ESSAYS ON DISCRETIONARY ENFORCEMENT AND ENVIRONMENTAL JUSTICE

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DECLARATION

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ABSTRACT

This thesis studies issues related to the enforcement of environmental laws and to environmental justice. The two main research questions are: 1) How do firms and environmental enforcement authorities interact, given their respective objective functions; and 2) Is there any evidence in Italy of environmental injustices or social inequalities being linked to air pollution. The thesis combines theoretical and empirical methods of investigation. Two game theoretic models are set out in chapter two to analyze the possible interactions among the main U.S. enforcement and justice authorities [i.e., the Environmental Protection Agency (EPA) and the Department of Justice (DOJ)] and the firms. The models are able to rationalize a role for discretion by the environmental authorities in deciding how to pursue environmental violations.

Chapter three explores the role of environmental agencies in deterring firms from polluting by means of two laboratory experiments. Evidences on the compliance behaviour of agents, faced with enforcement conditions consistent with the theoretical models of chapter two, are reported and discussed under the different experimental treatments performed.

Chapter four provides an empirical investigation on air pollution emissions using data from the latest available Italian Census to assess the role that the demographic structure of Italian population could play in influencing environmental outcomes and the role that specific economic factors, such as income, could have on pollution emissions, alongside measures of the efficiency of the judicial system.

A discussion of the potential policy implications from both the theoretical models and the empirical analyses, together with indications for possible future research, is provided in the concluding chapter five.

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CHAPTER ONE
INTRODUCTION

> *"[...] Most of the rules of conduct which govern our actions, and most of the institutions [...] are adaptations to the impossibility of anyone taking conscious account of all of the particular facts which enter into the order of society".*
>
> Friedrich August von Hayek
> *Law, Legislation and Liberty* (1973, page 13 - vol.1)

1.1 LAW AND ECONOMICS - ORIGINS OF THE DISCIPLINE

The development of Law and Economics is the history of a success deriving from the application of economics, in particular microeconomics, to law. Norms are considered not only in reason of their legal content, but especially for their effects on individual behaviour and for their ability to lead toward efficient allocations. The main objective of law and economics is to evaluate how norms can improve the use of scarce resources and maximize social welfare.[1] More specifically, David Friedman (1998) identifies three advantages of applying economics to law. First, economics can be used to predict the effects of legal rules. Second, economics can be used to determine which rules are economically efficient. Third, economics can be used to predict legal rules.

The basic idea of law and economics is that the application of economic theory can improve the knowledge of legal phenomena, either to explain the implications of norms and their reforms on individual behaviour, or to better understand the implications deriving from the use of alternative norms. As emphasized by Cooter and Ulen (1988), economics allows to perceive a legal system in a way which is extremely useful to jurists and policy makers; if economists learned how to understand the law, their models would be closer to

[1] Many are the books in law and economics. I would like to remember, in particular, Posner (1972); Polinsky (1983); Shavell (1987); Cooter and Ulen (1988); Friedman (2000); Backhaus (2005).

reality.

Despite the fact that the earliest historical roots of law and economics can be traced back to economists like Adam Smith (1776) with the analysis on the economic effects of legislation, Jeremy Bentham (1782, 1789) with the theory on legislation and on utilitarianism, and Arthur Pigou (1932) with the application of the pigouvian tax to correct negative externalities, it is, in reality, in the first half of the 1960s that a more mature awareness develops about the interdependences between economics and law and the analysis, among others, of Ronald Coase (1960), Guido Calabresi (1961)[2] and Pietro Trimarchi (1961). It is, in fact, starting from these years that a new methodological perspective begins to emerge combining the different methods proper of the two disciplines, thereby generating a strong interaction between economic theory and legal studies.[3]

There is a certain tendency to subdivide law and economics in two branches of studies (Posner, 1983). The "old" law and economics, which dates back to Adam Smith (1776), was focused on studying mainly the legislation regulating the market (*i.e.*, individuals' and firms' market behaviors).[4] The "new" law and economics pioneered by Coase, Becker (1968) and Calabresi studies the legislation regulating non-market behaviour (*e.g.*, criminal law and family law) whose objective is to apply "*economics to core legal doctrines and subjects such as contract, property, tort and criminal law*" (Duxbury, 1995).

It has been argued (Dari Mattiacci, 2000) that we are now in the third generation of law and economics. The first generation was created by the founding fathers and was dominated mostly by lawyers with some understanding of economics. The second generation was characterized by economists who placed more emphasis on the use of mathematical methods, with a consequent shift towards a dialogue between economists and lawyers. The third generation is the actual generation of young professors and researchers, who have studied both

[2] The paper by Coase published on the *Journal of Law and Economics* in the 1960 and the one by Calabresi published on the *Yale Law Journal* in the 1961, in reality, were written contemporaneously; the paper by Calabresi, in fact, was published in the 1961 for purely editorial matters.
[3] The work by Backhaus (ed., 2005), *The Elgar Companion to Law and Economics*, contains several biographic sections devoted to the precursors and to the first European exponents of the law and economics movement.
[4] An extensive review of the history of law and economics is provided by MacKaay(2000).

law and economics, and of lawyers and economists who have become able to share issues of mutual interest.

1.2 DIFFERENT SCHOOLS OF THOUGHT

Law and economics builds on a number of diverse contributions which have converged into a unified paradigm but originate from different roots (Backhaus, 2005). The economic analysis of law stems from different schools of thought: the Chicago school, the Yale school, the Public Choice school, the neo-paretian, and the neo-institutionalist (Chiassoni, 1999). However, its two main souls are the Chicago school (characterized by a neoclassical approach, in which individuals are always informed rational maximizers and their behaviour is easily predictable) with Posner's "positive" analysis, and the Yale school with Calabresi's "normative" analysis. The economic analysis of law, at its very beginning, was qualified as "Chicago-style" or "Yale-style" according to the positive and normative approach of each school (Parisi, 2004).

While the positive (or descriptive) approach focuses on the analysis of economics to analyze if and how legal rules are consistent with the Pareto efficiency criterion, the normative (or prescriptive) approach takes a step forward and aims to recommend which legal rules, if applied, would deliver the most efficient solution both for legislators and judges.[5] The economic analysis of law, *tout court*, includes both these approaches since it tries to explain not only socially undesirable behaviour but also to suggest the optimal ways to control such conduct.

These two schools of thought, developed almost simultaneously, are characterized by methodological differences concerning mainly the idea of economic efficiency. According to the Chicago school, the idea of efficiency corresponds to the economic efficiency of a competitive market. It focuses on static aspects (a norm is efficient or not) and keeps efficiency and distributive

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[5] Posner (1972) provides an example on crime. Positive law and economics can help explain and predict how punishment will affect the behaviour of criminals (i.e., a certain sanction might deter from committing a crime). This analysis by itself does not mean that the law should be adopted, but it can be used to influence normative analysis on whether the law would be beneficial to society.

considerations separate. The idea of efficiency according to Calabresi and to the Yale school, by contrast, holds that there is a greater need for legal intervention to correct market failures (Parisi, 2004; MacKaay, 2000). Distributional concerns are central to this school. An important implication of the Chicago approach to law and economics is the idea that the common law induces efficient results. This result is known as the "*efficiency of the common law hypothesis*", according to which common law rules are able to allocate resources in either a Pareto or Kaldor-Hicks[6] efficient manner (Ehrlich and Posner, 1974; Rubin, 1977; Priest, 1977).

So, whereas the Chicago school emphasizes the inherent efficiency of legal rules and maintains that efficient legal rules evolve naturally, the Yale school views the law as a tool for solving market failures and distributional inequalities. According to Calabresi, the legal rule "*becomes instrument*" for the achievement of economic objectives while, according to the Chicago school, efficiency is considered an instrument able to evaluate the goodness of legal rules (Pulitini, 2002). Unlike its Chicago counterpart, the Yale school maintains that the ultimate goal of a legal system can never be efficiency as such, but rather the need to pursue justice and equity in the distribution of resources.

More recently a third approach has developed: the so-called Virginia school, which has been defined (Parisi, 2004) as "*functional*" since it is neither fully positive nor fully normative. The Virginia approach stems from Public Choice theory. By integrating the findings of the public choice theory into law and economics, it seeks to bridge the different perspectives between the positive and the normative approaches (Parisi, 2004). The functional school, by recognizing that while there are economic forces that lead to markets' failures, there are also structural forces that can inhibit the development of efficient legal rules, rejects both the ex-post corrective function of law assumed by the normative school and

[6] Under Kaldor-Hicks efficiency, an outcome is considered more efficient if a Pareto optimal outcome can be reached by arranging sufficient compensation from those that are made better-off to those that are made worse-off, so that all would end up no worse off than before. The Kaldor-Hicks criterion is typically used as a test of Pareto efficiency rather than as an efficiency goal in itself. It is used to determine whether a reallocation shifts the economy towards Pareto efficiency. Any change usually makes some people better-off while making others worse-off, so these tests ask what would happen if the winners were to compensate the losers. The Kaldor-Hicks criterion provides a rationale for cost-benefit analysis.

the naturally evolving efficient system view endorsed by the positive school (Parisi and Klick, 2005). This way, the functional approach extends the field of research of law and economics to include the analysis on how institutions can affect legal regimes.

1.3 ENVIRONMENTAL LAW AND ECONOMICS

The earliest theoretical applications of law and economics were mainly to issues pertaining to corporate law, contract theory and competition law. At present, law and economics has come to encompass remarkable and innovative methods for the analysis of legal rules in all areas of law, from tort and property law to commercial law, constitutional law, criminal law and environmental law. As noted by Pardolesi (1987, p. 312), the economic analysis of law by itself *"is susceptible to be adapted to the most diverse and disparate situations".* It has been argued (Nicita and Pagano, 2005) that the most recent developments of the standard law and economics approach have shifted from legal rules to a more general concept of "institutional" rules, including informal rules, and enforcement institutions. Nicita and Pagano (2005) also stress the need to go beyond both the traditional (Chicago school) law and economics approach to assessing the possible interactions among legal rules, economic behaviour and institutional changes.

Since Coase's (1960) article "*The Problem of Social Cost*" which has established a new paradigm for controlling environmental pollution by challenging the conventional pigouvian approach, there has been a large body of literature (Bouckaert and De Geest, 1992; 2000) on optimal environmental policies. It is difficult to delineate the boundaries of environmental law and economics literature since, by one side, the law literature focuses essentially on law and environmental regulations and does not study how to control environmental risk in an economic perspective (*i.e.*, emission taxes, transferable permits); the economic literature, on the other side, analyses the effects of economic instruments for controlling the level of environmental pollution, but the legal instruments (*i.e.*, liability, criminal law) are not usually considered (Faure, 1998).[7]

In the economic literature, the early contributions on environmental risks have considered models in which the regulator maximizes a welfare function decreasing with the level of damage and the level of abatement costs (Roberts and Spence, 1976; Kwerel, 1977; Dasgupta *et al.*, 1980; Baron, 1985). The law and economics literature has focused mainly upon the role of legal institutions and common law rules in achieving efficiency and distributive goals (Calabresi, 1970; Landes and Posner, 1987; Shavell, 1987), in particular in the area of environmental policy (Polinsky, 1980; Landes and Posner, 1984; Tietenberg, 1989; Kornhauser and Revesz, 1994). The challenge that the economic analysis of law poses to scholars and researchers is to realize increasingly stronger interdisciplinary interactions between law and economics in favour of a unified frame of analysis.

Environmental law and economics focuses not only on the role that institutions can play in the presence of environmental problems, but also on the potential interactions among agents due to negative externalities and on all the instruments, both economic (pigouvian tax, marketable permits, etc.) and legal (civil liability regimes, *i.e.* strict liability and negligence),[8] that can be used to maximize social welfare or to minimize environmental damages.

Thus, environmental law and economics focuses on several issues related not only to the effects of regulations and to the alternative instruments (economic and legal) for controlling environmental risk, but also on the importance of designing optimal schemes of enforcement. Enforcement is any action or intervention taken in case of non-compliance (Weiss, 1999): it includes actions that encourage (through incentives) or force (through sanctions) compliance with environmental law. According to Becker (1968), the authorities have to determine

[7] It is nevertheless important to remember that among the numerous textbooks on environmental economics, there are several ones that do discuss the importance of legal instruments. These include, for instance, Ackerman *et al.* (1974), Baumol and Oates (1979), Eide and Van den Bergh (1996), Endres (1985), Field (1994), Kahn (1995), Oates (1996), Pearce and Turner (1990), Portney (1990), Revesz (1997), Richardson, Burrows and Ogus (1982), Tietenberg (1992) and Ward and Duffield (1992).

[8] Faure (1998) has highlighted a methodological issue that overcomes the terminological distinction between these instruments arguing that legal instruments are also economic, in the sense that they provide an incentive to comply with certain policy objectives, and economic instruments are also legal in the sense that a system of taxes or marketable pollution permits needs an adequate institutional framework to be effective.

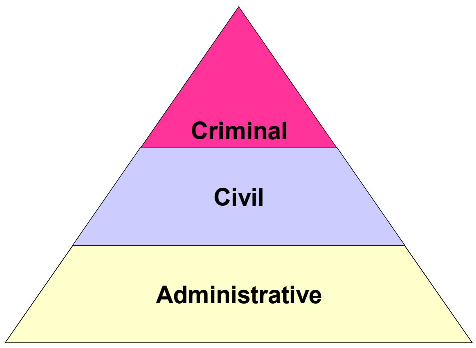
the amount of resources to prevent offenses and to apprehend offenders. In particular, Becker tries to identify those expenditures on law enforcement and on punishment that minimize the social loss. This loss is the sum of damages, costs of apprehension and conviction, and costs of carrying out the punishments. Assuming that potential criminals are rational utility maximizers, who base their decisions to commit or not to commit a crime on an expected utility calculation, they will comply with the law as long as their benefits of compliance outweigh their costs (Becker, 1968).

The vast theoretical literature on enforcement (e.g., Polinsky and Shavell, 1984, 2000; Posner, 1985, 2003; Shavell, 1993, 2003; Stigler, 1970; Garoupa, 1997, 2001, 2004) show the fundamental importance of acting upon socially efficient enforcement strategies. The basic prescription of enforcement theory (Becker, 1968) is that potential violators behave according to both the probability of being detected and the severity of the sanction. This implies that deterrence may be improved either by raising the sanction, by increasing the expenditures on enforcement in order to raise the likelihood that the violator is captured, or again by changing the legal rules in order to increase the probability of detection (Cohen, 1998). From an economic perspective, perfect compliance is neither possible nor desirable: since monitoring and enforcement activities are costly for the regulatory authority, the socially optimal level of enforcement has to be found at the point where the costs of law enforcement outweigh the benefits of harm prevention. This is a very crucial point and its importance is demonstrated by the fact that most of the law and economics literature above mentioned has been focusing on how best to induce compliance at a lower enforcement cost.

1.4 THE U.S. ENFORCEMENT OF ENVIRONMENTAL LAWS

In the present thesis, the U.S. enforcement of environmental laws is examined. This generally consists of three basic forms of enforcement: administrative, civil, and criminal. In addition to these three government enforcement options, each specific environmental law also provides that civil actions seeking injunctions and civil penalties can be pursued by individual citizens or by organizations through citizen suits. This system can be viewed as a pyramid (see figure 1.1), formed by a base level where a large number of relatively minor violations is handled through administrative actions, followed by an intermediate level where a smaller number of more serious violations is handled through civil actions and, finally, a superior and last level where a small number of very serious violations is handled though criminal prosecution (Mandiberg and Smith, 1999). Also Ayres and Braithwaite (1992) have suggested the use of an enforcement pyramid consisting of several layers, in which each layer represents a different enforcement strategy that could be used to enforce the law. The enforcement strategies escalate from lenient approaches at the bottom to more severe enforcement strategies with sanction-based approaches like the revocation of licenses and the application of jail time sentences at the top of the enforcement pyramid.

Figure 1.1 The enforcement pyramid



As emphasized by Ayres and Braithwaite (1992), environmental laws should be enforced by way of a bottom-up approach: when enforcing environmental law, persuasive mechanisms should be utilized first, and gradually harsher sanctions should be adopted if the regulated parties continue to breach the law. Almost every normative provision, any regulation emanated by the Environmental Protection Agency, and any permit condition is assisted by one or more enforcement options. While the choice of electing the administrative action belongs only to the EPA, the use of civil and criminal proceedings requires the involvement of the DOJ and the U.S. Attorneys, and usually implies an increase in both the time required and the cost of enforcement. EPA has broad discretion to choose among administrative, civil judicial, and criminal proceedings when it seeks to impose environmental penalties. A civil judicial environmental enforcement actions begins with a referral from EPA to DOJ. DOJ will not go ahead with a civil action on its own initiative; its only authority is to proceed on EPA's behalf. If DOJ does decline, EPA can in theory proceed on its own. If and when it refers to DOJ, EPA will request criminal or civil prosecution. A more detailed discussion on the mechanisms underneath both EPA's administrative and investigative discretion and DOJ's prosecutorial discretion is provided in chapter two.

1.5 RESEARCH QUESTIONS AND STRUCTURE OF THE THESIS

The present thesis addresses two key research questions: 1) how do the regulated community (firms) and environmental enforcement authorities interact in order to maximize their respective objective functions, and 2) whether there is any evidence in Italy of environmental injustices or social inequalities linked to air pollution, that is to say, if economic characteristics, such as income levels, and the demographic composition of population, such as the percentage of foreigners, might have some influence on air pollution emission levels.

The thesis combines theoretical and empirical investigations. This allows, on the one hand, to improve the understanding of the importance of different enforcement strategies in the environmental regulatory context, and on the other hand to investigate the relationship between air pollution and enforcement of regulations, in order to beseech that economic and political limitations of minorities or disadvantaged groups may apply.

