TECHNOLOGY, INCENTIVES, AND FIRMS
Scope of Economic Incentives and Abatement Technologies to Regulate a Natural System's Resilience in a General Equilibrium Model

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This paper discusses a general equilibrium model consisting of a productive sector generating externalities on another sector having clean production, and on consumers, affecting the property of resilience of a natural system that feeds the economic system. The scope of efficiency of economic incentives is analyzed simultaneously with production activities in the polluting sector and the use of a pollution abatement technology. Our model predicts a boomerang effect: the polluting sector could find itself in a worse situation in the equilibrium with externalities; this sector initiated the problem, but at the end it is highly affected. In any case, the use of economic incentives helps keep pollution levels to maintain more valuable equilibria of nature. JEL codes: D50, H23, Q56

I. Background Research

The instruments that regulate externalities may be grouped into two categories: command and control (CAC) and economic incentives. CAC refers to emission caps—performance standards—and technological constraints—design standards—while economic incentives apply to taxes, subsidies, tradable permits, and deposits. Economic incentives are preferable in a first best world, but their effectiveness depends mainly on the ability to measure all indirect marginal damages, low market transaction costs, the possibility of defining and protecting property rights, their ease of implementation, regulation and surveillance,

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the state's fiscal appetite, technical possibilities, and the costs of using abatement technologies. There may also be classification criteria such as equity, political and ethical dilemmas (Eskeland 1999; Fullerton and Heutel 2007). Additionally, Loeb and Magat (1979) and Popp et al. (2010) have stated that when abatement technologies are available, market-based regulations encourage behavior through market signals rather than through explicit directives regarding CAC, thus allowing firms some flexibility to choose or identify the lowest-cost solutions to meet the policy goal.

Instrument effectiveness depends on a series of factors associated to the characteristics of innovation and pollution; whether the companies are heterogeneous or they have market power; whether technology is available and it is possible to adapt the abatement technology, or investments on research and development should be done, taking into consideration the underlying disincentives due to the probabilistic character of the innovation and its becoming a public good once it is produced; whether the abatement technology type completely reduces pollution—which is pure fiction—or slightly mitigates it; whether technology helps reduce pollution per product, per input, saves power consumption per unit produced, or whether replacement for a cleaner energy source is approved (Löschel 2002). It also depends on the concavity or convexity of the function that represents the effects of pollution on the economy (Xabadia et al 2005). Moreover, some regulator behaviors (such as commitment or shortsightedness) have been researched once the abatement technology is already available or under development (depending on the phase and success of innovation) in order to foster its diffusion (Nelissen and Requate 2007; Montero 2011; Goulder and Parry 2008).

The ranking of policy instruments also depends on the number and type of interactions, and on the innovator's ability to appropriate spillover benefits. An initial motivation to include subsidies is that market-based policies also reduce production, and a mix of tax pollution and subsidies may be better suited to overcoming the joint market failure: a negative externality from pollution and a positive externality of R&D, given the public nature of innovation (Popp et al., 2010). In addition, the presence of a successful innovator could motivate discriminatory regulations since even this innovator would prefer CAC to raise costs for competitors.

Under conditions of uncertainty concerning the costs of pollution or the benefits of its reduction[1], and considering monitoring and enforcement costs and the regulator's commitment, among other second best situations, a combination of certain features of both price-based (market signals) and quantity-based (CAC) regulations in their pure form—usually named hybrids—has been suggested (Perino 2008; Montero 2011). These conditions may provide further justification for setting performance standards or mandating a particular suite of technologies on certain sector failures (Goulder and Parry 2008). Linares and Labandeira

1. Goulder and Parry (2008) also argue, "Abatement costs uncertainties would be accompanied of provisions such as banking and borrowing or subsidies, however the instruments and the level of support are less clear and lesser when technologies are available."

