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Abstract

We determine the emergence of the Porter Hypothesis in a large oligopoly setting where the industry-wide adoption of green technologies is endogenously determined as a result of competition among coalitions. We examine a setting where the initial technology is polluting, firms decide whether to be brown or green and compete in quantities. We find that the Porter hypothesis may emerge as a market configuration with all green firms spurred by environmental regulation, even if consumers are not environmentally concerned. Finally, we single out the necessary and sufficient conditions under which the green grand coalition is socially optimal and therefore yields a win-win outcome.

JEL codes: L13, L51, Q50.

Keywords: emission taxation; pollution; coalition stability; green technology.

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1 Introduction

Over the last two and a half centuries, since the very beginning of the industrial revolution, the bulk of industrial activities and the associated growth of the world economy have relied on brown energy delivered by the intensive exploitation of nonrenewable fossil fuels. It is now widely recognised that, should the economic system continue to go the brown way, the planet would run out of nonrenewable polluting resources in a matter of generations; exactly how many is a matter of opinions and estimates, but compared to the farthest future, it is certainly too small a number. Additionally, future generations would inherit a planet which would be not only depleted of its pristine stock of resource, but heavily and perhaps even irreparably transfigured for the worse by climate change. So, the question is whether a mix of private incentives and public policies may avoid the realization of this scenario. In this paper we model this interplay to show that there may exist a way of combining profit incentives and policy tools to open up a green production path.

The key question is: will a number of energy-intensive industries, or even the whole world economy put itself on a sustainable growth path?[1] Is there any hope that large populations of profit-seeking corporations will indeed turn themselves green as a reaction to a changing landscape, by positively responding to the introduction of new regulatory instruments building up binding limits to the environmental impact of firms' activities? According to the *Porter hypothesis* (Porter, 1991), we may expect profit-seeking firms to behave like that, expecting to be better off if they do so, under appropriate policy stimula.

Over more than two decades, the Porter hypothesis (PH, hereafter)[2] has generated a lively trend of thought about the existence of promising links between public environmental concern and firms' green strategies (or the lack thereof). The foundation of this debate asserts the possible existence of positive private returns to pollution control investment, possibly large enough to more than offset the cost of compliance. If this is true, then a win-win solution triggered by environmental regulation and driven by firms' reaction to it is in fact within reach. The essence of the PH boils down to the

[1] Here, 'sustainable' means not necessarily altogether green but simply 'low carbon', as the basic requirement boils down to reducing the emission rate of production and consumption activities to a level compatible with the environment's capability of absorbing and recycling CO_2 and other greenhouse gases, as it did for ages before the beginning of the industrial revolution.

[2] See Ambec *et al.* (2013) for an exhaustive survey of the debate on the PH.

idea that strict but flexible environmental regulation encourages innovations enhancing competitiveness and contributing to make firms more profitable, and therefore happy to deliver a socially efficient outcome such as a clean (or at least cleaner) environment, as a by-product of their own private incentives. Porter and van der Linde (1995a,b) in particular, claim that pollution is often a waste of resources. Under certain conditions, reducing the latter may drive an increase in firms' productivity and profits. Regulations therefore may ultimately help firms by unlocking unexpected profit opportunities.[3] With this in mind, Porter and van der Linde's (1995a,b) view privileges market-based instruments (like emission taxes and the costly allocation of pollution rights) rather than command-and-control instruments (like environmental standards).

The stream of research generated by Porter and van der Linde (1995a,b) has investigated two different versions of the PH. The *weak* one claims that firms do respond to environmental regulation by investing in R&D for green (either abatement or replacement) technologies, which in turn may not lead to higher profits. The *strong* version of the PH says instead that one of the consequences of environmental policy is indeed that of increasing firms' profit perspectives.[4] Obviously, the strong version has generated a debate which would not have stemmed out of the weak alternative formulation, the reason being that conventional wisdom has it that, in general, limiting firms' freedom should ultimately compromise their performance (cf. Palmer *et al.*, 1995). Hence one could say that, in a way, the effective merit of Porter and van der Linde's (1995a,b) papers has been that of convincing businessmen (among whom the PH is receiving a growing amount of attention) as well as policy makers about the potentially proficuous nature of environmental regulation.

