&U, in our setting incentives towards asymmetric adoption under cap-and-trade stem from the exploitation of the positive impact of uncertainty on expected profits when the two firms use different technologies in equilibrium, and are therefore subject to uncorrelated cost shocks. Along these lines, our results are coherent with what is obtained by Krysiak (2011), among others, who show how price or quantity based instruments can affect the incentives to adoption through the impact on firms' expected profits *via* uncertainty[2].

We start from this literature and extend it to account for the complex way in which overlapping policy instruments affect the relationship between uncertainty and the incentives of regulated firms to adopt. We apply our results to investigate the impact of a feed-in tariff that provides investors in low-emission technologies with a buffer against price fluctuations. Given our focus on the differential impact of uncertainty across the various policy instruments, we assume, for simplicity, that the feed-in tariff does not change the average return from the investment, but simply provides the investor with a fixed remuneration regardless of the market conditions. While feed-in tariffs are becoming an increasingly popular way to promote renewable technologies both in Europe and in the United States, the prevailing view among economists is that the combination of feed-in tariffs with carbon tax or cap-and-trade is inefficient (Bohringer and Rosendahl 2010), but their coexistence can be justified on the basis of technology adoption considerations and related market and policy failures (Lehmann and Gawel 2013). We contribute to the debate by showing that the feed-in tariff not only eliminates the revenue shocks of the firms subject to it, but it may also alter the correlation of the revenue shocks across firms. We find that, while a feed-in tariff unambiguously decreases technological adoption under a carbon tax system (close to the MSR introduced in the EU ETS), its effects under a cap-and-trade regime are subtler, and depends, among other things, on the productivity per emission of the "dirty" and "clean" technology. As a result of our analysis, endogenous uncertainty can, under certain conditions, be an additional theoretical justification for the overlapping of energy and climate policies.

We then perform a welfare comparison of the different possible policy mixes. As a carbon tax only triggers, in our symmetric setting, either full or no adoption, we conclude that a carbon tax maximizes welfare only when symmetric adoption patterns are socially desirable. In a more general setting, this would

[2] An extensive literature delves into the relation between uncertainty and environmental policy instruments, starting from the seminal work by Weitzman (1974). A variety of papers explicitly consider technological adoption under uncertainty and under alternative market-based policy instruments. In particular, Weber & Neuhoff (2010) analyze optimal cap-and-trade schemes with and without price controls when the regulator's optimal policy considers incentives for appropriate adoption of enhanced abatement technologies. Baldursson & Von der Fehr (2004) introduce the assumption of risk-aversion. Storrosten (2013) considers the choice between two abatement technologies with different degrees of flexibility. In these papers, differently from ours and from Krysiak (2011), the technological adoption choice does not affect the level of uncertainty, nor the degree of correlation across the shocks faced by the firms.

suggest that a hybrid system (like the one introduced by the EU MSR), is less flexible than a cap and trade scheme.

When a feed in tariff is introduced, different scenarios are analysed. More specifically, under an exogenously set feed-in tariff, we might observe overinvestment both under a carbon tax and under cap and trade; under an optimally (endogenously) set feed-in tariff, the social optimum is clearly achieved (two instruments are available to reach two goals - namely adoption and emissions reduction); we also model explicitly the case in which the feed-in tariff is set by national regulators, while environmental policy level is set by the central government (e.g. the EU). In this setting, we suggest that there would be room (or not) for free-riding by national regulators, depending on whether the game is simultaneous or sequential.

Finally, we show how optimal policies change when carbon mitigation policies and direct support schemes to renwables are chosen in two subsequent stages.

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