Asymmetric Regulation of Identical Polluters in Oligopoly Models*

Rabah Amir† and Niels Nannerup‡

January 2004

Abstract

Studies of second-best environmental regulation of identical polluting agents have invariably ignored potentially welfare-improving asymmetric regulation by imposing equal regulatory treatment of identical firms at the outset. Yet, cost asymmetry between oligopoly firms may well give rise to private as well as social gains. A trade-off is demonstrated for the regulator, between private costs savings and additional social costs when asymmetric treatment is allowed. Asymmetry is indeed optimal for a range of plausible parameter values. Further, it is demonstrated that for a broad class of abatement cost functions, there is scope for increasing welfare while keeping both total output and total emission constant. Some motivating policy issues are discussed in light of the results, including international harmonization and global carbon dioxide reduction.

Keywords: Asymmetric emissions regulation, polluting oligopolists, EU harmonization.

JEL classification: Q2, D8

*The authors are grateful to Anna Stepanova for very competent research assistance and helpful feedback on this work.

† CORE and Department of Economics, U.C.L., 1348 Louvain-la-Neuve, Belgium. (E-mail: amir@core.ucl.ac.be)

‡ Department of Economics, University of Southern Denmark, DK-5230, Odense M, Denmark; E-mail: nna@sam.sdu.dk.

1 Introduction

In the literature on environmental regulation, it has invariably been taken for granted in much theoretical as well as applied work that any optimal environmental regulation of identical polluting firms would involve setting the same requirements for all firms. Whether identical treatment of symmetric agents is always well-founded from a normative standpoint has hardly ever been questioned. When discrimination appears in practice, economists have typically resorted to arguments of political economy and interest group influence or strategic behaviour of decision-makers to explain observed outcomes.[1] In the international arena, most policy economists also approve of identical requirements across polluting units to secure Pareto improvements. For instance, this is reflected within the European Union where harmonisation of environmental standards and taxes is given high priority on the political agenda to reduce distortions of trade. In the context of instrument design at the national level, the US method of grandfathered emission permits treats firms equally if and only if these firms are considered identical (in terms of historical emission, production level, etc.)

Recent economic theory has however seriously challenged the conventional wisdom of unconditional symmetric treatment. Salant and Shaffer (1999) and Long and Soubeyran (2001) provide general analyses of two-stage games where producers compete a la Cournot in the second stage, upon first-period actions that determine their marginal costs, taken either by the firms or their government. In such settings, rearranging marginal costs between *ex ante* identical firms while keeping the sum of marginal costs unaltered may result in a rise in welfare relative to the initial outcome[2]. This result follows from the following

[1] Frederiksson (1997) analyses the design of pollution taxes in a political equilibrium influenced by workers, industrialists and environmentalists. Nannerup (2001) provides arguments relying on strategic behaviour to explain differentiated taxes across industrial sectors.

[2] For applications of such rearrangements, see Long and Soubeyran (1997, 1999) and Salant and Shaffer (1998). These papers analyse asymmetric investments in research joint ventures and basically show that joint profits of firms can be increased by reallocating symmetric R&D investment across firms.

insight provided by Bergstrom and Varian (1985a,b) for a Cournot oligopoly composed of firms with constant marginal costs: Aggregate production costs will fall if the variance of marginal costs across firms is increased without altering the sum of marginal costs. Further, total industry output will not change implying that price and thus consumer surplus are also unchanged.

The paper provides a formal analysis of the potential benefit from asymmetric regulation in an environmental setting. Many problems of pollution can be analyzed within the basic two-stage game where a government in stage one imposes emission standards or taxes on an industry, thus affecting marginal costs in the ensuing Cournot game. Asymmetric regulation would then entail otherwise identical producers facing different levels of standards/taxes.[3]

The set-up and assumptions we consider in this paper constitute the basic framework for numerous analyses of regulation of industry, both in the industrial organization and the environmental economics literatures. The scope for asymmetric regulation is our main concern here.[4] The environmental instrument invoked is a direct emission standard, the level of which directly determines firms' marginal abatement costs. As a preview, interpreting the asymmetry result in the context of pollution indicates that symmetric regulation may conflict with a minimization of total private production costs of industry (including costs of emission abatement). However, along the lines of Bergstrom-Varian, we first demonstrate that asymmetric treatment of equal firms, in terms of changes in marginal costs keeping a constant sum, will not necessarily be welfare improving, basically because such induced changes via environmental policy are likely to raise total emission from the industry. This suggests an interesting trade-off with respect to the effects on private and social costs of introducing asymmetry in environmental regulation. We subsequently find that, for a given marginal

[3] In a broader setting than in the present paper, asymmetric environmental regulation is analysed in Long and Soubeyran (2001). See also Long and Soubeyran (1999).