(2010), for example, emphasize on the necessity of mixed market-based regulations with subsidies or standards to account for uncertainty, bounded rationality, and social acceptability.[2]

However, the whole is not necessarily the sum of its parts; the use of multiple instruments is not the same as the use of a hybrid instrument. As the number of policy instruments grow, so does the interaction, being either detrimental or beneficial. For instance, those CAC instruments that help reduce the risk of high emissions but entail high costs for the emitters provide an opportunity to pay a tax or purchase a permit in order to cover the emission excesses over the standards, thus reducing the abatement costs (Montero 2011). These additional emissions or the quantities of permits have a cap, but these permits may reduce incentives for innovation, which would be motivated by emission caps (Perino 2008).

Fankhauser et al. (2011) show that in order to achieve an adequate carbon price and constrain its fluctuations to combat climate change, some European policy makers are combining *cap and trade* with *carbon taxes* or with *feed in tariff*—renewable energy obligations. Adding a carbon tax or feed-in tariff to the existing carbon system (EU ETS) also reduces the carbon price to such an extent that the overall price signal would remain unaffected. It aims to shift the burden of payment and depress the carbon price, rather than to achieve any additional emission reductions, unless the tax is so high that it replaces and thereby intensifies the price signal from the trading scheme. In any case, it must be clear that the best policy would be to auction original permits (caps) to pollute rather than to grant them free. For example, they could be assigned in an options market since the spot market may lower the prices of a license for using abatement technologies and, consequently, may reduce incentives for innovation (Laffont and Tirole 1996; Fairley 2009).[3]

2. "Carbon taxes may be more attractive theoretically. However, auctioned cap-and-trade systems, while retaining the rent-capturing feature of taxes, also allow for redistributing more explicitly and more easily than taxes a part of the cost, and may therefore be more politically acceptable. Their acceptability would even be higher if they are combined as hybrid instruments, such as safety valves, to hedge against unexpected high costs. These more efficient instruments should probably be coupled in some sectors – those closer to the final customer – with technology standards to account for bounded rationality and also to improve acceptability; with technology policies (both market-pull and market-push, depending on their situation in the learning curve) to counteract knowledge spillovers; with education and training policies to reduce bounded rationality and to decrease perceived costs, and with voluntary approaches when performance is not easily observable" (Linares and Labandeira 2010).

3. Lastly, the type of innovation must be distinguished. If it reduces marginal pollution, it is called an end-of-pipe solution—such as installing a water treatment plant adjacent to the production plant. On the other hand, it might involve changing the production process, thereby making the marginal abatement cost steeper. Note that in this last case, CAC policies would be more efficient than market-based policies for promoting innovation, since they also imply diminishing production. Nonetheless, if high levels of mitigation are required, marginal abatement costs will rise acutely, so it is better to invest in new production processes. In this sense, moderate efficiency gains in conventional technologies will have a great impact on the economy, since these technologies are widely used (Caper et al. 2008; Popp et al. 2010).

II. Resilience of a Natural System

A natural system N has two fundamental properties: Stability, or the existence of multiple equilibria and the possibility to return to them after a disturbance, and Resilience, or its persistence and its capacity to absorb changes and shocks while maintaining the same relation between its populations and functions, such that it allows for the provision of environmental goods and services (Holling 1973). A natural system can eventually return to an equilibrium similar to the one that existed prior to the disturbance, and depending on the distance to its ecological threshold, the response will be smooth or abrupt (Groffman et al. 2006). Therefore, if the disturbances are of sufficient magnitude or duration, they can deeply affect the original equilibrium, thus reaching another less desirable equilibrium with different processes and structures, and may take up to a critical point where recovery is not feasible.

