INTEGRATED vs SEPARATED REGULATION

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Abstract

The regulation of monopolistic firms has been widely investigated in the economic literature. Particular emphasis has been placed on the relationship between the regulated monopolist and the regulator. The present work deals with problems that may arise from the presence of several regulators. If regulators have different objective functions, inefficiency is likely to arise. A theoretical model with two regulators, a renewable natural resource and non-linear taxation is presented. In this set up the level of demand relative to the sustainable use of the water resource plays a major role, in shaping the different equilibria. The main results is a characterization of several scenarios contrasting the integrated regulator and the separate regulators equilibria. It turns out that the price of water tends to be systematically higher in the separate regulators case, while the integrated regulator equilibrium tends to be more stable to changes in relative demand.

JEL Classification: *C70, L51, L95, Q25.*

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1 Introduction

1.1 Motivations

Water is life. Any kind of society needs access to water resources to survive and develop. From an economic point of view, what matters is how to provide water with a limited amount of resources available. In this respect the choice can be either to provide the service directly, by the government, or leave the organization to market forces. In the latter case, however, some "market failures" are likely to arise. The problems are mainly the presence of natural monopoly phases in the production process, such as the ownership of the pipelines, and strong externalities, related to environmental problems and health issues.

In this case, the government should think about regulating the action of the firm operating the service. Most OECD countries have opted for the market mechanism, mitigated by a regulatory structure. For instance, in England the service is run by private companies under the "surveillance" of an economic regulator, OFWAT (Office for Water), a separate environmental regulator, Environment Agency, and an agency for the quality of water, the Drinking Water Inspectorate (DWI). Italy reformed the water sector in 1994, with the so called Galli Law (Law no. 37/1994), by prescribing the creation of local economic authorities ATO (*Autorità Territoriale Ottimale*), formed by local councils; while a national regulator, the Ministry of Environment, is concerned with environmental issues. In the U.S. there is a federal authority for the environment EPA (*Environmental Protection Agency*) and state level economic regulators. The common feature of water regulation in these countries is the split of the main objectives that the policy maker wants to address over separate regulators.

Given this scenario, it is natural to investigate the relationship among regulators. Is it possible to treat them separately, e.g. studying the relation between firm and economic regulator? Or would it be better to consider also the effect that the other regulators could have on the regulatory outcome? The objective of this work is to study the institutional structure of regulation, investigating the effect of multiple regulators on the behavior of the firm. The starting point is that the outcome of regulation will be different whether it is pursued by one regulator or by separate regulators. This issue should be taken into account when the government decides how to shape the regulatory structure of any utility sector. The question is also present in debates among manager of utility companies. For example, in the *"2003 National Drinking Water Symposium"* held in Colorado USA, one of the most important issues was the need for cooperation amongst economic, environmental and public health regulators.

When we think about water problems, the first thing that strikes our mind is the image of desert areas, poor countries in the driest places of the world (Saharan countries, Middle East, etc.). The problem of water, however, it is not only linked with drought. A major role is played by the demand of water relative to water reserves. Therefore even in places relatively rich of water there can be problems. In fact, while the per-capita demand for water is quite rigid, the aggregate level may change for various reasons. Among them one is quite important for developed countries: the dynamics of demography. Demand of water can increase dramatically with migration flows concentrated in few areas. A recent article in the July 2005 issue of the "National Geographic", addresses the problem of water in the United States. The main point of the article is that along with drought, caused by climate change, there is an institutional problem (conflict between Federal and State level), conflicts between users (especially farmers and private consumers, e.g. Idaho), and dramatic population growth (such as in Colorado and Las Vegas). It is therefore important to consider the pressure on the water supplied, as the following quote suggests:

> "According to the Palmer Drought Severity Index (PSDI), which measures temperature, rainfall, and soil moisture, the 1930s Dust Bowl was far worse than the current [last 5 years] drought. But the PSDI and other climatic indexes don't capture a key variable: the growing demand for water". (National Geographic - Geographica). "I tend toward a definition of drought that takes demand as well as supply into account" (Kelly Redmond in National Geographic).

In this scenario, the choice of the institutional structure is very important, especially once the demand has reached a problematic level. The aim of the present work is to present a positive analysis of the regulation process when several authorities regulate the same firm, under several demand conditions.

1.2 Multiple regulators, results of the model

There are at least two ways in which this work contributes to the economic literature. The first one, and perhaps the main contribution of the paper, is on the theory of economic regulation. It represents one of the few attempts to analyze a regulatory set up in which more than one regulator operates. The main question addressed is the effect of "competing" regulators on the equilibrium decisions of a monopolistic firm. The policy maker decides the institutional set up in which regulation takes place.

I present a theoretical model where two regulators, an economic one and an environmental one compete for the regulation of the same firm, operating in the water sector. There are two objectives that the policy maker wants to pursue, an environmental control of the activity of the firm and an "efficiency" control. The model, however, can be applied to any multiple regulator scenarios, in which there is a monopolistic firm and the use of a renewable resource, as water, or fishery, or timber industry, etc.

The main result obtained is the importance of the demand in the outcome of the regulation and the fact that not always there is a different equilibrium outcome in the two scenarios. That is, even if regulators have conflicting objective functions, not always the resulting equilibrium is different. The discriminant comes from the demand side and the marginal environmental damage. First of all, when the demand is very low, there is no environmental damage. Since the renewable nature of the resource, the production must exceed a certain threshold to be non sustainable. However, even when the demand is higher, we have some cases in which the equilibrium output is the same. When the marginal environmental damage is very high in both scenarios the equilibrium quantity of water is at the sustainable level. It is when the demand is high and the marginal environmental damage is low, that we have a different equilibrium.

When the "competition" actually results in a different equilibrium it is important to characterize it in term of equilibrium price, quantity, and environmental tax. The separate equilibrium price is higher then the integrated one. That is because in the separate case, the economic regulator set the price always at the competitive level[1]. The level of the equilibrium quantity depends on the demand and the level of the marginal environmental damage, as we will see in greater detain in the following sections. Lastly, it appears that in the integrated equilibrium, the environmental tax is never higher that the marginal environmental damage, while this is not true for

[1] The level which clears demand and competitive supply of the firm.

the separate equilibrium.

An other issue considered is the distribution of welfare among the various components of the regulator's objective function, namely consumers' surplus, producer's surplus, and environmental benefit. For instance, it emerges that in some cases the consumers' surplus is lower in the separate equilibrium, while both producer's surplus and environmental benefit are higher. If we interpret environmental benefit as future consumers' surplus, and consumers' surplus as a short run return, we see that the policy maker can choose whether to rule in favour of short or long run benefit[2].

The last comment to make is about the choice of the water industry. The water sector represents a typical scenario in which regulators' objectives are in conflict. That is the case between the economic regulator and the environmental regulator. From the web site of one of the UK regulated companies, the SOUTHERN WATER company[3], "Southern Water, like all water companies, is regulated by both a financial body and an environmental body." and the role of the regulators are defined as "OFWAT is our economic regulator, and monitors our business to ensure we are providing a good quality and efficient service at a fair price", and "[it] does this by setting price limits"; while the other regulator is " Environment Agency, [which] monitors the company's performance to ensure environmental standards". Concerning the effect of this multi-regulator scenario, it is illuminating the

[2] Here political economy considerations naturally arise.

[3] At the web address: `http://www.southernwater.co.uk/corporate/aboutUs/waterRegulation.asp`

following sentence "The continual challenge for Southern Water is to achieve a balance between the separate financial and environmental demands made by both independent regulators".

The other contribution of the paper is on the environmental economics literature. Indeed, the firm uses a renewable resource: the underground water. The literature[4] has mainly focused on the intertemporal problem that the use of a renewable resource produces, i.e. the definition of an optimal rate of intertemporal consumption. My attention is on the implementation of the policy, though. As previously mentioned, most countries leave the water service to private company, under the supervision of regulators. It is therefore important, also from an environmental point of view to investigate what is the effect that separation of regulators have on the management of the resource. The model can be applied to any type of renewable natural resource, such as, fishery, timber industry, etc.