[4] In a model with non-identical firms, Long and Soubeyran (2002) show how the optimal firm-specific taxes are related to the structure of heterogeneous costs and emission-output ratios under different market forms. Their model does not allow for firms' abatement efforts and costs, which is the focus of the present model.

cost sum, asymmetric regulation will lead to welfare improvements when total welfare is convex along the path of constant aggregate marginal costs. Based on these insights, we leave the aggregate marginal costs focus to examine a perhaps more obvious question for an environmental authority: Is there scope for increasing welfare by deviating from an equal distribution of aggregate emission levels while keeping total output and total emission constant? Our analysis reveals that for a broad class of abatement cost functions and general demand function, this is indeed the case. For these cost functions, we further provide the theoretical conditions for welfare gains from unequal treatment under the constant emission and output restrictions.[5]

This finding also gives rise to second thoughts regarding a commonly used procedure when a social welfare function is maximized in analytical models involving identical agents. Most often a *symmetry restriction is imposed at the outset* to simplify derivations, meaning that the possibility of a solution characterized by asymmetry is a prori ruled out. Several analytical derivations of optimal policies in related contexts have thus characterized symmetry-constrained maxima of social welfare, the regulator's objective.

The regulatory issues analyzed in the present paper deal with second-best regulation, i.e. situations where the regulator takes it for granted that the firms under consideration will continue to behave in a strategic or imperfectly competitive manner in the market after the regulatory scheme enters into effect. The present paper has not investigatd whether any of the purpoted benefits of asymmetric second-best regulation would necessarily carry over to a world of first-best regulation that includes some control over the firms' market behavior.

The next section presents the basic model. Based on interpreting the Bergstrom-Varian result, this section presents the asymmetry phenomenon and the trade-off

[5] An extension of the model to more general specifications of market primitives could be based on recent results on Cournot oligopoly obtained in Amir (1996) and Amir and Lambson (2000). In this regard, recall that the key result of Bergstrom and Varian (1985a,b) holds for a very broad class of inverse demand functions: Those satisfying the natural property of declining marginal revenue (i.e., with $P'(x) + xP''(x) < 0$, for all $x \geq 0$.)

arising from unequal treatment between private cost savings and higher damage costs. In section 3 the focus shifts to abatement cost formulations and we examine the scope for asymmetric regulation to be socially costless as environmental damage is unchanged. Section 4 is devoted to a discussion of robustness and some possible applications. In light of the formal analysis, the prospects for generating additional social benefits from an asymmetric policy for a range of local and global environmental issues will be discussed.

2 The model

There are two identical firms, indexed $i = 1, 2$, competing in a Cournot market with output levels q_1 and q_2 respectively The firms face an inverse downward sloping demand function $P(Q)$, where $Q = q_1 + q_2$ is total output.[6] Production generates pollution, which can be abated at some cost. Assume that the level of polluting emission e_i of firm i is given by $e_i = q_i/a_i$, where a_i is the level of abatement units chosen by the firm. Emission is thus increasing in production, but firms are able to reduce the negative environmental consequences of their activity by devoting resources to emission abatement. Denote the price of an abatement unit by r. For simplicity we ignore direct production costs.Prior to production decisions, the government intervenes in production by imposing an emission standard on the producers. We thus consider a simple two-stage game. Standards, being the only instrument available, are assigned to firms in stage one by a national government maximizing social welfare. The two domestic producers, knowing both limits, play a Cournot game in stage two. We focus on subgame-perfect equilibria of this two-stage game. It is assumed throughout that the inverse demand function satisfies $P'(Q) + QP''(Q) < 0$, for all $Q \geq 0$, or that $P(\cdot)$ is log-concave, i.e. $P(Q)P''(Q) - P'^2(Q) < 0$, for all $Q \geq 0$.Under either one of these assumptions, the Cournot duopoly is a game of strategic substitutes (i.e. the reaction curve is downward-sloping). Furthermore, there is

[6] We restrict attention to duopoly for the sake of a simplified presentation only. The analysis at hand fully carries over to a model with n identical firms.

a unique Cournot equilibrium if production costs are linear (see e.g. Novshek 1985, Amir 1996 and Amir and Lambson, 2000.)

