Environmental policy and technology diffusion under imperfect competition

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Chapter 1

Scope of the study

1.1 Background

Since the environmental problem was put on the political agenda around the 1970s, a parting of the ways between pessimists and optimists in the discussion on economic growth and the environment has emerged. In the pessimists' view economic growth and a good environmental quality cannot go together, while the optimists argue that technological progress can save the environment from further degradation, provided that a vigorous environmental policy with an adequate use of market mechanisms is pursued. As Jaffe *et al.* (2000, p.66) state:

> The potential long-run consequences of today's policy choices create a high priority for broadening and deepening our understanding of the effects of environmental policy on innovation and diffusion of new technology. [..] For both benefit-cost and cost-effectiveness analysis we need to know the magnitudes of these effects, and these magnitudes are likely to differ across markets, technologies, and institutional settings.

The pollution intensiveness of certain industries depends on the specific use of technologies among the firms that constitute the industries. In essence, one might recognize that the degree of pollution is contingent on the relative distribution of different technologies employed by the firms in the various industries. That is, pollution depends on the degree of diffusion of different technologies within industries. In particular, it could be expected that the implementation of those environmental policy instruments that induce a faster and higher degree of market penetration of environmentally benign technologies will be helpful to bring down the total level of pollution. This is at the heart of early arguments made by Orr (1976) and Kneese and Schultze (1978) that given the technology adoption incentives of environmental policy, diffusion of pollution abatement technology is generated, which subsequently affects pollution at the local, national and international levels, making the environmental quality contingent on the diffusion of pollution abatement technologies.

From the date of the appearance of these seminal contributions, the literature dealing with innovation and diffusion in relation to environmental policy has expanded enormously. This body of literature mainly emphasizes markets characterized by perfect competition. Within such a framework a general consensus regarding the superiority of so-called market-based instruments prevails; like for instance emission taxes and tradable pollution permits over direct regulation (e.g. Zerbe, 1970; Smith, 1972; Orr, 1976; Marin, 1978; Downing and White, 1986; Baumol and Oates, 1988; Milliman and Prince 1989; Jung *et al.*, 1996; Stavins and Whitehead, 1997). However, it is less unequivocal to what extent different measures of environmental policy stimulate the degree of diffusion of pollution control technology within imperfect competitive markets (Jaffe *et al.*, 2000). This research area is still unexplored to a large extent. Taking a view encompassing imperfect competition rather than perfect competition, seems also empirically to be more justified. For instance, it has been shown that most of the pollution intensive industries are quite concentrated (e.g. World Bank, 1992).

Furthermore, the current existing literature on how instruments of environmental policy affect the introduction and diffusion of less polluting technologies, follows almost exclusively a comparative static approach. It focuses on the end (equilibrium) state of diffusion. The end state is then compared with the position before the instrument was applied. Comparative static analyses do not tell how the adoption of environmentally benign technologies within industries evolves over time and how it affects total pollution. In addition, the present literature also features a large gap between the theoretical comparative static studies on the one hand and the dynamic literature on the other. The former group of studies make qualitative predictions about the adoption and diffusion of pollution abatement technologies that ultimately will occur due to the implementation of specific environmental policy measures; the latter group of studies rather focus on the dynamic process of diffusion, but often lack an economic underpinning of the choices of adopters and non-adopters of new technology.

These three gaps in the literature on diffusion of environmental friendly technologies - imperfect competition, dynamic analysis and extending the link between economic theory and diffusion models - are the challenges for research to be faced in this thesis.

1.2 Objective, research questions and method

As stated above, most work on the diffusion incentives induced by the implementation of environmental policy focuses on market equilibria. In contrast to this, the objective of this thesis is to contribute to the literature by also addressing the dynamic diffusion path and analyze how different instruments of environmental policy affect diffusion of an environmentally benign technology. In addition, the goal is to work out the consequences of diffusion for production, the profitability of firms, pollution and welfare under the various environmental policy regimes. The case to be examined will be the competition between a product produced with a relatively dirty technology and a new product manufactured by a relatively clean technology, which causes less emissions per unit of production. The products are sold on an oligopolistic output market. The examination of the impact of environmental policy on the adoption and diffusion of clean technology directs its attention therefore to a product market with an imperfect competitive market structure. This brings us to the following research questions:

- How do the characteristics of demand, costs and competition in the product market affect diffusion of an environmentally benign technology under imperfect competition?

- Is there a unique long-run diffusion equilibrium or do multiple equilibria exist?

