

INTEGRATED vs SEPARATED REGULATION: AN APPLICATION TO THE WATER INDUSTRY

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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, one monopolistic firm and a renewable natural resource is presented. In this set up the level of demand relative to the sustainable use of the water resource plays a major role. The main result is the characterization of the cases in which the outcome of the regulation actually differs between the integrated-regulator and the separate-regulator scenarios. We find that the main determinants of the equilibrium are the level of demand and the marginal environmental damage. The equilibria obtained are analyzed in terms of price, environmental tax levels, and in terms of welfare distribution among the components of the regulator(s)' objective function.

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1 Introduction

1.1 Motivations

Water is essential for 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, the failures of which mitigated through 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, the Environment Agency, and an agency for the quality of water, DWI (*the Drinking Water Inspectorate*). 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 managers 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.). Water problems do not arise solely due to draught but more importantly, by the interaction between the demand of water and the water resources available. Therefore, even places relatively highly endowed with water can face water 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, also institutional problems (conflict between Federal and State level), along with conflicts between users (especially farmers and private consumers in Idaho), and dramatic population growth (such as in Colorado). 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” (Dr. Kelly Redmond, Deputy Director of the Atmospheric Science Division at the Desert Research Institute, Reno (USA), this quote appeared in the July 2005 issue of the 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, and they have conflicting objectives.

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, is on the theory of economic regulation. This paper represents one of the few attempts to analyze a regulatory set up in which more than one regulator operates. In a situation in which there are two contrasting issues the policy maker faces, namely, economic efficiency and environmental impact,

what is the role of separate regulators? In other words, is it better to have a unique regulator or one regulator for each issue? These questions, along with the analysis of the impact of the equilibrium decisions of a monopolistic firm, represent the main focus of this paper.

I propose a model with a monopolistic firm operating in the water sector, where from an underground resource water is pumped-up and distributed to consumers. The policy maker wants to regulate this industry because he/she cares for the environmental impact on the underground water resource and the economic efficiency of the firm - which has a big impact on consumers' surplus. In order to do so, the policy maker may devise two separate regulators, an environmental one and an economic one, concerned with the exploitation of the renewable resource and the efficiency of the firm's production function, respectively. I contrast this scenario with the benchmark case, where only one regulator cares for both issues.

The main results concern the importance of the demand for water 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. This is in contrast with the previous literature (see Baron (1985) and Dixit (1996)), where the presence of multiple regulators would create inefficiency.

The difference comes from the interaction between the demand side and the marginal environmental damage. First of all, when demand is very low, there is no environmental damage; given the renewable nature of the resource, the production must exceed a certain threshold to be non sustainable. However, even when the demand is high, we have some cases in which the equilibrium output is the same. For instance, for large values of the marginal environmental damage, the equilibrium quantity is the same in both scenarios.

When competition between the two regulators actually results in a different equilibrium it is important to characterize it in terms of price level, quantity, and environmental tax. The importance of this analysis resides in the role the equilibrium level of price and tax play in 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 favor of short or long run benefits. In other words, there is a trade off between welfare of today and the welfare of future generations. When demand increases with

respect to the marginal environmental damage, the equilibrium quantity chosen by the firm becomes non sustainable. However, in the case of separate regulators, this quantity is lower than in the case of an integrated regulator. A paternalistic government would prefer separate regulators if consumers are deemed not to care enough for the welfare of future generations¹.

The second contribution of the paper is on the environmental economics literature. Indeed, the firm uses a renewable resource: underground water. The literature² 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. In this paper, we focus on the implementation of policies, though. As previously mentioned, most countries leave the water service to private companies, under the supervision of regulators. It is therefore important, 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 resources such as fishery, timber industry, etc.

Another feature to stress is the choice of the water industry as an application of the theoretical model. 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 regulated companies operating in the English market, the SOUTHERN WATER company³, "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 the " Environment Agency, [which] monitors the company's performance to ensure environmental standards". Concerning the effect of this multi-regulator scenario, it is illuminating the 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".

¹The debate about inter-temporal distribution is very important, the main issues concerning the discount rate of future welfare and the possibility of altruism between generations.

²For a review of the literature on natural resources, see, for instance Kneese and Sweeney (1985) and Tietenberg (2003).

