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ENVIRONMENTAL POLICIES AND TECHNOLOGICAL INNOVATION

SUMMARY FINAL REPORT

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I. OBJECTIVES

It is widely accepted that, in the absence of specific policy measures, firms do not internalise the environmental costs of their actions.

Recognition of the need for external policy measures in controlling industrial pollution, has generated a long debate which has mainly focused on two major issues:

- (i) first, "which is the most efficient policy instrument that should be used to reduce polluting emissions?";
- (ii) second, "how should institutions be designed in order to maximise the environmental benefit and to reduce the related economic costs?".

Projects addressing these questions had to deal with three problems. First, the assumption that markets are perfectly competitive. Second, the innovation capacity of firms. Third, the potential effects of re-cycling the tax revenues.

This report focused on the first two issues. The fact of focusing on environmental innovation in oligopolistic market structures has the following implications: first, more than one externality has to be accounted for. Second, a dynamic partial equilibrium analysis becomes necessary.

The externality issue is quite relevant. When only the environmental externality is introduced into the model, an environmental tax is indeed the optimal policy. However, when the economic system is characterised by more than one externality, other policy tools have to be associated to the environmental tax in order to maximise social welfare. In particular, firms' strategic behaviour and interaction in oligopoly create two additional externalities: on the production side, the equilibrium level of output is lower than the optimal one, thus reducing the consumer's surplus. On the innovation side, there is an incentive to profit from R&D spillovers thus reducing the innovation effort. The presence of these two additional externalities is sufficient to make the environmental tax sub-optimal, thus calling for further policy instruments. Moreover, the team were able to introduce other externalities (or second-best issues): the ones arising from the presence of asymmetric information, and the ones arising from international competition (firms compete on oligopolistic international markets). Asymmetric information concerns the game between the domestic regulator and the domestic firms; the international externality concerns the game between different governments trying to protect the domestic industry.

Accounting for all these externalities changes dramatically the characteristics of the policy problem. It is inappropriate to ask the environmental tax to solve so many economic inefficiencies; on the other hand, all the above externalities are interdependent which implies that environmental issues cannot be separated from industrial and trade issues. Hence a new policy approach becomes necessary which involves the implementation of several policy strategies. The development of this policy strategy in the context of a dynamic model of environmental innovation is the objective of this report, even if the same methodological approach could be applied to other contexts as well.

II. METHODOLOGY

First, in order to evaluate the role and effectiveness of environmental policies, the team studied how the standard environment-growth trade-off can be loosened if the government designs policies that induce firms to develop a technology with a lower emission-output ratio. Second, in order to take into account the actual functioning of the national and international markets, the team modelled the effects of the environmental innovation policies by considering the strategic interactions that exist both among firms, and between the firms and the government.

The project has been conducted in two phases. As a basis, they have reviewed the main achievements in the literature on environmental innovation, focusing in particular on the models which can be related to the recent developments of innovation theory in the industrial organisation literature. In the second phase, they developed an environmental innovation model that could take explicitly into account the interdependence between government's environmental policy and firms' strategic decisions. In particular, they have considered a model where there exists asymmetric information between the regulator and the polluting firms, and where firms can be located in different countries (so that international cooperation issues arise). In this model, the governments' aim was to design the optimal policy which can induce firms to invest in R&D and develop a technology with a lower emission-output ratio.

The approach used essentially relies on recent developments of both game-theory and the theory of industrial organisation. Key variables are emissions, environmental innovations and environmental policies. The integration of the game theoretic approach into the environmental innovation modelling, leads to study three types of games:

1. the game among firms in an oligopolistic industry;
2. the game between the domestic government setting his environmental policy, and the firms;

3. the game among governments of different countries that try to coordinated their environmental policy decisions.

Therefore, contrary to the prevailing approaches found in the environmental innovation literature, the game-theoretic framework permitted to model the interactions in the national and international markets as they are in reality; that is, by considering that they are the result of strategic decisions in which the operators (let them be firms or governments) act given the expectations they have about other agents' behaviours.

III. MAIN RESULTS

a) First phase : analysis of the existing literature on environmental innovation.

The general results derived from a survey of this literature seemed to suggest that economic instruments tend to perform better than regulatory instruments as far as the incentive to innovate is concerned. Despite this result, the analysis showed that the choice of the economic instrument is however strictly related to the economic context under study. In particular, in the absence of strategic interactions among firms, the models analysed showed a certain superiority of a policy based on an environmental tax rather than on an innovation subsidy. On the other hand, when considerations of strategic behaviour among firms come into play, the desirable policy intervention has turned out to be a combination of environmental taxes and innovation subsidies, rather than the adoption of only one of the two instruments. These results, are also substantially confirmed when we allow for endogenous growth. In particular, one of the major conclusions of the research was that not only caring for the environment need not reduce growth but can, under certain circumstances, even favour it.

