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COMBINING MINIMUM QUALITY STANDARDS AND EMISSION TRADING IN A PRODUCT LINE COMPETITION FRAMEWORK

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Combining minimum quality standards and emission trading in a product line competition framework.

(preliminary draft. Please do not quote without permission)

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Abstract

For a few industries, polluting emissions do not come from firm's production but from the consumption of its products. We investigate the inclusion of these industries in a emission trading system where multiproduct firms are made responsible for emissions arising from the consumption of less energy efficient goods sold in the market. Using a standard model where firms supply goods of different quality we show that the possibility to offset emissions related to lower quality goods by buying emission permits can usually increase firms' profits even when firms would not unilaterally benefit from producing less of the polluting model.

1. Introduction

As is well known, policies to mitigate the global effects of carbon dioxide (CO_2) and other greenhouse gases strongly rely on emissions trading. The political appeal of the Emission Trading Scheme set up within the European Union (EU-ETS) is clearly related to the promise of combining the setting of a predefined level of emissions while giving firms the possibility to choose the cost efficient way (i.e. abating or buying emission permits in the market) to cope with their own assigned objectives.

The EU-ETS may be considered the cornerstone of European Union policies to meet the Kyoto Protocol's emission limitations, and presently covers about 45% of the EU's carbon dioxide emissions. (30% of overall European greenhouse gases) (EC, 2005). The scheme embraces only large point sources of energy-related emissions, which certainly are a main source of greenhouse gases emissions, but have been decreasing in the share of overall emissions. By contrast, so far the EU-ETS has not been applied to the transportation industries, families and retail sectors. However, sectors not covered by the ETS may display dramatic increases in overall emissions, creating difficulties for compliance. In particular, the transportation industries are a source of major concern.[1]

A characteristic of many of these markets excluded from emission trading schemes is that most of the emission impact of firm's activities comes not from its production but from the consumption of its goods and services. An example relates those products whose use entails the consumption of large amounts of electricity (e.g., domestic equipments such as refrigerators, lighting and washing machines), or large amounts of fossil fuels (car industry and transportation in general, a sector whose emissions keeps growing strongly, or large amounts of energy in general terms (public and private buildings).

Though these goods and services are particularly important in the context of greenhouse gas

[1] The EU has approved plans to include aviation in the ETS and this could in principle move to consider bringing shipping within the scheme.

emissions and global warming, they not only elude the inclusion in ETSs but also mostly avoid to be the subject of a systematic application of standard economic instruments (e.g., higher consumption taxes on gasoline or universal carbon taxes) due to political opposition.

Not surprisingly, it is in this kind of markets that green labels systems and other voluntary approaches have been lengthy applied. In fact, another fundamental characteristic of these industries is that firms usually produce a range of products of different quality that vary in their energy efficiency. As is well known, in the European market the environmental quality in terms of energy efficiency is usually recognized by means of publicly recognized systems of labels or certifications. Some of the mostly known examples are those relating to electrical equipments, car engines, and recently to buildings.[2] In these sectors firms can produce different versions of a product that vary in their energy efficiency which firms can produce different versions of a product. This occurrence has been extensively studied in the literature (e.g. Johnson and Myatt, 2003; De Fraja, 1996; and early contributes by Gal-Or, 1983) and Champsaur and Rochet, 1989), with a series of models where firms usually compete by matching each other's product line rather than specialising in a single variety of goods.

This paper deals with these kind of markets and the related literature by sketching, somewhat provocatively, a framework where emissions related to the use of energy intensive varieties produced by firms could be, in principle, fully recognized within an ETS and imputed to producers. We contribute to the literature on environmental quality differentiation by studying how voluntary quality positioning is affected by the presence of an emission trading market. In particular, we consider a situation where firms are made responsible of the highest emissions related to the consumption of less efficient models of their product line through the "grandfathering" of a fixed level of allowances to produce polluting goods. Though, firms are allowed to under-comply and purchase allowances to make up the difference in case of excessive production

[2] See for example the website and the documents of the European Committee of Domestic Equipment Manufacturers (e.g., see CECED, 1997, 2008), of the European Automobile Manufacturers' Association (e.g. Michaelis and Zerle, 2006), and the KlimaHous project (2009).

of low quality goods.