³At the web address: <http://www.southernwater.co.uk/corporate/aboutUs/waterRegulation.asp>

1.3 Review of the literature on economic regulation

The literature on economic regulation pays a lot of attention to the relationship between the regulator and the firm⁴. However, not so much attention is devoted to scenarios in which several regulators operate. One important exception is Baron (1985). Baron considers a case in which a firm produces electricity and, as byproduct, pollution. There are two agencies that influence the behavior of the firm: an environmental agency and a public utility commission. The latter regulates the natural monopoly by setting a tariff while the former deals with pollution abatement, by imposing an environmental tax. The key point of the article is the fact that the 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 electricity production and suffer from the pollution created. Since the public utility commission must set a tariff that covers all firm's costs, the 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's paper is 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 considering an imperfect information set up cannot clearly separate the effect of the asymmetric information from the lack of cooperation between the two regulators. Also, the nature of the environmental problem is different because in this paper we deal with a renewable resource.

Three more recent papers address the issue of multiple regulators. Dixit (1996) sets 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 becomes third best if regulators are competing among themselves, but it is not clear what is the part of inefficiency stemming from the presence of several regulators. Also Martimort (1999) considers an asymmetric information set up – a "common agency" model – in which regulator(s) seek to maximize their welfare over two periods devising a renegotiation proof contract at the beginning of period 1. Finally, Laffont and Martimort (1999) consider a political economy model in which the presence of several regulators reduces the risk of regulatory capture.

The present work, by assuming perfect information, focuses only on the effect of multiple regulators. Moreover, the model proposed allows to evaluate the effect of demand on the equilibrium.

⁴For a review of this literature see Armstrong et al. (1994) and Newbery (1999).

1.4 Organization of the paper

The rest of the paper is organized as follows. In the next section, we present the general set up of the model, then in the unique regulator and the separate regulator cases are analyzed in section 3 and 4, respectively; in section 5 the results obtained in the two scenarios are discussed; in section 6 the analysis is restricted to specific functional forms – linear – which allows to consider welfare implications; finally, concluding comments and further developments are discussed.

2 Model set-up

Let us consider a monopolistic firm running the water service, which consists in extracting water from an underground resource and distributing it. The monopolistic nature of the market makes 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 consists in the imposition of an environmental tax⁵ 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 integrated regulator scenario, the unique regulator is both concerned with setting the price to be charged to consumers 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:

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

where q^s represents the firm's supply of water, and $D(q)$ the inverse demand for water⁶;

⁵Even 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.

⁶It is assumed a downward sloping demand.

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

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

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 matters 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 $\delta > 0$ represents the marginal environmental impact, and it will play a very important role in the characterization of the equilibrium;

- also the environmental tax function is non linear,

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

where t is the tax rate per unit of water extracted above γ . The assumption of non linearity deserves a further analysis. 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 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 actual 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 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. One way to proceed could be to set the limit at the marginal environmental damage, i.e. $\bar{t} = \delta$. This seems a sensible assumption, the policy maker could enforce only tax level that are not higher than the social cost of the environment. However, I find it interesting not to restrict the analysis a priori, in order to see the taxing behavior of the regulator when the maximum tax is above the marginal environmental damage.

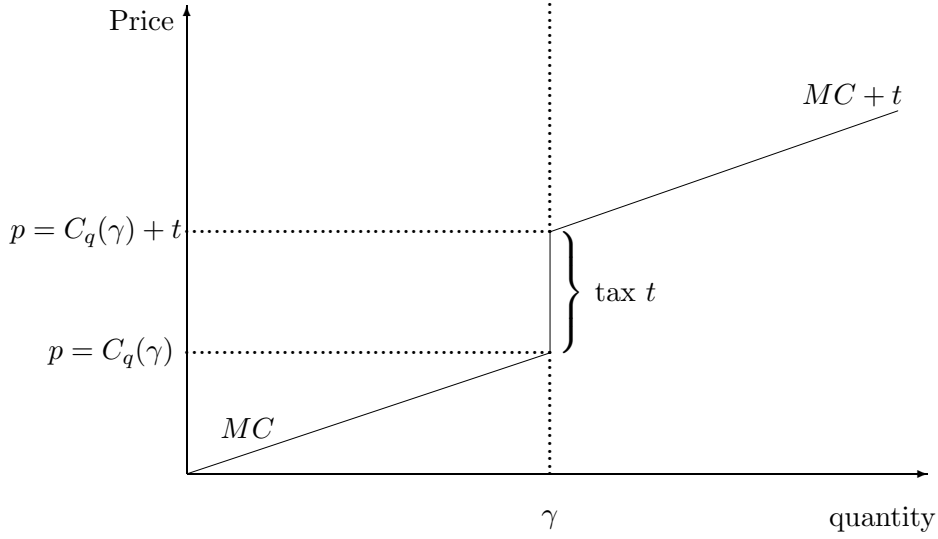


Figure 1: Competitive supply for a fixed, arbitrary t

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 it is strictly convex. Subscripts indicate the variable to differentiate for.