If put into being, the virtuous mechanism embodied in the strong version of the hypothesis would produce a win-win outcome in which both a cleaner environment and a higher financial performance would go hand in hand, as a result of the reciprocal alignment of private (profit) incentives and social (welfare) incentives.

A distinctive feature of the PH is that it does not necessarily require any consumers' environmental awareness, relying primarily on pure profit incentives towards

[3] Since Gore (1993), politicians have viewed the green economy as a chance for growth and competitiveness for the industry. See also Wagner (2003).

[4] A third version of the PH is known as *narrow*, and claims that flexible policy instruments outperform command-and-control instruments as for the resulting innovative incentives perceived by firms. For more on different formulations of the PH, see Jaffe and Palmer (1997).

green innovations to neutralise environmental regulation. Several studies (indeed, too many to be exhaustively mentioned here) have shown that world-wide, consumers' appetite for green products has increased significantly in the past years (see Kim and Choi, 2005; Chen, 2008, *inter alia*). The rise of such consciousness has resulted in significant environmental improvement (Reitman, 1992). More companies around the world have reacted by developing eco-friendly products and pollution control investments (Chang, 2011). Higher costs required for the progressive eco-technology are sustainable due to larger demands of green consumers. PH is seemingly easier to implement if green consumption is in place. This is crucial to justify the trade-off between costs and benefits rendering the policy acceptable. Interestingly, Constantatos and Herrmann (2011) for instance propose a duopoly model where consumers recognise the green quality of the products only with a time lag. Thus if regulation does not impose a simultaneous adoption of the eco-friendly technology among companies, a firm unilaterally may lose profits due to higher costs (which represents a *direct* effect) and reduce market share due to higher product prices (which is a *strategic* effect).

Unlike much of the current literature on environmental issues, including the PH, the present analysis sets aside the assumption of environmental awareness. Our intention is to emphasize the possibility to obtain beneficial impacts from regulation simply due to the spontaneous firms's reaction to an environmental policy, the latter being not amplified or accompanied by any environmental consciousness on the part of consumers. No variations in demands or information of green technology adoption are needed, and we will assume that the representative consumer is characterised by a concave utility function where there is no room for the environmental impact of either consumption or production. Our point simply rests on the streamlined background idea that competitive pressure intensified by regulation pushes innovation and the resulting mechanism yields a Pareto efficient outcome for firms and society alike.[5]

The extant debate on the PH mostly relies on duopoly models (Ambec and Barla, 2002, 2006; André *et al.*, 2009; Constantatos and Herrmann, 2011; Lambertini and Tampieri, 2012; *inter alia*). We instead model an oligopolistic Cournot sector in partial

[5] Note that our approach has the aim to highlight the role of competition, but does not exclude - in principle - the presence of environmental awareness. Intuitively, green consumers taking into account the firms' environmental attitude in shaping their consumption decisions would generally prefer to buy from firms endowed with green technologies. This would be in line with the results supporting the Porter hypothesis, and would plausibly facilitate the attainment of a win-win solution.

equilibrium, where firms individually decide whether to be brown or green and then compete in quantities. Brown firms are subject to a tax rate on polluting emissions. On the other hand, green firms do not bear any taxes, but incur both a cost of investment in clean technology and a higher marginal production cost. To characterise firms' choices concerning the nature of their production technology, we resort to a tool borrowed from coalition theory (cf. d'Aspremont *et al.*, 1983; Donsimoni, 1985; Donsimoni *et al.*, 1986; and Thoron, 1998). Using the concepts of internal and external stability of a coalition and assessing the welfare properties of the oligopoly under consideration, we identify the conditions on the two key parameters of the model, the emission tax and the exogenous R&D cost of obtaining the green technology, such that the green grand coalition (i) is stable and (ii) generates a win-win solution, thereby yielding a theoretical vindication of the PH in its strong formulation.

