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A Note on Clean Technology Adoption and its Influence on Tradeable Emission Permits Prices

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Abstract In this paper, we give an example in which the price of tradable emission permits increases despite firms' adoption of less polluting technology, a result that is in contrast with Montero (J Environ Econ 44:23–44, 2002) and Parry (J Regul Econ 14:229–254, 1998), among others. If two Cournot players switch to a cleaner technology, the price for permits may increase due to an increase in the net demand for permits and a decrease in the net supply of permits after the clean technology is adopted. This is only the case when output demand is quite elastic.

Keywords Environmental innovation · Tradable emission permits · Cournot interaction

JEL Classification D43 · L13 · Q55

1 Introduction

The motivation of this paper is to show how the introduction of clean technology influences permit prices when the interaction of the permits with the output market is taken into account. The permits' price change is important because it influences firms' decisions to adopt clean technology. This paper relates to the literature on environmental innovation. Conclusions from this literature are generally based on the argument that environmental innovation yields a decrease in permit prices. In addition, this literature generally neglects the

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interaction between tradable permit markets and the output market. In contrast, the present paper takes into account the interaction between the two markets. Downing and White (1986), Milliman and Prince (1989), Tietenberg (1985) and Wenders (1975) show that market-based instruments such as tradable permits provide higher incentives to invest in environmental innovation than command-and-control instruments[1]. More recently, other authors like Parry (1998) and Requate (1998) have explicitly introduced a competitive output market in their analysis. To the best of our knowledge, only Montero (2002) considers the impact of strategic interaction in the output market on incentives for environmental innovation. Montero (2002) finds that investment in clean technology produces a decrease in the tradable permits price. This decrease results in a direct effect on the innovator's profits (positive or negative, depending on whether the firm is a buyer or a seller of permits) and in an indirect effect due to the decrease in production costs that allows the innovator and his rival to increase output. Incentives to innovate depend on the net effect. In fact, after the implementation of a cleaner technology, one expects the buyer of permits to decrease demand (and the seller of permits to increase supply) because firms are able to produce the same amount of output they were producing with the dirty technology but using less permits.

However, when the effect of the interaction between the two markets on permit prices is considered, we find that permit prices can either increase or decrease as a result of the adoption of clean technology. In our model, two symmetric Cournot competitors in the output market can use either a clean or a dirty technology, taking the price of the input (permits) as given. This last assumption is also present in other papers dealing with strategic agents subject to a tradable emissions permits market, like Malueg (1989, 1990) and Sartzetakis (1997a,b), and is inspired by the fact that firms trading in a region-wide market for emission permits operate in different local markets, making each single firm's influence in the region-wide market very low[2]. As in Bréchet and Jouvet (2008), we define the clean technology as a technology that has a lower degree of pollution intensity per unit of output than the dirty one. In this context, we show that other authors' intuition regarding a decrease in the permits price after the implementation of a clean technology is only true when output demand is inelastic. Instead, when the cap on emissions is binding and/or the decrease in the polluting intensity of output after the implementation of the clean technology is low enough, the price of permits may increase with the implementation of a clean technology. In particular, this is the case when output demand elasticity is high enough to induce an increase in firms' production. Firms then use the increase in efficiency, due to the implementation of the clean technology, to increase output production. Under these assumptions, the resulting equilibrium after the implementation of the clean technology yields a higher demand and a lower supply of permits.

Our results are in line with Malueg (1989, 1990) in the sense that the link between markets is due to the fact that the price of permits reflects the cost of output production. Given the technology used by each firm and the corresponding marginal input (permits) productivity, the permits price is both the unit cost (or revenue) of trading permits and the unit cost of output production.

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[1] See also Requate and Unold (2003) for a discussion.

[2] This is the case when thinking of the European Union Emission Trading Scheme (EU-ETS).

2 The Model

Assume that two symmetric firms (1, 2) competing *à la* Cournot are producing a homogenous good and face a linear output demand, i.e. $p(y_1 + y_2) = 1 - y_1 - y_2$. For simplicity, we assume zero costs of production. Production of good y generates emissions e as a by-product with an intensity k. We consider a linear production function $y = ke$ where the polluting intensity of output is $k = 1$ in the case of the dirty technology and $k > 1$ in the case of the clean technology. Firms are subject to an environmental regulation that establishes a binding cap S on total emissions and requires firms to hold permits for the exact amount of pollution emitted. A fraction α of total permits S is allocated for free to firm 1 and a fraction $(1-\alpha)$ to firm 2. The total amount of permits available S and the fractions α and $(1-\alpha)$ are common knowledge. We assume that firms comply with the environmental regulation: hence, emission levels and use of permits coincide. If the amount of permits received for free is different from the optimal amount of permits needed for output production, firms engage in permits trading.