1.5.1 CHAPTER 2

In chapter two, by examining the U.S. environmental enforcement authorities, i.e. the Environmental Protection Agency (EPA) and the Department of Justice (DOJ), it is shown how a discretionary enforcement can be interpreted as an essential component in a coherent strategy to encourage firms to adopt a compliant environmental behaviour, in the context of game theoretic models where the firm's behaviour is influenced by the course of actions discretionally implemented by both the EPA and the DOJ.

More specifically, the results of two different game theoretic models, based on strategic interactions among the players, are analyzed through a morphological analysis of the U.S. environmental authorities' behavioural mechanisms. Two game theory models are developed: i) a first model which is based on the assumption that EPA and DOJ share the same objective function, and ii) a second model which is based on the assumption that EPA's objective function is different from DOJ's objective function. The two game theoretic models explore the role of discretion that such authorities enjoy, either in deciding how to pursue environmental violations (investigative and prosecutorial discretion) or in judging them (judicial discretion), with the purpose of identifying both the optimal firms' behaviour in terms of compliance, and the DOJ's and EPA's optimal strategies in terms of enforcement actions to undertake.

The innovative contribution of this analysis resides in the fact that, contrary to most of the literature, discretion is interpreted as a key element in encouraging firms to adopt compliant environmental behaviour, and thereby constitute a crucial element in the management of any environmental policy. It is shown that an enforcement strategy partially unpredictable can produce a greater level of compliance compared to an environmental policy known in advance and with certainty. From a policy perspective, the results obtained allow to identify the most effective strategies to maximize firms' compliance and, thus, environmental quality.

1.5.2 CHAPTER 3

In chapter three, the outcomes of two experimental empirical validations are presented. Departing from the setting of the game theory models developed in chapter two, the role of EPA and DOJ in deterring firms from polluting is empirically tested, by means of two laboratory experiments. Laboratory evidence on compliance behaviour of firms when faced with enforcement conditions consistent with the theoretical models set up are discussed for the different experimental treatments performed.

The overall experimental findings lead to somewhat mixed considerations in terms of environmental policy implications. The first set of experimental results (relative to the game theory model in which EPA and DOJ are assumed to share the same objective function) suggests that it is more efficient to let the EPA resolve the cases internally (administratively) rather than refer them to the DOJ for civil or criminal prosecution. From the experimental test it emerges, in fact, that the intervention of the DOJ acts merely as an additional enforcement cost, which, in turn, might reduce the probability of conducting inspections by the EPA without affecting the probability of firm's compliance. This implies that enhancing criminal enforcement programs would not necessarily strengthen deterrence since criminal fines might not be able to give polluters the adequate incentives to prevent environmental crimes. The second set of experimental results (relative to the game theory model in which EPA and DOJ are assumed to have different objective functions) however, shows that criminal enforcement enhances deterrence by improving firms' compliance.

On the whole, the results are supportive of the view that an environmental approach in which the choice of the enforcement strategy is randomized can be successful in encouraging firms' compliance. One of the main implications of the experimental results in terms of environmental policy recommendations is that the EPA and the DOJ, even though jointly working towards a better environmental quality, should not share the same objective functions but should keep them separate.

The main innovative contribution provided by this chapter consists in bringing new evidence on enforcement and discretion in the law and economics experimental literature. The chapter represents, to the best of my knowledge, the first attempt to offer an empirical validation on the combination of administrative and civil/criminal environmental enforcement approaches by means of laboratory experiments. The experimental treatments allow us to study how compliance choices respond to the different enforcement approaches in a novel theoretical framework in which the enforcement agency and the Department of Justice interact together.

1.5.3 CHAPTER 4

The fourth chapter provides an empirical investigation on environmental justice issues in the context of air pollution in Italy. Environmental Justice refers to the fair treatment of people of all races, income levels, and cultures with respect to the implementation and enforcement of environmental laws and regulations (US EPA, 2004). Fair treatment implies that no one group should bear a disproportionate environmental risk in terms of polluted air or water and under-enforcement of environmental laws. Environmental justice issues are closely related to enforcement issue. Only a coherent and homogeneous enforcement of laws guarantees against the presence of social or ethnic inequalities in exposure to environmental risk.

Air pollution emissions data at provincial level were combined with data from the latest available Italian Census to assess the role, if any, that the gender composition of Italian population could play in influencing environmental outcomes and the role that economic factors, such as income, could have on pollution emissions.

The estimates obtained are consistent with an inverse U-shaped environmental Kuznets curve: once income exceeds a turning point, air pollution decreases with increasing income. Moreover, the results show evidence of higher air releases in provinces with higher concentration of females as households' head and higher concentration of children.

This chapter provides an innovative contribution aiming at filling the gap in the environmental justice literature since, by contrast to the United States and to several others European countries, in Italy the impact of socioeconomic factors on environmental outcomes has been rarely studied. The results of the research yield new insights in the sense that they do not find evidence of any environmental discrimination based on ethnicity, suggesting that environmental justice issues in Italy are not likely to be perceived in racial and ethnic terms but rather in terms of social categories and gender composition of the population.

1.5.4 CHAPTER 5

The concluding chapter gives a brief summary of the main findings of the research. It offers some discussions of its policy implications, from the theoretical models and from the empirical analyses, and suggests possible proposals for future research directions.

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CHAPTER TWO

DISCRETIONARY ENFORCEMENT AND STRATEGIC INTERACTIONS BETWEEN FIRMS, REGULATORY AGENCY AND JUSTICE DEPARTMENT.

> *«[...], greater uncertainty will cause rule-governed behavior to exhibit increasingly predictable regularities, so that uncertainty becomes the basic source of predictable behavior.»*
>
> Ronald A. Heiner
> The Origin of Predictable Behavior, in *American Economic Review*, 1983, 73(4), p.570.

2.1 INTRODUCTION

The traditional approach of law and economics (Shavell, 1987) has focused on two regulatory approaches: the *ex ante* and the *ex post* regulation systems. An *ex ante* regulatory system is based on a control scheme a priori defined and is applied before (or at least independently of) the occurrence of harm. An *ex post* regulatory system, also defined as a liability system, occurs after the damage is verified. An *ex ante* regulation is based upon both direct (i.e., the traditional command and control system, such as standards) and indirect regulation instruments (i.e., green taxes, tradable permits and voluntary agreements). Since the polluting firm must compensate the victim for the damage eventually brought, it will be induced to prevent meaningful environmental damages in all those circumstances in which the prevention costs are smaller than the damage. An *ex post* regulation system, instead, is based upon compensation mechanisms, mainly through the application of two liability regimes: fault (or negligence) and strict (or objective) liability.[9] If the damage is verified, the firm is

[9] Under strict liability, injurers are liable for damages they cause regardless of culpability, i.e. of the level of care they exercise. Under a fault-based liability regime, a person is held liable for environmental damage only if he or she is proven to be at fault. Fault is determined on the basis of whether or not the person to whom the damage is attributed observed the prescribed duty of care in carrying out the activity. This must normally be proven by the person bringing a claim. Strict liability, on the other hand, applies regardless of whether or not the person to whom the damage is attributed is at fault, i.e. whether or not he or she observed the duty of care. The claimant is only

held responsible to reimburse the victims and, thus, to sustain the cost of the externality.

In the U.S., the activity of the EPA provides a clear example of *ex ante* regulation by an independent environmental authority. This agency establishes standards, runs inspections and brings actions to the federal courts. In the E.U., by contrast, the European Environmental Agency (EEA) plays only a very limited role,[10] firstly because its task consists mainly in providing relevant and reliable information to policy makers and to the public and, secondly, because it does not make or enforce European Union environmental policy or legislation (which is responsibility of the European Commission and of other E.U. institutions).

The U.S. experience is well established also with regard to the *ex post* regulatory system. The issue of environmental damage liability has emerged since the beginning of the 1980s, when the U.S. Congress enacted the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and created a Superfund for the quick and effective clean-up of dangerous waste sites,[11] based upon a strict liability regime accordingly to the polluter pays principle (for which who causes an environmental damage is financially responsible for it).

In Europe, the different juridical system and the normative fragmentation of the different member States give a less homogeneous picture. The European Community has been trying for many years to define a common system of liability for environmental damages. In 1993, the European Commission published the Green Paper on Remedying Environmental Damage[12] and in 2000

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required to prove the damage and the causal link, but not a failure to observe the duty of care. Strict liability is generally advantageous for the claimant, as fault can be difficult to establish.

[10] The European Environment Agency was formally established by EEC Regulation 1210/90 in 1990 (amended by EC Regulation 933/1999 and EC Regulation 1641/2003). The decision to locate in Copenhagen was taken in 1993 and the Agency has been operational since 1994. The European Environment Agency is the leading public body in Europe dedicated to providing timely, targeted, relevant and reliable information to policy makers and the public, to support sustainable development and to help achieve significant and measurable improvements in Europe's environment.

[11] The Superfund enabled the government to begin cleaning-up of priority sites placed on the National Priority List with money generated principally by taxes on cruel oil, corporate income, petrochemical, feedstock, and motor fuels.

[12] Commission of European Communities, Communication from the Commission of the Council and Parliament: *Green Paper on Remedying Environmental Damage*, COM (93) 47 final, Brussels, 14 May 1993, OJ 1993 C 149/12.

released the White Paper on Environmental Liability.[13] It is only with the Directive 2004/35/CE of the European Parliament and of the Council on the environmental liability that it has been established a common framework of liability based on the strict liability principle.

Shavell (1984) shows that no regulation system alone leads to exercise the socially desirable level of care, emphasizing that a complete solution to the problem of the control of risk should involve the joint use of liability and regulation. In addressing the problem of the comparison between *ex ante* and *ex post* regulation, Kolstad, Ulen and Johnson (1990) conclude that the two policies should be applied jointly in a complementary (and not substitutive) relationship.

Over the last three decades in both the E.U. and the U.S., notwithstanding their different juridical systems, environmental regulatory regimes have become increasingly centralized (Vogel *et al*., 2010). In the U.S. by the second half of the 1970s federal standards have been established for all forms of air and water pollution. In the E.U, actually the majority of environmental laws in the Member States are effectively European law (it consists of European environmental regulations and directives which have been implemented into national law).

However, a crucial difference between the two regulatory systems is that while in the U.S. the EPA has direct enforcement power, it can control directly environmental quality setting federal standards and undertake enforcement actions in court, the E.U. has no EPA with centralized enforcement power, and it is dependent upon Member States to implement and enforce European environmental law. The European Commission does not dispose of inspectors to verify whether environmental laws are actually applied. Thus, while the rules are set at the European level, implementation and enforcement is entirely left to Member States. For its effectiveness, therefore, European environmental law needs a strong cooperation between the E.U. and the Member States (Faure and Johnston, 2008; Goodrich, 2004; Krämer, 2002; Kelemen, 2000).

Nevertheless, in both the E.U. and the U.S., state regulations continue to play an important role in environmental policies generating often some disputes

[13] Commission of European Communities, "*White Paper on Environmental Liability*", COM (2000) 66, 9 February 2000.

about the relative competence of central and state authorities to regulate matters of environmental policy (Vogel *et al.*, 2010).

Another, not less important, longstanding debate focuses on the best way to achieve compliance with the provisions of environmental statutes and regulations. As a matter of fact, law and economics scholars (Ogus and Abbott, 2002; Ogus, 2004; Bowles *et al.*, 2008; Faure and Svatikova, 2009; Almer and Goeschl, 2010) have given substantial attention to the question of why the criminal law is used at all and why criminal sanctions are applied (in terms of their cost-effectiveness).

The environmental enforcement strategies adopted in the United States and in Europe have been quite different. Since the beginning of the 1990s, the United States have become increasingly vulnerable to criminal liability for violations of environmental laws and this tendency, proved by the recent stiffening of criminal environmental sanctions, suggests that tougher enforcement is likely to continue (Babbit *et al.*, 2004). In Europe, instead, the most common approach for inducing compliance with environmental regulations has been mainly through administrative and civil remedies, even though, recently, the European Union has reviewed its environmental enforcement strategies (European Commission, 2007). After various unsuccessful attempts, Europe has promulgated Directive 2008/99/EC on the protection of the environment trough criminal law, harmonizing and strengthening the role of criminal law and forcing the Member States to enforce a large number of environmental violations through criminal law. This directive seems to favour criminalization but is in contrast with the trend in several European countries (Germany and Netherlands, for instance) where the use of administrative sanctions is the main enforcement tool for environmental regulation (Faure and Svatikova, 2009). This opens up the question of whether relying strongly on criminal law, as the E.U. Directive does, is socially desirable.

In this chapter the role of the U.S. Environmental Protection Agency (EPA) and of the U.S. Department of Justice (DOJ) is investigated with regard to their discretion in the enforcement of environmental laws. This can take the form of administrative and investigative discretion for the EPA, and prosecutorial discretion for the DOJ. More specifically, we explore the motivations behind the use of discretion in terms of the effectiveness of the enforcement mechanisms available to the environmental authorities.

This analysis is motivated by the observation that in the enforcement of environmental laws some violators are sentenced at criminal level while some others, who have in substance committed the same crime, are not punished or are sanctioned with a purely administrative or civil fine. For instance, it has been demonstrated (Cory and Germani, 2002; Babbit, Cory, *et. al.*, 2004) that for similar violations to the U.S. Clean Water Act, seemingly similar defendants may receive very disparate sentences.

These inconsistencies run the risk of creating serious social and economic policy distortions, either toward an over-criminalization attitude or in favour of a more lenient approach, by creating respectively over-deterrence or under-deterrence. One of the main tasks for the EPA is to determine which violators to prosecute, and whether to pursue violations at the administrative, civil or criminal levels. In fact, the major U.S. environmental statutes, together with the Federal Sentencing Guidelines,[14] afford substantial discretion to the EPA, the Department of Justice, and the courts: they can be more aggressive or more friendly on environmental violations, and can carry out a weaker or a stronger enforcement.

Our contribution consists mainly of trying to gain a better understanding of why there are these apparent inconsistencies in the prosecution of environmental violations. We present two game theoretic frameworks to explore the possible interactions between environmental authorities and firms. Even though unpredictable and contradictory enforcement can create uncertainty and adverse effects that could potentially limit the effectiveness of environmental policies, we provide a possible rationale for these apparent incongruities. Since there are no dominant strategies for the environmental agencies, their optimal rule of conduct requires that they randomize among their alternative strategies.

[14] In 1984, the U.S. Congress passed the Sentencing Reform Act (SRA) that completely transformed the traditional sentencing process in an attempt to reduce unwarranted disparity in sentencing, to ensure certainty, proportionality and uniformity of punishment, and to establish more serious penalties for specific categories of offenses. In order to achieve these goals, Congress created the United States Sentencing Commission as an independent, permanent agency in the judicial branch with the main purpose to develop an unprecedented body of laws to regulate federal sentencing: the Federal Sentencing Guidelines. The Sentencing Guidelines went into effect in November 1987, and apply to all federal crimes committed on or after that date.

Overall, we suggest that making environmental enforcement less predictable for the firms, and thus creating a degree of uncertainty for the violators, can help encourage deterrence and, thus, improve compliance. In other words, a partly unpredictable enforcement strategy may generate more compliance than an environmental policy that is known with certainty in advance.

The unpredictability of the enforcement strategy need not be meant as a literal randomization of the strategy of the environmental authorities. Rather, it can be seen as reflecting the heterogeneity of the members of the environmental agencies, and the impossibility by the firm of knowing in advance with which members it will be matched. Thus, even if each individual member of the environmental agency were to follow a pure strategy, their heterogeneity would lead the firm to behave as if the agency as a whole were randomizing its strategies. This interpretation of the results is consistent with Harsanyi's Purification Theorem (Harsanyi, 1973) in game theory.

This chapter is organized as follows. Section 2 reviews some of the main literature directly related to this issue. Section 3 identifies the key points underlying the two enforcement game theory models developed. Section 4 explores, within the context of the first theoretical model, the strategic interactions between the EPA and the firm, first, and then, in a more complex game, the role of the DOJ and its relationship with the EPA. Section 5 analyzes, within the context of the second game theory model, the probability of compliance by the firm and the enforcement strategies of the two environmental agencies when they have different objective functions. Section 2.6 discusses the main policy implications of the analysis and offers some conclusions.

2.2 RELATED LITERATURE

Our analysis is closely related to the literature on selective enforcement (Friesen, 2003; Lando and Shavell, 2004) pioneered by Harrington (1988), who had noted the following paradox: firms' rate of compliance is high even though the EPA's enforcement activity is carried out at low levels and often violators are not punished even if discovered. This paradox shows, therefore, that even though enforcement and monitoring actions are often weak, firms may still be substantially compliant.[15] Revisiting the Harrington paradox, Heyes and Rickman (1999) analyze the role of regulatory dealing by which the enforcement agency can use tolerance in some contexts and for some types of violations, in order to increase compliance in other contexts and for other violations. The authors interpret discretion as an important aspect of the strategic agency's behaviour and as a necessary element of any environmental policy, by showing that the introduction of a regulatory dealing will improve both the rate of compliance and the whole environmental performance of the firms.

While the focus of Harrington and of Heyes and Rickman is on studying the optimal enforcement scheme and the optimal use of sanctions (Polinsky and Shavell, 1984, 2000; Posner, 1985, 2003; Shavell, 1993, 2003; Stigler, 2002; Garoupa, 1997, 2001, 2004), our contribution consists of analysing how the EPA and the DOJ can influence firms' behaviour by randomizing, on purpose, enforcement rules and by modeling their interactions in a strategic game characterized by discretion. We can thus investigate: 1) whether the implementation of administrative or civil/criminal actions could help improve environmental compliance, and 2) how both EPA and DOJ choose to handle cases, that is civilly or criminally.