The following is the profit function of the firm:

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

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

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

The function 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,

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

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.

$$\begin{cases} R = CS(q^s) + \lambda[\pi(q^s)] & \text{for } q \leq \gamma \\ R = CS(q^s) + \lambda[\pi(q^s)] + \mu[T(q^s, t) - d(q^s)] & \text{for } q > \gamma \end{cases}$$

In this case the tax revenue is considered as a compensation for the environmental damage, as in Baron (1985)⁷. The tax instrument is delegated to the regulator which will use it to pursue her objective function.

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 regulator⁸, and $\lambda = 1$ which implies the regulator cares equally about consumers' and producer's surplus. The importance of these assumptions and the implications will be discussed in a subsequent section.

The objective function of the regulator becomes,

$$\begin{cases} R = CS(q^s) + \pi(q^s) & \text{for } q \leq \gamma \\ R = CS(q^s) + \pi(q^s) + T(q^s, t) - d(q^s) & \text{for } q > \gamma \end{cases} \quad (3.1)$$

The whole model with a unique regulator reduces to the interaction between firm and regulator. I consider 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.

⁷Also 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.

⁸Although the possibility of $\mu < 1$ represents an interesting issue, especially from a political economy point of view, it is not pursued in this work.

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, namely environmental protection and surplus enhancement.

3.1 Equilibrium

In this section, I analyze 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 Subgame Perfect Equilibrium.

There are two main factors driving the results: the level of demand and the marginal environmental damage, δ . As regards the former, note that when the demand is low there is no environmental problem. Since the resource is renewable, low levels 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 $q \leq \gamma$. 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, but 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. The analysis focuses on cases in which the demand is not so low. In other words, 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, and 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, δ , 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 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 result 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.*

First of all note that the level of δ is high or low relative to the demand for water. The same level δ_0 is high if the demand is low and it is low if the demand is high.

Let us closely analyze the case of “low δ ”. When the marginal environmental damage is not very high, it means that the demand meets the social marginal costs of production at a level of $q > \gamma$, or, equivalently, that δ is such that $\{C_q(\gamma) + \delta < D(\gamma)\}$, as shown in figure 2 by demand D^H (we can also see that if the demand is lower D^L the best the regulator can do is to have the firm produce $q = \gamma$). In this case, it is convenient for the regulator to accept some environmental damage in “exchange” for a higher consumers’ and producer’s surplus. Indeed, the equilibrium quantity is greater than the sustainable level, $q^* > \gamma$. The equilibrium is characterized by the values p^* and t^* which solve the implicit equation $D(q^*(p, t)) = C_q(q^*(p, t)) + \delta$. There are several values of p and t that satisfy this condition; the equilibrium quantity is unique, however.

As a corollary of the equilibrium, we may note that p is at the market clearing⁹ level if and only if $t = \delta$, while it is lower when $t < \delta$. The intuition can be grasped from figure 2. 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.

The same kind of argument applies for the case of “high” marginal environmental damage. The difference being that the regulator prefers not to exploit the underground water resource because the benefit in terms of higher consumers’ surplus and tax revenue do not compensate for the environmental damage. The equilibrium is characterized by the values of p and t which sustain a quantity level $q^* = \gamma$.

Results obtained are summarized in the following proposition.

Proposition 1 (i) if δ is such that $C_q(\gamma) + \delta < D(\gamma)$, the equilibrium is characterized by $q^* > \gamma$ and t^* , p^* satisfying $D(q^*(p, t)) = C_q(q^*(p, t)) + \delta$; (ii) if δ is such that $C_q(\gamma) + \delta > D(\gamma)$, the equilibrium is characterized by $q^* = \gamma$ and $t \leq \hat{t}$ and $C_q(\gamma) \leq p \leq C_q(\gamma) + \hat{t}$, where \hat{t} is such that $D(\gamma) = C_q(\gamma) + \hat{t}$.

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 environmental problem. The higher the level of γ , the lower is the probability of a problem in terms of sustainable use of the natural resource. Note that the regulator might shift from facing a “high δ ” level to a “low δ ”

⁹The price at which demand is equal to supply and there is no rationing.