A useful starting point which nests into the theoretical framework referred above is the model used by Ahmed and Segerson (2008, henceforth AS) to interpret strategic voluntary overcompliance by a few firms' associations in the European Union market,[3] which have been shifting their production shares reducing the amount of "brown" varieties of their goods and increasing the production of "greener" models. AS explain why in these market unilateral collective commitments may emerge aimed at reducing or eliminating less energy efficient models, by relating firm behaviour to strategic interaction oligopolistic markets.[4]

Building on the framework by AS I propose a partial equilibrium analysis where symmetric multi-brand firms compete *à la* Cournot and simultaneously produce different qualities (in energy efficiency terms) of a good. Firms are faced to an upper production limit to the energy inefficient models of their product line, but are allowed to buy emission permits proportional to the additional quantity of low quality goods exceeding the upper limit. By assuming simmetry among firms, I will not consider the possibility of being a net seller of permits, which incidentally could become a way of reinforcing the clean image of the firm. I also compare the combination of emission trading with a cap to the production of less energy efficient goods to a situation where firms are voluntary or mandatory constrained to a fixed upper limit.

2. The analytical framework

Let us consider a market where, for sake of semplicity, environmental quality is defined in a discrete fashion. Namely, assume that only two models of a product line are made available. We label by L the model characterised by a low energy efficiency (hence more polluting in CO_2 terms) by H the highly efficient variety. In line with De Fraja (1996) and Johnson and

[3] In particular, AS discuss the well known case of the CECED association of domestic appliance producers, which in the last decade has voluntary promoted the greening of their products and adopted a system of energy labels.

[4] For a standard classification of voluntary approaches in environmental policy see OECD (1999, 2003), Lyon e Maxwell (2002) and Brau and Carraro (2006).

Myatt (2003) – and differently from the traditional literature on qualitative choice[5] – we study a case where identical firms compete in the market not achieving a complete specialization, but producing both varieties of the good and carrying out a simultaneous choice of quality and quantity. As well known from the industrial organization theory, perfect symmetry among firms emerge in equilibrium under these circumstances.[6]

2.1 Characterisation of the demand side.

Let us assume the existence of N potential consumers with heterogeneous preferences with respect to the environmental quality of the produced good. Such heterogeneity may be due to genuine green consumerism effects or, more simply, to the different modality by means of which the good is used by consumers, which makes more or less convenient in relative terms the use of energy efficient models.[7] We model this kind of heterogeneity by assuming that each consumer can be identified by a parameter $\theta \in [0, 1]$ uniformly distributed.

By following AS, this assumption can yield the following simplified utility function for a type θ consumer who purchases the good $i = H$ or $i = L$:

$$\begin{aligned} V_H^\theta &= \lambda\theta - P_H, \\ V_L^\theta &= \delta\theta - P_L \end{aligned}$$

where:

[5] Firm's voluntary overcompliance strategies in a context of product differentiation have been studied by applying *à la* Hotelling models to green differentiation strategies (Lutz, Lyon and Maxwell, 2000; Arora and Gangopadyay, 1995). The crucial assumption in this kind of models is that the market is segmented because consumers display a different attitude towards "green" efforts by firms or "green" product characteristics. Moreover, interaction among firms is usually modelled as a two-stage game where firms first decide their product's relevant characteristic (e.g., the choice of emission technology), then compete on prices or quantities.

[6] As it is shown by Motta (1993) sequential choice always leads to asymmetric equilibria. On the other hand, simultaneous choice constitutes a suitable framework for achieving symmetry, which is a useful result for the analysis of those industries where several large firms compete by offering each of them both low and high quality models of the same good. (De Fraja, 1996).

[7] For example, diesel cars and very highly efficient electrical engines are mostly demanded by strong users, and less by occasional users.

- $\lambda = 1 - p_E x_H$ and $\delta = 1 - p_E x_L$. With this modelling, λ e δ reflect the marginal utility from using, respectively, high and low efficiency models.

- p_E is the unit price of energy, whilst x_i is the unitary energy consumption (e.g. per hour or per product unit) of model i. Notice that the low efficient model requires a higher energy use, so that $x_L > x_H$. As a consequence $\lambda > \delta$.

- P_i is the price of a generic model i.