According to Firestone (2003), the EPA does not pursue all enforcement cases administratively. In order to explain why and how EPA makes its decisions, Firestone, in his work, explored the implications of five main theoretical "alternative" motivations for EPA enforcement decisions: social welfare maximization; violation minimization; case maximization; environmental harm minimization; and political support maximization. Firestone's main results are that when EPA seeks to maximize social welfare, to minimize the number of violations, or to maximize political benefits, it would find judicial remedies less attractive and thus increasingly will choose to handle violations administratively. Only when EPA seeks to minimize environmental harm, as the actual or potential for harm increases, it will invest greater financial resources to punish the conduct

[15] The main result of Harrington's paradox is that firms may have an incentive to comply with the law even though their cost of compliance exceeds the expected penalty for violation or even the maximum penalty that can be applied.

criminally. Overall, the objectives of maximizing social welfare and minimizing environmental harm appear to be the main motivations for EPA, while there is little empirical support for the political maximization objective.

Our findings are consistent, in some respects, with Firestone's results, in the sense that we observe a greater probability for violations to be resolved administratively, but we also provide further insights on the possible interactions between the violator and the EPA and especially between the EPA and the DOJ.

Related works are also those by Franckx (2001; 2002) and by Tsebelis (1989). In Tsebelis, individuals' offending behaviour has been modelled as a one-shot 2x2 game between public and police; the game does not have a pure strategy equilibrium, instead it has a unique mixed strategy equilibrium. Franckx considers inspection games between polluting firms and an inspection agency to identify under which conditions ambient inspections can improve compliance. In another game theoretic framework by Scholz (1991) the EPA's enforcement approach depends on where the agency and firm are in the enforcement process implying that the regulatory enforcement involves the regulator and firm in an ongoing series of prisoner's dilemma games. Because the regulatory game is played repeatedly, the regulator chooses its action based on the firm's behaviour in the prior round. If the firm has cooperated, the agency should cooperate, but if the firm defects, the agency should punish until the firm again adopts a cooperative behaviour.

Compared to the extensive theoretical literature on monitoring and enforcement aspects of environmental regulation (Cohen, 2000a; Polinsky and Shavell, 2000), the empirical literature is still lagging behind. In particular, relatively little is known about why firms decide to comply or not with environmental regulations, partly because comprehensive data on compliance and enforcement have been difficult to obtain (Cohen, 2000b), but also because there is a serious lack of empirical data on the motivations influencing firms' compliance behaviour. However, most of the empirical research looks at the factors that can influence the inspection decisions of environmental agencies - some examples are Magat and Viscusi (1990), Laplante and Rilstone (1996), Dion *et al.* (1998), Helland (1998), Dasgupta *et al.* (2000), Stafford (2003), Anderson and Stafford (2003), Rousseau (2007) - where it is extensively shown that increases in the frequency of inspections in regulated facilities increase compliance. Glicksman and Earnhardt in their work (2007) show that the threat of inspections improves firms' compliance. They contrast the effects of administrative and civil fines, finding that civil fine are significantly more effective than administrative fines in terms of their general deterrence. Other studies focusing on the effects of sanctions show that an increase in penalties also results in an increase in compliance rates (Stafford, 2002; Shimshack and Ward, 2005).

There is, therefore, the need for more empirical research especially for what concerns authorities' discretion in their enforcement of environmental regulation, in order to better understand how firms perceive their relationship with environmental regulators and how they react to their enforcement strategies. The need for further empirical analysis is equally essential for regulators to assist them in undertaking the mix of enforcement approaches more suitable to attain the highest level of compliance by regulated industries.

Related literature also includes, in the macroeconomic field, the literature on rules versus discretion on the conduct of monetary policy (Kydland and Prescott, 1977). Other relevant studies are those by Subrahmanyam (1995) in which rules versus discretion in the context of market closure rules are analyzed, and by Kleinig (1996) in which several analyses on the use of discretion by police in law enforcement are provided. Our work relates to these papers, since the utilization of randomized strategies can be interpreted as the exercise of discretion.

2.3 THE TWO GAME THEORY MODELS

The economic structure of the enforcement problem is analyzed throughout two game theory models in both of which the violator's behaviour is influenced by the course of actions discretionally implemented by both the EPA and the DOJ. In particular, firms' behavior is likely to change as a consequence of its revised expectations on the exercise of discretion at both the EPA and the DOJ levels. We describe these interactive situations through strategic games in order to determine the payoff maximizing strategies for the players and consequently determine the expected outcomes of the game.

We develop two game theory models:

1. a model under the assumption that EPA and DOJ share the same objective function (model I: section 2.4);
2. a model under the assumption that EPA's objective function is different from DOJ's objective function (model II: section 2.5).

Regarding the objective functions of regulatory agency, in the literature, there is no consensus on their specification, ranging from minimization of levels of noncompliance to maximization of social welfare, from minimization of agency budgets constraints to maximization of agency political support (Viscusi and Zeckhauser, 1979; Jones and Scotchmer, 1990; Niskanen, 1975; Peltzman, 1976). The most common objective function incorporated in theoretical models of enforcement assumes that the enforcer acts to minimize non-compliance subject to a budget constraint (examples include Heyes and Rickman, 1999, and Harrington, 1988).

In the first model that we set out, we assume that both EPA and DOJ share the same objective function, i.e., minimization of environmental violations at the minimum costs of enforcement. We assume also a profit maximizing firm.

In the second model, we assume that EPA and DOJ do not share exactly the same objective function, since the DOJ aims to minimize environmental violations but it has to take into account also other factors, such as its own prestige/ popularity/reputational factors related to prosecutors' concerns (as in Glaeser *et al.*, 2000; Rasmussen *et al.*, 2009; Posner, 1993, etc.).

Each of the two game theory models is subdivided into two sub-games. The first sub-game we consider has the following structure, which is identical for the two models. The firm can decide between complying with environmental regulations and not complying, by assessing the costs and benefits of compliance *versus* pollution. The EPA, not knowing the strategy chosen by the firm, must decide whether to carry out inspections or not. If the firm complies, it has to sustain a cost. This cost is not incurred if the firm decides not to comply. The EPA also has to incur a cost if it decides to carry out an inspection. If EPA carries out an inspection and the firm is not complying, EPA can levy a fine on the firm. However, if the EPA does not carry out an inspection and the firm does not comply, the EPA will internalize the cost of the environmental damage.

In the second game, the DOJ is introduced in the model (the structure of this game within the two models will be explained in more details in the next sections). Now, the EPA could serve a notice of violation to the firm and the latter will be referred to DOJ which exercises its discretion by deciding whether to initiate a civil or a criminal proceeding.

Therefore, EPA's exercise of discretion comes into play in two instances: first with regard to the decision of whether to investigate or not on the violation, and then, in the case it does decide to investigate, regarding whether to initiate an administrative, civil or criminal enforcement action. Moreover, if EPA decides to pursue a case civilly, it has two options: it may handle the matter internally or seek fines in a federal court.[16] If the EPA decides to deal with the case administratively, then it issues a Notice of Violation (NOV) ordering compliance and/or assigning a penalty to the violation. A notice of violation describes the violation and commands the violator to stop the activity.[17] At this point, the firm must again decide whether to be compliant or non-compliant. If it does not comply and if the case cannot be resolved at the administrative level, then the EPA will refer it to the Department of Justice for civil or criminal prosecution. At this stage, the DOJ can exercise its discretion on whether to initiate a civil or a criminal proceeding. Solving the game by backward induction allows us to see how the enforcement strategy chosen by the DOJ will affect the game between the environmental agency and the firm.

A similar structure of analysis is conducted in the second game theory model (section 2.5) in which EPA's and DOJ's objective functions are different. Both games show that, since there are no pure strategies Nash equilibria, the

[16] As noted by Firestone (2003), administrative and civil judicial enforcement share many elements. The primary distinguishing characteristic is that with administrative enforcement, EPA typically functions as both the enforcer and the adjudicator. A judge or EPA, as appropriate, may impose a civil sanction in an environmental matter whenever a person has violated or is violating a law or a permit condition [see, e.g., 42 U.S.C. § 7413(a)(3) (2000)].

[17] The purpose of a NOV is to initiate corrective action that will stop the violation. To provide an incentive for continuing compliance, NOVs for the Clean Water Act may result in monetary penalties up to $27.500 per day, per violation, according to 33 U.S.C. §1319.

environmental authorities have to resort to randomized strategies consistent with a mixed-strategy Nash equilibrium.

2.4 MODEL I: THE BASELINE MODEL

2.4.1 STRATEGIC INTERACTIONS BETWEEN THE FIRM AND THE EPA

The interactions between the firm and the EPA are modelled as a coordination game. The game tree corresponding to the extensive form of the game is illustrated in Figure 2.1, and the payoff matrix associated with the normal form of the game is given in Table 2.1. All figures and tables are presented at the end of the chapter. The firm decides whether to comply with the environmental regulations or not. The environmental agency must then decide whether to carry out an inspection or not, without knowing the action of the firm. We denote by v the value to the firm if it does not comply, by c the cost of compliance to the firm, by e the environmental damage that is generated if the firm does not comply and that would be internalised by EPA, by i the cost of inspection, and finally by f the fine that would be levied by EPA on the firm if the latter is found to be non-compliant.

For simplicity, all players are assumed to be risk neutral. All the above parameters are strictly positive. We assume that the following additional restrictions on parameter values must hold:

(1) $$i < e$$

(2) $$c < f \leq \bar{f}$$

Condition (1) states that the environmental damage must be larger than the cost of inspection and is required to rule out the trivial result that never to inspect is a dominant strategy for EPA. Allowing for a corner solution in which the EPA never inspects (when i > e) does not add substantive insight to the analysis. The first part of condition (2) requires that the value of the fine levied by the EPA must be greater than the cost of compliance, and is required to rule out the trivial result that never to comply is a dominant strategy for the firm. Again, to keep the analysis straightforward, it is convenient to rule out the possibility that $c > f$ because in this case the costs of compliance would be higher than the fine, and the firm would never comply no matter how great the firm's value is. The upper bound on the fine, $\bar{f}$, rules out the possibility that EPA may set its fine at an infinite value.[18]

Figure 2.1 illustrates the strategic form of the game by showing the moves that the firm and EPA can make. It is immediate to verify that, if the firm knows that the EPA will carry out an inspection, it will be better off by complying, since its expected pay-off is v-c if it complies and v-f if it does not comply, with $v-f < v-c$ by assumption (2). On the other hand, if EPA decided not to carry out the inspection, the firm will be better off by not complying, since its expected pay-off is v-c if it complies and v if it does not comply, with $v > v-c$.

Conversely, if the firm complies then the EPA would be better off by not carrying out the inspection. By contrast, if the firm does not comply, it would be preferable for the EPA to inspect.

Hence, the game has no Nash Equilibrium in pure strategies. There does exist, however, a mixed strategy Nash Equilibrium where the firm and the EPA randomize their choice of action (Ordershook, 1986). In a mixed-strategy Nash equilibrium, a player is indifferent between all of the available pure strategies with positive probabilities, but he randomizes so as to hide his intentions from the other players.[19] In 1973, Harsanyi presented the so-called "purification" interpretation of mixed strategy Nash equilibrium: the idea is that players play pure strategies, but by introducing some kind of heterogeneity (generated, for example, by incomplete information or random matching), a player is no longer sure that his opponent is choosing the same action, but has a diffuse belief over his opponent's moves. In Harsanyi's interpretation, a mixed strategy represents uncertainty for a player on

[18] Some of the justifications for assuming an upper bound for the feasible fine are: i) financial constraints on the side of the firm lead to reasonable fines in order to avoid bankruptcy; ii) the "punishment fits the crime" principle (Michael, 1992) requires that the severity of penalty for a wrongdoing should be reasonable and proportionate to the severity of the infraction and is another reason for assuming a restriction on the feasible fine.

[19] This is a standard property of mixed-strategy Nash equilibrium, since the objective function is linear in the probability.

how the other players will choose their strategies, rather than deliberate randomization (Morris, 2008).

According to the purification theorem of Harsanyi, thus, it could be that the firm and the EPA randomize their behaviours in the following way. Let us denote by p be the probability of compliance by the firm and by q be the probability of inspection by the EPA. The expected payoff to EPA if it carries out an inspection is given by:

(3) $$E(\pi_{EPA}^{I}) = p(-i) + (1-p)(-i-e+f) = -i-e+f+ep-fp$$

The expected payoff to EPA if it does not carry out an inspection is:

(4) $$E(\pi_{EPA}^{NI}) = p(0) + (1-p)(-e) = ep-e$$

The firm will choose the probability of compliance, p, in such a way that the EPA must be indifferent between inspecting or not. This requires that $E(\pi_{EPA}^{I}) = E(\pi_{EPA}^{NI})$. Solving for p yields:

(5) $$p = 1 - \frac{i}{f}$$

Note that p is a well defined probability ($0 < p < 1$) since $0 < i < e$ by condition (1). Hence, $i < f$ for $p > 0$ and $i > f$ for $p = 0$.

The expected payoffs to the firm under compliance and non-compliance are respectively:

(6) $$E(\pi_{F}^{C}) = q(v-c) + (1-q)(v-c) = v-c$$

(7) $$E(\pi_{F}^{NC}) = q(v-f) + (1-q)v = v-qf$$

The EPA will choose the probability of inspection q in such a way that the firm is indifferent between complying or not: $E(\pi_{F}^{C}) = E(\pi_{F}^{NC})$. Solving for q

yields:

(8) $$q = \frac{c}{f}$$

Note that $q < 1$ since $c < f$ by condition (2). The above results can be summarised by the following proposition.

Proposition 1. *The game played by the firm and EPA has no pure strategy Nash Equilibrium. The mixed strategy Nash Equilibrium is characterised by the following randomized strategies:*

(a) The firm complies with probability $p = 1 - i / f$ *;*

(b) The EPA carries out an inspection with probability $q = c / f$ *.*

The probability of compliance by the firm is a decreasing function of the cost of inspection and an increasing function of the fine. An increasing penalty would have a deterrent effect and the firm would have a greater incentive to comply. On the other hand, if the cost of inspection increases, the probability of compliance decreases: given that inspections may induce firms to improve their environmental performance, if they perceive that inspection and monitoring costs are high for the environmental authority, they will tend to decrease their level of care thus reducing the level of compliance.

The probability of inspection by EPA is an increasing function of the cost of compliance by the firm. This implies that when compliance costs are higher and the firm would have greater incentive to violate, the probability of firm's inspection by EPA must accordingly increase. On the other hand, the probability of inspection is a decreasing function of the fine. This implies a trade-off between the fine and the probability of inspection: the greater the fine, the lower the probability of inspection. In other words, a greater fine, which would increase the costs of violating for the firm, is compensated by a lower probability of inspection. This confirms the classic results by Becker (1968) and by Polinsky and Shavell (2000) that, in any optimal enforcement scheme, it always makes sense to substitute a higher fine for a lower probability of detection and vice versa. Hence, if the EPA wishes to minimize its enforcement cost, it will set the fine at the largest possible level: $f = \bar{f}$, which would imply that the probability of inspection becomes $q = c / \bar{f}$.

Proposition 1 also provides a possible solution to Harrington's paradox. In equilibrium, the probability of compliance by the firm, p, can be high even if the probability of inspection by the environmental agency, q, is low.

2.4.2 THE STRATEGIC GAME BETWEEN THE FIRM, THE EPA AND THE DOJ

In this second version of the interaction between the firm and EPA we introduce a role for the DOJ by letting EPA serve a notice of violation if the firm is found to be non-compliant. The firm is then referred to the DOJ and has the opportunity to put right its wrongful action. The DOJ may proceed against a violator with either a civil suit or a criminal charge.[20] It retains exclusive authority to prosecute criminally[21] and has the authority to initiate all criminal cases referred by the EPA.[22,23]

The DOJ can exercise discretion on whether to initiate civil or criminal

[20] The DOJ's charging decision is subject to administrative guidance. Prosecution should proceed only if there is probable cause to believe such a crime has been committed and the evidence is likely to sustain a conviction (2000 United States Attorneys' Manual, at § 9-27.200). In the decision to proceed the following seven factors are considered: 1) federal law enforcement priorities; 2) the nature and the seriousness of the offense; 3) the deterrent effect of prosecution; 4) the offender's culpability; 5) the offender's criminal history; 6) the offender's willingness to cooperate; and 7) the offender's probable sentence or other consequences of conviction (United States Attorneys' Manual 2000, at § 9-27.200). More specifically, with regard to the decision to prosecute environmental crimes, DOJ guidelines consider the following four factors: 1) voluntary disclosure of a violation or other cooperation with the authorities; 2) the entity's level of noncompliance; 3) the existence of preventative measures and compliance programs; and 4) whether the entity pursues its own internal disciplinary actions and produces subsequent compliance.

[21] See generally, U.S. Dept. of Justice in cooperation with the National Association of Attorneys, General Guidelines for Joint State/Federal Civil Environmental Enforcement Litigation (2003), available at http://www.naag.org/issues/pdf/env-joint_enf_guidelines-full.pdf

[22] In the memorandum entitled "Factors in Decisions on Criminal Prosecutions for Environmental Violations in the Context of Significant Voluntary Compliance or Disclosure Efforts by the Violator" (1991) are described the factors that the DOJ in order not to create a disincentive to or undermine the goal of encouraging critical self-auditing, self-policing, and voluntary disclosure.

[23] The U.S. DOJ considers all of the following factors in deciding whether to exercise prosecutorial discretion: voluntary, timely, and complete disclosure of the matter under investigation; the degree and timeliness of cooperation; existence and scope of any regularized, intensive, and comprehensive environmental compliance program; pervasiveness of non-compliance; effective internal disciplinary action; and efforts to remedy any ongoing non-compliance promptly and completely.

proceedings. It is assumed that a criminal prosecution is more expensive than a civil prosecution, but also that jail can be a more effective deterrent than a pecuniary sanction that takes the form of a fine. A jail term would be more costly to administer than a fine, but the DOJ would suffer a penalty – that could be rationalised as a reputation cost - if an offending firm is punished with a fine rather than with a jail term.