1.3 Review of the literature

The literature on economic regulation pays a lot of attention to the relationship between the regulator and the firm[5]. However, not so much attention is devoted to investigate scenarios in which several regulators operate. One important exemption is Baron (1985). Baron considers a case in which a

[4]For the literature about natural resources see, Kneese and Sweeney (1985) and Tietenberg (2003).

[5]For a review of this literature see Armstrong et al. (1994) and Newbery (1999).

firm produces electricity and, as side product, pollution. There are two agencies that influence the behavior of the firm: an environmental agency and a public utility commission. The latter one regulates the natural monopoly by setting a tariff while the former one deals with pollution abatement, by imposing an environmental tax. The key point of the article is the fact that the negative externality is non localized. While people living in the neighborhood of the firm suffer from pollution and benefit from the electricity, people living far from the firm don't get any benefit from firm production and suffer from the pollution created. Since the public utility commission must set a tariff that covers all firm's costs, reduction of pollution, by increasing firm costs, leads to a high tariff level. Therefore people served by the firm are going to bear the whole cost of reducing the externality. The conclusion of Baron paper is indeed that cooperation is the better option. If the agencies do not cooperate the firm can exploit an informational rent because of the conflict between the two agencies. However, Baron consider a imperfect information set up, therefore the lack of cooperation sums up with asymmetric information in determining the inefficiency. The environmental problem is also different because does not produce non convexities in the firm's production function.

Two more recent papers address the issue of multiple regulators. Dixit (1996) set up a "common agency" model where the regulators are the principals and the monopolistic firm is the agent. Dixit shows how the second best solution of regulation with asymmetric information becomes third best if regulators are competing among themselves. Also in this case it is not clear what is the part of inefficiency stemming from the presence of several regulators. Also Martimort (1999) consider a "common agency" model with imperfect information. While Laffont and Martimort (1999) consider a political economy approach to regulation in which the presence of several regulators reduces the risk of regulatory capture.

1.4 Organization of the paper

The rest of the paper is organized as follow. In the next section I present the model with a unique (integrated) regulator, then I extend the model to consider two regulators with conflicting objective functions. In the following sections I restrict the analysis to specific functional forms - linear - which allows to get some results on the distribution of welfare, and also to better understand the model. Finally, concluding comments and further developments are presented.

2 Model set-up

Let us consider a monopolistic firm running the water service. It consists in extracting water from an underground resource and distributing it. The monopolistic nature of the market make it advisable to control the price, while the renewable nature of the water resource asks for a control on the quantity of water extracted. This control is played through the imposition of an environmental tax[6] on the water extracted in excess, i.e. over the sustainable level. There are no transfers from the government to the firm. However, contrary to the mainstream literature on regulation I do not explicitly consider a budget constrain for the firm. The firm is free to set the level of quantity she prefers, and the demand plays the role of a constraint. Given the price and the tax the firm will supply water only if her profit is non negative.

In the integrate regulator scenario, the unique regulator is both concerned with setting the price to be charged to consumers of water and the environmental tax rate. In the separate case, an Economic regulator sets the price while an Environmental regulator sets the tax rate. I impose perfect information, in order to focus the attention on the effect of having two regulators.

Let us consider the following structure:

- The consumers' surplus is given by:

$$CS = \int_0^{q^s} D(q)dq - pq^s \tag{2.1}$$

  where q^s represents the firm's supply of water, and $D(q)$ the inverse demand for water[7];

[6]Even though in most cases environmental agencies have not the power to impose a tax, they nevertheless have instruments which eventually produce an increase in the firm's costs. The tax is used as a proxy of any such instrument.

[7]It is assumed a downward sloping demand.

- the environmental damage caused by an unsustainable production is characterized by the following non linear equation

$$d(q^s) = \begin{cases} \delta(q^s - \gamma) & \text{if } q^s \geq \gamma \\ \\ 0 & \text{otherwise} \end{cases} \tag{2.2}$$

where the sustainable production of water is given by the exogenous parameter γ. The idea is that the underground water resource is renewable, and as such what is important is the balance between inflows and outflow of water. I just assume that there is a fixed inflow of water, while the outflow is given by the production of water q. Since the main focus is on the regulatory structure, the whole issue is simplified by imposing $q = \gamma$ as the sustainable level of water production; the parameter δ represents the marginal environmental impact, and it will play a very important role in the characterization of the equilibria;

- also the environmental tax function is non linear,

$$T(q^s, t) = \begin{cases} t(q^s - \gamma) & \text{if } q^s \geq \gamma \\ \\ 0 & \text{if } q^s < \gamma \end{cases} \tag{2.3}$$

Where t is the tax rate per unit of water extracted above γ. The questions deserve a further analysis. The first one is the fact that in most cases we have a linear environmental tax. For instance the abstraction charge applied in the UK is linear. In fact, there is an information problem about the value of γ, and eventually a monitoring

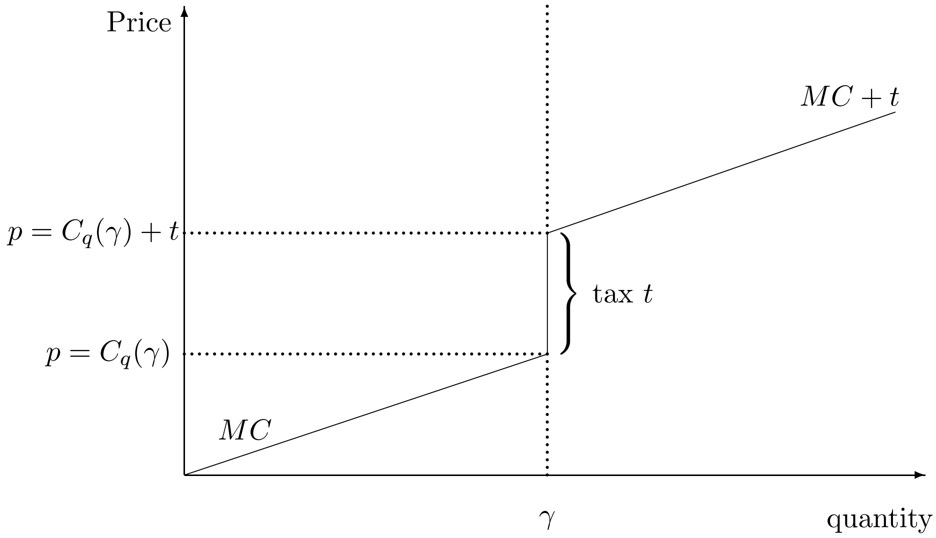

Figure 1: Competitive supply for a fixed, arbitrary t

cost associated with a non linear tax. However, from a theoretical point of view it seems more "natural" to tax the firm only when there is an environmental damage. If information and monitoring costs are not too high the best choice should be this type of tax system.

The second issue is whether to impose an upper bound limit to the tax level. This limit could be interpreted as the limit in the possibility of the tax revenue to compensate for the environmental damage. I will analyze the results in both cases, limited and unlimited taxation.

2.1 The firm

The firm is assumed to have a profit maximizing behavior. The firm faces a price p set by the regulator and a total cost function $C(q)$ such that $C(0) = 0$, $C_q(0) = 0$ and strictly convex. Subscripts indicate the variable to differentiate for.

The following is the profit function of the firm:

$$\pi(q) = \begin{cases} pq - C(q) - t(q - \gamma) & \text{for } q > \gamma \\ pq - C(q) & \text{for } q \leq \gamma \end{cases} \tag{2.4}$$

The competitive supply is given by the maximization of equation 2.4, which depends on the price and tax rate:

$$q^* \text{ s.t. } \begin{cases} p = C_q(q^*(p,t)) & \text{if } p < C_q(\gamma) \\ p = C_q(q^*(p,t)) + t & \text{if } p > C_q(\gamma) + t \\ q^* = \gamma & \text{if } C_q(\gamma) \leq p \leq C_q(\gamma) + t \end{cases} \tag{2.5}$$

Equation 2.5 represents the firm's best response to p and t. This is *not* the supply of water, however. The supply is determined by the lowest between the competitive supply and the demand of water,

$$q^s = min\{q^*(p,t), D(p)\} \tag{2.6}$$

In the appendix, I show that without loss of generality we can restrict the analysis to $q^s = q^*(p,t)$, i.e. the market supply is given by the firm supply.