In order to define precise recommendation for policy behaviour, it is of fundamental importance to consider the role of asymmetric information between the regulating authority and the firms. It is unrealistic to consider that regulators have complete information about the situation of the industry they want to regulate, about the parameters of the demand and costs functions that firms face. Incomplete information, is a much more common situation.

Finally, even if there is still a lack of contributions in this area of research, the analysis of the current literature on environmental innovation in an open market context seemed to suggest that international cooperation among governments should be pursued as it is in general welfare improving.

b) Second phase : development of a new environmental innovation model to examine the effects of different environmental policies on firms' decisions to innovate. In the model not only have the team explicitly allowed for strategic behaviour among firms and for asymmetric information between the firms and the regulator, but they moreover took into account the international dimension of environmental policies. For this aim, they examined the optimal environmental policy under two different institutional regimes: one in which environmental taxation is internationally coordinated, and one in which, according to the subsidiarity principle, governments are free to set their domestic tax rate. The major findings of the analysis can be summarised as follows.

The first insight that emerged from the model, is that an adequately designed emission taxation scheme can effectively induce firms to invest in R&D and innovate. In particular, the analysis has shown that firms tend not to innovate simultaneously; that is, they do not introduce the less polluting technologies at the same time. In this sense, the innovation process is therefore diffuse. A fundamental point to note is that this finding still holds even when firms are identical; that is, even if the firms produce the same product and have the same cost-structure, there still exists diffusion in the innovation process. The economic intuition behind this fundamental result is that, even if in the presence of an emission tax policy, all firms find it profitable to innovate, they can have an advantage in waiting for the others to introduce the new technology since they might enjoy positive spillovers effects. These two findings, optimal from a private (firm's) perspective, have turned out to be optimal from a social point of view and, therefore, desirable.

However, the results also suggested that the optimal private timing of innovation is different from the timing which would be optimal for the society as a whole. In particular, they have found that in general, firms find it profitable to postpone the adoption of the new, less polluting, technology. Again, the basic intuition behind this result is straightforward. The firms, interested in their own profits, do not internalise the environmental damages associated with their production decisions and therefore tend to postpone the introduction of the new technology. On the other hand, in determining the socially optimal timing of innovation, the government takes into account both firms' profits (competitiveness), and the environmental damages, thus requiring an earlier innovation date.

Given that firms tend to postpone the introduction of the environmental innovation, the policy question becomes one to find an instrument that can induce firms to innovate with socially optimal timing. The research suggested that this problem can be solved with the introduction of an innovation subsidy. More precisely, the project has shown that the innovation process can be accelerated by granting the firms a subsidy to recover part of the costs borne for the realisation and implementation of new, less polluting, technology.

The above conclusion makes it clear that when firms find it profitable to postpone the adoption of the new technology, an emission tax alone is not the optimal policy, but a policy that combines taxes and subsidies is required in order to induce firms to innovate with a socially optimal timing. However, in these circumstances, the crucial policy problem is the design of the optimal subsidy scheme. In fact, if the development of the optimal subsidy scheme is quite trivial in a context of complete and symmetric information, such design becomes rather complex in the more realistic context of asymmetric information where firms have better knowledge about their innovation costs, (so that *adverse selection* problems arise). In these circumstances, the design of the optimal innovation subsidy is complicated by the fact that the regulator does not exactly know the costs borne by the firms in their innovation activity, and firms thus have an incentive to overstate their innovation costs in order to obtain a higher subsidy.

To overcome this problem and obtain the necessary information, the regulator could in principle choose to monitor the polluting firms. However, in reality, this option is likely to be too demanding and expensive for being feasible. The alternative left is therefore the implementation of an incentive mechanism that induces firms to reveal their true innovation costs.

A wide range of mechanisms has been proposed in the literature which can induce economic agents (firms) to reveal the truth. This research proposed a mechanism which consists of a family of contracts each specifying an innovation date and a subsidy, where the latter embodies an information premium necessary to separate different types of firms. The analysis, essentially confirms a standard result of incentive theory, according to which this premium has to be relatively larger for the more efficient firm. In this way, it is possible to design an optimal subsidy scheme which does not grant the same subsidy to all firms, but substantially rewards the most efficient ones.