The structure of the game is illustrated in Figure 2.2. The additional notation relative to the game of section 2.4.1 is as follows. We denote by c_1 the additional compliance cost if the firm did not comply in the first instance, by f the fine from civil prosecution, by j the cost to the firm from criminal prosecution, by k_c the cost to DOJ of enforcing civil prosecution, by k_j the cost to DOJ of enforcing criminal prosecution, and finally by r the reputation cost to DOJ of letting off an offending firm with a fine.

The previous parameters are all positive. In addition, we assume that the following plausible restrictions hold:

(9) $$f < c_1 < j \leq \bar{j}$$

(10) $$k_c < k_j$$

(11) $$k_j - k_c < r$$

Condition (9) requires that the additional compliance cost must exceed the fine from civil prosecution, but must be less that the cost to the firm if a criminal sentence is imposed. Even though the first part of condition (9) might seem peculiar, Harrington (1988) has already found out that a firm could have an incentive to comply with regulations even though the cost of compliance exceeds the expected penalty for violation. The logic behind these additional costs is the following. If the firm that has been ordered to return to compliance does not comply with that order in the first instance (c), its delay to return to compliance implies higher costs (c_1) to due to higher clean up costs.

Condition (9) might seem to contradict one of the main optimal enforcement theoretical prescriptions (Becker, 1968) which requires that the fine should be set at its maximum level, but we do not analyze the determination and the magnitude of the optimal fine by the regulator and we do not look at the impacts that a low fine or a high fine might have on the degree of compliance by the firm. We focus, instead, on the interactions between EPA, DOJ and the firm and characterize the conditions under which enforcement and compliance decisions take place. Similarly to condition (2) for civil prosecution, there is an upper bound $\bar{j}$ to the largest criminal sentence that can be imposed. Condition (10) says that the cost to DOJ of enforcing criminal prosecution must be greater than the cost of enforcing civil prosecution. Finally, condition (11) requires that the reputation cost to the DOJ of letting off an offending firm with a fine is larger than the difference between the cost of enforcing criminal prosecution and the cost of administering a fine.

The model can be solved by backward induction in two steps. In the first step, we solve the sub-game between the firm and DOJ. In the second step, we replace the outcome of this sub-game into the sub-game played between the firm and EPA to find their optimal strategies.

2.4.3 THE SUB-GAME BETWEEN THE FIRM AND THE DOJ

Let us consider first the sub-game between the firm and the DOJ. The payoff matrix for this game is shown in Table 2.2. It is possible to verify that this sub-game has no pure strategy Nash Equilibrium. For instance, if the DOJ were to resort to civil prosecution, the firm would find it profitable not to comply. However, if the firm does not comply, the DOJ would be better off by enforcing a criminal rather than a civil prosecution.

The sub-game between the firm and the DOJ does, however, admits a mixed strategy Nash Equilibrium. In this equilibrium, the probabilities of compliance by the firm and of enforcing a civil prosecution by DOJ are obtained by requiring that the other player is indifferent between its actions.

The outcome of the sub-game is then replaced into the game played between the firm and EPA in order to compute the mixed strategy Nash Equilibrium of this game.

The expected payoff to DOJ if it enforces a civil prosecution is:

$$(12)\qquad E(\pi_{DOJ}^{CI}) = p_1(-k_c) + (1-p_1)(-e-k_c-r) = -(k_c+r+e) + p_1 r + p_1 e$$

The expected payoff to DOJ if it carries out a criminal prosecution is:

$$(13)\qquad E(\pi_{DOJ}^{CR}) = p_1(-k_j) + (1-p_1)(-e-k_j) = -k_j + p_1 e - e$$

The firm will choose the probability of compliance, p_1, in such a way that the DOJ is indifferent between a civil and a criminal prosecution: $E(\pi_{DOJ}^{CI}) = E(\pi_{DOJ}^{CR})$. Solving for p_1 yields:

$$(14)\qquad p_1 = 1 - \frac{k_j - k_c}{r}$$

Note that $0 < p_1 < 1$ since $k_j < r + k_c$ by assumption (11).

The expected payoffs to the firm if it complies or does not comply are respectively:

$$(15)\qquad E(\pi_F^{2,C}) = q_1(v-c-c_1) + (1-q_1)(v-c-c_1) = v-c-c_1$$

$$(16)\qquad E(\pi_F^{2,NC}) = q_1(v-f) + (1-q_1)(v-j) = v-j+q_1(j-f)$$

The DOJ will choose the probability of civil prosecution q_1 in such a way that the firm is indifferent between complying or not: $E(\pi_F^{2,C}) = E(\pi_F^{2,NC})$. Solving for q_1 yields:

$$(17)\qquad q_1 = \frac{j-c-c_1}{j-f}$$

where $0 < q_1 < 1$ since $c + c_1 > f$ by assumption (9).

The above results can be summarised by the following proposition.

Proposition 2. *The sub-game played by the firm and DOJ has no pure strategy Nash Equilibrium. The mixed strategy Nash Equilibrium is characterised by the following randomized strategies:*

(a) *The firm complies with probability* $p_1 = 1 - (k_j - k_c) / r$.

(b) *The DOJ carries out a civil prosecution with probability* $q_1 = (j - c - c_1)/(j - f)$.

The probability of compliance by the firm is a decreasing function of the cost of criminal prosecution and an increasing function of the cost of civil prosecution and of the reputation cost to DOJ. This implies that when the cost of civil prosecution and the reputation costs are higher and DOJ would have greater incentive to avoid these costs, the probability of compliance by the firm must accordingly increase. On the other hand, it is a decreasing function of the cost of criminal prosecution: the greater this costs, the lower the probability of compliance. The probability of civil prosecution by DOJ is an increasing function of the fine and of the criminal sanction and a decreasing function of the cost of compliance by the firm. The DOJ can minimise the probability of enforcing a costly criminal prosecution ($1 - q_1$) by committing itself to imposing the maximum sentence $\bar{j}$, which would imply that the probability of a civil prosecution becomes $q_1 = (\bar{j} - c - c_1)/(\bar{j} - f)$.

Note that, in equilibrium, the expected payoff to the firm from the second-stage sub-game is:

(18) $$E(\pi_F^2) = v - c - c_1$$

and the expected payoff to DOJ is:

(19) $$E(\pi_{DOJ}) = -k_j - (k_j - kc)\frac{e}{r}$$

2.4.4 THE GAME BETWEEN THE FIRM AND EPA

The payoff matrix for this game is shown in Table 2.3. Also in this case, the game has no pure strategy Nash equilibria. The game however does have a unique mixed strategy Nash Equilibrium.

The expected payoff to EPA if it carries out an inspection is:

(20) $$E(\pi^{I}_{EPA}) = p(-i) + (1-p)(-i-e+f) = -i-e+f+ep-fp$$

The expected payoff if it does not carry out an inspection is instead:

(21) $$E(\pi^{NI}_{EPA}) = p(0) + (1-p)(-e) = ep - e$$

The firm will choose the probability of compliance, p, in such a way that the EPA is indifferent between inspecting or not: $E(\pi^{I}_{EPA}) = E(\pi^{NI}_{EPA})$. Solving for p gives:

(22) $$p = 1 - \frac{i}{f}$$

Note that $0 < p < 1$ since $0 < i < e$ by assumption (1).

The expected payoffs to the firm if it complies and if it does not comply are respectively:

(23) $$E(\pi^{1,C}_{F}) = q(v-c) + (1-q)(v-c) = v - c$$

(24) $$E(\pi^{1,NC}_{F}) = q(v-c-c_1) + (1-q)v = v - q(c+c_1)$$

The EPA will choose its probability of inspection q in such a way that the firm is indifferent between complying or not: $E(\pi_F^{1,C}) = E(\pi_F^{1,NC})$. Solving for q yields:

(25) $$q = \frac{c}{c + c_1}$$

Note that $0 < q < 1$ since $c > 0$, $c_1 > 0$. The above results can be summarised by the following proposition.

Proposition 3. *The game played by the firm and EPA has a no pure strategy Nash Equilibrium. The mixed strategy Nash Equilibrium is characterised by the following randomized strategies:*

(a) The firm complies with probability $p = 1 - i/f$.

(b) The EPA carries out an inspection with probability $q = c/(c + c_1)$.

The probability of compliance by the firm in the first stage of the game is a decreasing function of the cost of inspection and an increasing function of the fine. The probability of inspection by EPA is an increasing function of the cost of compliance by the firm in the first stage of the game and a decreasing function of the cost of compliance in the second stage of the game.

There are some interesting aspects of these results that need to be emphasized. The probability that the firm complies under proposition 3 is the same probability we find under proposition 1, that is $p = 1 - i/f$. This implies that, in equilibrium, the threat posed by the application of criminal sanctions does not affect the probability of compliance by the firm. This is important, of course, because indicates that compliance can occur even without the need of recurring to criminal enforcement. Financial and/or interdictive sanctions, such as the revocation of the license or the suspension of the firm's activity, can also be harsh deterrent measures.[24]

The probability of inspection by the EPA under proposition 3 is

[24] Penalties for non-compliance may take various forms, including legal costs, fines, loss of reputation, etc. See, among others, Dewees (1990), Hamilton (1995), Lanoie and Laplante (1994).

$q = c/(c + c_1)$, while under proposition 1 it is $q = c/f$. With an unvarying probability of compliance by the firm, the probability of inspection decreases compared to the one obtained in the first stage of the game in which the intervention of the DOJ was not considered. This implies that it would seem more efficient to let the EPA resolve the cases internally (administratively) rather than refer them to the Department of Justice for civil or criminal prosecution. Combining these findings with the fact that the firm's probability of compliance is not affected by the presence of the DOJ, leads us to state that, within the framework of our model, the intervention of the DOJ acts merely as an additional enforcement cost, which in turn, reduces the probability of conducting inspections by the EPA without affecting the probability of firm's compliance. Hence, we shall maintain that, under the assumptions of our model, the criminal enforcement reduces the effectiveness of enforcement policies.

2.5 MODEL II: AN EXTENDED MODEL WITH HETEROGENEOUS OBJECTIVE FUNCTIONS

2.5.1 EPA'S AND DOJ'S DIFFERENT OBJECTIVE FUNCTIONS

In this and the following sections we still consider a strategic model between EPA and DOJ, but now we assume that they may be characterized by different goals, with possibly conflicting objective functions.[25]

The first author to hypothesize some sort of divergence between EPA and DOJ has been probably Niskanen (1975) for whom, instead of being driven by a desire to maximize general deterrence, EPA or DOJ may be driven by self-interest. In particular, EPA may choose to maximize the number of enforcement cases. Yeager (1991) with regard to the enforcement of the U.S. Clean Water Act underlines a problem of regulatory competition between EPA and DOJ: "*The*

[25] Blondiau and Rousseau (2010) discuss three objective functions for the enforcing authority: 1) social welfare maximization: it implies that the regulator balances compliance costs with environmental damages; 2) deterrence maximization: it implies that the costs associated with violating the rules should always be larger than the cost of compliance; 3) providing justice. The main objectives for a judge when penalizing violators are to protect society from harm, to show that society disapproves of certain acts and to foster recovery from the harm done; these elements are mainly related to reducing environmental harm and thus with maximizing deterrence and providing justice.

Agency refrains from referring some prosecutable cases because the EPA does not wish to share credit for the case with the Department."

In the literature there has been, in fact, a widespread support for introducing a certain degree of differentiation between the regulatory agency and the justice authority. Barker (2002) affirms that coordination between the two agencies can be exacerbated by varying goals, prosecutors giving more importance to conviction rates and being less tolerant of losing cases. Due to the fact that EPA may wish to have independence without coordination with the DOJ, or to the fact that EPA does not wish to share merit for the case with the Department, different motivations can be assumed as the basis for their respective enforcement decisions. This can also open up the problem of prosecutorial behaviour, which is extensively studied in the law and economics literature, especially with regard to career concerns underlying the importance of the incentives facing State and federal prosecutors. Posner (1993) was the first author to maintain that judges behave just like "ordinary people", in a rationality-based framework; since then, a significant body of theoretical research has been developed for understanding judicial behaviour at a trial.[26]

Prosecutors are assumed to be concerned not only with providing justice[27], but to be also sensitive to their own personal goals: factors such as the possibility of promotion to a higher position or political re-election can affect their decisions (i.e., what penalty to seek, which offenses to prosecute). Dimento (1993) notes that prosecutors may respond to incentive structures that favour pursuing cases other than the most important environmental violations.

Rasmussen *et al*. (2009) focus on the problem of prosecutorial discretion in terms of case selection, i.e., whether to allocate resources broadly over many cases or intensively to a few cases. Forced by limitations of time and resources, prosecutors drop some cases, prosecute others, and prosecute some more intensely

[26] Public choice has developed around the notion that political and bureaucrats behaviour can be explained, in part, as a result of individual utility maximization.

[27] Justice has been approached in many different ways such as procedural justice, retributive justice and restorative justice. Procedural justice incorporates a theory of procedural fairness for civil dispute resolution (see Solum, 2004). The concept of retributive justice is based on the principle "*Let the punishment fit the crime*" such that the severity of the penalty for a violation should be reasonable and proportional to the severity of the infraction (see Zaibert, 2006). Restorative justice, on the other hand, is concerned with making the victim whole and reintegrating the offender into society (see Braithwaite, 2002).

than others. A prosecutor's high conviction rate may not be a sign that he is tough on crime; instead, he might just be taking on easy cases and letting too many criminals go without prosecuting them.

Glaeser *et. al.* (2000) in their model of prosecutors' behaviour find that they tend to select which cases to pursue. Even though they generally aim to reduce crime, different incentives can create a desire among them on one hand to pursue the most dangerous criminals ("crime reduction" incentive) and, on the other hand, to pursue violators who will bring them private returns ("private career" concerns).

So, in formulating the expected payoff of DOJ in this second model, it seemed reasonable to assume that its objective may not be merely to minimize environmental damages but that it might be concerned both with stopping environmental violations and with the success/reputation of prosecutors, who are the most significant representative component of DOJ. Therefore, the firm's objective function is to maximize profits at minimum compliance costs, the EPA's objective function consists of minimizing environmental violations at minimum inspection costs. We assume that the DOJ's objective function is to minimize environmental violations taking into account not only social costs of civil and criminal sanctions (as in Blondiau and Rousseau, 2010) but also prestige/ popularity/ voting/ reputational factors related to prosecutors' concerns (Glaeser *et al.*, 2000; Rasmussen *et al.*, 2009; Posner, 1993, etc.).

2.5.2 THE STRATEGIC GAME BETWEEN FIRM, EPA AND DOJ

The structure of this game is substantially the same as discussed in sections 2.4, except for the fact that a variation is introduced before the EPA's decision of referring the case to the DOJ, as illustrated in Figure 2.3. Now the EPA, if after inspections it finds out that a firm is not compliant with some regulatory prescriptions, orders the violator to stop the activity (with a notice of violation). If the firm complies (spontaneously or through informal negotiations) then the case ends (on the game tree, the firm chooses to move on the left). If the case cannot be resolved in the administrative process, then the EPA will refer it to the Department of Justice for civil or criminal prosecution (the firm chooses the strategy on the right).

The additional notation relative to the model of section 2.4 is as follows. We denote by c_1 the abatement and clean-up costs to the compliant firm, by c_2 abatement and cleanup costs to the non-compliant firm, by f_1 the fine from EPA if the firm is compliant after being served with a notice of violation, by f_2 the fine from civil prosecution when the firm chooses to remain non-compliant, by j the cost to the firm from criminal prosecution, by k_c the cost to DOJ of enforcing civil prosecution, by k_j the cost to DOJ of enforcing criminal prosecution, and finally by r the reputation cost to DOJ of letting off an offending firm with a fine.

The previous parameters are all positive. In addition, we assume that the following plausible parameter restrictions must hold:

(26a) $$f_2 + c_2 < c + c_1$$

(26b) $$c + c_1 < c_2 + j \leq c_2 + \bar{j}$$

(26c) $$c_1 < c_2$$

(26d) $$k_c < k_j$$

(26e) $$k_j - k_c < r$$

(26f) $$f_2 < r$$

(26g) $$f_2 + k_j < r + k_c$$

(26h) $$f_2 < j$$

(26i) $$i < c_1\left(\frac{k_j - k_c}{r - f_2}\right) + c_2\left(\frac{k_j - k_c}{r - f_2}\right)$$

Conditions (26a)-(26i) rule out the possibility of trivial solutions to the strategic game between firm, EPA and DOJ. For instance, (26a) rules out compliance as a dominant strategy for the firm in the sub-game with the DOJ. If (26a) does not hold, the firm would always trivially find it optimal to comply irrespective of whether the DOJ implements a civil or a criminal prosecution. Similarly, (26b) rules out that non-compliance is always a dominant strategy for the firm, irrespective of the DOJ's prosecutorial decision. Similarly to condition

(2) for civil prosecution, there is an upper bound $\bar{j}$ to the largest criminal sentence that can be imposed.

As before, the model can be solved by backward induction in two steps. In the first step, the sub-game between the firm and DOJ is solved; in the second step, the outcome of this sub-game is replaced into the game played between the firm and EPA to find their optimal strategies.

2.5.3 THE SUB-GAME BETWEEN THE FIRM AND DOJ

Following the same methodology as before, let us consider first the sub-game between the firm and the DOJ. The payoff matrix for this game is shown in Table 2.4. It is possible to verify that this sub-game has no pure strategy Nash Equilibrium. For instance, if the DOJ were to resort to civil prosecution, the firm would find it profitable not to comply, since $v - f_2 - c_2 > v - c - c_1$ by condition (26a) above. However, if the firm does not comply, the DOJ would be better off by enforcing a criminal rather than a civil prosecution since $-e + c_2 - k_j > -e + c_2 + f_2 - r - k_c$ by (26g).