The structure of the model described insofar is common to both integrate and separate cases. Now the analysis will focus on these two specific scenarios.

3 Integrated Regulator

The integrated regulator is a unique organization whose objective function is the weighted average of consumers' surplus, producer's surplus and the net environmental impact.

$$R = CS(q^s) + \lambda[\pi(q^s)] + \mu[T(q^s, t) - d(q^s)]$$

In this case the tax revenue is considered as a compensation for the environmental damage, as pointed out by Baron (1995)[8]. The parameters λ and μ indicate the importance of producer's surplus and environmental issues, respectively. Throughout the paper is assumed $\mu = 1$, which rules out the possibility the integrated regulator cares less about the environmental issue than the separate regulator[9], and $\lambda = 1$ which implies the regulator cares equally about consumers' and producer's surplus. I acknowledge the

[8]Also in Dawid et al. (2004), the tax revenue is considered in the regulator's payoff function. This seems to be a sensible assumption when dealing with renewable resources, because the regulator could use the money to improve natural replenishment.

[9]Although the possibility of $\mu < 1$ represents an interesting issue, especially from a political economy point of view, it is not pursued in this work, in order to focus on the impact of the institutional scenario on the outcome of the regulation process.

importance of this assumption and the implications we will be discussed in a subsequent section.

The objective function of the regulator becomes,

$$R = CS(q^s) + \pi(q^s) + T(q^s, t) - d(q^s) \tag{3.1}$$

The whole model with a unique regulator reduces to the interaction between firm and regulator. I model a sequential game *à la* Stackelberg, with perfect information, in which the regulator moves first. The importance of this part of the analysis is twofold. Firstly, it represents a benchmark to contrast the case of separate regulators with; secondly, it sheds some light on the regulation process when the regulator faces two tasks, both of which are "non-linear"[10].

3.1 Equilibrium

In this section, I deal with the equilibrium of the integrated regulator, sketching the main intuition behind the results. The formal treatment of the equilibrium is in the appendix.

We consider a sequential game in which the regulator moves first choosing the level of price, p, the environmental tax, t, and eventually the firm chooses the level of q. The equilibrium concept used is the Nash Equilibrium of this extensive game.

[10]The non linearity of the problem comes from the fact that the resource is renewable, and therefore the environmental problem kicks in only after a threshold level is reached.

There are two main factors driving the results: the level of demand and the marginal environmental damage, δ. As regards the former, let us note that when the demand is low there is non environmental problem. Since the resource is renewable, low level of production do not hinder the replenishment cycle. For "low" levels of demand, I mean a level of demand such that $D(q) = C_q(q)$ at a level of $q \leq \gamma$ (see figure 2). This case is not particularly interesting because no environmental damage occurs. In fact, the firm will produce a larger q only if a higher price is granted. However, at a higher price consumers' are not willing to buy that amount of water. This account for a first, trivial, case in which the institutional set up does not matter.

Hence the analysis focuses on cases in which the demand is not so low. In other word, consumers would be willing to buy a quantity of water greater than the sustainable level. This is a level of demand such that $D(q) = C_q(q)$ at a level of $q > \gamma$.

The reason why the demand is driving the results is that the regulated firm does not receive a direct transfer from the government, the firm has to sell the water on the market, an therefore only with a large demand consumers are willing to accept a large quantity of water.

The other important determinant of the equilibrium is the marginal environmental damage. That is the impact of an additional unit of water on the sustainable use of the resource. In this case the trade-off is between

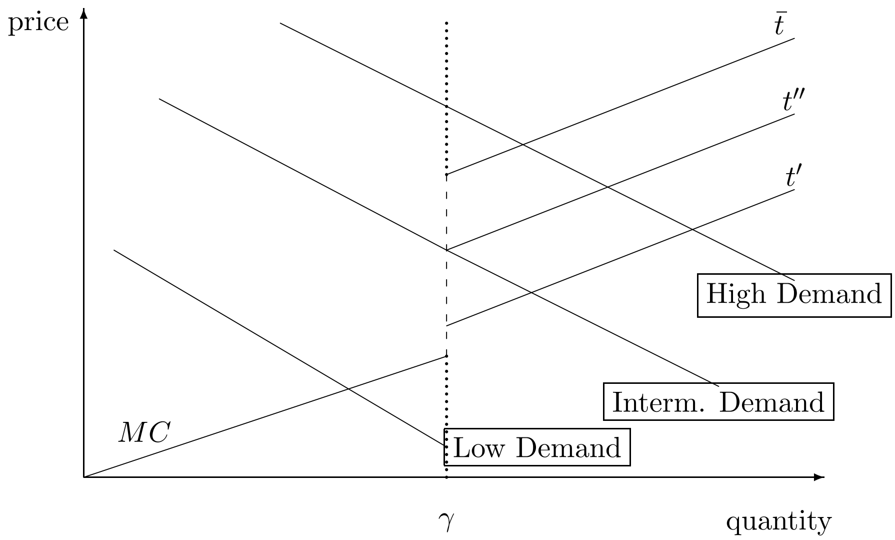

Figure 2: Definition of demand levels

consumers/producer's surplus and the environmental impact. If production is kept at a sustainable level, demand is rationed, while if demand is not rationed production is above the sustainable level.

The main results obtained is that the unique regulator will set a level of p and t such that $q = \gamma$ when the marginal environmental damage is very high, while the regulator will set a level of p and t such that $q > \gamma$ when the marginal environmental impact is not so large. Let us closely analyze the role of δ.

For a given level of demand, I define a *high* level of δ as follows. The parameter δ is high if $\{C_q(\gamma) + \delta > D(\gamma)\}$. As can be seen in figure 3, the situation is such that in order to offset the environmental impact, the tax must be so high - and as a consequence also the price - that it is better to have the demand rationed and produce at $q = \gamma$. Although there is not a unique equilibrium, the quantity of water is the same in all equilibria, i.e. $q^* = \gamma$. This equilibrium level of water can be sustained by several combinations of price and tax. The regulator can achieve this result with either p or t. That means that the regulator can also drop the environmental tax, i.e. $t = 0$, as long as it sets $p = C_q(\gamma)$. In general, the equilibrium values p^* and t^* have to satisfy the following conditions: $t \leq \hat{t}$ and $C_q(\gamma) \leq p \leq C_q(\gamma) + \hat{t}$, where $\hat{t} \in [0, \bar{t}]$ is such that $D(\gamma) = C_q(\gamma) + \hat{t}$. For instance, setting $p = C_q(\gamma)$ and any value of t is an equilibrium. Figure 3 provides a graphical representation of these equilibria.

As a corollary of this equilibrium we have that the value of the environmental tax would never be greater than δ, the environmental damage.

The other case to consider is when the environmental damage is not very high, meaning that the demand meets the social marginal costs of production at a level of $q > \gamma$, or, equivalently, that δ is such that $\{C_q(\gamma) + \delta < D(\gamma)\}$, see figure 4. In this case, it may be convenient for the regulator to accept some environmental damage in exchange for a higher consumers' and producer's surplus. Also in this case the equilibrium even if not unique, is characterized by a unique level of water produced, which is given by q^* which solves the implicit equation $D(q^*(p,t)) = C_q(q^*(p,t)) + \delta$. In fact, there are several values of p and t that sustain the value q^*, according to the profit function of the firm. As a corollary, the equilibrium level of p is the market clearing level if and only if $t = \delta$, while it is lower when $t < \delta$. The intuition can be grasped from figure 4. The graph shows that if the equilibrium is given by q^* then the equilibrium level of p and t is not unique, but it must satisfy the conditions we have previously specified. The equilibrium is indeed characterized by $q^* > \gamma$ because the regulator can compensate for the environmental damage with the tax and the increase in the surplus of consumers and producer.