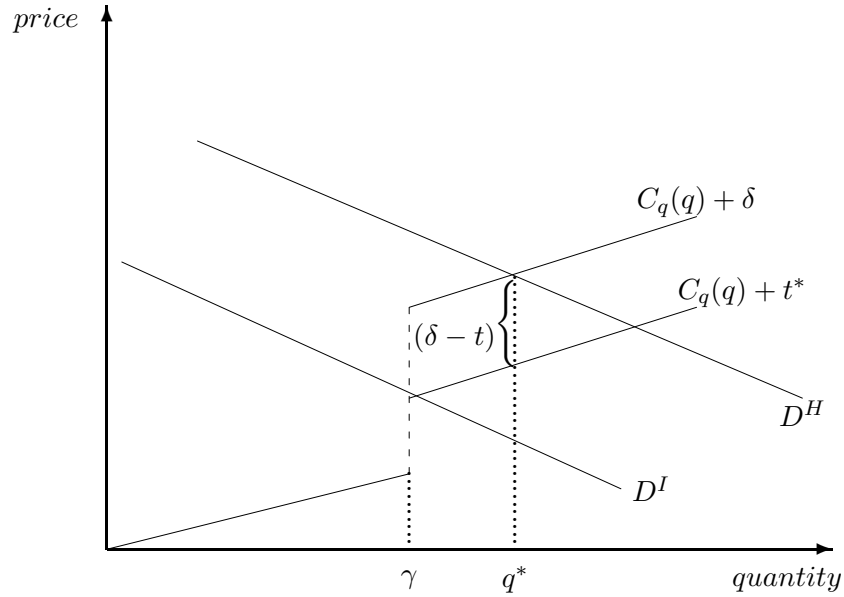


Figure 2: Integrated regulator equilibrium when δ is *Low*

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 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 $\mu = 1$. 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 another part of the paper.

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 this situation as a simultaneous-move game¹⁰.

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.

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

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 level¹¹, $q > \gamma$. The regulator seeks the maximization of its payoff function, R_2 .

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

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^* . The tax instrument delegated to the environmental authority is used in order to maximize the regulator objective function. This does not necessary coincide with the social welfare, and therefore the tax level is not necessarily the level of a Pigovian tax¹²; the tax level could be higher because the environmental regulator does not care about the effect of the tax on the firm's surplus.

4.1 Equilibrium

We characterize the Subgame Perfect Equilibrium (SPE)¹³ in which 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 this scenario. As

¹⁰The 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.

¹¹In 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; 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.

¹²A Pigovian tax would be set at a level in which $R_2 = 0$.

¹³A more detailed analysis of the equilibrium is given in the appendix.

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 in the previous section, the equilibrium depends on the marginal environmental damage, δ . Since regulators are separate the maximum level of taxation \bar{t} becomes relevant for the strategy of the environmental regulator.

The most interesting case is when δ is “low” relative to the demand for water, and $\delta \leq \bar{t}$. This is the case in which the environmental regulator can compensate the environmental damage with the monetary revenue of the tax, as previously argued.

The equilibrium values of p and t are the solution of the following system of implicit functions,

$$D(q(p, t)) - C_q(q(p, t)) - t = 0 \quad (4.3)$$

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

The equilibrium is unique and characterized by a level of $q^* > \gamma$. It is interesting to note that the equilibrium strategy of the environmental regulator is to set t such that $q^* > \gamma$. This is obviously due to the fact that the monetary revenue from taxation can compensate the environmental damage.

In all other cases, the environmental regulator has a dominant strategy in setting the tax rate at the maximum level. The equilibrium in these cases depends on the level of the demand. If the demand is not very high (or equivalently δ is high) then the equilibrium quantity is characterized by $q^* = \gamma$. But if the demand is very high, then the economic regulator may have the firm producing $q > \gamma$ by setting a price p such that $D(q) = C_q(q) + \bar{t}$.

For completeness, let us consider the case in which $\hat{t} < \delta$, in which the environmental regulator has less power. Now the economic regulator will set a price p such that $q^*(p, \hat{t}) > \gamma$ even in case of “high δ ”. This result is clearly driven by the poor power of the tax instrument.

Results are summarized in the following proposition.

Proposition 2 .