Environmental damage is assumed to depend on the unweighted sum of emissions from the two firms:

$$D(e_1, e_2) = \frac{d}{2}(e_1 + e_2)^2,$$

where $d > 0$. This specific function is chosen in order to present the basic point on asymmetry as simply as possible.

Before formulating the social welfare function, it is useful to cast the argument of Bergstrom and Varian (1985a-b) in this context of environmental regulation. Let e_1 and e_2 denote the emission standards set in stage one. Using $a_1 = q_1/e_1$, in the Cournot game, firm 1 will choose the level of q_1 in the second stage that maximizes its profits given by

$$\Pi_1(q_1, q_2) = Pq_1 - \frac{r}{e_1}q_1.$$

The first-order condition is

$$P(q_1 + q_2) + P'(q_1 + q_2)\, q_1 - \frac{r}{e_1} = 0. \tag{1}$$

Adding this condition to the equivalent first-order condition for firm 2 yields

$$2P(Q) + P'(Q)Q = r\left(\frac{1}{e_1} + \frac{1}{e_2}\right).$$

It appears that total output in the Cournot equilibrium will depend only on the *sum of the reciprocal standards* and not on the distribution of these across the firms. Any change in environmental policy leading to another *interior* Cournot equilibrium that keeps this sum unchanged will then result in the same total production in the industry. Thus the market price also remains the same, and consequently, consumer surplus in the market is unchanged. Hence, there is scope for a redistribution of environmental requirements across firms affecting neither industry revenue nor total consumer surplus in the market. In relation to Bergstrom and Varian (1985a,b), the above result obtains because, for a given emission standard (as well as r), the firms' expenditures for emission abatement lead to a constant effective marginal cost structure.

The immediate policy implication is that a rationale for imposing different emission limits on the two firms must be found at the cost side of production. We thus ask whether asymmetric treatment of the firms leads to a minimum in private and social costs of production, that is, whether incentives exist for a welfare maximizing environmental authority to deviate from uniform emission limits. As a first step in understanding this issue, consider a simple formulation of social welfare, W. If we assume that all production is for the domestic market, social welfare can be measured as the sum of profit and consumer surplus, CS, less environmental damage. It also proves convenient to redefine the choice variables of the government from (e_1, e_2) to $(\gamma_1, \gamma_2) = (r/e_1, r/e_2)$, so that we may view the government as directly deciding on firms' marginal costs through environmental policy.[7] We then have

$$\begin{aligned} W &= \Pi_1 + \Pi_2 + CS - D \\ &= S - \gamma_1 q_1 - \gamma_2 q_2 - \frac{d}{2} r^2 \left(\frac{1}{\gamma_1} + \frac{1}{\gamma_2} \right)^2, \end{aligned} \tag{2}$$

where $S \triangleq \int_0^Q P(t)dt$ expresses consumers' surplus plus firms' total revenue. Social welfare is then S minus private and social costs of production. Using the industry equilibrium first order conditions $q_i = (\gamma_i - P)/P'$ in (2) yields

$$W = S + \frac{P}{P'}(\gamma_1 + \gamma_2) - \frac{1}{P'}\left(\gamma_1^2 + \gamma_2^2\right) - \frac{d}{2} r^2 \left(\frac{1}{\gamma_1} + \frac{1}{\gamma_2} \right)^2. \tag{3}$$

We know from above that a change in policy that preserves the sum $\gamma_1 + \gamma_2$ will not change the level of S or the second term in the RHS of (3). However, for a given sum, a deviation from uniform emission standards is a variance-increasing shift for marginal costs, and the third term reveals that such a change will then always decrease private production costs (as $P' < 0$). This is the Bergstrom-Varian point in the context of a polluting duopoly. The immediate logic is that a deviation from uniform emission limits implies a gain in market shares in

[7] As r/e_i is a strictly monotonic transformation of e_i, this convenient change of variable will not alter the solution of the optimization problem.

the Cournot equilibrium for the *ex post* low-cost firm so that a larger share of the unaltered industry output is produced at lower cost. In contrast, the last term in (3) reveals that increasing the variance of firms' marginal costs leads to higher damage costs because *total emission will rise*. Equal treatment of producers thus leads to the maximum for industryb4s production costs and a minimum for damage costs, caused by a minimized aggregate emission level. In the words of Long and Soubeyran (2001), for this particular set-up, there is a, 'cost of manipulating marginal cost' through environmental standards in terms of a higher emission level. It follows that deviations from equal environmental regulation of identical producers is not always welfare increasing.