As an aside, note that the equilibrium would not be different if the demand is so high that even for $t = \bar{t}$, the firm will produce more than the sustainable level. This point will turn important in the analysis of separate regulators.

Results obtained are summarized in the following proposition.

Proposition 1 *When δ is such that $C_q(\gamma) + \delta < D(\gamma)$, then the equilibrium is not unique and characterized by t^* and p^* such that $D(q^*) = C_q(q^*) + \delta$, when δ is such that $C_q(\gamma) + \delta > D(\gamma)$ then the equilibrium is not unique and is characterized by any $t \leq \hat{t}$ and $C_q(\gamma) \leq p \leq C_q(\gamma) + \hat{t}$.*

3.1.1 Comments on the integrated regulator equilibrium

The analysis conducted shows the importance of the demand level and the supply function on the behavior of the Regulator. Indeed, it is the relationship between demand and sustainable threshold that creates an envi-

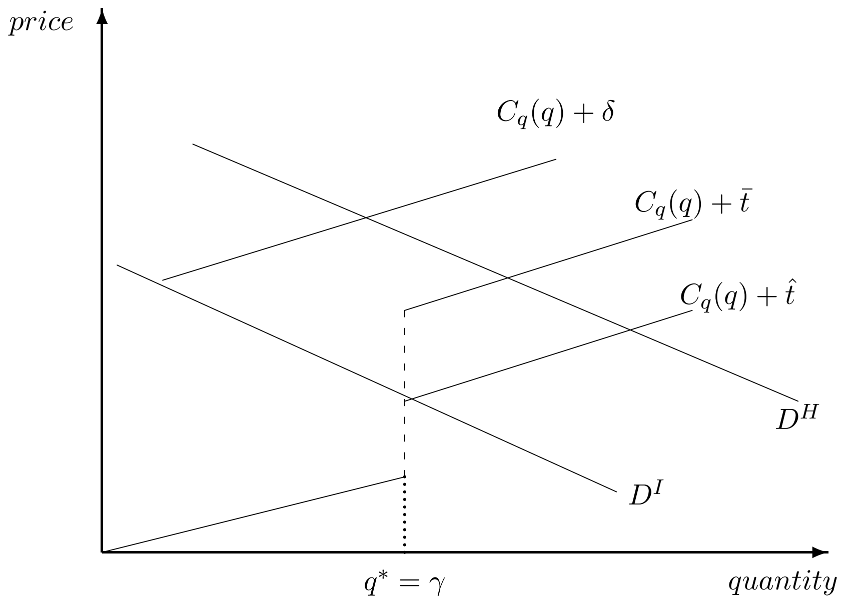

Figure 3: Integrated regulator equilibrium when δ is *high*

ronmental problem. The higher the level of γ, the lower is the probability of a problem in terms of sustainable use of the natural resource.

The demand plays a very import role, too. The regulator might shift from facing a *high* δ level to a *low* δ level as a consequence of an increase in the demand for water. That is because what matters is the environmental damage relative to the demand for water. With a high demand the cost of rationing is higher and therefore the regulator is willing to exceed the sustainable level, while with the same δ but a lower level of demand she would prefer to make the firm produce the sustainable level.

The other important consideration is on the instruments the regulator

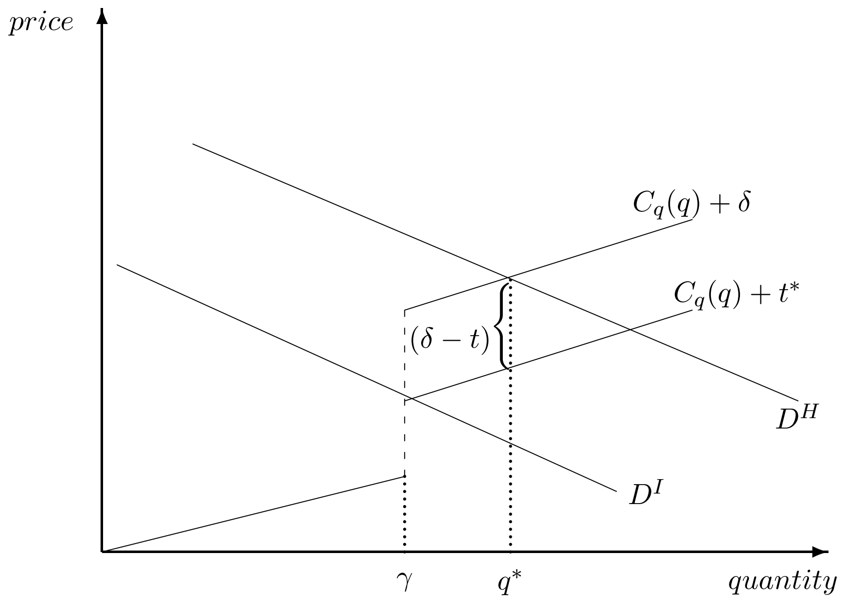

Figure 4: Integrated regulator equilibrium when δ is *Low*

is endowed with to prevent an excessive exploitation of the resource. The value of the tax rate t does not play a major role because of the assumption of $\mu = 1$. However, any equilibria (combination of p and t) has a different impact on the distribution of welfare among each part of the regulator's payoff function, as we will see in a following section.

An important implicit assumption is that there is perfect monetary compensation for the environmental damage, i.e. tax revenue can offset the negative impact of environmental damage, so that if $t = \delta$ the environmental impact is completely compensated by the tax.

4 Separate Regulators

In this section, we consider the effect on the equilibrium analysis of the presence of two separate regulators, each one concerned with a particular task. Since we have two regulators I need to say something about the way in which they behave. I proceed by assuming that they have the same "political" power, so that no one has an *a priori* external advantage. I model the situation as a simultaneous-move game[11].

Economic Regulator is concerned with the consumers' and producer's surplus. This regulator sets the level of price p in order to maximize its payoff, R_1. The supply of water is $q^s = q^*(p,t)$ as in the previous section.

$$R_1 = \begin{cases} \int_0^{\gamma} D(q)dq - C(\gamma) + \int_{\gamma}^{q^*} D(q)dq - C(q^*) - t(q^* - \gamma) & \text{for } q > \gamma \\ \int_0^{q^*} D(q)dq - C(q^*) & \text{for } q \leq \gamma \end{cases} \tag{4.1}$$

Environmental Regulator is concerned only with the environmental impact of the production process. This regulator can set an environmental tax on the firm when the production level is above the sustainable level[12], $q > \gamma$. The regulator seeks the maximization of its payoff

[11]The way in which regulators interact is relevant only in case of Low δ; in all the other cases it is irrelevant, because players have weakly dominant strategies.

[12]In principle, the environmental regulator could set a tax even for low values of q. However, independent agencies are given some general rules to follow by the policy maker;

function, R_2.

$$R_2 = \begin{cases} (t-\delta)[q^*(p,t)-\gamma] & \text{for } q > \gamma \\ 0 & \text{for } q \leq \gamma \end{cases} \tag{4.2}$$

The payoff function is concave with respect to the tax rate. In particular, it assumes value zero in $t = \delta$ and in $q^* \leq \gamma$. An increase in t has the effect of increasing R_2 because of the first term, but at the same time it decreases R_2 by reducing q^*. Figure 5 shows R_2 as a function of t.

The tax revenue in the regulator's payoff represents a compensation for the environmental damage. In this case, the regulator not necessarily wants the firm to reduce production below the sustainable level. In case the environmental regulator was not receiving any tax revenue, than only one strategy would be pursued: a level of t which guarantees an equilibrium with $q^* = \gamma$.

4.1 Equilibrium

Let us consider a *simultaneous* Nash Equilibrium[13]. The two regulators simultaneously set the level of p and t.