- (i) *In case of a “high δ ” and $\delta \leq \bar{t}$, the equilibrium is characterized by $q^* = \gamma$, $t = \bar{t}$ and p such that $D(q^*) = C_q(q^*)$; if $\delta > \bar{t}$ the equilibrium is characterized by $q^* > \gamma$, $t = \bar{t}$ and p such that $D(q^*) = C_q(q^*) + \bar{t}$;*

	Integrated Eq.	Separated Eq.
high δ	$q^i = \gamma$	$q^s = \gamma$
low δ	$q^i > \gamma$	$q^s > \gamma$

Table 1: Summary of equilibrium results

(ii) in case of “low δ ” the equilibrium is characterized by $q^* > \gamma$, and if $\delta \leq \bar{t}$, p^* and t^* solve the system of equations 4.3 and 4.4, while if $\delta > \bar{t}$, $t = \bar{t}$ and p^* is such that $D(q^*) = C_q(q^*) + \bar{t}$.

5 Contrasting the two scenarios

From the analysis emerges the importance of the demand for water relative to the marginal environmental damage. The institutional set up, single or multiple regulators, does not matter when the demand is low relative to the environmental damage, as shown in the case of “high δ ”. In fact, even if the regulators are separated, the economic regulator cannot have the firm producing more than the sustainable level because the demand is not large enough - relative to the level of environmental damage.

The difference emerges as soon as the demand becomes large with respect to the marginal environmental damage. In both scenarios, the quantity of water chosen by the firm is higher 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. Now, even if the environmental regulator wants the firm to produce at the sustainable level, the economic regulator can have the firm producing more because of the large demand. The firm is willing to produce more than the sustainable level if the price is high enough to cover for the environmental tax, and only with a large demand consumers are willing to buy at a high price.

The equilibrium quantity is different in the two scenarios, separation of regulators leads to a lower quantity level, i.e. in case of “low δ ” (and with $\hat{t} \geq \delta$) we get $q^s < q^i$. In a way, the environmental regulator limits the exploitation of the natural resource when demand is large (“low δ ”).

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 equilibrium 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. In other words, low prices may lead to rationing the demand.

The equilibrium level of p and t leads us to the question we originally posed: when two contrasting issues are present, is it better to have a unique regulator or one regulator for each issue? To answer the question, we need to consider the welfare implications of the equilibrium in the two scenarios. In particular, we need to check how the welfare is distributed among the three main components of the regulators' objective function, the consumers' surplus, producer's surplus and environmental impact.

The next section is devoted 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 on how the model works, let us restrict the analysis to linear demand and supply functions. Firstly, I address the question of *efficiency*, considered as the sum of the three components: consumers' surplus, producer's surplus and environmental benefit. Then I proceed to investigate how each component is influenced by changes in the institutional scenarios - i.e. one or two regulators.

The answer to the first question is that the total welfare is always maximized by the integrated regulator. This is fairly trivial given the way in which the model is constructed, still it is important to note that the loss of efficiency is a measure of the effect of the introduction of two regulators¹⁴. The reason for the inefficiency might be also a result of the assumption of only one industry, the environmental regulator in reality deals with more than one sector (water, electricity, transports, etc.).

More interesting is the analysis of the single component of welfare. As we will see in the next section, consumers enjoy a higher payoff in case of integration, while the firm and the environment receive a higher payoff in case of separated regulators. This issue is important for the policy maker that can decide which part of the objective function wants to favor. In particular, if we consider environmental benefits as future consumers'

¹⁴Since the asymmetric information setup, previous works could not isolate this effect.

surplus, the choice seems to be between immediate or future consumers' payoff. A paternalistic state could prefer separation of regulator if it deems consumers not to care enough about the future.

6.1 Specific functional forms

The focus is on a level of demand and sustainable level, γ , that makes the environmental problem relevant, i.e. demand and competitive firm supply meet before γ . Let us consider the case of a linear demand function and a quadratic cost function.

$$\begin{aligned} P &= 1 - q(p, t) && \text{inverse demand function} \\ TC &= \frac{q(p, t)^2}{2} && \text{total cost function} \end{aligned}$$

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 more than the sustainable level, as shown in figure 3. 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 firstly for the integrated regulator case and then for the separate-regulator scenario.