To illuminate this result further, it is useful to reformulate the welfare expression in (2). We will consider the shape of the welfare function under the benchmark of a given sum of marginal costs, $k = \gamma_1 + \gamma_2$. Assume for the rest of the section a linear inverse demand function $P = A - q_1 - q_2$. First, in the stage two industry equilibrium, firm 1's first order condition (1) now yields, after substituting home output for rival output (from firm 2's first order condition):

$$q_1 = \frac{1}{3}\left(A - 2\gamma_1 + \gamma_2\right). \tag{4}$$

After inserting (4) in (2), and as S equals $\int_0^{q_1+q_2}\left[A - q_1 - q_2\right] d\tilde{q} = A\left(q_1 + q_2\right)$ $-bd\left(q_1 + q_2\right)^2$, social welfare becomes

$$W = \frac{1}{9}\left[4A^2 - 4A\left(\gamma_1 + \gamma_2\right) + \frac{11}{2}\left(\gamma_1^2 + \gamma_2^2\right) - 7\gamma_1\gamma_2\right] - \frac{d}{2}r^2\left(\frac{1}{\gamma_1} + \frac{1}{\gamma_2}\right)^2. \tag{5}$$

Now eliminate $\gamma_2 = k - \gamma_1$ in (5). The welfare expression then yields

$$\begin{aligned} \hat{W} \quad &= \quad \frac{1}{9}\left[4A^2 - 4Ak + \frac{11}{2}\left(\gamma_1^2 + \left(k - \gamma_1\right)^2\right) - 7\gamma_1\left(k - \gamma_1\right)\right] \\ &\quad -\frac{d}{2}r^2\left(\frac{1}{\gamma_1} + \frac{1}{k - \gamma_1}\right)^2. \end{aligned} \tag{6}$$

Differentiating (6) with respect to γ_1 now means that the effects of a change in γ_1 can be considered under the assumption that γ_2 adjusts to keep $\gamma_1 + \gamma_2$

constant at the level k. The first derivative is given by

$$\frac{d\hat{W}}{d\gamma_1} = (4\gamma_1 - 2k) + dr^2 \left[\frac{1}{\gamma_1} + \frac{1}{k-\gamma_1}\right] \left[\frac{1}{\gamma_1^2} - \frac{1}{(k-\gamma_1)^2}\right]. \tag{7}$$

This expression may be negative or positive. However, for the symmetric point where $\gamma_1 = \gamma_2$ the derivative is *always* equal to zero, as both the first term, representing the change in production costs, as well as the second term, representing the change in damage costs, are zero. This can all be verified by inserting $k = 2\gamma_1$. This explicitly shows that welfare is at a minimum or at a maximum for any symmetric allocation of the standards. The second derivative now yields

$$\frac{d^2\hat{W}}{d\gamma_1^2} = 4 - 2dr^2 \left[\frac{1}{\gamma_1} + \frac{1}{k-\gamma_1}\right] \left[\left(\frac{1}{\gamma_1^2} - \frac{1}{(k-\gamma_1)^2}\right) + \left(\frac{1}{\gamma_1^3} + \frac{1}{(k-\gamma_1)^3}\right)\right].$$

For the symmetric point where $\gamma_1 = \gamma_2 = \gamma$ and $k = 2\gamma$ we get

$$\frac{d^2\hat{W}}{d\gamma^2} = 4 - 8dr^2\frac{1}{\gamma^4}. \tag{8}$$

When (8) is positive, welfare is convex around the symmetric point, and hence a symmetric allocation cannot be optimal: Any small deviation from $\gamma_1 = \gamma_2$ along the line $\gamma_1 + \gamma_2 = k$ will increase welfare. In figure 1, equilibrium welfare in (5) is depicted as function of the choice variables (γ_1, γ_2) for welfare levels in the interval $[-20; 20]$ and for the fixed parameter values $d = 8$, $r = 3$, and $A = 10$. It clearly appears that asymmetric regulation will be optimal as the figure shows increasing welfare as one moves away from the diagonal towards the 'corners' of the figure, i.e. as regulation becomes increasingly asymmetric[8]. In line with the zero value of (7) for $\gamma_1 = \gamma_2$, it appears that, for a given sum of marginal costs, symmetric regulation is either a local maximum or a local minimum for welfare.

[8] When seeking a global maximum for welfare, the welfare function should be examined under the condition that both producers stay in the market, that is $q_1, q_2 > 0$. The global maximum is of minor interest in a setting of (environmental) regulation if it implies that the regulator would force one of two firms out of the market. We thus disregard the problem of finding the optimal sum of $\gamma_1 + \gamma_2$.