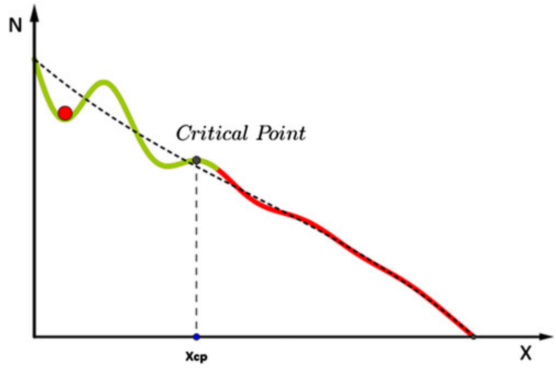
Figure 1 shows the negative relation between the production of polluting sector X and N's production assuming a one to one relation between the production of X and the amount of contamination that it generates. Given the characteristics of resilience, N reacts to negative externalities striving to keep balance; that is, trying to maintain its initial equilibrium.

It can be observed that every oscillation produced by X represents less valuable equilibria. If the system surpasses the critical point, it will inevitable go down, being impossible to go back to the "safe" zone. Moreover, the dotted line represents the envelope function: changes of concavity also reflect the critical point (**cp**), where its resilience drops more quickly. The mechanics of natural systems should be considered in general equilibrium models that incorporate natural capital, given the increasing environmental problems associated to pollution, resource extraction and removal of functional groups, being resilience a fundamental property that involves other characteristics of natural systems.

This property has become a fusion of ideas from multiple traditional disciplines, including the *stability of ecosystems* (Holling 1973; Gunderson 2000), *infrastructure engineering* (Tierney and Bruneau 2007), *psychology* (Lee et al. 2009), *behavior sciences* (Norris 2011), and the *risk reduction of disasters*[4] (Cutter et al. 2008).

4. Particularly, Computable General Equilibrium (CGE) models, according to Rose and Liao (2005), is a promising approach for analyzing the impact of disasters on resilience, as it is possible to model the behavioral response to the shortage of inputs and changing market conditions. Rose and Liao (2005), Rose and Liao (2002) analyze natural disasters in regional economies, conceiving resilience as an inherent property of the system that enables it to return to its previous situation within a reduced time horizon after a crash caused by an unforeseen event (an earthquake, a natural disaster, a terrorist attack). For this preparation, they considered the importance of avoiding overlooking costs and essential investing in actions to mitigate the effects and maintain or increase this capacity for resilience. Meanwhile, Fadali et al. (2012) found that the value of water in the U.S. is in constant motion and that this is because resilience is affected by changes in water supply, demand, changes in prices of inputs and factors, prices of production, income, government policies and institutions. See Schouten et al. (2009) for a discussion of the issues brought about by resilience in rural areas. On a macro level, resilience can be linked to financial institutions and norms, and to the role of scarce resources.

FIGURE 1. Affectation on Resilience Caused by the Pollution of an Economic Sector



Multilateral organizations have recently appropriated this property, which is an example of how the capacity of recovering theory to the politics and practice in general is being developed (Bahadur et al. 2010; Brown 2011; Herr 2011).

III. THE MODEL

We propose formalizing a general equilibrium model splitting the world into a polluting industrial sector **X**, a clean industrial sector **Y**, a representative consumer **C**, and nature **N** (Christopherson et al. 2010; Wing 2011).[5] This model admits a simultaneous selection between production activities, pollution, the use of economic incentives (Pigouvian taxes[6]) and the option of adapting abatement technologies. We include an *end-of-pipe* solution for a given production process, available in the market, in a first best world. This model is static and there are not transaction costs or the figure of a regulator explicitly coordinating agents. Preferences and technologies are given by the following equation system:

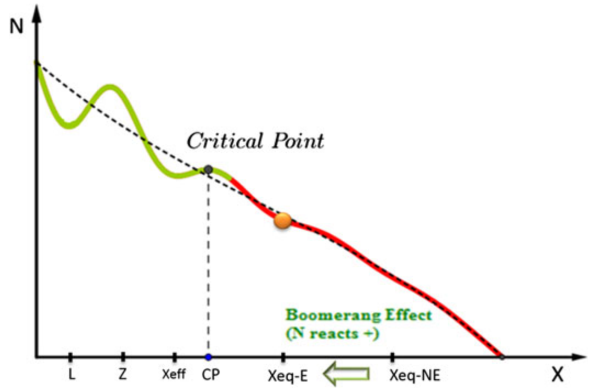
$$U = X_C^{\alpha} Y_C^{\beta} N_C^{1-\alpha-\beta} X^{-\gamma}, \quad X = H.N_X^{\delta} Y_X^{\varepsilon}, \quad Y = M.N_Y^{\pi} X_Y^{\theta} X^{-\rho} \tag{1}$$