6.2 Integrated regulator

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

$$\begin{cases} R = \int_0^q (1 - q) dq - \frac{q^2}{2} & \text{for } q \leq \frac{1}{4} \\ R = \int_0^{1/4} (1 - q) dq - \left(\frac{1}{4}\right)^2 \frac{1}{2} + \int_{1/4}^q (1 - q) dq - \frac{q^2}{2} - t(p - t - \frac{1}{4}) + (t - \frac{1}{4})(q - \frac{1}{4}) & \text{for } q > \frac{1}{4} \end{cases}$$

The second equation 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

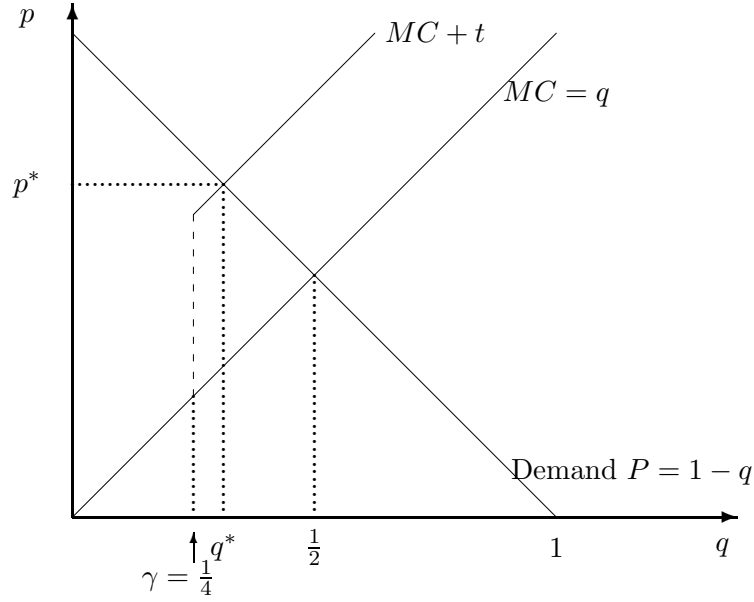


Figure 3: Linear demand and supply functions

given by an additional production of water, this is counterbalanced by the last term, which represents the environmental impact.

The regulator in order to maximize its payoff function wants the firm to produce a level of water¹⁵ 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 $[0, \frac{1}{4}]$, which satisfy $p - t = q = \frac{3}{8}$. Note that in this case the value of t is never greater than δ ¹⁶.

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 $p - t = \frac{3}{8}$, $p \in [\frac{3}{8}, \frac{5}{8}]$ and $t \in [0, \frac{1}{4}]$.

Let us consider the consumers' surplus. Its value depends on the particular equilib-

¹⁵This value is obtained maximizing the regulator's objective function with respect to q , as shown in the appendix.

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

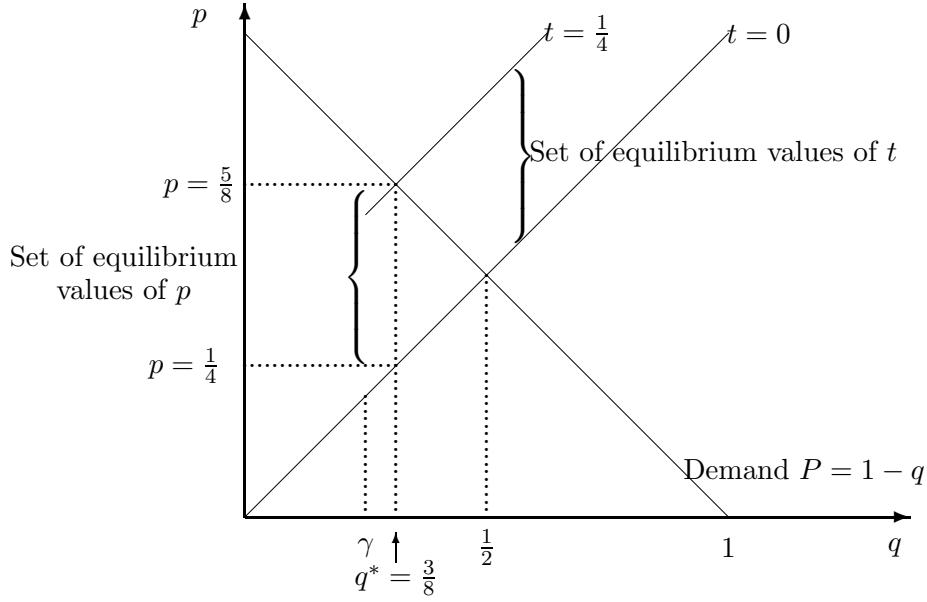


Figure 4: Equilibrium values of p and t .

rium 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,

$$CS = \int_0^{q^*(p^*, t^*)} (1 - q^*(p^*, t^*)) dq - p^* q^* \quad (6.2)$$

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 consumers 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 $[\frac{9}{128}, \frac{21}{128}]$.