As mentioned above, in order to take into account the international dimension of environmental policies, in the model the team have examined the optimal environmental policy under two different institutional regimes: one in which environmental taxation is internationally coordinated, and one in which, according to the subsidiarity principle, governments are free to set the domestic tax rate. With this respect, the findings suggested that all the above results hold both in the cooperative and non-cooperative regime: that is, in both regimes, the innovation process results diffuse and firms find it profitable to postpone the adoption of the environmental innovation, so that an innovation subsidy is required in order to induce firms to innovate with socially optimal timing.

However, despite the above similarities, a fundamental finding that emerges from the analysis is that the equilibrium tax rate resulting from the non-cooperative regime is lower than the cooperative one, even though it may still be sufficient to induce innovation. This result has obviously important effects in terms of total social welfare. In fact, since in the non-cooperative regime the equilibrium tax rate is lower, both polluting emissions and firms' profits tend to be higher than in the cooperative case. Despite the fact that these two effects tend to counterbalance each other, the research has revealed that on the whole a lower tax rate implies that total welfare is lower in the non-cooperative case than under the cooperative one. Finally, in the non-cooperative regime, both private and socially-optimal adoption dates are delayed with respect to the cooperative case.

To conclude, a fully-coordinated environmental policy, in which domestic tax rates are set at a supra-national level, tends to provide countries with larger welfare than a policy in which countries agree about the environmental taxation scheme, but set differently their domestic tax rates based on the subsidiarity principle. Moreover, harmonized tax rates induce firms to increase their abatement effort, thus reducing emissions more than under the non-cooperative regime.

IV.SCIENTIFIC INTEREST AND POLICY RELEVANCE

(i) Scientific Interest and Novelty

(a) The project explicitly considered the role of innovation in environmental protection, showing that a policy that induces firms to develop less polluting technologies, with lower emission-output ratio thus allowing to control pollution without excessively penalising economic activity.

- (b) The project modelled the competition among firms on the output market as a dynamic oligopoly. The game-theoretic approach allows to explicitly consider the strategic interactions among firms with respect to both output and R&D decisions.
- (c) The project modelled the innovation process as a lengthy, resource-consuming process strictly related to the other strategic choices of firms. The finding of invention depends on the amount of resources devoted to research. In particular, the larger the investment in R&D, the earlier the less polluting technology is achieved.
- (d) The project defined the environmental innovation as a change in the production technology, rather than an end-of-pipe abatement-process, given the existing production technology.
- (e) The project modelled the regulating relationship between the government and the firms as a complex long-term one, involving strategic behaviours on both parts.
- (f) The project analysed the effectiveness of the environmental policies assuming the presence of asymmetric information between the regulating body and firms. In particular, the information asymmetry has been modelled in terms of adverse selection, in which firms are better informed than the government about their cost functions and technological capabilities. In the model, an incentive mechanisms has been therefore designed in order to induce firms to reveal the truth.
- (g) Finally, the project has used its model to analyse the effects of the international game among governments on innovation, market behaviour and polluting emissions. In particular, such analysis has been conducted considering both a cooperative and non-cooperative regime.

(ii) Policy Relevance

- (a) The effects of emission taxes cannot properly be evaluated without accounting for firms' R&D and investment strategies that lead to technological changes. The effects through technological changes are likely to be larger than direct effects achieved through output changes.
- (b) Emissions can be reduced without large negative effects on output growth if the marginal taxation-emission rate is high enough to induce environmental innovation through appropriate R&D. This suggested that a S-curve describes the impact of an emission tax on output: as the marginal tax grows, firms first reduce output, then switch to the new technology, thus raising output and profits; finally, output is lowered by a larger tax after the new technology has been introduced. It is therefore important to design a progressive taxation scheme in which the marginal rate is neither too low, nor too high.
- (c) The timing of environmental innovation is relevant for a precise understanding of environmental policy. In particular, the adoption of environmental innovation in the industry is likely to be diffuse since firms find it profitable to delay innovation with respect to the socially optimal timing. This problem could be solved introducing an innovation subsidy: that is, environmental policy should combine tax and subsidy for firms R&D investment to achieve the level that guarantees the socially optimal timing of innovation. However, firms generally have an information advantage with respect to the government about their innovation costs. In these circumstances, it is likely that firms tend to overstate their costs in order to obtain a higher subsidy. Therefore, in the presence of information asymmetries, an incentive mechanism is necessary in order to induce firms to reveal their true characteristics. In particular, an incentive mechanism where the subsidy embodies an information premium, tailored according to firms' efficiency, is recommended.
- (d) Finally, the findings show that international cooperation should be encouraged since it guarantees higher welfare gains. Moreover, international cooperation should be welcome also because it can have the other positive effect of accelerating the innovation process (i.e. reducing the delay with which the environmentally-friendly technological innovation is adopted by the firms).