Finally, we assume that the parameters of the model satisfy $k \leq 2$ and $\frac{k-1}{2k-1} \leq Sk \leq \frac{2}{3}$. These conditions guarantee that both firms make non-negative profits in any possible outcome[3].

2.1 Using the Dirty Technology

Taking the price of permits as given, firms maximize profits i.e.

$$\Pi_1(y_1, y_2) = (1 - y_1 - y_2)y_1 - r(e_1 - \alpha S),$$
$$\Pi_2(y_1, y_2) = (1 - y_1 - y_2)y_2 - r(e_2 - (1 - \alpha)S),$$

where r is the price for permits and $(e_1 - \alpha S)$ and $(e_2 - (1-\alpha)S)$ represent each firm's net demand for permits. For $\alpha < 1/2$, firm 1 is a buyer and firm 2 a seller of permits.

2.1.1 Output Market Equilibrium

Given that both firms are using the dirty technology (i.e. $y = e$), the profits of firm 1 can be expressed as

$$\Pi_1(e_1, e_2) = (1 - e_1 - e_2)e_1 - r(e_1 - \alpha S). \tag{1}$$

Similarly, profits for firm 2 are

$$\Pi_2(e_1, e_2) = (1 - e_1 - e_2)e_2 - r(e_2 - (1 - \alpha)S). \tag{2}$$

After computing the first order conditions and solving the system of equations, we find the optimal use of permits for both firms (where d stands for *dirty*)

$$e_{1,d}(r) = e_{2,d}(r) = \frac{1-r}{3}, \tag{3}$$

and thus the output equilibrium quantities

$$y_{1,d}(r) = y_{2,d}(r) = \frac{1-r}{3}. \tag{4}$$

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[3] The condition $k \leq 2$ is necessary for the existence of equilibrium in the permits market. This condition yields a positively sloped supply of permits. In addition, we will see that the equilibrium price of permits is not negative if $Sk \leqslant \frac{2}{3}$, whereas equilibrium levels of emissions are not negative if $Sk \geqslant \frac{k-1}{2k-1}$. The domain $\{k, S\}$ satisfying these restrictions is not empty.

The resulting market solution (Y_d^*, p_d^*) is:

$$Y_d^* = 2\frac{1-r}{3}, \tag{5}$$

$$p_d^* = 1 - 2\frac{1-r}{3}. \tag{6}$$

Notice that the output market solution depends on the permit price determined in the permits market where firms are price takers. This is typical in the setup used to model successive markets (see Salinger 1988).

2.1.2 Permits' Market Equilibrium

Firms claim their position as a buyer or seller of permits, given their output production choice. Notice that we assume that firms do not take into account that r is a function of $e_1 + e_2$ when maximizing profits in the output market. This is equivalent to assuming that firms are price-makers in the output market, but they are price-takers in the permit market, as we believe is the case in the EU-ETS market. This assumption is based on the same assumption[4] in Sartzetakis (1997a,b), wherein the pollutant in question is emitted by many industries in many countries producing goods with zero cross-price elasticity of demand and the clean technologies available are similar across countries. Thus, although the specific output industry in question is imperfectly competitive, the global permits market is competitive.

The permit market clearing condition yields the equilibrium price r_d^*:

$$r_d^* = 1 - \frac{3}{2}S. \tag{7}$$

Now, substituting (7) in (3) we obtain the equilibrium use of permits for both firms:

$$e_{1,d}^* = \frac{S}{2} = e_{2,d}^*, \tag{8}$$

and the equilibrium level of each firms' output

$$y_{1,d}^* = y_{2,d}^* = \frac{S}{2}. \tag{9}$$

2.2 Using the Clean Technology

The analytical solution for this symmetric Cournot case is the same as the previous one. The difference is that now both firms use the clean technology, $y = ke$, and therefore they maximize profits respectively:

$$\Pi_1(e_1, e_2) = (1 - ke_1 - ke_2)ke_1 - r(e_1 - \alpha S),$$
$$\Pi_2(e_1, e_2) = (1 - ke_1 - ke_2)ke_2 - r(e_2 - (1-\alpha)S).$$

Accordingly, the optimal use of permits is

$$e_{1,c}^* = e_{2,c}^* = \frac{(k-r)}{3k^2}. \tag{10}$$

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[4] This belief is shared with a number of authors who have contributed to the literature analyzing the EU-ETS market. See, for example, Convery et al. (2008).

The resulting market solution (Y_c^*, p_c^*) is then

$$Y_c^* = 2\frac{(k-r)}{3k^2}, \tag{11}$$

$$p_c^* = 1 - 2\frac{(k-r)}{3k^2}, \tag{12}$$

where the c stands for *clean*. Using (10) and the fact that supply and demand of permits must be equal, we find the equilibrium permits price, i.e.

$$r_c^* = k(1 - \frac{3}{2}kS). \tag{13}$$

Consequently, as in the dirty technology case, when both firms innovate $e_{1,c}^* = \frac{S}{2} = e_{2,c}^*$. The optimal output for each firm obtains as

$$y_{1,c}^* = y_{2,c}^* = k\frac{S}{2}. \tag{14}$$

The symmetric Cournot equilibrium is now realized for a higher output production than the level of production reached with the dirty technology.