The level of demand with respect to the sustainable threshold γ and the marginal disutility from environmental damage, δ play a major role also in

therefore we can think about a policy maker who justifies the use of a tax only to reduce environmental damage or to compensate for the damage.

[13]For a more detailed analysis of the equilibrium is given in the appendix.

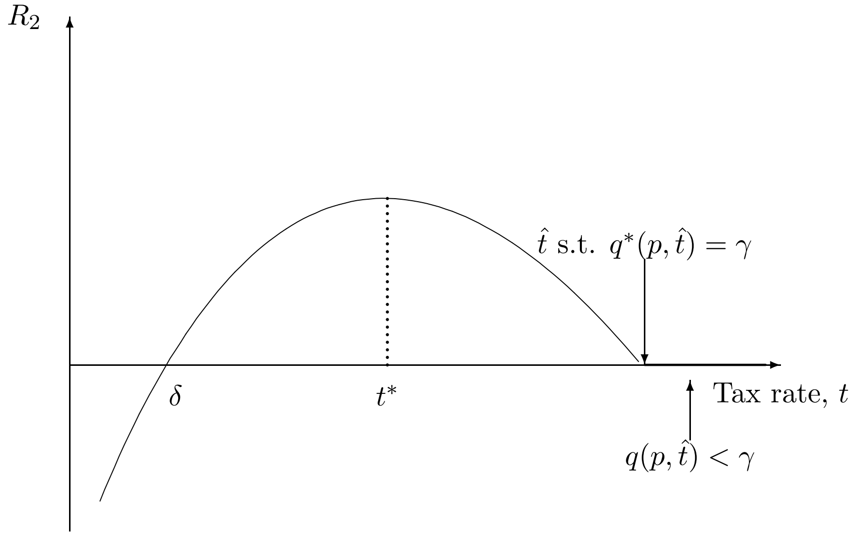

Figure 5: Environmental Regulator's payoff function.

this scenario. As we have seen in the previous section, when demand is low, there is no environmental problem.

Let us consider the equilibrium when the demand is high enough to cause some environmental problem. As before, I consider two cases, according to the value of δ.

For a high value of delta the environmental regulator has a *weakly dominant* strategy in setting t at the maximum level, i.e. $t = \bar{t}$. The strategy of the economic regulator depends on the level of demand.

In general, the economic regulator will set a level of p such that the resulting equilibrium quantity is $q^* = \gamma$. In this case the equilibrium is unique and characterized by $t = \bar{t}$ and $p = p^*$ such that $q^*(p^*, \bar{t}) = \gamma$.

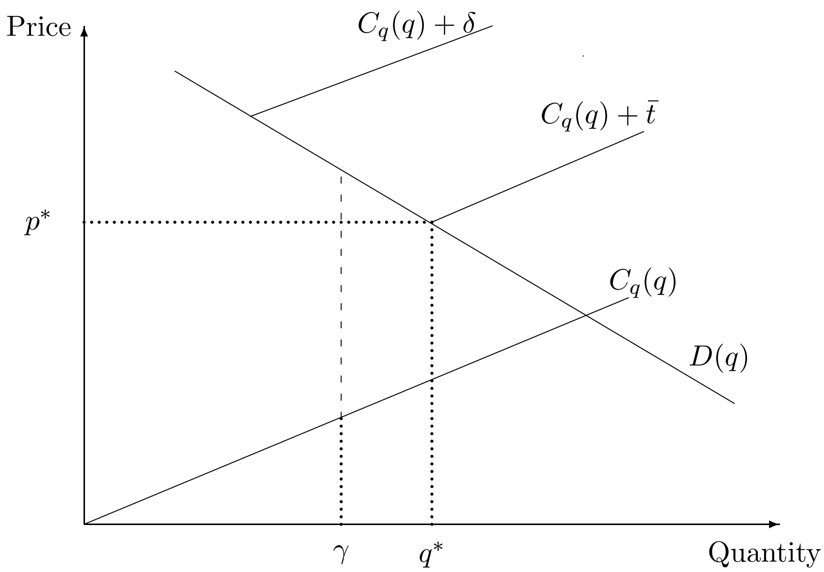

Figure 6: Equilibrium with a high marginal environmental damage and $\delta > \bar{t}$

The level of demand is not high enough to sustain a production over the sustainable level. In fact, with a very high demand, such that $D(q) = C_q(q) + \bar{t}$ at $q > \gamma$ as depicted in picture 6, the regulator optimal strategy is to set $p = C_q(q) + \bar{t}$, which is the competitive price. The resulting equilibrium is unique and characterized by $q^* > \gamma$.

In case of low marginal environmental damage, the situation is more complex, and both players have a wider range of strategies. First of all if $\delta \geq \bar{t}$, the environmental regulator has again a *weakly* dominant strategy in setting $t = \bar{t}$. The optimal reply of the economic regulator is to set p at the competitive level, i.e. $p^* = C_q(q) + \bar{t}$. In this case the equilibrium is unique and characterized by $q^*(p^*, \bar{t}) > \gamma$. In case $\delta < \bar{t}$ the environmental regulator has no more a dominant strategy. The equilibrium values of p and t are determined as a solution of the following system of implicit functions:

$$D(q(p,t)) - C_q(q(p,t)) - t = 0 \tag{4.3}$$

$$q(p,t) - \gamma - (\delta - t)\frac{\partial q}{\partial t} = 0 \tag{4.4}$$

The equilibrium is unique and characterized by $q^* > \gamma$, which guarantees a non negative payoff for the environmental regulator (it will be zero only if the equilibrium requires $t = \delta$). This case is driven by the fact that the environmental regulator receives a benefit from the environmental taxation. In this case the environmental regulator is willing to accept some environmental damage in exchange for a monetary return. We can think about the case in which the environmental regulator can use the money to improve the environment in some other way. For instance in fishery, or timber industry, the tax revenue could be used to increase the sustainable threshold.

Results are summarized in the following proposition.

Proposition 2 *The separate-regulator equilibrium, for a high δ, is characterized by $q^* = \gamma$, $t = \bar{t}$ and $p = C_q(q^*)$; and if $\delta > \bar{t}$, there is $q^* > 0$, $t = \bar{t}$ and $p = C_q(q^*) + \bar{t}$. While with δ low, $q^* > \gamma$ and p, t defined by equations A.1 and A.2.*

5 Contrasting the two scenarios

The first important result is that not always the equilibrium in the two scenarios is different. In case of a low demand the same outcome is obtained, this result is mainly due to the presence of a renewable resource. However this is not the only case. Even with a higher demand, when the marginal environmental damage is very high, both scenarios lead to the equilibrium quantity $q^* = \gamma$[14].

The fact that the equilibrium quantity is identical, does not preclude a difference on the value of p and t, between the two scenarios. Indeed, the integrated regulator is not unique. In particular, the price in the integrated regulator case is always lower or equal to the price in the separate regulator case. This result seems counterintuitive, indeed the economic regulator should pursue a lower price because is more concerned with the consumers' welfare than the integrated regulator who cares also for the environment. In fact, the firm in order to produce need a price which covers the costs, and the higher the price the larger is the output the firm is willing to produce.

This aspect is important for differences in the distribution of welfare, which will be the object of the next section.

Only with a not very high marginal environmental damage, there is a dif-

[14]In fact, only if the maximum tax level is not enough to have the firm producing the sustainable level, the integrated equilibrium is still $q^* = \gamma$, while the separate equilibrium prescribes $q^* > \gamma$.

ferent output. In both scenarios there is an equilibrium production of water greater than the sustainable level. This is because the environmental cost is not very high and therefore it is compensated by the increase in consumers' and producer's surplus. However, the equilibrium quantity is different in the two scenarios, as well as the level of the price and the environmental tax.