The sub-game between the firm and the DOJ does, however, have a mixed strategy Nash Equilibrium. In this equilibrium, the probabilities of compliance by the firm and of enforcing a civil prosecution by DOJ are obtained by requiring that the other player is indifferent between its actions.

The outcome of the sub-game is then replaced into the game played between the firm and EPA in order to compute the mixed strategy Nash Equilibrium of this game.

The expected payoff to DOJ if it enforces a civil prosecution is:

$$(27) \qquad E(\pi_{DOJ}^{CI}) = p_2(-e + c_1 - k_c) + (1 - p_2)(-e + c_2 + f_2 - k_c - r)$$
$$= -p_2c_1 - p_2c_2 - p_2f_2 + p_2r + c_2 + f_2 - k_c - r - e)$$

The expected payoff to DOJ if it carries out a criminal prosecution is:

$$(28) \qquad E(\pi_{DOJ}^{CR}) = p_2(-e + c_1 - k_j) + (1 - p_2)(-e + c_2 - k_j) = p_2c_1 - p_2c_2 + c_2 - e - k_j$$

The firm will choose the probability of compliance, p_2, in such a way that the DOJ is indifferent between a civil and a criminal prosecution: $E(\pi_{DOJ}^{CI}) = E(\pi_{DOJ}^{CR})$. Solving for p_2 yields:

$$(29) \qquad p_2 = 1 - \frac{k_j - k_c}{r - f_2}$$

Note that $p_2 < 1$ since it is assumed that $k_j > k_c$ and $r > f_2$.

The expected payoffs to the firm if it complies or does not comply are respectively:

$$(30) \qquad E(\pi_F^{2,C}) = q_2(v - c - c_1) + (1 - q_2)(v - c - c_1) = v - c - c_1$$

$$(31) \qquad E(\pi_F^{2,NC}) = q_2(v - f_2 - c_2) + (1 - q_2)(v - c_2 - j) = v - c_2 - j + q_2(j - f_2)$$

The DOJ will choose the probability of civil prosecution q_2 in such a way that the firm is indifferent between complying or not: $E(\pi_F^{2,C}) = E(\pi_F^{2,NC})$. Solving for q_2 yields:

$$(32) \qquad q_2 = \frac{j - c - c_1 + c_2}{j - f_2}$$

where $0 < q_2 < 1$ since by assumption (9a) $c + c_1 - c_2 > f_2$.

The above results can be summarised by the following proposition.

Proposition 4. *The sub-game played by the firm and DOJ has no pure strategy Nash Equilibrium. There is a mixed strategy Nash Equilibrium which is characterised by the following randomized strategies:*

(a) The firm complies with probability $p_2 = 1-[(k_j-k_c)/r-f_2]$

(b) The DOJ carries out a civil prosecution with probability

$$q_2 = (j - c - c_1 + c_2)/(j - f_2).$$

The probability of compliance by the firm is a decreasing function of the cost of criminal prosecution and of the fine f_2, and is an increasing function of the cost of civil prosecution k_c and of the reputation cost r to DOJ. The probability of civil prosecution by DOJ is an increasing function of the fine f_2, of the criminal sanction j and of the cleanup costs by the firm c_2, and is a decreasing function of the cost of compliance c and of the abatement pollution costs by the firm c_1. Also here, we can assume that the DOJ can minimise the probability of enforcing a costly criminal prosecution $(1-q_2)$ by committing itself to imposing the maximum sentence $\bar{j}$, which would imply that the probability of a civil prosecution becomes $q_2 = (\bar{j} - c - c_1 + c_2)/(\bar{j} - f_2)$.

Note that, in equilibrium, the expected payoff to the firm from this sub-game is:

(33) $$E(\pi_F^2) = v - c - c_1$$

and the expected payoff to DOJ is:

(34) $$E(\pi_{DOJ}) = c_1 - c_1\left(\frac{k_j - k_c}{r - f_2}\right) + c_2\left(\frac{k_j - k_c}{r - f_2}\right) - k_j - e$$

2.5.4 THE GAME BETWEEN THE FIRM AND EPA

The payoff matrix for this sub-game is shown in Table 2.5. Note here that, in equilibrium a firm will never comply when the EPA serves a notice of violation/refers the case to DOJ because for the firm the non-compliance strategy dominates, since $v - c - c_1 < v - c$.

The expected payoff to EPA if it serves a notice of violation and if DOJ implements civil prosecution is:

(35) $$E(\pi_{EPA}^1) = p_2(-i - e + c_1) + (1 - p_2)(-i - e + c_2)$$

$$= -i - e + p_2 c_1 + (1 - p_2) c_2$$

where $p_2 = 1 - \frac{k_j - k_c}{r - f_2}$, whence:

(36) $$E(\pi_{EPA}^2) = -i - e + \left(1 - \frac{k_j - k_c}{r - f_2}\right) c_1 + \left(\frac{k_j - k_c}{r - f_2}\right) c_2$$

The expected payoff to EPA if it serves a notice of violation and DOJ prosecutes criminally is:

(37) $$E(\pi_{EPA}^2) = p_2(0) + (1 - p_2)(-e) = ep_2 - e = (-e)(1 - p_2)$$

Since we are solving the game by backward induction, we can replace these expected payoffs at the node that initiates the first game between the firm and EPA. The payoff matrix for this game is shown in Table 2.6. Now, the expected payoff to EPA if it carries out an inspection is:

(38) $$E(\pi_{EPA}^I) = p_1(-i) + (1 - p_1)\left[-i - e + \left(1 - \frac{k_j - k_c}{r - f_2}\right) c_1 + \left(\frac{k_j - k_c}{r - f_2}\right) c_2\right]$$

and the expected payoff if it does not carry out an inspection is:

(39) $$E(\pi_{EPA}^{NI}) = p_1(0) + (1 - p_1)(-e) = ep_1 - e = (-e)(1 - p_1)$$

The firm will choose the probability of compliance, p_1, in such a way that EPA is indifferent between inspecting or not: $E(\pi_{EPA}^I) = E(\pi_{EPA}^{NI})$. Solving for p_1,

(40) $$p_1 = \frac{-i + \left(1 - \frac{k_j - k_c}{r - .f_2}\right) c_1 + \left(\frac{k_j - k_c}{r - f_2}\right) c_2}{\left(1 - \frac{k_j - k_c}{r - f_2}\right) c_1 + \left(\frac{k_j - k_c}{r - f_2}\right) c_2}$$

We can rewrite (40) as follows:

(41) $$p_1 = 1 - \frac{i}{\left(1 - \frac{k_j - k_c}{r - f_2}\right)c_1 + \left(\frac{k_j - k_c}{r - f_2}\right)c_2}$$

Note that $0 < p_1 < 1$ because of condition (26i).

The expected payoffs to the firm if it complies and if it does not comply are respectively:

(42) $$E(\pi_F^{1,C}) = q_1(v - c) + (1 - q_1)(v - c) = v - c$$

(43) $$E(\pi_F^{1,NC}) = q_1(v - c - c_1) + (1 - q_1)v = v - q_1(c + c_1)$$

The EPA will choose its probability of inspection q_1 so that the firm is indifferent between complying or not: $E(\pi_F^{1,C}) = E(\pi_F^{1,NC})$. Solving for q_1 yields:

(44) $$q_1 = \frac{c}{c + c_1}$$

Note that $0 < q < 1$ since $c > 0$ and $c_1 > 0$.

In equilibrium, then, the expected payoff to the EPA is:

(45) $$E(\pi_{EPA}) = -\frac{ei}{c_1 + \left(\frac{k_j - k_c}{r - f_2}\right)(c_2 - c_1)}$$

The above results can be summarised by the following proposition.

Proposition 5. *The game played by the firm and EPA has no dominant strategy Nash Equilibrium. However, there exists a mixed strategy Nash Equilibrium which is characterized by the following randomized strategies:*

(a) The firm complies with probability

$$p_1 = 1 - \frac{i}{\left(1 - \frac{k_j - k_c}{r - f_2}\right)c_1 + \left(\frac{k_j - k_c}{r - f_2}\right)c_2}$$

(b) The EPA carries out an inspection with probability $q_1 = c/(c + c_1)$

The probability of compliance by the firm is a decreasing function of the cost of inspection, of the reputational costs and of the cost of civil prosecution and is an increasing function of the fine, of the cost of criminal prosecution, and of the cleanup costs if compliant (c_1) and of the cleanup costs when it is not compliant (c_2) and is forced to clean up by DOJ.

In equilibrium, the expected payoff of EPA is a decreasing function of both inspection costs and environmental damages, and is an increasing function of the cleanup cost if compliant (c_1), the cleanup cost when non compliant (c_2) and the incentive that the DOJ might have to prosecute civilly $(k_j - k_c)/(r - f_2)$.

There are some interesting aspects of these results that need to be emphasized. Comparing the EPA's payoffs in the potential different strategies prefigured in the game between the firm, EPA and DOJ, we can observe that the EPA's payoffs, independently of the strategy chosen by DOJ, is $(-i - e + c_1)$ if the firm is compliant, and $(-i - e + c_2)$ if the firm is not compliant.

If $c_1 = c_2$, the EPA is indifferent to the strategy chosen by the firm, but if $c_2 > c_1$, the EPA will be better-off if the firm decides to be non-compliant since the cleanup costs in this case are higher. This implies that, in equilibrium, the EPA will be better-off in expected value of its payoff if the firm decides not to comply. Note also that, if $c_2 > c_1$, the probability of compliance by the firm increases if the incentive the DOJ might have to prosecute civilly $(k_j - k_c)/(r - f_2)$ increases. If $c_2 > c_1$, the incentive for DOJ to prosecute civilly $(k_j - k_c)/(r - f_2)$ increases as the cost of criminal prosecution and the fine increase, and as the cost of civil prosecution and reputational costs decrease. So, if DOJ has a greater incentive to prosecute civilly (because it is less resource intensive), the firm is more likely not to comply, generating higher cleanup costs and making the EPA better-off for this.

Since the EPA would have greater incentive to inspect, the firm will try to offset this motivation by increasing its probability of compliance.

Therefore, all these considerations imply that in equilibrium: a) the DOJ, when the cost of criminal prosecution increases, is more likely to initiate a civil action; b) the EPA would have greater incentive to inspect; and 3) the firm will increase its probability of compliance.

In equilibrium, when the EPA is indifferent to the strategy chosen by the DOJ, the firm has a even greater probability of compliance, given that $v\text{-}c > v\text{-}c\text{-}c_1$.

So, while in the first type of theoretical framework (under the assumption that EPA and DOJ share the same objective function), the intervention of the DOJ does not affect the probability of firm's compliance and this, in turn, reduces the probability of conducting inspections by the EPA, within the second framework of our model the involvement of DOJ might improve the firm's probability of compliance, strengthening, as a result, the effectiveness of enforcement policies.

2.6 POSSIBLE EXTENSIONS OF THE MODELS

The interactions between the firm, the EPA and the DOJ were modelled as games in which the players simultaneously decide the strategy to choose and were developed in two different ways to make them fit the reality to which they are being applied. However, there are a number of potentially interesting extensions that could be explored in future research. Investigating the dynamic aspects of the compliance and enforcement problem might enrich the results of optimal policy derived from the static models developed here. In a context in which regulators (EPA), justice authority (DOJ) and firms interact repeatedly through time, the rules of the game may change since the "history" (which accumulates as time elapses) also changes. Moreover, we have restricted our analysis to a single firm. Setting up repeated games with several firms to assess the aggregate behaviour of polluting firms is another possible subject for future research.

For instance, Harrington (1988), Harford and Harrington (1991) and Harford (1991) have developed dynamic repeated games between the enforcement agency and the firm, where the agency's enforcement strategy depends on the firms' past compliance behaviour (i.e., it alters the expected penalty and the inspection frequency on the basis of the firms' past compliance performance). In Harrington (1988), firms are assigned to two groups depending on their compliance history. Ignoring firms that are never monitored, group 1 contains firms found to be in compliance at their last inspection (low-risk of violation group) and group 2 contain those firms found to be out of compliance (high-risk of violation group). Group 2 firms would be subject to a higher monitoring probability, to stricter regulatory standards, or to higher fines than firms in group 1. Harrington shows that firms' optimal strategy in this scheme depend upon their individual costs of compliance. Low cost firms are always in compliance, high cost firms are never in compliance and medium cost firms move in and out of compliance depending on the results of previous inspections. Harrington shows, also, that the compliance rate of firms in the second group is maximized by setting fines as high as possible for the second group but equal to zero (the lowest possible) for firms in the first group.

Two main approaches are employed in the literature on dynamic relationships [see, for instance, Franckx, (2001)]. The first approach considers the existence of reputation effects. It might be interesting to develop a model in which there is some kind of reputational issue on the side of the EPA, too. The EPA may decide to inspect firms in order to develop a reputation that it will inspect again in the future. The second approach employs infinitely repeated games. Given that, in reality, pollution has stochastic features, constructing repeated games with imperfect or asymmetric information between the firm and the EPA could be an appropriate way to extend the actual game theoretic framework. Most results in the theory of repeated games are based on the assumption that the actions of all players are revealed after each interaction (Fudenberg and Tirole, 1995, pp. 146-147). However, the action chosen by the firm, in any stage of the game, would be revealed to the EPA only if an inspection takes place. The EPA can make its play observing the history of the game only if it chooses to inspect the firm: if it does not inspect, the strategy chosen by the firm will never be revealed to the EPA. In a repeated game framework, a firm might have different compliance cost in every round of the game and the EPA may treat the firm differently given its prior records of non-compliance. This suggests that if the EPA and the firm meet more than once, equilibrium behaviour could be different from the equilibria in a non-repeated interaction.

For instance, in the first type of theoretical framework (under the assumption that EPA and DOJ share the same objective function), the EPA would be able to differentiate the firms who have committed a violation in the previous inspections and those who have not. Through this selective enforcement (using tolerance for some types of violations and being more severe for others), the EPA may improve the rate of compliance by the firms (Harrington, 1988; Heyes and Rickman, 1999) and the results obtained in the static models might remain the same. In fact, the use of selective enforcement can improve the effectiveness and the efficiency of the EPA's activities and one could expect that the intervention of the DOJ might still not affect the probability of firm's compliance, thereby strengthening the results already obtained.

In the second theoretical model (under the assumption that EPA's and DOJ's objective functions are different), however, once repeated interaction is taken into account and the EPA can differentiate its enforcement strategies among firms based upon their past performance, whether and how the probability to inspect by the EPA may vary (namely either increase, decrease or remain the same) is not a clear-cut intuition. It is plausible to think that, through the use of selective enforcement, the EPA may be able to inspect a greater number of outrageous non-compliant firms and since the DOJ will also take account of firm's previous compliance history in determining a sentence, the DOJ may well have a stronger role to play in deterring violating firms, thus confirming one of the main results of the second theoretical model,. However, if, accordingly to Harrington (1988), the EPA (after observing the firms' compliance history) does not apply any penalty upon a group 1 firm (low-risk of violation group) but a maximal penalty upon a group 2 firm (high-risk of violation group), thus confirming the scenario in which $c_2 > c_1$, one possibility might also be that the DOJ would have a greater incentive to prosecute criminally (because it has to deal with firms who have committed more serious violations) in contrast to what, in equilibrium, we have observed in the current model.

So, within the second game theory model, in a repeated framework one might expect that, with a more selective approach by the EPA, the involvement of DOJ might still improve the firm's probability of compliance (it may be that firms comply more fully or more frequently than would be suggested by consideration of the payoffs in a static game). In equilibrium, however, this would imply a disincentive for the EPA to inspect and, consequently, the firms would decrease the probability of compliance. The extent to which these intuitions are valid remain, of course, work to be done.

2.7 CONCLUSIONS

In the U.S. environmental enforcement system, predicting whether an environmental violation will be pursued administratively, civilly or criminally is a difficult task. In some circumstances civil injunctions are issued to prevent further harm and to begin cleanup procedures, while in some others, criminal sanctions are applied to further punish the violator.[28]

As noted by Rechtschaffen (2003), the enforcement process is filled with discretionary decision points at literally every stage of the process and, to use the words of Yeager (1991), "*rightly or wrongly some cases are handled administratively instead of ending up in the courts [...]*". When a violation or a case is raised, the EPA has wide discretion in choosing how to enforce the law; it may choose which cases to decline to pursue, which ones to deal with administratively, which ones to refer to the DOJ for civil action, and which ones to refer for criminal charges (Mandiberg and Smith, 1997).

The selective enforcement policy of the DOJ turns also upon two critical discretionary decisions: the initial decision to prosecute and the decision whether to settle the case through civil or criminal actions. Even though the exercise of

[28]The application of civil sanctions, generally, includes fines, negative publicity and installation of pollution-control technology, while the application of criminal sanctions includes also fine and imprisonment. The main distinction between sanctions in the criminal and civil systems is the availability of criminal non-monetary sanctions, such as incarceration and probation.

discretion is generally considered as a source of discriminatory enforcement, we show that the actual approach used by both the EPA and the DOJ, in which the choice of the enforcement rule is randomized, is successful in encouraging firms' compliance.

We do believe that the results can offer important insights into the regulator's behaviour. The main result of the first theoretical model shows that it is more efficient to let the EPA solve the cases internally (administratively) rather than refer them to the Department of Justice for civil or criminal prosecution. It emerges, in fact, that the intervention of the DOJ acts merely as an additional enforcement cost, which, in turn, might reduce the probability of conducting inspections by the EPA without affecting the probability of firm's compliance. This may suggest that some institutional mechanisms (such as that of enhancing criminal enforcement programmes) would not necessarily strengthen deterrence since criminal fines might not be able to give polluters adequate incentives to prevent environmental crimes; criminal enforcement may, indeed, reduce the effectiveness of enforcement policies.