Due to their lower utility, in equilibrium less energy efficient models must be cheaper than high efficiency ones, so that $P_H > P_L$. In particular, AS easily show that the inverse demand functions become

$$P_H = \lambda (1 - Q_H) - \delta Q_L \tag{1a}$$

$$P_L = \delta (1 - Q_H) - \delta Q_L \tag{1b}$$

$$Q_H = (1 - \theta_H) \tag{2a}$$

$$Q_L = (\theta_H - \theta_L) \tag{2b}$$

As can be seen, both high and low quality goods affect in the same way the other good inverse demand function (by the δ parameter). Moreover, symmetric variations in equilibrium quantities imply higher prices for good H and lower prices for good L.

2.2 Characterisation of the supply side:

Let set to zero the marginal production cost for low quality goods ($c_L = 0$) and assume higher and quadratic marginal costs for high efficiency models:[8]

$$C_H(q_H) = c_H q_H^2. \tag{3}$$

Let also assume the presence of a cap-and-trade system aimed at limiting the production of CO_2 emissions as a consequence of the use of energy intensive products. Similarly to what has happened in the EU-ETS, we can hypothesize that firms get allowances for free which entitle them to produce up to $\hat{K}$ units of the energy intensive good. The firm is still allowed to exceed this limit, but it will be asked to buy permits emission trading market proportional to the additional quantity of L goods which it produces. Notice that given fims' simmetry, which implies the same equilibrium solutions for each firm, such a model does not include the case where permits are sold.

To keep the model as simple as possible, it can be assumed that each energy unit used by consuming the good corresponds to a unito of CO_2 emissions. As a consequence, it becomes possible to define the overall quantity of emissions imputed to the firm by means of the following relationship:

$$E = x_L Q_L + x_H Q_H \tag{4}$$

For those case where the $\hat{K}$ limit is binding with respect to firm's 'free' choices, standard expressions of the profit function must be modified accordingly by introducing a term expressing the cost of emission reduction by means of the emission trading market. Let us define this function as follows:

[8] Given the normalization $c_L = 0$, it is not possible to assume quadratic costs for both goods, though AS state to do that. To ensure the positivity of equilibrium productions, we must also impose $C_H > 1$.

$$C_{ETS} = wz,$$

where z is the "exceeding" quantity of low environmental quality which can be marketed provided that the firm offsets additional emission by acceding the emission trading system. Hence, this quantity will be equal to the constraint:

$$z \geq Q_L^P - \hat{K}, \tag{5}$$

where the apex "P" stands for 'permit trading'.

Given the previous assumption (1 unit of energy = 1 unit of emissions), it can be stated that each low quality good implies a x_l quantity of emissions. The number of permits which must be purchased by the firm is, therefore, equal to $z * x_L$. By labelling the price of a allowance for a unit of emissions with p_Z, we get:

$$w = p_Z * x_L. \tag{6}$$

Hence, the symbol w expresses the cost of emission allowances per unit of energy inefficient good. In order to ensure the positiviy of equilibrium production, we must make the reasonable assumption

$$p_E \geq p_Z, \tag{7}$$

i.e. the unitary price of energy must be larger than the price of emission allowances for a energy unit.

On the whole, the firm's profit maximisation problem will take the form:

$$\Pi^P = P_H^P Q_H^P + P_L^P Q_L^P - c_H \left(Q_H^P\right)^2 - wz \tag{8}$$

$$\text{subject to the constraint} \qquad z \geq Q_L^P - \hat{K}$$

From the previous expression, one easily understands that the framing of firms' activities within an ETS may be seen whether as a constraint, or an opportunity. It is of course a constraint with respect to a situation where firms are totally free to choose their own preferred combination of low and highly energy efficient goods sold in the market, but also an opportunity with respect to a situation where production of energy inefficient goods is limited (compulsory or voluntary) to a fixed maximum level (say $\overline{K}$). We will develop a comparative analysis with respect to this situation (which is the one studied by AS) in section 5.

3. The monopolist's case.

By using the previous model in the case of a unique producer (labelled with the apex M) the following results for equilibrium quantities, prices and profits are obtained.[9]

The optimal production quantity of the highly energy efficient good is equal to:

$$Q_H^{MP} = \frac{w + \lambda - \delta}{2\left(c_H + \lambda - \delta\right)}. \tag{9}$$

Hence, the presence of a cap-and trade scheme implies a larger equilibrium production of energy efficient goods *vis à vis* a market where no $\hat{K}$ limit are introduced. Moreover, the emission permits' price has a constant positive effect on the equilibrium quantities of high quality goods.