Let us refer to the equilibrium level with the superscripts i and s for the integrated and separate case, respectively. If the environmental tax can compensate for the marginal environmental damage, i.e. $\delta \in [0, \bar{t}]$, then we have that $q^s < q^i$. The separate equilibrium results in a lower level of water produced. The opposite result is obtained when $\delta > \bar{t}$, in this case the separate equilibrium output is larger than the integrated equilibrium quantity. The latter result is obviously due to the relative weakness of the environmental regulator, which cannot prevent the firm from producing a large amount of water.

It is clear that when the environmental damage is high, the regulator(s) would prefer not to exceed the sustainable threshold, because it is not worth it. Here the importance of the regulatory set up is evident, in case of separate regulators, only the environmental one does not want to produce more than γ. In case of high demand, the economic regulator would like to produce more than the sustainable level. This conflict may lead to over exploitation in case of $\delta > \bar{t}$. With a high demand is more difficult for the environmental regulator to stop the firm (and the other regulator), because the firm can have a positive profit even with a very high tax rate.

The last issue to talk about is the implication of the equilibrium for the distribution of welfare in the two scenario. I devote the next section to this task.

6 Analysis of the equilibrium with specific functional forms

In order to better analyze the implications of the equilibrium in terms of welfare distribution and give a useful insight of how the model works, let us restrict the analysis to linear demand and supply functions.

The focus is on a level of demand and sustainable production level, γ, that makes the environmental problem relevant, i.e. demand and competitive firm supply meet before γ.

6.1 Specific functional forms

Let us consider the case of a linear demand function and a quadratic cost function.

$$P = 1 - q(p,t) \qquad \text{inverse demand function}$$

$$TC = \frac{q(p,t)^2}{2} \qquad \text{total cost function}$$

The first thing to note is that, given that demand function, if γ is greater than $\frac{1}{2}$, there is no environmental problem, i.e. the firm will not produce

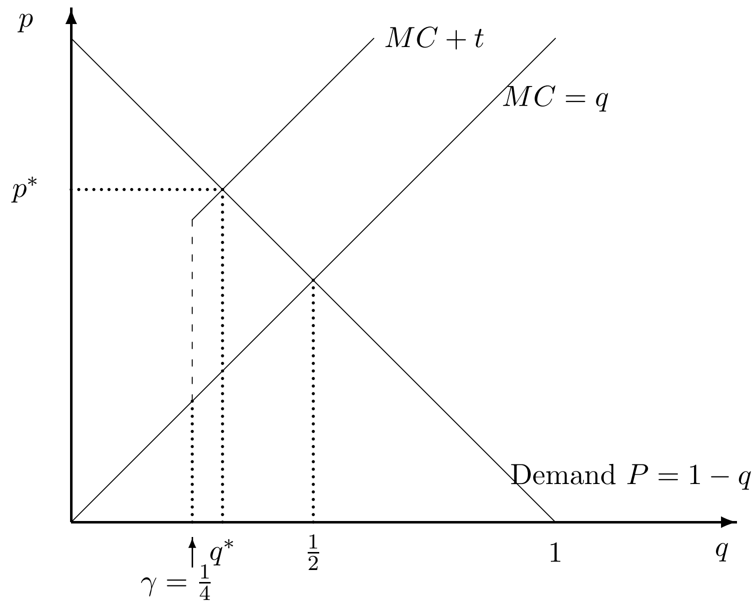

Figure 7: Linear demand and supply functions

more than the sustainable level, as shown in figure 7. Let us assume $\gamma = \frac{1}{4}$ and a marginal environmental damage $\delta = 1/4$. It corresponds to the case of relatively low marginal environmental damage.

The production level supplied by the firm is given by

$$q^s = \min\{(1-q), (q+t)\} \tag{6.1}$$

which represents the minimum value between the demand and the firm's best response, $q = p - t$.

The analysis will be conducted first in the integrated regulator case and then in the separate regulators scenario.

6.2 Integrated regulator

Given the assumptions made, the objective function of the regulator looks like

$$R = \int_0^q (1-q)dq - \frac{q}{2}^2 \tag{6.2}$$

for $q \leq \frac{1}{4}$, and

$$\begin{aligned} R &= \int_0^{1/4} (1-q)dq - \left(\frac{1}{4}\right)^2 \frac{1}{2} + \int_{\frac{1}{4}}^q (1-q)dq - \frac{q^2}{2} - t(p-t-\frac{1}{4}) + \\ &\quad +(t-\frac{1}{4})(q-\frac{1}{4}) \end{aligned} \tag{6.3}$$

when $q > \frac{1}{4}$.

Equation 6.3 represents the payoff when the quantity of water produced is above the sustainable level. Note that the first part represents the surplus from producing exactly $q = \gamma$, while the second integral represents the increase in surplus given by an additional production of water, this is counterbalanced by the last term, which represents the environmental balance.

The regulator in order to maximize its payoff function wants the firm to produce a level of water[15] equal to $q^u = \frac{3}{8}$, which is greater than the sustainable level. The equilibrium is characterized by any value of p in the set $[\frac{3}{8}, \frac{5}{8}]$, and t in the set $[0, \frac{1}{4}]$, and satisfying $p - t = q = \frac{3}{8}$. Note that in this case the value of t is never greater than δ[16].

[15]This value is obtained maximizing equation 6.2 and 6.3 with respect to q, as shown in appendix C.

[16]The proof is based on the fact that when $t > \frac{1}{4}$ the supply of the firm is limited by

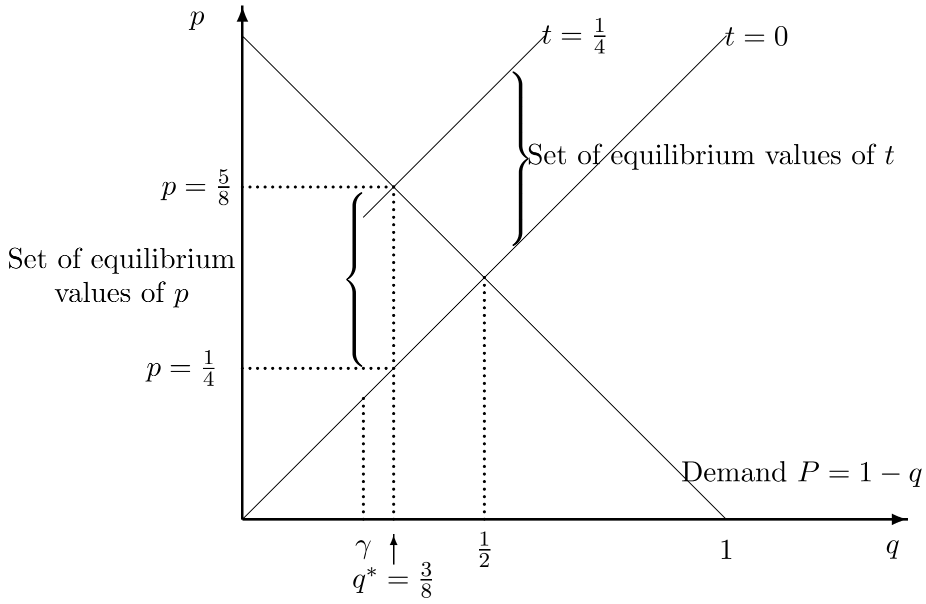

Figure 8: Equilibrium values of p and t.

For instance, it is possible to show that the couple $p = \frac{5}{8}$ and $t = \frac{1}{4}$ is an equilibrium. However, this is not the only equilibrium, since the regulator gives the same weight to the consumers' surplus and the environmental tax revenue, less tax t is compensated by a higher consumers' surplus. To sum up, any equilibrium is characterized by $q = \frac{3}{8}$, the relation $p - t = \frac{3}{8}$ and $p \in [\frac{3}{8}, \frac{5}{8}]$ and $t \in [0, \frac{1}{4}]$.