J_i suggests that the firm produces good i using input j. In its turn, i represents the production of good i. H and M are the technology of sectors X and Y where the

5. For the sake of clarity, we can imagine an economy grouped in either polluting or non-polluting sectors and heavily relying on a natural system. See Wing (2011) for a proposal of a general equilibrium model incorporating varied interactions of nature and the remaining sectors, even though nature appears as receiving negative externalities and as a provider of common use public goods (positive externalities). This author also analyses the incidence of taxes, CAC measures and the option of acquiring abatement technologies, but without establishing any prioritization among them.

6. The nonexistence of transaction costs and the fact that the firms are owned by the representative consumer cause the allocation of pollution permit payments to be equivalent to taxes, in terms of efficiency and welfare.

FIGURE 2. Regulating Resilience Loss Caused by the Contamination of an Economic Sector



initial values of different parameters are in agreement with a neoclassical economy, and γ and ρ show the negative marginal impact of sector X.

Yet, Nature is also affected by X pollution, disturbing particularly its resilience. In order to model **N**, a specific functional form is proposed considering: (1) an initial natural capital stock **A**; (2) a marginal contribution of human resources intended to try to maintain, increase or shift such a *stock* (Y_N) (Brand 2009); and (3) a component accounting for the resilience capacity. We are assuming that **N** should be transformed to produce a profit-generating environmental service, but with costly reproduction, which might become highly expensive or impossible depending on the level of **X**.

Therefore, $N = AY_N^{\sigma} f(X)$, so that $\sigma \to 0$. The function $f(X) = g(X) + \lambda(X)$ accounts for the resilience property, where $g(X) = s * \sin(w * X)$ represents the function associated to the long-run trajectory oscillations[7] and $\lambda(X) = aX^3 + bX^2 + cX + d$ denotes the envelope function.[8] The mechanics call for building several general equilibrium models to analyze the following cases: differences between efficiency allocation and market equilibrium, payment of taxes, and the option of acquiring pollution abatement technologies, and making a hybrid with them both. As property rights on **N** are supposed to be allocated taking into consideration that it is considered to be a private good, this system allows for three markets and three price levels: P_X, P_Y, P_N. The equilibrium prices were found using simultaneously the *Newton-Raphson*, *the Secant* and *Brent's* method in order to find the roots of resultant non-linear equation system.[9]

7. This continuous function allows to model required oscillations; parameters s and w are associated to the amplitude and period of the function.

8. The characteristics of the function are $\frac{d\lambda}{dX} < 0$ *and* $\frac{d^2\lambda}{dX^2} > 0$ *if* $X < cp$, $\frac{d^2\lambda}{dX^2} < 0$ *if* $X > cp$, $\frac{d^2\lambda}{dX^2} = 0$ *if* $X = cp$, being **cp** the critical point.

9. We used *Wolfram Mathematica* software for this calculus.

IV. Main Results

In market equilibrium, sector X maximizes its private benefits, pollutes, and does not internalize the social cost of pollution. When comparing this situation with a world without externalities, the welfare of all agents in the economy drops as a consequence of them. Unexpectedly the externality that X generates is reverted in a fall in its own demand, price and benefits (Xeq-E vs. Xeq-NE). We called this a *Boomerang effect*. Additionally, Nature loses its resilience at increasingly higher rates. This is reflected in such an overproduction of X that the critical point threshold is exceeded (Figure 2).