One of the main results of the second theoretical model, however, is that criminal enforcement can enhance deterrence by improving firms' compliance. In terms of environmental policy implications, our result suggests that, even though EPA and DOJ have to work together for a better environmental quality, they should not share the same objective functions to maximize the level of compliance by the firms. Overall, both theoretical results may be somewhat surprising since they run counter to the general consensus in the literature that a consistent and predictable enforcement is preferable: we suggest, by contrast, that a discretionary enforcement strategy may generate higher compliance. Another common crucial point of our results is that EPA and DOJ engage in strategic interaction in their environmental enforcement behaviour. We show that not only do they influence each other in their enforcement decisions, but they also impact on decisions by the firms and increase (under certain circumstances) their probability of compliance.

Table 2.1 Payoff matrix for the strategic game between firm and EPA

		EPA: Inspect	EPA: Do not inspect	
Firm	Comply	$(v-c,-i)$	$(v-c,0)$	p
	Do not comply	$(v-f,-i-e+f)$	$(v,-e)$	$1-p$
		q	$1-q$	

Table 2.2 Payoff matrix for the sub-game between firm and DOJ (model I)

		DOJ: Civil	DOJ: Criminal	
Firm	Comply	$(v-c-c_1,-k_c)$	$(v-c-c_1,-k_j)$	p_1
	Do not comply	$(v-f,-e-r-k_c)$	$(v-j,-e-k_j)$	$1-p_1$
		q_1	$1-q_1$	

Table 2.3 Payoff matrix for the game between firm and EPA in the two-stage game (model I)

		EPA: Inspect	EPA: Do not inspect	
Firm	Comply	$(v-c,-i)$	$(v-c,0)$	p
	Do not comply	$(v-c-c_1,-i-e+f)$	$(v,-e)$	$1-p$
		q	$1-q$	

Table 2.4 Payoff matrix for the sub-game between firm and DOJ (model II)

		DOJ		
		Civil	Criminal	
Firm	Comply	$(v-c-c_1,-e+c_1-k_c)$	$(v-c-c_1,-e+c_1-k_j)$	p_2
	Do not comply	$(v-f_2-c_2,$ $-e+c_2+f_2-r-k_c)$	$(v-c_2-j,-e+c_2-k_j)$	$1-p_2$
		q_2	$1-q_2$	

Table 2.5 Payoff matrix for the game between firm and EPA in the second-stage game (model II)

		EPA		
		Inspect	Do not inspect	
Firm	Comply	$(v-c,-i-e+c_1)$	$(v-c,0)$	p_2
	Do not comply	$(v-c-c_1,-i-e+c_2)$	$(v,-e)$	$1-p_2$
		q_2	$1-q_2$	

Table 2.6 Payoff matrix for the game between firm and EPA in the first-stage game (model II)

		EPA		
		Inspect	Do not inspect	
Firm	Comply	$(v-c,-i)$	$(v-c,0)$	p_1
	Do not comply	$\left(v-c-c_1,-i-e+\left(1-\frac{k_j-k_c}{r-f_2}\right)c_1+\left(\frac{k_j-k_c}{r-f_2}\right)c_2\right)$	$(v,-e)$	$1-p_1$
		q_1	$1-q_1$	

Figure 2.1 Strategic game between firm and EPA in extensive form

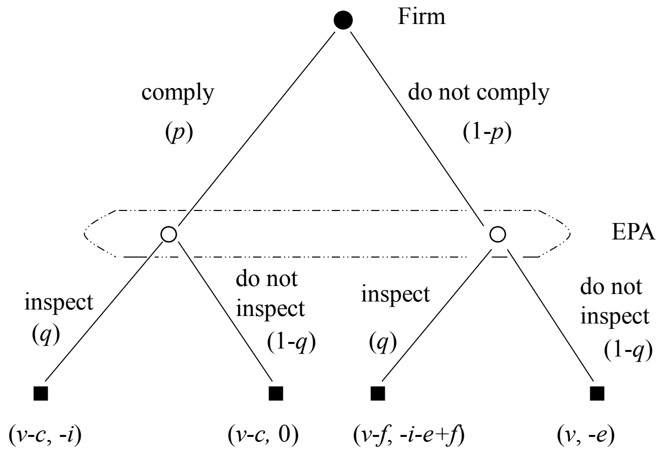


Figure 2.2 Strategic game between firm, EPA and DOJ in extensive form

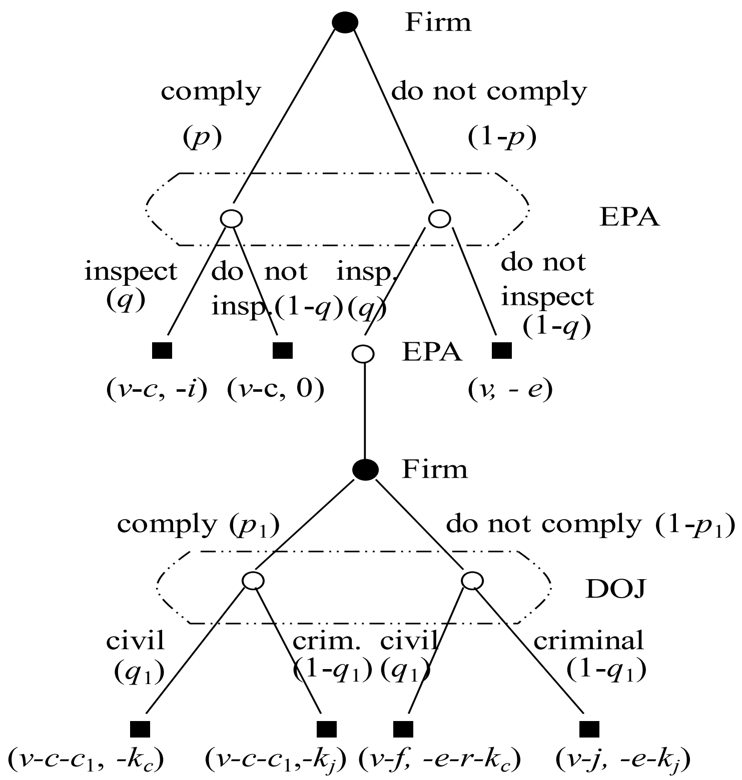
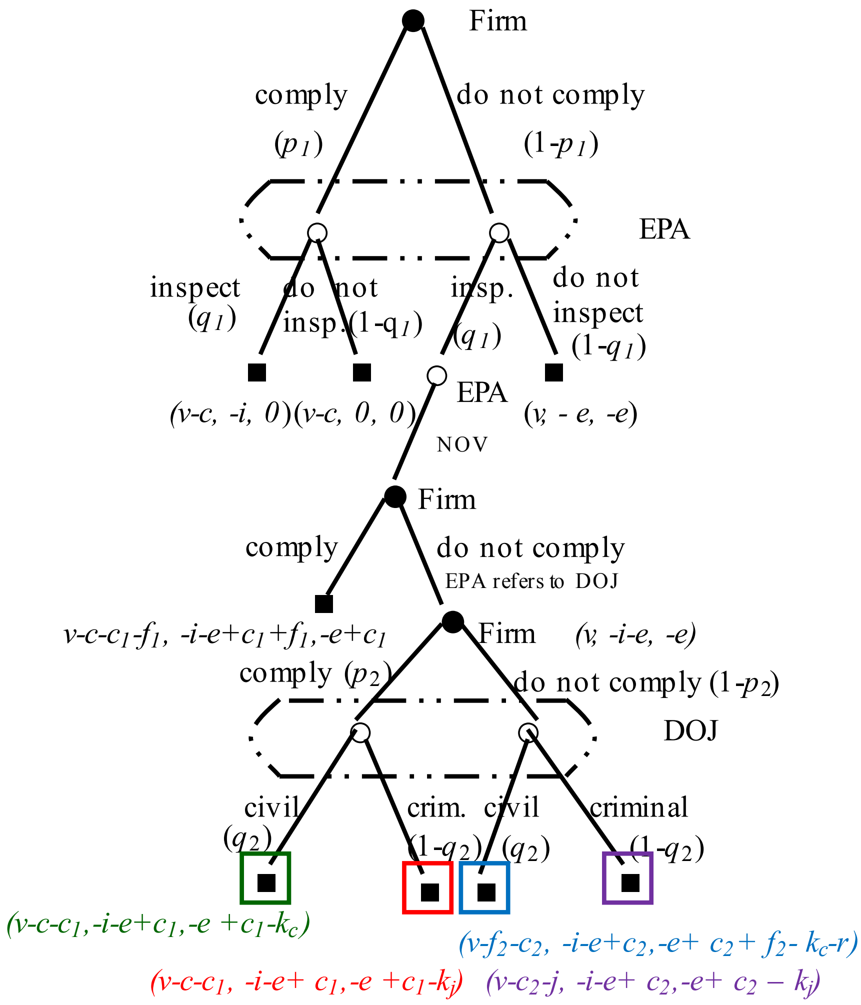


Figure 2.3 Strategic game between firm, EPA and DOJ in extensive form



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CHAPTER THREE

EXPERIMENTAL ANALYSIS OF DISCRETIONARY ENVIRONMENTAL ENFORCEMENT

3.1 INTRODUCTION

Departing from the game theory models previously developed, this chapter empirically tests, by means of laboratory experiments, the role of the Department of Justice (DOJ) in deterring firms from polluting. One of the main purposes of laboratory experiments is to test theoretical predictions when there is a lack of natural occurring data.

Recently, Arlen and Talley (2008) stated that experimentalism and empiricism are important complementary methodologies in a number of ways. It is often difficult for a researcher to establish whether behavioural changes are determined by changes in legal rules or rather whether the result is influenced by omitted variables or reverse causality problems. Experimental approaches are often the most adequate tools able to deal with these shortcomings and can be one of the most persuasive way of testing existing theories or developing new ones.

We tested, through two different experiments, the two game theoretic models discussed in chapter two, *i.e.* the first one where it is assumed that EPA and DOJ share the same objective function (we refer to this model as to Model I), and the second one where different objective functions are defined (we refer to this model as to Model II). The two experiments were conducted in different Italian Universities in different periods of time.

The results of the first experiment are consistent with the theoretical predictions of Model I and suggest that the introduction of civil and/or criminal enforcement reduces the probability of compliance by firms, undermining the efficacy of the enforcement strategy. In other words, under the game theoretic model parameterisation, the presence of the Department of Justice does not increase the number of complying firms independently by the probability of inspection by the EPA.

The results of the second experiment are also consistent with the theoretical predictions of Model II to the extent that the introduction of DOJ (i.e., adding-on DOJ civil and criminal enforcement to the EPA administrative enforcement actions) produces a rise in the firms' compliance rate.

This work brings new evidence in the realm of enforcement and discretion studies since, to the best of our knowledge, it is the first attempt to offer an empirical validation on the efficacy of a combined use of administrative and civil/criminal enforcement approaches by means of laboratory experiments.

The present chapter is organized as follows: in the next section a brief excursus on experimental economics literature is presented; in section three the key aspects on the experimental methodology are outlined; section four reviews the two theoretical models to be tested; section five describes the different experimental methodologies employed; section six discusses the design of the experiments; section seven presents the experimental findings and section eight offers some concluding remarks.

3.2 EXPERIMENTAL ECONOMICS: A BRIEF EXCURSUS

The first economic experiment can be dated back to 1931 when the American psychologist Thurstone tried to determine experimentally individual's indifference curves. In his experiment, each subject was asked to make a large number of hypothetical choices between various combinations of commodities (hats and coats, hat and shoes, or shoes and coats). He reported detailed data for one female subject and from the tradeoff between hats and shoes and hats and coats that she exhibited, it was possible to estimate a curve which fit quite closely the data relative to the choices between shoes and coats. Thurstone concluded that these choice data could be represented by indifference curves and that it was possible to reduce the indifference curves to experimental treatment. Wallis and Friedman (1942) critically discussed Thurstone's experiment. One of their major criticisms was that the experiment was based on poorly specified and hypothetical choices.[29] At this criticism a similar experiment followed up, at the beginning of the 1950s, constructed by Rousseas and Hart. They also attempted to empirically derive indifference curves, departing from Thurstone's experiment and taking into consideration the Wallis-Friedman critique. Their experiment involved graduate sociology students at Columbia University and was built on what they viewed as a more realistic choice situation by having subjects choose among different breakfast combination, consisting of a specified number of scrambled eggs and bacon strips. To add concreteness, they specified that "*each individual was obliged to eat all of what he chose – i.e., he could not save any part of the offerings for a future time*" (p. 291).[30] Their experiment had the advantage of avoiding the artificiality of having subjects make many choices of the same type, but their hypothesis of taste homogeneity and the way in which the choices combinations were put together to form indifference curves appeared quite arbitrary. From these early steps, as it has been recently noted by Fiore (2009), it emerges a feature that has become a constant in experimental economics: knowledge is part of a *cumulative process* in a system of experiments related to each other (Roth, 1988; Kagel and Roth, 1992).

Experimental law and economics is a special subset of experimental analysis, and can play important role in both testing and generating theories. Much of the experimental work in law and economics has been focused on testing the leading theories of behaviour employed to predict the consequences of legal rules. The experimental economics literature has interlaced law and economics on several points: particularly important for the study of law and economics are the experimental analyses on bargaining and the Coase theorem and on litigation and settlement process.

Hoffman and Spitzer (1982; 1985) were the first to introduce the idea of experimental law and economics, by running a set of experiments to test the

[29] Their position can be summarized as follows: "*it is questionable whether a subject in so artificial an experimental situation could know what choices he would make in an economic situation; not knowing, it is almost inevitable that he would, in entire good faith, systematize his answers in such a way as to produce plausible but spurious results*" (pp. 179-180).

[30] Moscati (2007) underlines that it is not clear whether this condition was just a theoretical constraint the students had to bear in mind while choosing among the different combinations or if the experiment considered a real consumption phase.

predictions of the Coase theorem (Coase, 1960). Their experiments confirmed the Coase theorem's predictions (in at least one version of its various forms) according to which, in the absence of significant transaction costs and irrespective of the initial allocation of legal rights, self-interested parties will tend to reallocate rights efficiently through bargaining. These early Coase theorem experiments, however, did not attempt to control for the information structure of bargaining. Subsequently, experimentalists started to test the Coase theorem in bargaining contexts characterized by asymmetrically informed parties (McKelvey and Page, 2000).

Another important area of research for experimental research in law and economics has been in litigation processes. In various set of experiments (Babcock *et al.*, 1995; Babcock and Loewenstein, 1997) subjects were instructed to act as attorneys in a dispute between two potential litigants, in which damages were known but liability was in doubt. Information was then elicited on what amount of money was likely to be remunerated the plaintiff, and on what amount of money a real judge would be awarded.

More recently, another field of application for experimental law and economics has been in enforcement issues. Arruñada and Casari (2007) analyze, in an experimental setting, how different political and judicial institutions may fail to produce enforcement and, thus, determine market failures. Their experiment simulates a credit market with two transacting parties and a third-party enforcer: a series of transactions take place between rich lenders and poor borrowers, and when a borrower defaults, the judge (third party) can either force the borrower to repay the loan or accommodate the default. They show that institutional arrangements may produce different enforcement results and provide decision makers with different incentive functions, by encouraging or discouraging enforcement actions.

3.3 ELEMENTS OF GOOD EXPERIMENTAL DESIGN

In a standard laboratory experiment, a number of subjects receive instructions that place them in a stylized representation of an economic situation.

Subjects are aware that the situation they face is somewhat artificial (in the sense that the only rules are those explicitly given by instructions) and they can normally choose between different options and different monetary payoffs. The experimenter collects subjects' decisions and uses them as a source of information for testing predictive theories and understanding economic behaviour.

Some of the major difficulties encountered in implementing experiments in social sciences arise from the fact that these kinds of experiments deal with "people", using a definition given by Sugden (2000) on experimental economics ("*theory with people in it*"). When conducting experimental research on human being, the variables that should be taken into account are, in theory, so numerous that it would be almost impossible to control for each one of them; as noticed by Fiore (2009) even the colour of the laboratory may have an effect. For this reason, current practices concerning the design of a laboratory experiment aim to create an environmental context as neutral as possible, in order to maintain an adequate control.

An experiment is, by definition, a planned and fully replicable observation of a phenomenon under controlled conditions, where "*control is the essence of experimental methodology*" (Smith, 1976, p. 275). As Arlen and Talley (2008) emphasized, there is no "*one size fits all*" set of desiderata for an experiment within law and economics, since the ingredients for a good experiment may depend on the purpose of the experiment and on the theoretic context on which the experiment is based. They specify several criteria that all experiments must satisfy, among which are control, internal consistency, falsifiability of theory, replicability and external validity.

- *Control*

Control is considered to be one of the essential conditions of experimental methods. An experiment is said to have achieved control if the experimenter controls the factors that affect choices. Crucial issues to attain control in the laboratory are related to instructions, experience and deception. Once subjects have entered in the laboratory, the first thing generally done by the experimenter is to instruct them about the task they will be asked to perform. Experimenters have developed rather common rules. First of all, instructions are required to be as simple as possible and to be framed in neutral words. Second, instructions are usually intended to give subjects only the relevant information to perform the experimental task. It is a common practice to avoid providing to the subjects the experiment's goal in order to not affect their choices. As stated by Plott (1982, p. 1490): "*the instructions make clear the opportunities available to subjects, but the motivation is supplied by the people*" and by Smith (1976): "*it may be preferable not to embellish instructions with well-intentioned attempts at realism*". This practice proves to be essential not to contaminate behaviour with reasons unrelated to experimental setting, so that the main motivation for participants remains the monetary reward. Third, usually experimenters read instructions loudly: in this way it is assured, at least theoretically, that every participant is given the same amount of information before the experiment starts, establishing a scenario of common knowledge among them. For instance, the prisoner dilemma experiment has become a classical example: the recommended practice is to not label the two available strategies as "defect" or "cooperate", but rather more neutrally as "strategy A" and "strategy B", or "strategy 1" and "strategy 2". Harrison and List (2004) and Guala (2003) argue that refraining from transferring any clues in experimental settings preserves the replicability of experiments even across different experimenters.