- Related to this, what is the incentive of the environmental policy instruments, such as emission taxation, subsidies per unit of emission reduction, tradable emission permits and tradable emission credits, on the diffusion equilibrium or equilibria? That is, how many firms will in the long-run adopt the clean technology under the various policy regimes?

- How does the implementation of the four policy instruments affect the dynamic diffusion process through which the long-run equilibrium is reached?

- How is the environmental quality affected by the diffusion of clean technology and how is this related to the type of policy instrument and to the market conditions that shape the diffusion process?

The methodology to analyze the above questions, and which makes it possible to link economic theory more tightly to the analysis of technology diffusion, is game theory and in particular *evolutionary* game theory. Game theory is a tool to analyze interactive decision making processes in which players act strategically. The latter implies that decision making among players is affected by both their own choices as well as the decisions of others involved in the game. In the classical sense, game theory is static and centers the analysis around the Nash equilibrium; a state where no single player has an incentive to unilaterally deviate from. Evolutionary game theory enriches this by also taking the 'out-of-equilibrium' states into account. By doing so, it explicitly pays attention to the dynamics of the game that may lead to the equilibrium or equilibria.

1.3 Outline of the thesis

The analysis of the thesis centers around the diffusion incentives of different environmental policy instruments. Emission taxation, subsidies per unit of emission reduction, marketable emission permits and marketable emission credits will be discussed and compared to each other on how they affect the diffusion of an environmentally benign technology. The analysis is conducted within an applied evolutionary game theoretical framework. An extensive discussion of evolutionary game theory can be found in chapter 2. The chapter starts with a brief historical account of evolutionary thinking and establishes a link with theories and concepts that are common in the biological science and may be transferred to and shared with the economic discipline as such. After having presented this background, the chapter concentrates on introducing and explaining the elements of evolutionary game theory and how these concepts can be applied to economic problems. The applied evolutionary game part of the chapter draws heavily on the work of Friedman (1991, 1998). In addition to this, it introduces the evolutionary game theoretical framework that will be elaborated and applied in chapters 6 to 9 to analyze the evolution of technology diffusion in an imperfect competitive product market.

Chapter 3 reviews classical diffusion models: the epidemic, probit and classic game theoretical model. Then we shift our attention to general evolutionary diffusion models, followed by an outline of the use of evolutionary game theory as a tool for analyzing technology diffusion. The purpose of the chapter is to illustrate the main differences between the various models. Once we know the limitations and advantages of the different models, it allows us to confine the boundaries of the models more sharply.

Chapters 2 and 3 are basically methodological in nature. Relevant parts of economic theory are reviewed in chapters 4 and 5. Chapter 4 contains a survey and interpretive assessment of the current literature dealing with the impact of environmental policy instruments on the adoption and diffusion of a pollution abatement technology. The chapter illustrates and criticizes the static character of the most influential models. The chapter has mainly an interpretive character.

In chapter 2 it will become apparent that an evolutionary analysis is quite appealing when markets are characterized by perfect competition. Enhanced competitiveness forces firms to produce efficiently in order to avoid elimination. However, in imperfect competitive markets competition is limited to only a small number of firms. Since the central market structure in this thesis is that of imperfect competition, chapter 5 examines the literature on evolutionary game models applied to these type of markets. The survey reveals that the literature focuses on determining whether the evolutionary game models generate output equilibria identical to the traditional static Cournot and Bertrand models or to other output levels.

Chapter 6 is the start of the actual evolutionary game modelling and analysis of diffusion of an abatement technology within an imperfect competitive product market. A parametric Cournot model is introduced that allows for both heterogeneous and homogeneous products, which can be produced by means of a dirty technology with high emissions per unit of production or with a clean technology which generates lower emissions per unit of output. We shall, however, mainly emphasize the case of product differentiation. The model in chapter 6 abstracts from any form of environmental regulation and will serve as a benchmark.

The model as presented in chapter 6 is adjusted for environmental policy in chapters 7 and 8. Chapter 7 analyzes the diffusion process of clean technology under the policy regimes emission taxation and subsidies per unit of emission reduction. The instruments tradable emission permits and tradable emission credits are examined in chapter 8. In chapter 9, the four instruments will be compared to each other on the basis of their corresponding diffusion incentives and welfare. Moreover, a scenario study is conducted in order to explore the effects of differences in the technologies' pollution intensiveness and the cost structure of the firms. The thesis is finalized by chapter 10, which contains a synthesis of the major results and conclusions.