From an empirical perspective, the possibility of systematically testing the emergence of the PH may be limited by several problems affecting the nature of the data as well as their availability. Indeed, regulatory compliance expenditures do not provide a truly exogenous measure of regulatory burden since the amount of these costs also depends on the adaptability to regulation of an industry. In light of this, Jaffe and Palmer (1997) show the existence of a positive link between R&D expenditures and pollution abatement costs, as a proxy for the stringency of environmental regulation. Popp (2005) examine the presence of the PH by calibrating a model of induced R&D when the the outcome of innovation is uncertain. The strong version of the PH is here supported in some cases. Lanoie *et al.* (2011) test the significance of the PH using data on environmental policy, research and development, environmental performance, and economic performance. They find strong support for the weak version but no support for the strong version. In a recent work, Rexhäuser and Rammer (2014) show that only innovation processes influencing the resource efficiency of firms have a positive net return. Hence the PH in its strong version does not hold in general, its emergence depending on the type of environmental innovation applied.

The remainder of the paper is organised as follows. The outline of the setup is in section 2. Section 3 contains the analysis of coalition stability. Section 4 illustrates the necessary and sufficient conditions for the strong formulation of the PH to emerge at equilibrium. Concluding remarks are in section 5.

2 The model

Consider a static market with $n \geq 2$ firms competing *à la* Cournot-Nash.[6] Firms supply a homogeneous good, whose demand function is $p = a - Q$, where a is a positive constant parameter measuring the reservation price and $Q = \sum_{i=1}^{n} q_i$ aggregates all firms' individual output levels q_i. Firms can be of two types, either brown or green. A brown firm uses a polluting production technology and bear an emission tax rate $t > 0$ imposed on each unit of output. Conversely, the production of green firms does not affect the environment, so that no taxation is levied on them. However, green companies face an investment costs k to implement their green production technology, and their marginal cost is higher than the one of brown firms. Without loss of generality, we normalise marginal production cost of a brown firm to zero, whereas the marginal production costs of a green firm are $c \in (0, a)$. This assumption reflects the higher cost of environmentally friendly resources in the real world. Reports from many countries show that, for instance, the energy produced with on/offshore wind and photovoltaics/thermal solar, is more costly than the energy obtained from coal or natural gas.[7]

Before market competition takes place, each firm decides whether to be brown or green. Suppose that the industry is populated by $1 \leq m \leq n$ green firms and $n - m$ brown firms. The demand function is thus:

$$p = a - mq_g - (n - m)\, q_b, \tag{1}$$

where subscripts b and g mnemonic for *brown* and *green*, respectively. The profits of a green firm are defined as follows:

$$\pi_g = (p - c)\, q_g - k, \tag{2}$$

while those of a brown firm are

$$\pi_b = (p - t)\, q_b. \tag{3}$$

In the remainder, we shall assume $a > t > c$. This assumption ensures that (i) the reservation price is large enough for both types of firm to be viable, and (ii) it may be

[6] See André *et al.* (2009) and Lambertini and Tampieri (2012) for a model of vertical differentiation in a duopoly framework with price and quantity competition, respectively. They both find that a policy regulation, i.e., a tax on brown technology is Pareto-improving for all firms. Mohr (2001) propose a similar framework looking at the impacts of the technological spillovers.

[7] See the OpenEI database for United States, the 2013 German report by Fraunhofer, and the 2010 British report by Pasons Binckernhoff, *inter alia*.

convenient for a firm to be green (otherwise, for any $t < c$, it would not be convenient to opt for the green technology). As it is usually assumed, the environmental damage S is a quadratic function of the quantity produced by brown firms:

$$S = \frac{v \left(\sum_{b=m+1}^{n} q_b \right)^2}{2}, \tag{4}$$

where v is a positive parameter.