The present results are consistent with Long and Soubeyran (2001) who in their general analysis on ex-ante identical firms find that when the objective function is strictly concave (stictly convex) in a global sense, for a given sum of choice variables, the solution is symmetric (asymmetric).

3 Unequal treatment with unaltered damage costs

It may often be vital in an environmental policy setting that asymmetry can be introduced costlessly, that is without costs of manipulation. The latter are present in the form of higher damage above because the unaltered sum manipulation of marginal costs leads to higher total emission, and thus to higher environmental degradation. It is however possible within our framework to uncover circumstances where asymmetry leads to cost savings without any degradation of the environment. We will address this issue by showing that for a broad class of abatement cost functions for producers, the regulator can induce welfare gains from asymmetry, via production cost savings while at the same time keeping both total output and total emission unaltered. Assume a general inverse demand function satisfying the conditions of Section 2. Again, we focus purely on costs of pollution abatement. Assume an abatement cost function for producers $C^i(q_i, e_i)$ with $C^i_q > 0$ and $C^i_e < 0, \quad i = 1, 2$. In the Nash-Cournot industry equilibrium, the producer now chooses output from $P + P'q_i - C^i_q(q_i, e_i) = 0$. Summation over the two first order conditions yields

$$2P(Q) + P'(Q)Q = C^1_q(q_1, e_1) + C^2_q(q_2, e_2).$$

When the right-hand side in this relation is given by additively separable terms in total output and total emission, manipulating standards under an unaltered total emission restriction will not imply changes in total output, price, CS or environmental damage. The question of interest here is whether such a manipulation can lead to cost savings.

Consider the following abatement cost functions (for $i = 1, 2$):

$$C^i(q_i, e_i) = bq_i^2 + (c - \delta e_i) q_i + f(e_i),$$

where $b, \delta > 0, c \geq 0, C_q^i = 2bq_i + c - \delta e_i > 0, C_e^i = -\delta q_i + f'(e_i) < 0.$

Observe that with this abatement cost function, asymmetric regulation with an unaltered total emission level $e_1 + e_2$ will leave Q and P unchanged. Indeed, the first order condition now yields $P + P'q_i = 2bq_i + c - \delta e_i, i = 1, 2$, which upon summation leads to $2(P - c) + (P' - 2b)Q = -\delta(e_1 + e_2)$.

Call the subgame-perfect equilibrium (or SPE) of the two-stage game where the regulator is restricted to choose an equal treatment solution *the constrained-symmetric equilibrium or CSE.* Let the corresponding price be P_s, and $e_1 = e_2 = e^s$, $e_1 + e_2 = k$ *and* $q_1, q_2 > 0$.

In the appendix we prove the following central result of this paper:

Proposition 1.

Assume a general inverse demand function satisfying the assumptions of Section 2, and let the producer abatement cost functions be of the form shown above with marginal costs being separable in output and emissions:

i) Relative to the CSE, an asymmetric regulation level along the path of total emission k, inducing oligopoly, will lead to welfare gains via cost savings if

$$\frac{2\delta^2 (P_S' - b)}{(2b - P_S')^2} + f''(e^s) < 0. \tag{9}$$

ii) Assume an initial (not necessarily symmetric) regulation, such that at the resulting Cournot equilibrium, price is P and $e_1 + e_2 = k$. *Given the fixed total emission* k, *increased asymmetry will always lead to higher welfare if*

$$\frac{4\delta^2 (P' - b)}{(2b - P')^2} + f''(e_1) + f''(e_2) < 0, \tag{10}$$

for any pair of emission levels (e_1, e_2) *inducing duopoly in the second stage.*

Note that i) is a rule that secures unequal treatment to be welfare improving relative to equal treatment for the given total emission k. Under this rule, a local change in regulation around the symmetric point will lead to cost savings, so that 'some' asymmetry causes efficiency gains. Further, an important corollary of ii) is that, when f is constant or linear in e_i, higher asymmetry will *always* lead to cost savings. In this case it is clearly seen that the above rule reduces to $P' < b$ which is always satisfied. To apply the proposition and to illustrate that the derived cost function reflects environmental and economic reality in a reasonable way, consider the following example.