By contrast, the quantity of the less energy efficient good which solves the monopolist's profit maximisation problem is the following:

[9] Notice that, for the following results, setting $w = 0$ yields the equilibrium quantities for a market without any constraint on the production of energy inefficient models. These values are extensively presented and discussed by Ahmed and Segerson (2006).

$$Q_L^{MP} = \frac{c_H (\delta - w) - w\lambda}{2\delta (c_H + \lambda - \delta)} \tag{10}$$

The previous expression is positive provided that the two regularity conditions $p_E \geq p_Z$ and C_H>1 hold.[10] As can be easily seen, a positive w implies lower equilibrium production, and has a negative effect on the equilibrium quantity of low energy efficiency goods. Moreover, in absolute terms this effect is always larger than that on the energy efficient model.[11]

As far as prices are concerned we have:

$$P_H^{MP} = \frac{\lambda (\lambda - \delta) + c_H (w + 2\lambda - \delta)}{2 (c_H + \lambda - \delta)} \tag{11}$$

$$P_L^{MP} = \frac{w + \delta}{2} \tag{12}$$

Hence, framing firms into the cap-and-trade system implies an increase of both equilibrium prices. Similarly to the effects on quantities, a variation of emission allowances prices has larger positive effect on the price of energy inefficient goods.

Finally moving to profits, we can easily get the following expression where the numerato can be expressed as second order polynomial in w:

$$\pi^{MP} = \frac{(c_H + \lambda) w^2 + 2\delta \left[2\hat{k} (\lambda - \delta) - c_H \left(2\hat{k} - 1\right)\right] w + c_H \delta^2 + \lambda\delta (\lambda - \delta)}{4\delta (c_H + \lambda - \delta)}. \tag{13}$$

The previous expression is always positive. Moreover, by taking the derivative with respect to w it is obtained that profits will be increasing for

$$w > \frac{2\delta \left[c_H (2k - 1) - 2k (\lambda - \delta)\right]}{c_H + \lambda}. \tag{14}$$

[10] See the appendix for a simple proof of this statement.

[11] Notice that, from equation (1a1a) this represents a necessary condition for having higher equilibrium prices for energy efficient goods.

Hence, a sufficiently high price of emission permits will ensure a positive relationship between emission permits prices and monopolists' profits. The previous condition will be satisfied for any positive value of w provided that:

$$\hat{k} < \frac{c_H}{2\left(c_H - (\lambda - \delta)\right)}. \tag{15}$$

The latter is the root of the first degree polynomial in w in the numerator of the profit function, and is strictly larger than the equilibrium supply of the less efficient good by the monopolist when no cap exists on the production of these goods.

Therefore, an interesting implication arises from the latter expression:

Proposition 1 *Profits will be always increasing in w provided that $\hat{K}$ is binding, i.e. $\hat{K} < Q_L^M$*

A second interesting result arise when comparing (13) with equilibrium profits when no limits exists for the production of the less energy efficient good. By setting $w = 0$ in (13) it is obtained that the difference between the two profit functions is given by:

$$\pi^{MP} - \pi^{M} = \frac{(c_H + \lambda) w^2 + 2\delta \left[2\hat{k}(\lambda - \delta) - c_H \left(2\hat{k} - 1\right)\right] w}{4\delta (c_H + \lambda - \delta)} \tag{16}$$

The complete characterisation of the previous expression may be somewhat tedious, but a sufficient condition for the positivity of the numerator is clearly given by the same value detected above, which ensures the positivity of the relashionship between emission permits prices and profits, namely $\hat{k} < \frac{c_H}{2(c_H - (\lambda - \delta))}$. This yields the following proposition.

Proposition 2 *Monopolist's profits are higher under the cap-and-trade system provided that the threshold $\hat{K}$ is binding, i.e. $\hat{K} < Q_L^M$*

On the whole, at a first sight these kind of results may seem quite unexpected. Intuitively, the reason why profits are increasing in w is related to the positive effect on both equilibrium quantities and prices of most energy efficient goods. In fact, in this kind of models, shifting from low to high quality models is not neutral since, as originally shown by De Fraja (1996, Corollary 2), the difference between price and cost increases with quality.

4. Duopoly and general oligopoly cases.

Let us now consider the case of two identical firms facing the demand and supply conditions defined above and engaged in Cournot competition.