Even though instructions are read loudly, subjects are always provided with some scripts: in this manner, they have always the opportunity to read again the instructions if they prove not to be clear enough.[31] This practice also distinguishes experimental designs in economics and psychology (Hertwig and Ortmann, 2001). Usually experimenters, both economists and psychologists, after reading instructions loudly, give subjects the opportunity to ask the questions they want and are strongly encouraged to do this.

Moreover, a more direct test to control if subjects have entirely understood

[31] However, sometimes the experimental design does not allow experimenters to read aloud instructions. For instance, this can happen in experimental games, where there are two types of players with completely different roles and strategies to be played, or in cases in which subjects are provided with different private information. Consider the case of oral double auction: as explained in Smith (1962) and Plott (1982), the payoff functions are induced by individual redemption values and cost schedules, for buyers and sellers, respectively, and the key-variable design is that everyone knows nothing about others' schedules. In general, the standard practice should be the public reading of written, simple, and neutral instructions unless opposite and reasonable motivations require differently.

instructions is usually conducted. Several methods are used at this aim, each having its advantages and disadvantages. Up to now, no commonly accepted methodology has emerged about this, and there is some disagreement among different research groups. A first method consists of running a written test (known as *control questions* in the experimental literature) just after the reading of instructions. Generally, participants are required to fill in a paper or an electronic form with some questions about the available strategies for playing the game or about some examples regarding how to compute the payoff. Answers are checked before the experiment starts so that the experimenter has the opportunity to clarify further the design. The main shortcoming of this method is that it could create an *anchoring effect*, i.e., subjects may regard the examples in the questionnaire as having a particular meaning so that they could be influenced by these reference points for the entire experiment.

A second method often used consists of running some *trial periods*. In this case, subjects play exactly the same game that they will play in the proper experiment for some periods, with the only difference that in these very first periods they will receive no rewards for decisions taken, being informed about this in advance. Friedman and Sunder (1994) named these as "*dry-run periods*". This method has advantages and disadvantages, too. The principal advantage is that subjects have the opportunity to familiarize themselves with the game (which is not possible with the control questions method). This could be especially important for computerized treatments, in which some subjects may present problems in interfacing with computers. On the other hand, the usual criticism against this method is that data referring to trial periods are not considered in further analyses, and that the significant part of learning usually takes place just in these very first periods.

A third method which was developed to avoid these problems, while maintaining the advantages of the first two methods, could be termed as "dummy practice treatment". This is substantially equivalent to running trial periods, except for the fact that parameter values in these periods are distinct enough from values used in the proper experiment, in order to avoid any possibility for anchoring effects, while obtaining some training about the task in general. As already pointed out, up to now no work has been done to see if these pre-experiment methods have any systematic effects on experimental results.

- *Internal consistency.*

Another important condition for a good experiment is its internal consistency. This implies that decisions made by subjects should not be affected by other factors not considered in the experimenter's tested hypothesis. Incentive compatibility between subjects' choices and their payoffs at the end of the experiment is important to internal consistency because there is no assurance that subjects evaluate choices with hypothetical payoffs in the same way that they evaluate choices with real payoffs.

The use of monetary incentives as rewards for participants at the experiments has triggered an intense debate in the literature (Roth, 1995; Hertwig and Ortmann, 2001). There are several reasons for which experimentalists in economics choose to pay participants at their experiments. First, as recognized by Hertwig and Ortmann (2001), given that economic agents are seen as rational agents maximizing their own utility, theoretically there is no reason to believe that participants' actions are not driven by the same incentives in the laboratory. Second, another common reason for financial incentives is the belief that rewarding participants has an important role in reducing variance in experimental data. The rationale behind this is that the financial incentives would induce more effort and would help in maintaining concentration. Consequently, they would produce more statistically reliable and more informative data. This belief has been supported by a survey study carried out by Smith and Walker (1993), in which they did find that "*in virtually all cases rewards reduce the variance of data around the predicted outcome*". So far, there has been general agreement that using financial incentives produces more reliable data given the reduction in variance empirically observed.

The experimenters' choice of subject pool also may present internal consistency (and control) concerns. A debated issue in making experiments is the general use of college students as experimental subjects. The main reasons for which researchers usually observe students' behaviour to test their hypotheses are the following. First of all, students are easy to recruit. In fact, usually researchers sign up subjects for their experiments by means of notices around university campuses, or, more simply, by inviting students to volunteer during lectures. More recently, making use of new technologies, some online recruitment systems have also been developed (e.g., Greiner, 2004). In this way, a better indirect control could also be achieved thanks to randomization in recruiting subjects. Secondly, students are an adequate subject pool, generally quick to understand their task in the experiment, and generally more capable than other population groups of using computers in case of computerized experiments. Thirdly, the particularly low opportunity costs make students the ideal subjects to make experiments. Generally, people participating in an experiment are paid according to their hourly wage rates: it is clear how much more convenient can be to use students as subject pool compared to professionals.

A further reason is of an empirical nature: some experiments compared students' behaviour with other subject pools and found virtually no significant differences (Lichtenstein and Slovic, 1973; Burns, 1985; Dyer *et al.*, 1989). In reviewing some results in labour market experiments, Falk and Fehr (2003) conclude: "*subject pool differences may be a real issue. However, the studies also show that the different subject pools do not behave in fundamentally different ways. [..] Thus, although there are some quantitative subject pool effects, the qualitative pattern of behaviour were rather similar across the different subjects pools*".

- *Falsifiability of underlying theory*

Since one of the main purposes of experiments is to test theoretical predictions, a theory's falsifiability is an important consideration in designing an experiment. A general statement is said to be falsifiable if it can be shown to be false by either empirical or experimental observation. In other words, a theory is falsifiable if and only if the theory makes non-trivial predictions that can in principle be empirically falsified. If a theory makes no falsifiable predictions, then the theory cannot be empirically evaluated.

- *Replicability*

Experimental approaches must be replicable, in that other experimenters should be able to employ the same techniques, the same protocols, and the same incentives to similar subject pools to attain comparable results. It is also quite common for authors to add instructions to their paper or to make them promptly available on request. This practice also contributes to reducing ambiguity and to enhancing replicability.

- External validity

External validity (generalizability) focuses on whether the decision that the experimentalist tried to examine can be said to provide insight into the real-world choices. External validity concerns are especially relevant when student subjects are used to examine decisions or behaviour by people who may have different experiences and preferences than the student subjects.

The issues dealing with subject pool bias are not limited to problems related to the extension of results to other population groups, but also include some statistical problems. Indeed, since very often the set of experimental subjects is entirely constituted by students, any kind of inference could be problematic since the data may not be representative for a larger population. In addition, usually no more than one or two hundreds subjects are involved in an experimental study, but often even less. Therefore, the "law of large numbers", in most cases, would be applied incorrectly. As pointed out by Harrison and List (2004) the problem with students is the lack of variability in their socio-demographic characteristics, not necessarily the unrepresentativeness of their behavioural responses conditional on their socio-demographic characteristics.

Regarding the misapplication of the law of large numbers, generally experimenters reply that the problem with small numbers is not effectively a real problem, since it is easily surmountable (usually they use small size sample because of financial constraints or because of practical implementation). Actually, it is sufficient to replicate the same experimental design with new subjects to enlarge the sample size.

We can say that these are the desiderata for experiments, but the relative and absolute importance of each may depend on the purpose of each experiment and on the domain of the underlying theories.

3.4 THE THEORETICAL MODELS TO BE TESTED IN THE LAB

Two laboratory experiments were conducted to explore compliance behaviour of firms when faced with enforcement conditions consistent with the model frameworks discussed in chapter two. More specifically, both experiments are grounded on the set up models proposed in sections from 2.4.1 to 2.5.4 where the firm's behaviour is influenced by the course of actions discretionally implemented by both the EPA and the DOJ. The two laboratory experiments were conducted to test the findings of:

1. the game theory model under the assumption that EPA and DOJ share the same objective function (model I: sections 2.4);
2. the game theory model under the assumption that EPA's objective function is different from DOJ's objective function (model II: sections 2.5).

As discussed in chapter two, each of the two models is subdivided into two games: first, the game between the firm and the EPA is considered. The firm can choose whether to comply with environmental regulations or not, by assessing the costs and benefits of compliance *versus* pollution. The EPA, not knowing the strategy chosen by the firm, must decide whether to carry out inspections or not. Subsequently, the DOJ is introduced in the model and a more complex game is considered. Now, the EPA can serve a notice of violation to the firm if the latter is found to be non-compliant and the task of environmental control is subsequently taken up by the DOJ, which exercises its discretion by deciding whether to initiate a civil or a criminal proceeding.

As already mentioned, one of the most important results deriving from Model I is that the probability of compliance by the firm is unaffected by the presence of the DOJ. This finding is rather interesting, as it shows that firms are deterred in their behaviour solely by EPA's administrative sanctions. Hence, it suggests that the presence of DOJ is just a cost for the society, as it does not increase the probability of firms following an environmentally sound behaviour. Opposite results were obtained in Model II, where the involvement of DOJ improves (under the assumptions of the model) the firm's probability of compliance.

Both theoretical findings were tested in the laboratory by means of two experiments (one for each game theory model) composed by two treatments each (one for each game). The first experiment was conducted through the elicitation of preferences by means of pairwise choice lotteries, whereas the second laboratory experiment was conducted by means of different experimental procedures in laboratory. More precisely, we calculate the probability of compliance by letting subjects play the two experimental treatments – i.e., a treatment without the DOJ and a treatment with the DOJ – under a) the *cold* method (in which individuals must provide a complete strategy profile for the game), b) the *hot* method (in which subjects make choices only for realized nodes) and c) the pairwise choice lotteries, to ascertain whether differences in behaviour can be identified in the elicitation methods of participants' decisions. Then, the experimental results obtained using the three methods are compared. This procedure allows for robust results, thus providing a generalization of the theoretical findings to a situation in which agents are not necessarily homogeneous and risk-neutral. We clarify these methodological issues in the following section.

3.5 EXPERIMENTAL METHODS

The elicitation method that the experimenter uses in the laboratory is a crucial aspect of any experiment, since it is important that the experimental design does not bias the choices made by participants. In order to elicit subjects' preferences, given the nature of the models discussed in chapter two, we can employ two methods well known in the experimental literature: *game methods* and *strategy methods*. Game methods are also named *hot* or *sequential decision protocol* or *direct-response* method, while strategy methods are also named *cold* or *strategy vector* method (from now on, we refer to these methods as to *hot* and *cold*). When a *hot* method is utilized to elicit choices, subjects make a single choice only for realized nodes. When a *cold* method is employed, subjects state choices for every decision node they may face. Individuals' decisions in *hot* condition could be different from those made in *cold* condition (the folk wisdom of counting to ten before one reacts is based on such a difference). Levitt and List

(2007) note that in the *hot* phase emotions might be quite important, whereas in the *cold* phase, immediate reactions may be suppressed.

So, while under *hot* protocol individuals make decisions as they encounter them in the game, under the *cold* method individuals must provide a complete strategy profile for the game, i.e., they have to make contingent decisions for all nodes at which they may have to play. One of the main advantages of the *cold* method is that it allows collecting more data, since subjects are asked to give a complete strategy. In fact, as Charness and Rabin (2002) pointed out, the *cold* method is potentially very useful for gathering experimental data, since observations can be obtained even at nodes that are only reached occasionally in the course of the game.[32]

It follows that the main distinction between the two methods is mainly about the amount of information experimentalists can obtain in the lab. Along this line of reasoning, we employed a third elicitation method (i.e., pairwise choice

[32] Note that, *a priori*, it is possible that *hot* and *cold* methods lead to different behaviour, but whether this conjecture is correct is an empirical question; theoretically there should be no differences between them. For some games, comparisons of the *cold* and the *hot* methods reported some differences in choices (e.g., Brandts and Charness, 2000; Cason and Mui, 1998; Oxoby and McLeish, 2004; Sonnemans, 2000). Brandts and Charness (2000), for instance, compare behaviour across *hot* and *cold* treatments of the prisoners' dilemma game and the chicken game. In these experiments behaviour was stable across both treatments, even though the *cold* treatment provided more opportunities for participants to reflect on the behaviour of themselves and others. From this, they conclude that the method of eliciting behaviour does not matter for simple sequential games. More recently, Murphy *et al.* (2007) using direct-response treatment, compare the results from Murphy *et al*. (2006) in which *cold* method was employed. Subjects play a game in the form of trust dilemma, where there are three people in a group, and each person can stop the game in continuous time. They found that in the *hot* condition there is more co-operation and a higher dispersion in the winning stopping times. Casari and Cason (2009) also use a trust game, where the first-mover could either pass his entire endowment or nothing. The trust game is a sequential prisoner's dilemma game in which the first mover decides how much money to pass to the second mover. In the *cold* condition, the responder made contingent choices for the possible cases, while with the *hot* condition the responder learnt the first-mover's choice. They found that while the two methods yield similar rates of trust, the *cold* method may generate lower levels of trustworthiness. They provide two possible explanations for the differences observed between the two elicitation methods. The first one is that the *hot* procedure may give a better contribution to understand the experimental task than the *cold* procedure. The second one, however, is that emotions influence choices more in the *hot* than in the *cold* procedure. So, they open up the issue of exploring the "understanding" versus the "emotional" conjectures. Schotter, Weigelt and Wilson (1994) by representing strategically equivalent games in either normal or extensive form, find that presentation effects are significant. Similarly, Rapoport (1997) finds that two different extensive forms corresponding to the same normal form yield different experimental behaviour. However, in some cases the qualitative results can be reversed just by changing the response elicitation method (e.g., Güth, *et al*., 2001; Brosig, *et al*., 2003; Cooper and Van Huyck, 2003) or by changing the response elicitation method in combination with changing another factor such as context in which the game is played (e.g., Falk *et al*., 2003; Cox and Deck, 2005).

gamble) that, as we believe, allows us to collect as much information as the *cold* method but helps reduce the noise that can be intrinsically related to behavioural choices.

In fact, since our game does not involve any strategic interaction among subjects (given that Nature plays always according to a common knowledge fixed probability consistent with the mixed strategy equilibrium in the theoretical model, i.e. the inspection starts with a fixed probability), we can decompose each node of the strategy method into two pairwise choice gambles, under the usual assumptions (transitivity, rationality, independence). The advantage associated to an elicitation method based on pairwise choice gamble rests on the evidence that subjects are less noisy when facing such elicitation framework - i.e., it has been proved (Hey, Morone and Smith, 2009) that pairwise choice gambles provide more accurate responses. In light of this, we believe that pairwise choice method allows to collect more accurate data.[33]

3.6 THE EXPERIMENTS

We shall now present the two experiments conducted in order to test each one of the game theoretic models briefly reviewed in section 3.4 and fully discussed in chapter two.

3.6.1 THE FIRST EXPERIMENT: THE BASELINE MODEL EXPERIMENT [34]

First we tested in the laboratory Model I, which is grounded on the assumption that EPA and DOJ share the same objective function. A paper and pencil experiment was conducted at the University of Foggia (Italy) in October 2008. Participants were first-year undergraduate students from the Faculty of Economics and the elicitation method employed was the pairwise choice lottery. The experimental session took place in a large classroom and subjects were seated so that they could not observe others' choices. A total of 51 undergraduate

[33] Although from a theoretical point of view the pairwise choice gambles are constructed to elicit exactly the same preferences as in the *hot* experiment, it is worth noting that one shortcoming that should be considered is that transforming an extended game into a set of pairwise choice gambles might introduce a frame effect and distort findings.

[34] Funding for subjects' payments was provided by the University of Foggia, Italy.

students participated in the study. None of them had previously participated in economic experiments. The experiment was facilitated through the use of a booklet, handed out to each subject. The booklet contained a brief instruction that was read aloud and that described the actual experiment to be carried out by each player. The whole procedure was carefully explained to all participants before starting the experiments. The subjects were encouraged to ask questions at any time during the experiment. The experiment was based on an incentive-compatible elicitation mechanism. Specifically, once players handed in their booklets, the experimenter randomly selected a subject who is paid accordingly to the outcome of his preferred lottery. In this way, all subjects have an incentive to report their true preferences among the lotteries. All other subjects received €5 as a participation fee.

The experiment builds on the decision problems described in the first game theory model in chapter two and briefly reviewed above. As mentioned before, there are two games corresponding to two experimental treatments. In the first treatment, players acting as firms play against the EPA (which is played by Nature). Each firm chooses between complying or not whereas the EPA chooses whether to carry out inspections or not with a given probability. If the firm complies, it has to sustain a cost. The EPA also has to incur a cost if it decides to carry out an inspection.[35]

In this treatment we assigned values to the parameters reported in figure 3.1 as follows: the probability q of EPA starting an inspection (chosen accordingly to the equilibrium conditions of the theoretical model) was set equal to 1/2 ($q = c/f$); the value for non-complying firm v was set equal to €50; the cost of compliance c was set equal to €5; the fine f was set equal to €10; the other two parameters reported in figure 3.1 the inspection cost ($-i$) and the environmental damage ($-e$) are not relevant to our experiment as they characterize the EPA pay-off which in the experiment is played out by Nature. All figures and tables are presented at the end of the chapter.