Total tax revenue is $T = t \sum_{b=m+1}^{n} q_b$, whereas consumer surplus is measured by $CS = Q^2/2$. Hence, social welfare is defined as the sum of industry profits, consumer surplus and tax revenue, minus the environmental damage:

$$SW = \sum_{g=1}^{m} \pi_g + \sum_{b=m+1}^{n} \pi_b + CS + T - S. \tag{5}$$

3 Stability analysis

To begin with, it is worth noting that the Cournot-Nash equilibrium of this industry is equivalent to that emerging in a situation in which there are two sets of asymmetric firms endowed different marginal production costs. Here, one is indeed a production cost while the other is mimicked by the emission tax rate. The market equilibrium is thus identified by the following pair of output levels:

$$q_g^m = \frac{a - c(n - m + 1) + t(n - m)}{1 + n}, \tag{6}$$

$$q_b^{n-m} = \frac{a + cm - t(m + 1)}{1 + n}, \tag{7}$$

for each of the m green firms and $n-m$ brown ones. The resulting individual equilibrium profits are

$$\pi_g^m = \frac{[a - c(n - m + 1) + t(n - m)]^2}{(1 + n)^2} - k, \tag{8}$$

$$\pi_b^{n-m} = \frac{[a + cm - t(1 + m)]^2}{(1 + n)^2}, \tag{9}$$

given two generic groups of size m and $n - m$, respectively.

The next step, which drives us into the real of coalition theory, consists in taking the fully brown industry where $m = 0$ as a benchmark, to examine the stability of the grand coalition made up by n brown firms, in view of the incentive for a firm to become a green singleton. Fixing, respectively, $m = 1$ in (8) and $m = 0$ in (9), we obtain the following profits expressions:

$$\pi_g^1 = \frac{[a - cn + t(n-1)]^2}{(1+n)^2} - k, \tag{10}$$

$$\pi_b^n = \frac{(a-t)^2}{(1+n)^2}, \tag{11}$$

which measure, respectively, (i) the performance of a single firm becoming unilaterally green, and (ii) that of each firm in the brown grand coalition. There exists an incentive to abandon the brown grand coalition unilaterally if and only if the following expression is positive:

$$\pi_g^1 - \pi_b^n = \frac{n(t-c)[2(a-t) + n(t-c)] - (1+n)^2 k}{(1+n)^2}. \tag{12}$$

Observing (12), we may claim

Lemma 1 *The brown grand coalition is unstable for all* $k \in (0, \overline{k})$ *, where*

$$\overline{k} \equiv \frac{n(t-c)[2(a-t) + n(t-c)]}{(1+n)^2}.$$

This implies that if the R&D cost of developing the green technology is sufficiently small, one has to expect unilateral deviations from the *status quo ante* in which all firms share the brown technology and bear the emission tax. This produces the additional question about how many firms will indeed choose to go green.

In order to determine the equilibrium partition of the population of firms between the brown and green types, we resort to a stability condition borrowed from coalition theory and used in the literature discussing the optimal size of a cartel facing a competitive fringe, as in d'Aspremont *et al.* (1983), Donsimoni (1985), Donsimoni *et al.* (1986) and Thoron (1998).

We take as the object of our interest the stable green coalition of size $m \geq 1$. In the present model, a partition $\{m, n-m\}$ with m green firms and $n-m$ brown ones is stable if no green firm desires to become brown (*internal stability*) and at the same time no brown firm desires to shift to green (*external stability*).

Consider first the internal stability criterion. For the green coalition of size m to be stable, there must exist no incentive for any of its member to deviate unilaterally and join the brown coalition. Let

$$\pi_b^{n-m+1} = \frac{[a + c\,(m-1) - tm]^2}{(1+n)^2}, \tag{13}$$

denote the profits of a brown firm, when a single green firm quits the m-sized green coalition to become brown, thereby increasing the numerosity of the brown coalition to $n - m + 1$.