An example

With $c = 0$ and $f(e_i) = \frac{\delta^2}{4b}e_i^2$, the above abatement cost function becomes $C^i(q_i, e_i) = bq_i^2 - \delta e_i q_i + \frac{\delta^2}{4b}e_i^2$. This function reflects the case of a linear relationship between emission, output and abatement effort of the kind $\frac{\delta}{2\sqrt{b}}e_i = \sqrt{b}q_i - a_i$, and, moreover, progressively increasing abatement costs in the effort variable according to the function a_i^2. This is easily verified by substituting $a_i = \sqrt{b}q_i - \frac{\delta}{2\sqrt{b}}e_i$ in the function a_i^2. Applying the rule in the proposition, we find that raising asymmetry implies cost savings if

$$\frac{2\delta^2[P' - b]}{[2b - P']^2} + \frac{\delta^2}{2b} < 0,$$

which, after some calculations, reduces to $P'^2 < 0$, which is false for any (e_1, e_2) with a constant sum. Hence, in this setting symmetric regulation is always optimal. Though a slight modification makes asymmetric regulation preferable. Assume that the cost function is now given by $a_i^2 + K_i(e_i)$ where the second term contributes to a more concave abatement cost function in emission in that $K_i''(e_i) < 0$. Assume for simplicity that $K_i(e_i) = -\frac{\delta^2}{4b}e_i^2$. Obviously, this implies that costs are linear in emission for q_i given, that is $C^i(q_i, e_i) = bq_i^2 - \delta e_i q_i$. In relation to the proposition, the function $f(e_i)$ is now zero and we can conclude that asymmetric regulation is optimal for any level of total emission. The second partial derivative in individual emission being positive (that is $C_{ee}^i > 0$, which is normally assumed), we could however still have an asymmetric welfare optimum. As $f''(e_s)$ in the condition (9) reflects this second partial derivative, it follows that if $C_{ee}^i < -2\delta^2[P' - b]/[2b - P']^2$, the welfare optimum is asymmetric. The right hand side of this inequality is clearly positive.

4 Conclusion

The paper has considered the prospects for asymmetric environmental regulation of identical producers based on insights achieved in recent analyses of oligopoly games. A trade-off is demonstrated to be likely between private cost savings and additional social costs when asymmetry is introduced. However for a broad class of abatement cost functions it has been shown that welfare gains will arise from asymmetric regulation without affecting total emission and thereby environmental quality. This indicates good perspectives for asymmetric environmental regulation in practice.

Other formulations of the environmental setting could make the perspective of welfare gains from asymmetry even better. In reality, it is most often the case that producers affect environmental quality differently, due to firms being located in different geographical regions or using different production processes. One of the firms could be located in a densely populated or otherwise more environmentally sensitive area. Alternatively, the so-called assimilative capacity of the environment for the particular emissions under consideration could differ between regions. Also one could think of different environmental quality preferences of local citizens across regions implying a weighted environmental damage function at the national level. Formally, this could be based on the damage cost function $D(e_1, e_2) = \frac{d}{2}(e_1 + \alpha e_2)^2, \ 0 < \alpha < 1$, showing that emission from firm 2's production causes relatively less damage to the environment. Reduced damage costs will then arise by allocating more environmental resources to region 2, implying that a higher emission limit should be imposed on producer 1, on environmental as well as efficient asymmetry grounds. Introducing marginal cost asymmetries through environmental requirements will, under this damage structure, lead to reduced externalities (up to some point), so that the effects of unequal treatment on industry costs and the environment work in the same direction. No qualitative result will change relative to a model consisting of some identical and some non-identical producers. Introducing emission standard asymmetry on identical producers in the manner shown in section 2 and 3 will not change total output, price or consumer surplus, and accordingly will give rise to possible welfare gains. This is naturally most important for real policy issues, where the simple case of identical agents rarely appears.

The motivation for the paper is to a large extent related to real policy and some instances of applications, where the findings challenges aspects of the conventional wisdom within environmental policy, are worth mentioning. These issues would be important extensions for future research.

In relation to global CO_2 reduction, accepting generally weaker CO_2 policies in certain countries implies *de facto* asymmetric regulation across international (identical) industrial sectors, and, according to our findings, the resulting outcome may for some industries welfare dominate equal treatment. Asymmetric regulation via environmental agreements may moreover constitute an interesting compromise alternative to side-payment strategies as it also contains indirect transfers via the recognition of higher market shares for countries taking weak measures, such as developing countries, relative to countries taking strong measures. Should the acceptance of asymmetric policies across nations, in fact, be treated as a powerful international distributional mechanism, which, in some situations, could replace politically complex side-payments between nations?