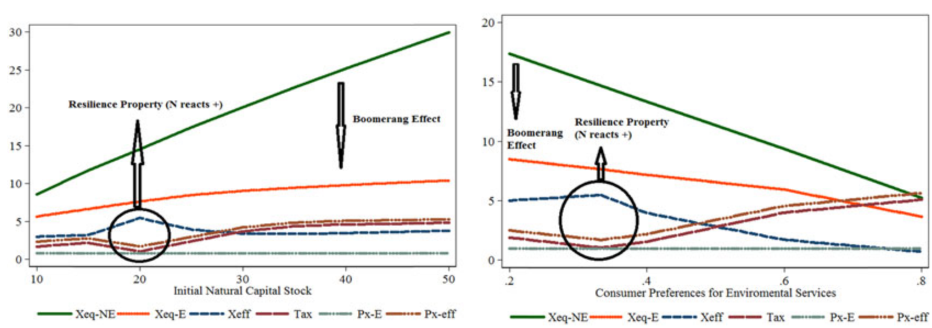
When the market is intervened to correct the externality, sector X maximizes its benefits, but it is subject to its technological restriction and tax payment. If taxes are equal to the marginal social damage the economy enters a “safe” or more resilient “zone”, because affectation by X has not yet reached the critical point. The insurance that society pays for maintaining itself inside a resilient zone can also mean unemployment, poverty and other undesirable consequences given that **X** decreases again (Xeff). Therefore, the tax highly increases P_X affecting significantly the allocation of resources in the whole economy.

Finally, if an *Abatement Technology* is available, a portion **L** of **X** production could be cleaned; while a tax is levied to another portion **Z**. Sector **X**’s benefits will be an increasing function of abatement technology productivity. This translates into an increase of the other agents’ profits and the economy moves farther from the critical point.

V. Stressing the Model

By increasing the initial natural capital stock parameter **A**, the level of economic activity and the level of **X** will also grow, but also the size of externality and, in consequence, the *boomerang effect* and the required taxes. Moreover, if N reacts positively, trying to maintain its initial equilibrium after a disturbance, taxes will be reduced. However, **N** loses its resilience property inevitably, being taxes the only insurance to not to lose this property (left side of Figure 3). By changing

Figure 3. Stressing the Model



the relative importance that **N** has in the consumer preferences, and contrary to the previous case, the level of economic activity and the level of X will be reduced, as well the boomerang effect. However, taxes will increase dramatically, even if the negative externality is lowered (right side of Figure 3).

VI. Conclusions and Future Work

This is a model of representative sectors whose inner interactions are not broken down. The main result of the market equilibrium with externalities is that the sector generating externalities as a whole is in a worse situation, but we may believe that inside the model, if it were to be broken down, there would always be those who benefit and those who are harmed in a higher proportion, which would depend on the relative demand for that sector's products by other sectors of the economy. Therefore, incentives to invest in abatement technologies would not be homogeneous.

The equation representing Nature aims to incorporate the resilience characteristic as a version of working within a natural ecosystem and shows its interrelation with the economic system. Thus, knowledge about this function in a feature summarizing an ecosystem's properties and its affectations is a result of resource extraction, pollution or random endogenous and exogenous events. While our model states that the use of taxes allows for maintaining the polluting sector's level of production so that resilience **N** is in a "safe" zone, it is also true that the tax is quite high in relative terms and agents take on much of it because of price increases, which could also be interpreted a kind of insurance for resilience.

It would be interesting to make some additional considerations within the bounds of this paper. First, to model the inclusion of uncertainty in resilience, reflecting the fact that it is virtually impossible to know to which extent nature would be able to endure affectation made on itself. Second, to analyze incentives to invest in abatement technologies between several polluting agents instead of supposing a representative agent. Third, to study the differences when pollution abatement technologies are not end-of-pipe solutions, but rather modify the production process of the polluting good. Last, to expand the model to a dynamic character so that, for example, accumulative or de-accumulative polluting functions represents better the nature inner functioning and how accumulating pollution affects it.

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