Likewise, one can easily compute the profits of a green firm when a brown firm changes its type becoming a green one, thereby increasing the size of the green coalition to $m + 1$:

$$\pi_g^{m+1} = \frac{[a - t + (n-m)\,(t-c)]^2}{(1+n)^2} - k. \tag{14}$$

Hence the stability conditions for a market structure with m green firms and $n - m$ brown firms are:

$$\begin{cases} \pi_g^m \geq \pi_b^{n-m+1} \text{ (internal stability)} \\ \pi_b^{n-m} \geq \pi_g^{m+1} \text{ (external stability)} \end{cases}. \tag{15}$$

A coalition is defined as internally stable if and only if, for $m \geq 1$, the profits of each single green firm associated to other $m - 1$ green firms are higher than those the same firm would attain by moving from the green coalition towards the alternative brown coalition. Conversely, a coalition of m green firms is defined as externally stable if and only if, for $m \leq n - 1$, there is no incentive for a firm in isolation to move from the brown coalition towards the green one. We already know from Lemma 1 that the degenerate coalition consisting in the singleton $m = 1$ is externally stable for all $k \in (0, \overline{k})$. We are about to show that, provided the cost associated with green R&D is not too high, the stability conditions (15) are simultaneously verified by some admissible values of m at least equal to one and at most equal to n. To this aim, define as (i) m_I the maximum value of m such that internal stability holds, i.e., $\pi_g^m > \pi_b^{n-(m-1)}$, and (ii) m_E the minimum value of m above which external stability holds, i.e., $\pi_b^{n-m} > \pi_g^{m+1}$. The following lemma applies:

Lemma 2 *Any* $k \in \left(0, \widehat{k}\right]$ *ensures* $m_I, m_E \geq 1$.

Proof. The first difference related to the internal stability shows that:

$$\pi_g^m - \pi_b^{n-(m-1)} = \frac{n\,(t-c)\,[2\,(a-c) - (t-c)\,(2m-n)] - k\,(1+n)^2}{(1+n)^2} \geq 0, \tag{16}$$

if and only if

$$m \leq m_I \equiv \frac{n(t-c)[n(t-c)-2(a-c)]-k(1+n)^2}{2n(t-c)^2}.$$

In turn, $m_I \geq 1$ for all $k \in \left(0, \overline{k}\right]$.

External stability requires

$$\pi_b^{n-m} - \pi_g^{m+1} = \frac{k(1+n)^2 - n(t-c)[2(a-t)+(t-c)(n-2m)]}{(1+n)^2} \geq 0, \tag{17}$$

which holds for all

$$m \geq m_E \equiv \frac{n(t-c)[2(a-t)+n(t-c)]-k(1+n)^2}{2n(t-c)^2}. \tag{18}$$

In turn, $m_E \geq 1$ for all $k \in \left(0, \widehat{k}\right]$, with

$$\widehat{k} \equiv \frac{n(t-c)[2(a+c-2t)+n(t-c)]}{(n+1)^2}. \tag{19}$$

Note that sign$\left\{\widehat{k}\right\}$ =sign$\{2(a+c-2t)+n(t-c)\}$. A sufficient condition for $\widehat{k} > 0$ is $a+c \geq 2t$. If instead $a+c < 2t$,

$$\widehat{k} > 0 \Leftrightarrow n > \frac{2t-a-c}{t-c}, \tag{20}$$

with $(2t-a-c)/(t-c) < 2$ always because $a > c$. Therefore, $\widehat{k}$ is positive everywhere.

Now observe that the difference between the two critical levels of the R&D cost k is equal to

$$\overline{k} - \widehat{k} = \frac{2n(t-c)^2}{(n+1)^2} > 0. \tag{21}$$

This indeed implies that, if $k \in \left(0, \widehat{k}\right]$, then $m_I, m_E \geq 1$. ■

It is worth stressing that since $\overline{k} > \widehat{k}$, what bites here is the highest admissible level of the R&D cost below which the external stability requirement is met by a coalition of admissible size, i.e., at least a singleton. This prompts for a comparison between m_I and m_E, because if m_E is higher than m_I, then no stable green coalition may exist. A quick comparison between the two relevant expressions delivers:

Corollary 1 *Take $k \in \left(0, \widehat{k}\right]$, so that $m_I, m_E \geq 1$. In this range, $m_I - m_E = 1$ everywhere.*

Since m must be an integer, Lemma 2 and Corollary 1 yield the following relevant result:

Proposition 1 *Take* $k \in \left(0, \widehat{k}\right]$, *so that* $m_I, m_E \geq 1$, *with* $m_I - m_E = 1$. *In this range, there exists a stable green coalition of size* $m \in [m_I, \min\{n, m_E\}]$.