The following proposition states what happens with permits prices.

Proposition 1 *When firms use the clean technology as opposed to the dirty one, the price for permits* r_c^* *increases if the decrease in the polluting intensity of output* k *is lower than the threshold value* $k < \frac{2}{3S} - 1$. *This threshold implies that output demand is quite elastic.*

Proof By direct comparison of permit prices in (7) and (13) , we find that the difference is positive, *i.e.*, $r_c^* - r_d^* > 0$, if $k < \frac{2}{3S} - 1$. □

This result may seem counterintuitive. One expects the buyer of permits to decrease his demand (or the seller of permits to increase his supply) after implementing the clean technology. Firms could produce the same amount of output they were producing with the dirty technology but using less permits. Then, each firm would have a larger number of permits available: the supplier would increase permits supply and the demander would buy less permits. This behavior of output-producing firms is only justified if the output demand is inelastic and there are thus no incentives to use the new technology to increase output production[5].

Otherwise, the symmetric Cournot equilibrium corresponding to the clean technology may be such that both firms wish to increase their output production proportionally to the increase in efficiency due to the utilization of the clean technology. Then, the gap of permits of the buyer (say firm 1) with the dirty technology, namely $e_{1,d}^* - \alpha S$, becomes even larger when the buyer switches technologies, $e_{1,c}^* - \alpha S$. For the same reason, the positive gap of the seller of permits with the clean technology, $e_{2,c}^* - (1-\alpha)S$, is smaller than the corresponding gap

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[5] Let us mention the difference between this result and Montero (2002). In Montero (2002)—see his Appendix E—the implementation of clean technology decreases total marginal abatement costs for each level of output (abatement costs are separable from production costs). Then, after innovation, the resulting price of permits that equalizes the now lower marginal abatement costs is naturally lower. Differently from Montero (2002), in our case the equilibrium price (13) depends on the use of permits for production in (10) that, in its turn, depends on the equilibrium that results from firms' strategic interaction in the output market, and consequently, on the elasticity of output demand.

$e^*_{2,d} - (1-\alpha)S$ with the dirty technology. In this case, then, the demand for permits increases and the supply of permits decreases. When this happens in all local markets, it generates a pressure on permit prices that produces an increase in their production costs. To this end, all the increase in production efficiency due to the implementation of the clean technology is used to increase output production, which pushes permit prices upwards. Then, we end up with a region-wide permits equilibrium price that is higher when the clean technology is in use.

The increase of permits prices requires that the output demand is *quite* elastic, namely that $k < \frac{2}{3S} - 1$. In fact, output demand is elastic for the pairs $\{k, S\}$ that satisfy $k < \frac{1}{2S}$, so that firms have strong incentives to increase output production. The condition $k < \frac{2}{3S} - 1$ is more restrictive. Therefore, not every level of elasticity of output demand leads to an increase of permits price. When $\frac{2}{3S} - 1 < k < \frac{1}{2S}$, the output demand is elastic but the price of permits decreases when implementing the clean technology. This is the case because firms will use part of their extra permits due to the implementation of the clean technology to increase production and another part to decrease their need of permits in the permits market (decrease demand or increase supply).

Proposition 1 underlines the importance of output demand characteristics and their influence in the permits market outcome. Moreover, it establishes the effect on permit prices of the interaction between the decrease in the polluting intensity of output due to the implementation of a clean technology k, the characteristics of output demand and the policy variable: the cap on emissions S.

3 Concluding Remarks

In contrast with previous literature, we have given an example in which the price of tradable emissions permits increases after firms adopt clean technology. In particular, we show that, if two Cournot players switch from a dirty to a clean production technology, the price for permits may increase due to an increase in the net demand for permits and a decrease in the net supply of permits. This is the case when the cap on emissions is binding and/or the decrease in the polluting intensity of output after implementing the clean technology is low enough. In particular, these conditions are only realized when output demand is quite elastic. Permits price change is one of the determinants of the incentives to adopt clean technology. Previous literature considers that each unit invested in R&D produces a (proportional) decrease in the separable cost of abatement. In this context one firm's innovation decreases permits prices, which on the one hand reduces its production costs (direct effect) but, on the other hand, increases competition in the output market (strategic effect) due to the decrease in the rival's production costs. The incentives to innovate then depend on the resulting net effect. In this paper, we show that under the circumstances underlined in Proposition 1, the direct effect may be by itself negative after innovation. Even if studying innovation incentives is beyond the scope of this paper, our findings suggest that innovation incentives provided by tradable emissions permits markets may depend on whether output market interaction is such that the condition in Proposition 1 is satisfied or not.

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