The important issue left to raise is the distribution of wealth among

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the demand, and the fact that setting $q < \frac{1}{4}$ is never convenient for the firm. Assume $t = \frac{1}{4} + \varepsilon$ with $\varepsilon > 0$ and arbitrarily small. Then $p = \frac{5}{8} + \varepsilon$ and the supply function becomes $q^s = min\{\frac{3}{8}; \frac{3}{8} - \varepsilon\}$. Therefore $q^s < \frac{1}{4}$, and the regulator gets a higher payoff by setting $q = \frac{1}{4}$, because when $q < \gamma$ there is no gain from the tax rate.

consumers, the firm, and the environment. Let us consider the Consumers' surplus first. It depends on the particular equilibrium chosen, i.e. on the equilibrium values of p and t. A higher price correspond to a lower consumers' surplus. The following equation identifies this relationship,

$$CS = \int_0^{q^*(p^*,t^*)} (1 - q^*(p^*, t^*))dq - p^*q^* \tag{6.4}$$

The range of values that the consumers' surplus may assume is determined by the range of values the equilibrium price may assume. The lowest equilibrium price $p = \frac{3}{8}$ defines $CS = \frac{21}{128}$, which represents the highest surplus consumer may obtain. On the other extreme, when price is $p = \frac{5}{8}$ the consumers' surplus is $CS = \frac{9}{128}$. To sum up, in case of integrated regulator the consumers' surplus lies in the range $\left[\frac{9}{128}, \frac{21}{128}\right]$.

The environmental payoff, depends on the level of the tax t, and it ranges from a minimum of $-\frac{1}{32}$ to a maximum of 0. This shows how the regulator can trade environmental damage with increase in the surplus of consumers and the firm.

6.3 Separate regulators

The environmental regulator cares only for the environmental damage and the tax revenue.

$$R_2 = \begin{cases} \left(t - \frac{1}{4}\right)\left(q(p,t) - \frac{1}{4}\right) & \text{for } q > \frac{1}{4} \\ \\ 0 & \text{for } q \leq \frac{1}{4} \end{cases} \tag{6.5}$$

Note that R_2 is concave with respect to t, and it can assume either positive or negative values, as shown in figure 5. It assumes value zero for $t = \frac{1}{4}$ independently of the price set by the economic regulator.

The payoff of the economic regulator, R_1 is identical to equations 6.2 and 6.3 without the part concerning the environment (the last part of equation 6.3).

The Nash equilibrium, in this case is unique, and determined by the solution of the system of equations derived by the maximization conditions of the Economic and the Environmental regulator. In our particular example the system looks like,

$$\begin{aligned} 1 - 2p + t &= 0 \qquad\qquad t^* = \frac{1}{3} \\ p - 2t &= 0 \qquad\qquad p^* = \frac{2}{3} \end{aligned}$$

and the equilibrium quantity is $q^* = \frac{1}{3}$.

Note that the economic regulator could always have the firm producing γ by setting a lower price; and the environmental regulator can always set $t = \delta$ in order to get a non negative payoff[17]. However, this solution to be an equilibrium must also satisfy $R_2 \geq 0$ and $R_1(q^*) \geq R_1(\gamma)$, Otherwise it could be that one of the two regulators could do better by having the firm to produce just the sustainable level. It is easy to check that the equilibrium is actually the one we have described, indeed, the payoff of the Economic regulator is $R_1(q^*) = \frac{7}{36}$ which is greater than $R_1(\gamma) = \frac{3}{16}$, while the Environmental regulator's payoff is $R_2 = \frac{1}{144}$, greater than zero.

The equilibrium values of p and t are both higher in the separate regulator case, $p^s = \frac{2}{3}$ is higher than the upper bound of the range of equilibrium values of p in the integrated equilibrium. The same is true for t, which is also greater than the marginal environmental damage.

The total payoff $R_1 + R_2 = \frac{29}{144}$ is lower than the case of integrated regulator $R = \frac{13}{64}$. In this case, the issue of cooperation arises. In a repeated game the integrated regulator outcome could be sustained by a retaliation strategy. The two regulators will share the difference in surplus according to their bargaining power. In fact, the environmental regulator would play the integrated equilibrium strategy only if the economic regulator commit

[17]That would be her dominant strategy if the regulator would not receive the revenue from the environmental tax.

herself to a credible transfer in favor of the environmental regulator[18]

It is also interesting to note how the single component of the surplus change from one equilibrium to the other. The consumers' surplus in equilibrium is $CS = \frac{1}{18}$, while the firm's surplus is $PS = \frac{5}{38}$. It is clear that while consumers are better off under integration of regulators, the firm is better off under separation. Note that the environmental side obtains a positive balance, while in the integrated equilibrium is at maximum equal to zero. Hence, it is only consumers who loses in the separation of regulators.

We can consider consumers' surplus as the short run surplus and the environmental benefit as the long run surplus, which will bear a benefit to the consumer only in the future.

If we increase the value of δ, such that $D(\gamma) < C_q(\gamma) + \delta$, the equilibrium solution in the two scenarios coincides. In both cases the equilibrium is characterized by the same level of output $q^* = \frac{1}{4}$, and no environmental damage. The difference between the two scenarios relies on the fact that in the separate case the economic regulator is better off setting a price that forces the firm to produce γ. The environmental regulator would like to set $t \geq \delta$, however at that level the payoff of the economic regulator is higher with $q = \gamma$. A lower level of t could give the economic regulator a higher payoff, but the environmental regulator would never set such a value of t.

[18]The problem, however, is the meaning of a monetary transfer for a regulator. We need to assume that the surplus can be represented in monetary terms. It may be ok for the environmental regulator, though.

The equilibrium strategy is t s.t. $D(\gamma) \leq C_q(\gamma) + t$ and $C_q(\gamma) \leq p \leq D(\gamma)$.

6.4 Case of high marginal environmental damage

The assumptions on the demand and cost function are the same as before, the only difference is the value of δ. I assume that the marginal environmental damage is equal to 3/4. In this situation the payoff of the integrated regulator is $R = \frac{3}{16}$ if $q \leq \gamma$, while by maximizing the payoff function for $q > \gamma$ we actually obtain a maximum in $q = \frac{1}{8}$, which is lower than the sustainable level. This means that the integrated regulator prefer the firm to produce $q = \gamma$. The equilibrium is characterized by $p \in \left[\frac{1}{4}, \frac{3}{4}\right]$ and $t \in \left[0, \frac{1}{2}\right]$. This equilibrium assures the following range of Consumers' surplus: $\left[\frac{1}{32}, \frac{5}{32}\right]$, according to the level of price chosen. Note that if the regulator is biased towards consumers, i.e. $\lambda < 1$, the the price chosen by the regulator would be $p = \frac{1}{4}$ and the consumers' surplus would be the maximum level.

In case of separate regulators, the equilibrium quantity is still $q = \frac{1}{8}$, however, the distribution of surplus is somehow different. In particular, we have a unique equilibrium price $p = \frac{1}{4}$ which assures a surplus of $\frac{5}{32}$. The striking fact is that with separation we get the maximum consumers' surplus even we the assumption of $\lambda = 1$.

7 Assumptions on λ and μ

Throughout the paper I assumed $\lambda = 1$ and $\mu = 1$. There are two questions to answer: is this assumption justified, and how results would change with different values of λ and μ?

Firstly consider the case of $\lambda < 1$, i.e. the economic regulator care less about the firm's surplus. The supply is always represented by the competitive supply, i.e. the price will be lower than the competitive price. This implies rationing of the demand, even when the demand is *Low*. The rationing of demand raises the question of the opportunity of measuring the satisfaction of consumers with the surplus.

However, the analysis is analogous to the case of $\lambda = 1$. In fact, the discriminant point is no more whether *demand* = *supply* at $q \lesseqqgtr \gamma$, but the whether the consumers' surplus is maximized at a value of q lower of higher than the threshold level. For instance, if the CS is maximized at $q < \gamma$ there would be no environmental impact and therefore no scope for the environmental regulator. As already mentioned the equilibrium price will be lower than the competitive price, and therefore lower than the case of $\lambda = 1$. That implies demand rationing.