Proposition 1 says that there exists an admissible partition of the parameter space (in particular, a range of values for k) wherein a green coalition is stable, and its size might even coincide with the entire population of firms. That is, at equilibrium we might observe the arising of a grand green coalition. To check it out, one has to perform the analysis of the conditions under which this outcome will indeed obtain and characterise its welfare properties, in order to verify whether we may expect the whole industry to attain the win-win solution implied by the strong version of the PH.

4 Green grand coalition and social optimum

In this section, we illustrate the conditions according to which the PH emerges in its strong version, and we determine the welfare properties of the grand coalition made up by n green firms.

To begin with, consider that, since $m_I - m_E = 1$, $n \in [m_E, m_I]$ is the necessary and sufficient condition to ensure that the grand coalition $m = n$ will indeed be the unique stable one. Now let a_I be the lowest level of the reservation price above which $m_I > n$, and a_E the highest level of the reservation price below which $n > m_E$, respectively. The following holds:

Proposition 2 *For* $k \in \left(0, \min\left\{\widehat{k}, \widetilde{k}\right\}\right)$ *and* $a \in (a_I, a_E)$, *the grand coalition consisting of* n *green firms is stable.*

Proof. The comparison between m_I with n yields:

$$m_I - n = \frac{a-c}{t-c} - \frac{n}{2} - \frac{k(1+n)^2}{2n(t-c)^2}. \tag{22}$$

This difference is positive for all

$$a > a_I \equiv \frac{k(1+n)^2 + n(t-c)[2c + n(t-c)]}{2n(t-c)^2} > 0. \tag{23}$$

Then, comparing n with m_E, we obtain:

$$n - m_E = \frac{k(1+n)^2 - n(t-c)[2(a-t) - n(t-c)]}{2n(t-c)^2}. \tag{24}$$

A sufficient condition for the r.h.s. of (24) to be positive is:

$$a \in (t, a_E); \; a_E \equiv \frac{n(t-c) + 2t}{2} > t. \tag{25}$$

Finally, $a_I < a_E$ iff

$$\frac{2n(t-c) - k(1+n)^2}{2n(t-c)} > 0, \tag{26}$$

which is true for all $k \in \left(0, \widetilde{k}\right)$, where $\widetilde{k} \equiv 2n(t-c)/(1+n)^2$. Comparing $\widetilde{k}$ against $\overline{k}$ and $\widehat{k}$, one finds that $\overline{k} > \widetilde{k}$ everywhere, while $\widehat{k} - \widetilde{k}$ has the same sign as

$$2(a-c) + (n-6)(t-c), \tag{27}$$

which is surely positive for all $n \geq 6$ but may change sign if industry concentration is sufficiently high. ■

The foregoing analysis has been carried out identifying thresholds for k below which (i) a green coalition of size m is stable, and (ii) the grand green coalition $m = n$ arises, possibly yielding a vindication of the PH in its strong formulation. Hence, one could say that the level of green R&D costs has a pivotal role in shaping the behaviour of firms. This, true as it may be, would leave aside the role of emission taxation. Indeed, the critical thresholds for k are defined in terms of $\{a, c, n, t\}$, i.e., the exogenous parameters and the policy instruments in the hands of the government. For any triple $\{a, c, n\}$ and any $k > 0$, the policy maker can in fact manipulate t so as to satisfy the two crucial conditions highlighted in Propositions 1-2, by fine-tuning the emission tax rate in such a way that $k < \widetilde{k}$, thus driving firms towards the generalised adoption of the green technology.