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 - or firm's surplus¹⁷.

¹⁷This is because CS and PS have the same weight in the objective function of the regulator.

6.3 Separate regulators

In this case the objective function of the economic regulator is analogous to the previous case, but the environmental impact. The environmental regulator cares only for the environmental damage and the tax revenue.

$$R_2 = \begin{cases} (t - \frac{1}{4}) (q(p, t) - \frac{1}{4}) & \text{for } q > \frac{1}{4} \\ 0 & \text{for } q \leq \frac{1}{4} \end{cases} \quad (6.3)$$

Note that R_2 is concave with respect to t , and it can assume either positive or negative values. 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 the objective function in the previous section, but the part concerning the environment.

The subgame perfect 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,

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

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 payoff¹⁸. 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 producing 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 integrated regulator's one $R = \frac{13}{64}$.

¹⁸That would be her dominant strategy if the regulator would not receive the revenue from the environmental tax.

The difference $\frac{1}{576}$ represents the loss in efficiency of the separate regulator scenario.

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. To sum up, in the separate case the firm obtains a higher equilibrium payoff, while consumers' surplus is lower; however, if we interpret environmental benefits as future consumers' surplus, it seems the the difference between the two scenarios, reduces to favoring today *vs* future consumers' surplus.

7 Assumptions on λ and μ

Consider the regulator's payoff function in case of non sustainable production,

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

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

The literature on regulation usually consider $\lambda < 1$ for two main reasons, to introduce redistributive concern and because it actually influences the equilibrium when the regulator faces asymmetric information - as shown in Loeb and Magat (1979). In my model the assumption is not very relevant, because the main concern is the trade off of consumers' surplus with the environmental damage. However, if $\lambda < 1$ the regulator is facing also another trade-off, he/she would care less about the firm's profit, and she would like to set a lower price, but at the same time a low price constraints the firm's supply of water. However, this trade-off is not relevant for the environmental impact, because the regulator will still balance the increase in consumers' surplus with the environmental impact.

The assumption of $\lambda = 1$ 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 , results 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 $\mu = 1$ is to have the same weight for the environmental issue 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. This result is due to the nature of the environmental problem, with non-renewable resources or with pollution produced at any level of production, there are no meaningful cases in which the results are the same in the two scenarios.

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 regulators, he/she should be aware of the fact that their objectives might be in contrast.

The model is 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 draw policy indications.

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.

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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 *With monotonic demand and supply function, for any level of quantity that does not clear the market there are two different prices associated with the demand and the supply.*

Proof. The reason comes from the fact that if demand and supply are monotonic they cross at maximum once (or they are the same function). The proof is similar to the “single crossing” condition proof. ■

Given lemma 1, I want to argue that it is indifferent for the regulator what price to set. The intuition comes from the fact that in the objective function the consumers' surplus and the producer's surplus have the same weight, and therefore what matters is the total sum of the two values — let us define $TS = CS + PS$, where TS is the total surplus.

Lemma 2 *It is indifferent for the regulator whether rationing demand or supply.*

Proof. I want to show that what drives the TS is the level of q . Let us consider the following payoff function for the regulator in case there is no environmental damage.

$$R = \underbrace{\int_0^{q(\hat{p})} D(q(\hat{p})) dq - \hat{p} q(\hat{p})}_{\text{consumers' surplus}} + \underbrace{\lambda[\hat{p} q(\hat{p}) - C(q(\hat{p}))]}_{\text{producer's surplus}} \quad (\text{A.1})$$

Note that when $\lambda = 1$, the above expression does not depend directly on the price level. Given a level of quantity that maximizes the expression it is indifferent whether rationing demand or supply. ■

For this reason we consider as supply in this model, the competitive supply q^* .

The model involves a two stage game between the firm and the regulators. In the first stage the economic regulator and the environmental regulators choose *simultaneously* the level of p and t , respectively. In case of single regulator, he/she chooses the two values. In the second

stage the firm chooses the value of q which maximize her profit. The equilibrium concept used is a sub-game Nash equilibrium (SPE), given by the values $\{q^*(p^*, t^*), p^*, t^*\}$.

We make the following two general assumptions on the functional forms of the model,

Assumption 1: demand and supply are monotonic functions

Assumption 2: the cost function is convex

Let us turn to the characterization of the equilibrium under the two scenarios. Firstly, note that when demand is very low, i.e. the market clears at a level of $q \leq \gamma$, the equilibrium does not involve any environmental damage, and it is simply characterized by the equality of marginal costs and price.