In the absence of any limit on the production of mostly polluting goods, a firm j will choose quantities q_H^j e q_L^j which maximise the following function:

$$\Pi^j = P_H^j q_H^j + P_L^j q_L^j - c_H \left(q_H^j\right)^2 . \tag{17}$$

Introducing an emission trading market and a cap $\hat{K}$ on firm's production of the less efficient models, the profit function which firms must maximise becomes:

$$\Pi^{j0P} = P_H^{j0P} q_H^{j0P} + P_L^{j0P} q_L^{j0P} - c_H \left(q_H^{j0P}\right)^2 - wz \tag{18}$$

$$\text{subject to } z \geq q_L^{j0P} - \hat{K}$$

Solving the game where firms simultaneously choose the two optimal quantities, we get the equilibrium values at the Nash equilibrium:

Firm's production quantities

a)*Duopoly*

$$q_H^{10P} = q_H^{20P} = \frac{w + \lambda - \delta}{2c_H + 3(\lambda - \delta)} \tag{19}$$

$$q_L^{10P} = q_L^{20P} = \frac{2c_H(\delta - w) - 3w\lambda}{3\delta\left[2c_H + 3(\lambda - \delta)\right]} \tag{20}$$

b) Oligopoly with n firms

$$q_H^{nP} = \frac{w + \lambda - \delta}{2c_H + (n+1)(\lambda - \delta)} \tag{21}$$

$$q_L^{nP} = \frac{2c_H(\delta - w) - (n+1)w\lambda}{(n+1)\delta\left[2c_H + (n+1)(\lambda - \delta)\right]}. \tag{22}$$

As for the monopoly case, the equilibrium quantities, prices and profits for the case where no constraint $\hat{K}$ can be recovered by setting w =0 in the previous expressions. It is immediate to remark that the equilibrium quantity of high quality goods is larger than the one for the base case. It is also confirmed that this quantity (hence the total quantity sold in the market) is increasing in the permits price w. On the contrary, the equilibrium production of the energy inefficient model is lower than in the base case (of course larger than the constraint $\hat{K}$ and is a decreasing function of w.

Equilibrium market prices

a) *Duopoly*

$$P_H^{2P} = \frac{3\lambda(\lambda - \delta) + 2c_H(2w + 3\lambda - 2\delta)}{3\left[2c_H + 3(\lambda - \delta)\right]} \tag{23}$$

$$P_L^0 = \frac{2w + \delta}{3} \tag{24}$$

b) Oligopoly with n firms

$$P_H^{MP} = \frac{\lambda(\lambda - \delta)(n+1) + 2c_H(\lambda + n(w + \lambda - \delta))}{(n+1)\left[2c_H + (n+1)(\lambda - \delta)\right]} \tag{25}$$

$$P_L^0 = \frac{nw + \delta}{(n+1)} \tag{26}$$

Again, equilibrium prices are higher than in the absence of the any constraint $\hat{K}$ combined to emission trading market. Differentiation of the previous expressions allows for a simple evaluation of the strength effect of permit prices. For example, in the duopoly case we get:

$$\frac{\partial P_H^{j0P}}{\partial w} = \frac{2}{3}\left[\frac{2c_H}{[2c_H + 3(\lambda - \delta)]}\right] > 0 \tag{27}$$

$$\frac{\partial P_L^{j0P}}{\partial w} = \frac{2}{3} > 0 \tag{28}$$

Hence, the effect of a variation of w is positive in both cases. Moreover, given that $\lambda - \delta > 0$, it is confirmed that a variation into the emission permit prices will affect to an higher degree the price of less energy efficient goods.

As for profits, again it is possible to get an expression where the numerator is a second order function of w.

$$\pi^{jP} = \frac{Aw^2 + Bw + C}{[3\delta(2c_H + 3(\lambda - \delta))]^2}, \tag{29}$$

where A,B and C are the following polynomials:

$$\begin{aligned}
A &\equiv [c(4c + 3(4\lambda - \delta)) - \lambda] \\
B &\equiv \delta\left[(\lambda - \delta)\left(81\hat{k}(\lambda - \delta) + 6c\left(18\hat{k} - 1\right)\right) + 4c^2\left(9\hat{k} - 2\right)\right] \\
C &\equiv 4c^2\delta^2 + \delta(\lambda - \delta)[3c(3\lambda + \delta) - \lambda]
\end{aligned} \tag{30}$$

Being the polynomials A and C positive, also equilibrium profits will be always positive.