We are left with one last task, which consists in checking whether a green grand coalition is indeed socially efficient industry configuration.

Proposition 3 *The green grand coalition is socially efficient for all* $k \in \left(0, \min\left\{\widetilde{k}, k^*, \underline{k}\right\}\right)$, *where*

$$k^* \equiv \max\left\{0, \frac{a[t - c(n+2)] + c[n(n+2)t - c(n(n+1) - 1)]}{(n+1)^2}\right\},$$

and

$$\underline{k} \equiv \frac{(a-c)^2}{(1+n)^2}.$$

Proof. The first order condition for the maximization of social welfare with respect to m yields:

$$\frac{\partial SW}{\partial m}=\alpha m^3+\beta m^2+\gamma m+\delta=0, \tag{28}$$

where

$$\alpha=2v\left(t-c\right)^2,$$

$$\beta=-3v\left(t-c\right)\left[a-cn+t\left(n-1\right)\right],$$

$$\begin{aligned}\gamma &= -2ct\left(2+n\right)+a^2v-2cnv\left[2a+t\left(n-2\right)\right]+ \\ & \quad t\left[t+v\left(a\left(4n-2\right)+t+tn\left(n-4\right)\right)\right]+c^2\left[3+n\left(nv+2\right)\right],\end{aligned} \tag{29}$$

$$\begin{aligned}\delta &= k-c^2\left(1+n\right)^2-a^2nv+cnt\left(2+n-nv\right)+n\left[k\left(2+n\right)+t^2\left(\left(n-1\right)-1\right)\right]+ \\ & \quad a\left[c\left(2+n+n^2v\right)-t\left(nv\left(n-2\right)+1\right)\right].\end{aligned}$$

We have to verify whether there exists an admissible subset of the parameter space $\{a,c,k,n,t\}$ where, at $m=n$, (i) $\partial SW/\partial m\geq 0$, (ii) the individual equilibrium profits of a green firm are positive, i.e., $\pi_g^{m=n}>0$; and (iii) conditions (15) for internal and external stability are simultaneously satisfied.

By fixing $m=n$, we may rewrite (28) as follows:

$$\left.\frac{\partial W}{\partial m}\right|_{m=n}=\frac{t\left[a+cn\left(2+n\right)\right]-c^2\left(n^2+n-1\right)-ac\left(2+n\right)-k\left(1+n\right)^2}{\left(1+n\right)^2}\geq 0, \tag{30}$$

for all

$$t\geq t^*\equiv\frac{c^2\left(n^2+n-1\right)+ac\left(2+n\right)+k\left(1+n\right)^2}{a+cn\left(2+n\right)}, \tag{31}$$

or, equivalently, for all

$$k\leq k^*\equiv\frac{a\left[t-c\left(n+2\right)\right]+c\left[n\left(n+2\right)t-c\left(n\left(n+1\right)-1\right)\right]}{\left(n+1\right)^2}, \tag{32}$$

whenever k^* is positive. This critical level of k must be evaluated against $\widehat{k}$ and $\widetilde{k}$.[8] This exercise reveals that $\widehat{k}>k^*$ everywhere, while

$$\widetilde{k}>\widehat{k}\Leftrightarrow t>c, \tag{33}$$

[8] Recalling that $\overline{k}>\widehat{k}$ always, $\overline{k}$ can be disregarded.

and

$$\widetilde{k} > k^* \Leftrightarrow t > \frac{a + nc\,(n+6) + \sqrt{a\,[1 - 2cn\,(3n+2)] + c^2 n\,[n^2\,(n+4) + 4\,(3n+2)]}}{4n}. \tag{34}$$

Consider now that the profit function in equilibrium is equal to:

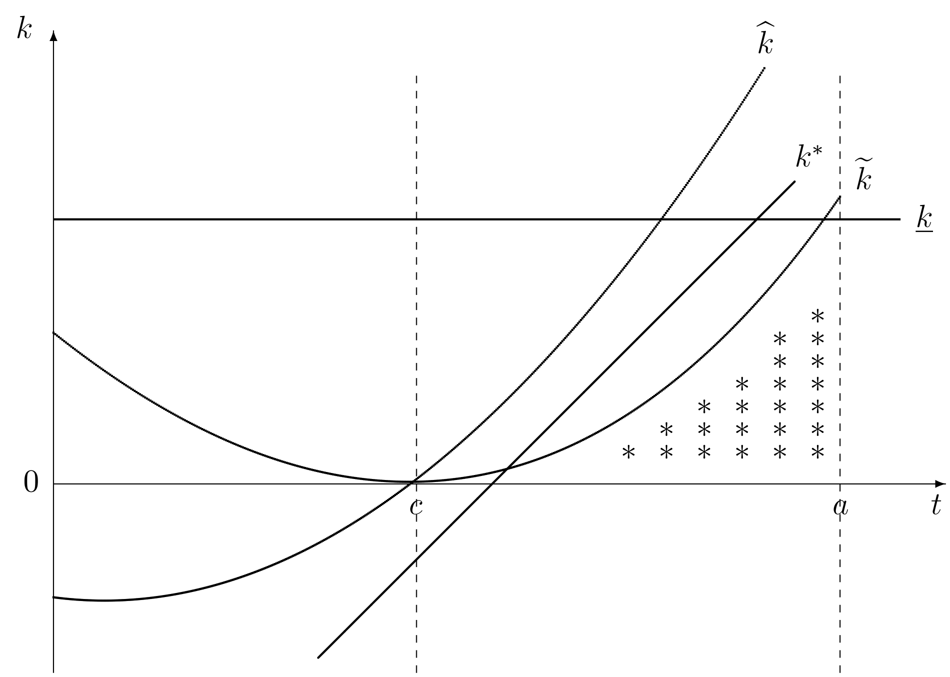
$$\pi_g^{m=n} = \frac{(a-c)^2}{(1+n)^2} - k > 0 \;\forall\; k < \underline{k} \equiv \frac{(a-c)^2}{(1+n)^2}, \tag{35}$$

and

$$\begin{aligned} \underline{k} &> \widetilde{k} \;\forall\; t \in \left(c, \frac{2cn + (a-c)\sqrt{2n}}{2n}\right), \\ \underline{k} &\leq \widetilde{k} \;\forall\; t \in \left[\frac{2cn + (a-c)\sqrt{2n}}{2n}, a\right). \end{aligned} \tag{36}$$

For any triple $\{a, c, n\}$, the critical levels $\left\{\underline{k}, \widehat{k}, \widetilde{k}, k^*\right\}$ can be drawn in the space (t, k), to obtain Figure 1.

Figure 1: The win-win solution in the space (t, k)



The vertical dashed lines at $t = c$ and $t = a$ delimit the admissible range. The starred area above the horizontal axis, below the lower envelope of $\left\{\widetilde{k}, k^*, \underline{k}\right\}$ and such that $t \in (c, a)$, identifies the region we are looking for, in which the green grand coalition $m = n$ is socially efficient and is indeed delivered by firms' incentives. That is, the starred area is where the strong version of the PH obtains and delivers a win-win solution. ■

5 Concluding remarks

In this paper we have examined the presence of the Porter Hypothesis in a large oligopoly where the adoption of green technologies is endogenously determined as a result of competition among coalitions. We have identified the conditions on the two key parameters of the model, the emission tax and the exogenous R&D cost of obtaining the green technology, under which the green grand coalition is stable and generates a win-win solution. The conditions emerge in equilibrium if the amount of the R&D cost is relatively contained. This result validates the Porter Hypothesis in its strong formulation, i.e., the introduction of an environmental policy may in fact increase firms' profits. Finally, the paper evaluates the conditions on the R&D cost under which a green grand coalition is also socially efficient industry configuration.

An important point is that our results did not rely on the standard assumption on consumers' environmental awareness. This shows that competition intensified by regulation is sufficient to push green innovation and in turn profits. We hope our findings will inspire a new, sustainable design of industrial and regulatory policies.

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