Therefore I will focus on situations in which the demand is large enough to create environmental problems, i.e. $D(q) = C_q(q)$ for $q \leq \gamma$.

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 $q^*(p, t)$. The regulator can actually determine the level of q by choosing an appropriate level of p and t . Hence, we can proceed by maximizing the regulator objective function with respect to q directly, and then 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 two first order conditions:

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

$$D(q) = C_q(q) + \delta \quad \text{for } q > \gamma \tag{A.3}$$

The first equation simply tells us that the quantity should be such that it equates the demand and the marginal cost of water. The second one that the optimal quantity must equate the demand and the marginal cost of water plus the marginal environmental damage, i.e. the social marginal cost of producing more than the sustainable level. Substituting back the two levels we can check which one gives the highest payoff to the regulator. However, note that, given Assumption 1, if the demand is such that $D(q) > C_q(q)$ at $q = \gamma$, the first FOC has a corner solution in $q^* = \gamma$. This argument just leads to the discriminant role played by δ in the equilibrium. As δ increases the quantity q which satisfies condition A.3 decreases. Let \hat{q} be the value which satisfies condition A.3, when this values is lower than γ it cannot maximize the objective function of the regulator, and therefore the best choice is $q = \gamma$ while in the other case,

$\hat{q} > \gamma$ then the optimum is to set $q = \hat{q}$; this is because the environmental damage is compensated by the tax and the CS, PS is higher.

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

$$p - C_q(q^*) - t = 0$$

where q^* is the optimal choice of the firm. The optimal level of p and t must respect this condition. For instance if $t = 0$ the level of p must be equal to $C_q(q^*)$. Since Assumption 2, the effect of the tax is to decrease the output, i.e. $\frac{\partial q^*}{\partial t} < 0$; while the price has a direct effect on the quantity, $\frac{\partial q^*}{\partial p} > 0$.

A.2 Separate-regulator equilibrium

In case of separate regulators, each one wants to maximize her own payoff function. The two regulators 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.

$$\max_p R_1 = \begin{cases} \int_0^q D(q) dq - C(q) & \text{for } q \leq \gamma \\ \int_0^\gamma D(q) dq - C(\gamma) + \int_\gamma^q D(q) dq - C(q) + C(\gamma) - t(q - \gamma) & \text{for } q > \gamma \end{cases} \quad (\text{A.4})$$

$$\max_t R_2 = \begin{cases} 0 & \text{for } q \leq \gamma \\ (t - \delta)(q - \gamma) & \text{for } q > \gamma \end{cases} \quad (\text{A.5})$$

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 SPE is given by the system of equations formed by the first order conditions of the two problems.

$$\frac{dR_1}{dp} \Rightarrow D(q) - C_q(q) - t = 0 \quad (\text{A.6})$$

$$\frac{dR_2}{dt} \Rightarrow (t - \delta) \frac{\partial q}{\partial t} + q - \gamma = 0 \quad (\text{A.7})$$

From equation A.7, we see that the environmental regulator is willing to accept a non sustainable level of q only if $t > \delta$, this is because $\frac{\partial q}{\partial t} < 0$. From equation A.6, 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; we make the following assumption,

Assumption 3: the marginal environmental damage δ is lower than the maximum tax level \bar{t} ,

i.e. $\delta \leq \bar{t}$.

Let us consider the following causal relationship: as the level of δ increases, equation A.7 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.6 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 we drop assumption 3, $\delta > \bar{t}$, the equilibrium strategy for the environmental regulator is to set $t = \bar{t}$. In this case, if from equation A.6 we get $q > \gamma$ then that is the equilibrium quantity, otherwise the equilibrium will be $q = \gamma$. This situation is characterized by an environmental regulator which has not enough power to contrast the environmental damage.

B Specific Functional Form: case of “high δ ”

The assumptions on the demand and cost function are the same as in section 6, 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 prefers the firm to produce $q = \gamma$. The equilibrium is characterized by $p \in [\frac{1}{4}, \frac{3}{4}]$ and $t \in [0, \frac{1}{2}]$. This equilibrium assures the following range of consumers’ surplus $[\frac{1}{32}, \frac{5}{32}]$, according to the level of price chosen. Note that if the regulator is biased towards consumers, i.e. $\lambda < 1$, 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 $q = \frac{1}{4}$, 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 with the assumption of $\lambda = 1$.