In general, however, the regulator would care less about the firm's profit, and she would set a lower price. A lower price also means lower supply, or higher rationing, which is not good for consumers' welfare. The assumption of $\delta = 1$ is pursued with the goal of accounting for a model in which the regulator has no equity or redistribution issues, being only concerned with the efficiency of the regulatory procedure.

As regards μ, result will change with a different assumption, the higher μ the lower would be the equilibrium level of q. In this case, however, the difference in the equilibrium between the two scenarios would be the result of a different political weight on the environmental issue. The reason for setting $\mu = 1$ to have the same weight for the environmental question in both scenarios.

8 Concluding remarks

The way in which the regulatory institutions are shaped plays a major role in the outcome of the regulation process. The monopolistic firm receives different incentives whether she faces one regulator or two of them. Also from an environmental perspective, deciding to have two separate regulators may or may not have a positive effect on the natural resource under consideration. In particular, the role of the demand and the marginal environmental impact is crucial for the equilibrium in each scenario.

However, it is not always the case that the equilibrium is different. With a *Low* demand there is no difference between the two scenarios. And even with a *higher* demand and relatively *high* marginal environmental impact there is no difference.

The perfect information set up allowed to single out the inefficiency brought by separation of regulators, and to characterize the distribution of surplus. That would not be possible with an asymmetric information set up, because we would always have an inefficient outcome. Moreover, it allows to consider a further source of inefficiency, other than asymmetric information. When the policy maker decides to create several separate regulator, should be aware of the fact that their objectives might be in contrast.

The model wants to be a first step towards a better understanding of the implication of independent regulators either in term of efficiency and of environmental impact, in fact, the "strong" assumptions made in the set-up of the model, limits the possibility to conduct a positive analysis.

Another limit is the absence of dynamics. In particular, we leave for future research the analysis of a model in which the firm could smooth the production of water in an infinity time horizon, taking into consideration the uncertainty linked with the availability of water and the demand.

Appendix

A Formal characterization of the equilibrium

In this appendix I formally characterize the equilibrium in the two scenarios: integrated and separate regulators.

Let us start by defining the level of supply of water. The supply is given by $q^s = \min q^*(p,t), D(p)$, the minimum level between the competitive supply and the demand level. I will show that without loss of generality we can restrict the analysis to $q^s = q^*(p,t)$. As long as the price is set at the clearing market level or below the market supply coincides with the firm's supply. When the price is above the market clearing the demand would not absorb all the supply the firm is willing to produce. The following lemma helps us in this case.

Lemma 1 *When the equilibrium quantity is greater than the sustainable level, $q^* > \gamma$, two possible level of p implements the quantity q^*, one above and one below the market clearing price. In this case the regulator is indifferent between the two prices.*

That means the regulator can obtain the same level q^* by setting two alternative prices, one above and one below the market clearing price. Since Lemma 1, we can assume, without loss of generality, that the regulator never chooses the price above the competitive level[19].

Let us turn to the characterization of the equilibrium under the two scenarios. Firstly, when demand is very low the equilibrium does not involve any environmental issue, and it is simply characterized by the equality between marginal costs and price. Therefore I will focus on situations in which the demand is large enough to create environmental problems.

[19]Note that if $\lambda < 1$ then water supply is always determined by the competitive supply, see appendix **??**.

A.1 Equilibrium conditions in the integrated regulator case

The integrated regulator chooses the level of p and t which maximize her payoff function, given the best response of the firm q^*. However, note that the regulator can actually determine the level of q by choosing an appropriate level of p and t. We can proceed by maximizing with respect to q directly, and eventually consider what value of p and t may sustain that quantity q. In this case the problem becomes,

$$\max_q R = \begin{cases} \int_0^{q^*} D(q^*)dq - C(q^*) & \text{for } q \leq \gamma \\ \int_0^{\gamma} D(q^*)dq + \int_{\gamma}^{q^*} D(q^*)dq - C(q^*) - t(q^* - \gamma) + (t - \delta)(q^* - \gamma) & \text{for } q > \gamma \end{cases}$$

Since the problem is not differentiable in $q = \gamma$ we need to consider the two cases separately. The maximization of the two equations lead to the following first order conditions:

$$D(q) = C_q(q) \quad \text{for } q \leq \gamma \tag{A.1}$$

$$D(q) = C_q(q) + \delta \quad \text{for } q > \gamma \tag{A.2}$$

The first equation simply tell us that the quantity should be such that equates the demand and marginal cost of water. The second one that the optimal quantity must equate the demand to the marginal cost of water plus the marginal environmental damage, i.e. the social marginal cost of producing more than the sustainable level. Comparing the two levels we can check which one gives the higher payoff to the regulator. However, note that the first equation, when the demand is high, is maximized for $q = \gamma$. If the optimal q from the second equation is greater than γ than that is the equilibrium value, in case it is lower than γ it is better to produce $q = \gamma$. This argument just leads to the discriminant role played by δ. As δ increases the quantity q which satisfies condition A.2 decreases.

The level of p and t must be such that the equilibrium quantity is implemented by the firm. The firm best response function is,

$$p - C_q(\hat{q}) - t = 0$$

where $\hat{q}$ is the optimal q chosen be the regulator. The optimal level of p and t must respect this condition. For instance if $t = 0$ the level of p must be equal to $C_q(\hat{q})$.

A.2 Separate-regulator equilibrium

In case of separate regulators, each one wants to maximize her payoff function. The two regulator choose the strategy simultaneously. Each regulator seeks the maximization of its own payoff function given the expectation on the strategy of the other regulator. The problem is to maximize R_1 and R_2 for the economic and environmental regulator, respectively.

$$\max_p R_1 = \begin{cases} \int_0^q D(q)dq - C(q) & \text{for } q \leq \gamma \\ \int_0^\gamma D(q)dq - C(\gamma) + \int_\gamma^q D(q)dq - C(q) + C(\gamma) - t(q-\gamma) & \text{for } q > \gamma \end{cases} \tag{A.3}$$

$$\max_t R_2 = \begin{cases} 0 & \text{for } q \leq \gamma \\ (t-\delta)(q-\gamma) & \text{for } q > \gamma \end{cases} \tag{A.4}$$

Since the non differentiability of both objective functions in $q = \gamma$ we need to consider separately the two cases. Let us start from the case in which $q > \gamma$. The Nash equilibrium in this case is given by the system of equation formed by the first order conditions of the two problems.

$$\frac{dR_1}{dp} \Rightarrow D(q) - C_q(q) - t = 0 \tag{A.5}$$

$$\frac{dR_2}{dt} \Rightarrow (t-\delta)\frac{\partial q}{\partial t} - q + \gamma = 0 \tag{A.6}$$

From equation A.6, we see that the environmental regulator is willing to accept a non sustainable level of q only if $t > \gamma$. From equation A.5, the economic regulator will set the price at the market clearing level, as long as the equilibrium quantity $q > \gamma$. In fact, if the equilibrium quantity stemming from the solution of the system is $q < \gamma$ the economic regulator would set a price such that the firm produces exactly $q = \gamma$. As we have shown in the previous section the *argmax* of R_1 for $q \leq \gamma$ is exactly γ.

The role of the marginal environmental damage, δ, is crucial for the equilibrium.

Let us consider the following casual relationship, as the level of δ increases, equation A.6 requires a higher t. As a consequence of a higher t, the level of the equilibrium output q is lower. There exists a threshold level $\hat{\delta}$, such that for $\delta > \hat{\delta}$ (we call this a *high* level of δ), the equilibrium quantity satisfying equation A.5 is $q < \gamma$. In this case, the economic regulator prefers to set p such that $q = \gamma$. For $\delta < \hat{\delta}$ the equilibrium quantity is $q > \gamma$ and the equilibrium level of p and t is given by the solution of the system of equations.

As a last remark note that if $\delta > \bar{t}$, the only strategy for the environmental regulator is to set $t = \bar{t}$. In this case, if from equation A.5 we get $q > \gamma$ then that is the equilibrium quantity, otherwise the equilibrium will be $q = \gamma$.

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