Along the same lines, the asymmetry result indicates that complete harmonization of environmental policy across countries may obviously be unwarranted. This insight is important and may be applicable to EU industries, which are characterized by a great deal of symmetry in that production is based on identical technology and human resources.[9]

It is also important to consider the informational feasibility of an asymmetric scheme and what this implies for real policy. In the present theoretical setting, policymakers need to possess perfect information on cost structures at the firm level in order to generate the potential gains from asymmetric policies. In the absence of perfect information for regulatory authorities in practice, the asymmetry result is a strong case for a decentralized regulation procedure where the environmental authority delegates the regulation of individual producers to industry itself, and, roughly speaking, limits market intervention to the imposition of an overall pollution reduction objective for the sector. The better-informed industrial associations and firm environmental planners can then be entrusted

[9] In the EU treaty, Article 100a aims at complete harmonisation and places responsibility on the European Commision for harmonising environmental laws of the member states.

as the driving force behind the asymmetric allocation of abatement costs.

It also seems interesting to compare the potential of asymmetric regulation for various environmental policy instruments. One may thus ask whether established findings on economic instruments and command-and-control instruments will hold given that asymmetric treatment of identical units leads to welfare gains. It is for example clear that uniform Pigouvian taxes cannot generate asymmetry. Does this mean that taxes should be differentiated? Moreover, due to their different marginal impacts on output and emission, taxes and standards may, in general, have different potential in inducing asymmetric allocations in various settings. These are immediate questions arising from the analysis. More work needs to be done for a better understanding of the differences between instruments, in light of the potential benefits of asymmetric treatment.

An obvious theoretical extension of the analysis is related to the asymmetric optimum. Having proved that asymmetric treatment may be optimal, it is still left open to fully characterize the globally optimal solution. This task is considered beyond the scope of the present analysis. Inspiration for analysing optimal solutions in the two stage game can be derived from Salant and Shaffer (1998). They identify a number of asymmetric optima for R&D investments in the prior stage of the two-stage game.

The analysis presented in this paper deals with second-best regulation, wherein the regulatory authority takes as given that the firms' conduct in the market is one of imperfect competition. While the bulk of regulatory intervention in free-market economies nowadays falls in this category, it can nevertheless be the case in some settings that this authority also has other regulatory tools at its disposal, such as taxes or subsidies, tools that may be used to partially or fully restore social optimality in the market before considering the symmetric or asymmetric regulatory scheme analyzed in this paper. An interesting open issue, for possible future work on this topic, is to investigate whether the conclusions derived here would extend to this idealized world of first-best regulation.

5 Appendix

Proof of Propostion 1.

Consider an initial (not necessarily symmetric) equilibrium, inducing duopoly. From the firm first order condition, output is given by $q_i = (P + \delta e_i - c) / (2b - P')$. Inserting this expression in the abatement cost function, equilibrium total abatement costs will be

$$\sum_{i=1,2} C_i (q_i, e_i) = \sum_{i=1,2} \left[b \left(\frac{P + \delta e_i - c}{2b - P'} \right)^2 + (c - \delta e_i) \left(\frac{P + \delta e_i - c}{2b - P'} \right) + f(e_i) \right]$$

After a large rearrangement, this sum can be expressed as

$$\frac{1}{(2b - P')^2} \left[K_0 + K_1 (e_1 + e_2) + \delta^2 (P' - b) \left(e_1^2 + e_2^2 \right) \right] + f(e_1) + f(e_2),$$

with $K_0 = 2(P - c)[cb + bP - cP']$ and $K_1 = \delta [2c(b - P') + PP']$. After substituting $e_2 = k - e_1$ into the cost expression, this yields

$$\frac{1}{(2b - P')^2} \left[K_0 + kK_1 + \delta^2 (P' - b) \left(k^2 + 2e_1^2 - 2ke_1 \right) \right] + f(e_1) + f(k - e_1). \tag{11}$$

For the second derivative in e_1 of (11) negative, total abatement costs are strictly concave, that is

$$\frac{4\delta^2 (P' - b)}{(2b - P')^2} + f''(e_1) + f''(k - e_1) < 0.$$

Under this condition, increased asymmetry leads to cost savings. Substituting $k - e_1 = e_2$ leads to the condition (11) in Proposition 1. This proves ii).

For the symmetric equilibrium, insert $e^s = e_1 = e_2$ in (10). Given the price P_S, this leads to $\frac{2\delta^2 (P'_S - b)}{(2b - P'_S)^2} + f''(e^s) < 0$. Total costs are then strictly concave around the symmetric point under this condition and deviating from symmetry implies a welfare gain. This proves i). □

References

[1] Amir, R. (1996), "Cournot Oligopoly and the Theory of Supermodular Games", *Games and Economic Behavior*, 15, 132-148.