As for the polynomial B, it will be negative for a sufficiently low value of $\hat{K}$, which is strictly higher than the equilibrium duopoly offer of the less energy efficient good in an unconstrained market.[12]

Taking the derivative with respect to w we obtain that profits will be increasing for $w > -\frac{B}{2A}$, which implies that any positive price w will ensure increasing profits provided that $\hat{K}$ is binding.

Finally, profits will always be larger in the presence of a cap and trade scheme than in an unconstrained market. By making the same considerations made for the monopolist's case we get:

$$\pi^{jP} - \pi^{j} = \frac{Aw^2 + Bw}{\left[3\delta\left(2c_H + 3\left(\lambda - \delta\right)\right)\right]^2}, \tag{31}$$

for which a sufficient condition for positivity is the K root of B already used for characterising the sign of $\frac{d\pi^{jP}}{dw}$.

We can summarise our findings as follows.

Proposition 3 *Proposition 1 and 2 hold also in the case of oligopolistic markets.*

Again, the result may seem quite counterintuitive, but is not completely new in the literature (e.g. Farzin and Akao, 2006).

Let us finally study the effect of a stricter cap on firms' profits. We easily get a positive sign ($\frac{\partial\pi^{jP}}{\partial K} > 0$) by simply taking the derivative of the polynomial B with respect to $\hat{K}$. Hence, though larger than in the absence of a cap and trade system, profits will decrease with a stricter regulation.

It turns out that firms will usually oppose the setting of stricter ceilings on the production of less efficient goods. From a policy implications perspective, a policy where the limit $\hat{K}$ is set to a quite strict level with a "one shot" decision would seem preferable in order to avoid industry

[12] This value is actually equal to $\hat{k} < q_L^j \left[1 + \frac{2c_H}{[2c_H + 3(\lambda - \delta)]}\right]$

opposition to further modifications once the emission trading option has been granted by the policy maker. To summarise.

Proposition 4 *A win-win policy is given by a "one shot" admission of firms to the emission trading market with immediate setting of the ceiling $\hat{K}$ to the long-run objective of the policy maker.*

4. Conclusions

For a few industries, polluting emissions do not come from firm's production but from the consumption of its products. Though these sectors are accounting for an increasing share of greenhouse gas emissions, there are difficulties in extending effective policies aimed at mitigating their environmental impacts whether for political opposition to using carbon taxes, or difficulties in extending ETS to families.

The basic aim of the model presented has been that of framing strategic interaction among "multi-brand" firms with an emission trading scheme where emissions related to the consumption of energy inefficient models are imputed to firms by imposing a cap to the production of these goods.

Both monopoly and oligopoly cases have been studied, by obtaining the same qualitative results. In particular, accounting for emissions of firms' energy inefficient goods within a cap-and trade scheme is effective in reducing the production of polluting goods and seems to imply a larger equilibrium production of energy efficient goods vis à vis a market where no $\hat{K}$ limit is introduced. The policy is also effective in targeting consumers who are the ultimate responsible of CO_2 emissions by positively affecting the good prices.

Due to the shifting from polluting and cheaper models to energy efficient and expensive varieties, the most striking result is that profits will always be larger in the presence of this particular ETS than in an unconstrained market.

Moreover, in product line competition models the price increase is determined by preference heterogeneity, which implies that consumer surplus is usually poorly affected in equilibrium. Together with the positive welfare effect induced by emission reduction, it is likely to detect potentially win-win situations, which of course may have important policy implications as far as the lack of political opposition is concerned.

Limits of this analysis are mainly related to not having considered the possibility for some firms to overcomply with the production limits and selling their own saved allowances. This is certainly difficult in a product line competition model where usually symmetry is obtained. Finally, an additional scope for future research would be represented by the endogenisation of the dynamics of permits' price.

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0.2 Appendix:

Let us compare w and δ:

$$w = P_Z * x_L$$

$$\delta = 1 - p_E x_L$$

By using the condition that $p_E \geq p_Z$, we get:

$$\delta > w.$$

Looking at the numerator of equation (10), we get that the maximum of the RHS polynomial would be obtained for $w = p_E x_L$ and $\lambda = 1$.

In the limit case $p_E = p_Z$ we would have:

$$c_H \left(1 - p_E x_L + p_E x_L\right) - p_E x_L * 1,$$

which is certainly positive for c_h>1.