[2] Amir R., and V. E. Lambson (2000), "On the Effects of Entry in Cournot Markets," *Review of Economic Studies*, 67, 235-254.

[3] Bergstrom, T. C. and Varian, H. R. (1985*a*), Two Remarks on Cournot Equilibria, *Economic Letters*, 19, 5-8.

[4] Bergstrom, T. C. and Varian, H. R. (1985*b*), When are Nash Equilibria Independent of the Distribution of Agents' Characteristics?, *Review of Economic Studies,* 52, 715-18.

[5] Frederiksson, P.G. (1997), The Political Economy of Pollution Taxes in a Samall Open Economy, *Journal of Environmental Economics and Management 33, 44-58.*

[6] Long, Ngo Van and Soubeyran, A. (1997), Greater Cost Dispersion Improves Oligopoly Profits: Asymmetric Contributions to Joint Ventures, in J.A. Poyago-Theotoky, ed., Competition, Cooperation, and R&D: The Economics of Research Joint Ventures, London, Macmillan, 1997, 126-37.

[7] Long, Ngo Van and Soubeyran, A. (1999), Asymmetric Contributions to Research Joint Ventures, Japanese Economic Review, 50, 122-37.

[8] Long, Ngo Van and Soubeyran, A. (2001), Cost Manipulation Games in Oligopoly, with Costs of Manipulating, International Economic Review, Vol. 42, No. 2.

[9] Long, Ngo Van and Soubeyran, A. (2002), Selective Penalization of Polluters: An Inf-Convolution Approach, Série Scientifique, Cirano, Montreal, 2002s-40.

[10] Nannerup, N. (2001), Equilibrium pollution taxes in a two industry open economy' *European Economic Review* 45, pp. 519-532.

[11] Salant, S. W. and Shaffer, G. E. (1998), Optimal Asymmetric Strategies in Research Joint Ventures, *International Journal of Industrial Organisation*, 16 (2), 195-208.

[12] Salant, S. W. and Shaffer, G. E. (1999), Unequal Treatment of Identical Agents in Cournot Equilibrium, *American Economic Review*, 89, 585-604.

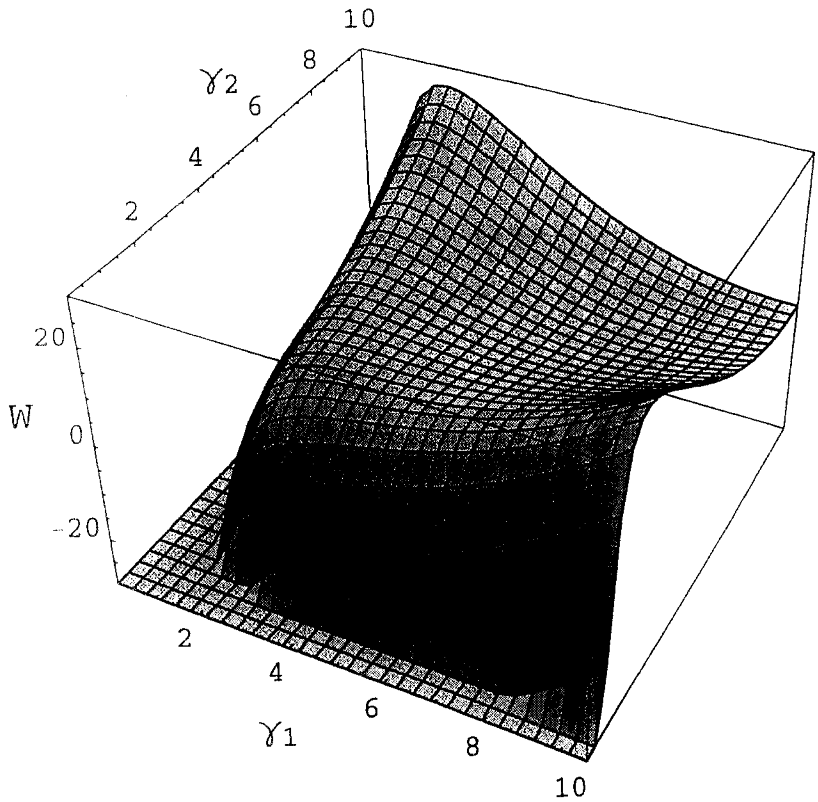

Figure 1. *The welfare function given by* (5) *for parameter values* $d = 8$, $r = 3$, *and* $A = 10$.