In the second treatment, the EPA can serve a notice of violation to the firm if the latter is found non-compliant. A notice of violation describes the violation

[35] Note that players during the experiment are simply asked to choose among two lotteries. No information is provided on the "environmental setting" of the model.

and commands the violator to stop the activity.[36] At this point, the firm must decide again whether to be compliant or non-compliant. If it does not comply, then the EPA will refer it to the Department of Justice for civil or criminal prosecution. Hence, the task of environmental control is taken up by the DOJ (also played by Nature) - which must then choose between a civil and a criminal prosecution.

In this treatment we assigned values to the parameters reported in figure 3.2: in this game, the probability q of EPA starting an inspection was set equal to 1/4; probability q_1 of DOJ starting a civil action was set equal to 5/6; the value v was set equal to 50 €; the cost of compliance c was set equal to €5; the additional compliance cost c_1, if the firm did not comply in the first instance, was set equal to €15; the fine from civil prosecution f was set equal to €10; the cost to the firm from criminal prosecution j was set equal to €40. Also in this case some parameters where not relevant to our experiment as they characterize the DOJ pay-off which in the experiment is played out by Nature (k_c the cost to DOJ of enforcing civil prosecution, k_j the cost of enforcing criminal prosecution, and finally r the reputation cost of letting off an offending firm with only a fine).

We elicit subjects' behaviour using pairwise choice gambles, presented as segmented circles - see fig. 3.3. All the presented risky lotteries were composed of the following outcomes €5, €30, €35, €40, €45, and €50. The probabilities of these outcomes are recorded in Table 3.1.

The pairwise choice gamble 1 reported in table 3.1 (visually presented in fig. 3.3), represents the firm's decision problem depicted in fig. 3.1 (i.e. treatment 1). On the one hand, if the firm decides to comply (see left gamble), whatever the EPA action is, it will receive v-c (set in the experiment equal to €45); on the other hand, if the firm decides to not comply its pay-off depends on the EPA action; more precisely it receives v-f (equal to €40) with probability q if the EPA decides to inspect, and v (equal to €50) otherwise (see right gamble). This is equivalent to choosing between lottery A and lottery B in figure 3.3.

[36] The purpose of a notice of violation (NOV) is to initiate a corrective action that will stop the violation. For instance, to provide an incentive for continuing compliance, NOVs for the U.S: Clean Water Act may result in monetary penalties up to $27,500 per day, per violation, according to 33 U.S.C. 1319.

Pairwise choice gamble 2 represents one part of the firm decision problem developed in the second game of the model and presented in fig. 3.2. More precisely, if the firm decides to comply (see left gamble in table 3.1), whatever the EPA action is, it gets *v-c*; if the firm decides to not comply, its pay-off depends on the EPA's action; if the EPA decides to not inspect it gets (with probability *1-q*) *v*; if the EPA decides to inspect and the firm reacts to the EPA's notice of violation by complying, then its payoff will be, independently of the DOJ decision, $v\text{-}c\text{-}c_1$ = €30 (see right gamble in table 3.1).

Pairwise choice gamble 3 represents the remaining part of the firm decision problem depicted in fig. 3.2. As always, if the firm decides to comply (see the left gamble in table 3.1), whatever the EPA action is, it gets *v-c*; if the firm decides to not comply and the EPA decides to not inspect, the firm gets (with probability *1-q*) *v*; if the EPA decides to inspect and the polluting firm does not react to the EPA's notice of violation by complying, then its pay-off is (with probability $q \times q_1$ = 5/24) *v-c-f* = €35 if the DOJ starts a civil procedure and (with probability $q \times (1-q_1)$ = 1/24) *v-c-j* = €5 if the DOJ starts a criminal procedure (see right gamble in table 3.1).

Finally, pairwise choice gamble 4 is a consistency test, as it allows to verify if subjects' preferences respect the transitivity axiom.

3.6.2 The Second Experiment: The Extended Model Experiment[37]

We tested in the laboratory also Model II (*i.e.*, under the assumption that EPA and DOJ do not share the same objective function). This second experiment was also a paper and pencil experiment conducted at the Law School of the University of Rome "Sapienza" (Italy) in December 2010, with subjects being first and second-year undergraduate students attending Economics classes. The experimental session took place in a large classroom and subjects were seated so that they could not observe each others' choices. None of the students had previously participated in economic experiments. The session lasted about 90 minutes including the initial instruction time and payment of subjects. Subjects earned on average €25 including the €5 show up fee.

[37] Funding for subjects payment was provided by the University of Rome "Sapienza" (Italy).

Each subject was provided with a booklet containing the games to be played as well as printed instructions, which were read aloud to all participants. The subjects were encouraged to ask questions at any time during the experiment. Each subject played a total of 10 games (i.e., 6 pairwise choice lotteries, 2 game trees played out under the *hot* and two game trees played out under the *cold* elicitation procedures). At the end of the experiment, one of the 10 games was chosen randomly and played for real (subjects were payed accordingly).[38] Upon completion of the experiment the subjects were asked one by one to approach the experimenter for payment of show up fees and payoffs from the game.

The experiment builds on the decision problems described in the model in chapter two and briefly reviewed above. As mentioned, there are two games corresponding to two experimental treatments and each treatment was played under both *cold* and *hot* procedures as well as under the form of pairwise choice lotteries. In the first treatment players, acting as firms, play against the EPA (which is played by Nature). Each firm chooses between complying or not whereas the EPA chooses whether to carry out inspections or not. If the firm complies, it has to sustain a cost. The EPA also has to incur a cost if it decides to carry out an inspection (see figure 3.4).

Similarly to the first experiment, to both treatments (the one in which firm chooses between complying or not and EPA chooses whether to carry out inspections or not, and the other one in which EPA can refer the case to DOJ for civil or criminal prosecution) were assigned values compatible with the parameters and the restrictions of the theoretical models. Under the second parameterization (associated with Model II where EPA and DOJ do not share the same objective function), we assigned values to the parameters reported in figure 3.4 as follows: the probability q_1 of EPA starting an inspection was set equal to 2/3; the value of non-complying firm v was set equal to €50; the cost of compliance c was set equal to €30; the fine f_1 was set equal to €20; the other two parameters the inspection cost ($-i$) and the environmental damage ($-e$) are not relevant to our experiment as they characterize the EPA pay-off which in the experiment is played out by Nature.

[38] The game tree n.1 was drawn under the *hot* procedure.

In the second treatment, if the firm is still found non-compliant after the EPA has served a notice of violation, it can be referred to the DOJ that can exercise discretion on whether to initiate civil or criminal proceedings.

In this treatment we again assigned values to the parameters as follows (figure 3.5): the probability q_1 of EPA starting an inspection was set equal to 2/3; the probability q_2 of DOJ starting a civil action was set equal to 4/5; the value v was set equal to €50; the cost of compliance c was set equal to €30; the additional compliance cost c_1, if the firm did not comply in the first instance, but did comply after EPA issuing a notice of violation, was set equal to €15; the further abatement and clean up costs to the non-compliant firm, c_2, was set equal to €16; the fine f_1, from EPA if the firm is compliant after being served with a notice of violation, was set equal to €20; the fine f_2 from civil prosecution when the firm chooses to remain non-compliant was set equal to €25; the cost to the firm from criminal prosecution j was set equal to €40. Also in this case some parameters where not relevant to our experiment as they characterize the DOJ pay-offs which in the experiment is played out by Nature (k_c is the cost to DOJ of enforcing civil prosecution, k_j the cost of enforcing criminal prosecution, and finally r is the reputation cost of letting off an offending firm with only a fine).

In the experimental parameterization, we decided to focus only on the case in which $c_2 > c_1$ [the cleanup costs for the firm when it is not compliant and it is forced to clean up by DOJ (c_2) are greater than the cleanup costs if it is compliant (c_1)] ignoring the other case in which $c_1 = c_2$ (under this circumstance, the EPA is indifferent to the strategy chosen by the firm).

As mentioned above, we elicited subjects' behaviour using *hot* and *cold* methodology, as well as pairwise choice gambles presented as segmented circles. All the presented risky lotteries were composed of the following outcomes: -€15, -€6, €5, €9, €20 and €50. The probabilities of these outcomes are recorded in Table 3.2.

Pairwise choice gamble 1 reported in table 3.2 (presented in figure 3.6) represents the firm's choice problem in treatment one (see figure 3.4). If the firm decides to comply (see left gamble), whatever the EPA action is, it will receive $v-c$ (set in the experiment equal to €20). If, instead, the firm decides to not comply its payoff depends on the EPA action; it will receive v-c-c_1 (equal to €5) with probability q_1 if the EPA decides to inspect, and v (equal to €50) otherwise (see right gamble).

Pairwise choice gamble 2 represents one part of the firm's decision problem developed in the second game and presented in figure 3.5. If the firm decides to comply (see left gamble in table 3.2), it receives v-c = €20 whatever the EPA action. If the firm decides to not comply, its pay-off depends on the EPA's action: if the EPA decides to not inspect it receives v = €50 with probability 1-q_1= 1/3; if the EPA decides to inspect and the firm reacts to the EPA's notice of violation by complying, then its payoff will be v-c-c_1-f_1 = -€15 independently of the DOJ decision (see right gamble in table 3.2).

Pairwise choice gamble 3 represents another part of game tree depicted in fig. 3.5. As always, if the firm decides to comply (see the left gamble in table 3.2), whatever the EPA action is, it receives v-c = €20; if the firm decides not to comply and the EPA decides not to inspect, the firm receives v = €50 with probability 1-q_1; if the EPA decides to inspect and the firm does not react to the EPA's notice of violation by complying, then its pay-off is depend on the DOJ's strategy. If the firm decides to remain not compliant its payoff is respectively: v-f_2-c_2 = €9 if the DOJ starts a civil procedure and v-c_2-j = -€6 if the DOJ starts a criminal procedure (see right gamble in table 3.2).

Pairwise choice gamble 4 represents another part of the firm's decision problem. If the firm decides to not comply and the EPA decides not to inspect, the firm receives v = €50 with probability 1-q_1; if the EPA decides to inspect and the firm reacts to the EPA's notice of violation by complying, then its payoff will be v-c-c_1-f_1 = -€15 independently of the DOJ decision (see left gamble in table 3.2). If, however, the firm decides to comply, after the EPA has referred the case to the DOJ, then its payoff is v-c-c_1 = €5, either if DOJ starts a civil procedure or if the DOJ starts a criminal procedure (see right gamble in table 3.2).

Pairwise choice gamble 5 represents almost the same decision problem described in pairwise choice gamble 4, except for the fact that the firm now chooses not to comply even after the EPA has referred the case to DOJ. So, in this case, if the firm decides not to comply and the EPA decides not to inspect, the firm gets v = €50 with probability $1-q_1$; if the EPA decides to inspect and the firm reacts to the EPA's notice of violation by complying, then its payoff will be $v-c-c_1-f_1$ = -€15 independently of the DOJ decision (see left gamble in table 3.2). If, however, the firm decides to remain not compliant, after the EPA has referred the case to DOJ, then its two additional payoffs are $v-f_2-c_2$ = €9 if DOJ starts a civil procedure and $v-c_2- j$ = - €6 if DOJ starts criminal procedure (see right gamble in table 3.2).

Pairwise choice gamble 6 is the last part of the firm's decision problem to be analysed. If the firm decides to not comply and the EPA decides to not inspect, the firm gets, as before, (with probability $1-q_1$) v = €50; if the EPA decides to inspect and the firm reacts to the EPA's notice of violation by not complying, but decides to comply after the case has been referred to DOJ, then its payoff is $v-c-c_1$ = €5 (see left gamble in table 3.2) independently by the enforcement action (civil or criminal) chosen by DOJ. If, however, the firm decides to remain non compliant, after the EPA has referred the case to DOJ, then its payoffs are $v-f_2-c_2$ = €9 if DOJ starts a civil procedure and $v-c_2- j$ = - €6 if DOJ starts a criminal procedure (see right gamble in table 3.2).

3.7 EXPERIMENTAL FINDINGS

3.7.1 EXPERIMENTAL FINDINGS – FIRST EXPERIMENT

Out of the 51 subjects who took part in the experiment, two did not pass the consistency test (i.e., they contradict the assumption of preferences' transitivity). One of these two subjects also displayed irrational behaviour in the second session of the experiment (i.e., when the DOJ was introduced). Henceforth, we drop them both from the database and conduct our analysis on the remaining 49 observations.

As discussed in the experimental design section, we first tested the strategic game between the EPA and the firm (figure 3.1). Out of the 49 subjects considered, almost half decided to comply (24 subjects – see figure 3.7). We then compared this result with those obtained in the second treatment of the experiment in order to test the finding for which the introduction of the DOJ does not affect the probability of compliance and, therefore, that the DOJ represents a net cost for society. In the game played among firm, EPA and DOJ only 11 subjects complied with environmental measures in the first move. This striking result would suggest that introducing the DOJ produces a sharp reduction in the rate of compliance.

However, we can observe that out of the 38 subjects that decided to pollute, almost 45% switched to non-polluting behaviour once the EPA notifies the violation. As set in the first game theory model, we know that the probability of inspection (and hence, for those firms who did not comply, of receiving a notice of violation) is $q_1 = c/(c+c_1)$. So, under our experimental parameterization, this probability will be equal to ¼, consistently with the equilibrium conditions and with the numerical payoffs, i.e., $q = 5/(5+15)$. Therefore, we can expect that out of the 38 firms that did not comply only 38/4 = 9.5 will be inspected by the EPA and then only 4.2 will switch to compliance.

All in all, this adds up to 11 + 4.2 = 15.2 complying firms, which is less than two thirds of the number of firms that decided to comply in the first game (figure 3.8). Hence, we can conclude that the introduction of the DOJ in the game reduces sharply the number of complying firms and, therefore, reduces the efficacy of the enforcement strategy.

In addition, we can calculate the threshold value of q_1 which would lead to an equilibrium in which the same number of firms would comply in both games with and without the DOJ. This value would be 0.76, implying that the EPA should conduct an inspection with a probability of 76%. Note that this probability is higher than that required to obtain the same level of compliance in the game without the DOJ (which was q = 0.5). In turn, under the model parameterization, these experimental findings suggest that the presence of the DOJ is a cost for society, as it increases the number of complying firms only if the EPA increases the number of inspections.

3.7.2 EXPERIMENTAL FINDINGS – SECOND EXPERIMENT

In this section we present the results of our experiment using the *hot*, the *cold* and the pairwise choice gamble elicitation methods. Out of the 33 subjects that took part in the experiment, one did not answered to all questions of the *cold* and of the *hot* design. Henceforth, we drop this subject from the databases relative to the cold and hot procedures and conduct our analysis on the remaining 32 observations. However, for the pairwise choice lotteries we have all the data relative to the 33 subjects.

As discussed in the experimental design section, we first tested the strategic game between the EPA and the firm. Out of the 32 subjects considered, on the one hand, more than half (20 out of 32 in the *hot* treatment, and 18 out of 32 in the *cold* treatment) decided to comply, on the other hand, in the lottery treatment only 12 out of 33 complied. We then compared this result with those obtained in the second treatment of the experiment in order to test whether the introduction of the DOJ does affect the probability of compliance. We report these results on the game tree in figures 3.9, 3.10 and 3.11 at the end of the chapter.

In the game played among firm, EPA and DOJ (as showed in figures 3.12, 3.13 and 3.14 at the end of the chapter) only 15 subjects complied with environmental measures in the first move under the *hot* treatment; 18 complied in the *cold* treatment and 12 in the lottery one. At first sight, this result would suggest that the introduction of the DOJ produces, in the first move, an incisive reduction in the rate of compliance in the *hot* treatment, does not affect subjects behaviour in the *cold* and in the lottery treatments. However, we can observe that in the *hot* treatment the 38% of subjects that initially decided to remain non compliant switched to a compliant behaviour once the EPA notifies the violation; this percentage rise to 75% in the *cold* treatment and up to a 79% in the lottery one. We can also notice that under the *cold* procedure, unfortunately, 50% of participants didn't provide any response on the second treatment (treatment with the DOJ) of the game. Even though in the experiment instructions, it was clearly stated that they should have made a decision every time they reached a node followed by dotted lines, only 16 subjects (out of 32) expressed their choices on the whole game tree.

These findings allow us to affirm that the different experimental elicitation methods employed have an influence only in quantitative terms, i.e. on the number of subjects that at the end of the overall enforcement procedures decide to be compliant. In fact, the number of subjects that chooses to be compliant, once the DOJ has been introduced, increases moving from *hot* to *cold* treatments (from 5 subjects out of 13 in the *hot* treatment to 12 subjects out of 16 in the *cold* treatment), and keeps increasing moving from *cold* to the lottery treatment (from 12 subjects out of 16 in the *cold* treatment to 26 subjects out of 33 in the lotteries). As set in the model, we know that the probability of inspection (and hence, for those firms who did not comply, of receiving a notice of violation) is $q_1 = c/(c+c_1)$. So, under our experimental parameterization, this probability will be equal to 2/3.

Therefore, we can expect that out of the 17 firms that did not comply, in the first instance, only 34/3 = 11.3 will be inspected by the EPA and then only 3 will switch to compliance. All in all, this adds up to 15 + 4.3 = 19.3 complying firms in the *hot* treatment. In the *cold* treatment we observe 14 firms that did not comply, in the first instance, 9.3 of which will be inspected and so we can expect that out of the inspected firms 7 will comply; this adds up to 18 + 7 = 25 complying firms in the *cold* treatment. In the lottery treatment we observe 21 firms that did not comply in the first move, consequently only 14 will be inspected and out of the inspected firm 11.03 will comply; all in all, in the lottery treatment we will end up with 21+11.03 = 32.03 complying firms.

We can affirm, therefore, that in qualitative terms there are no divergences among the different elicitation methods since, once the EPA has referred the case to the DOJ for civil or criminal prosecution, the firm's probability of compliance might improve, consistent with one of the main results of the theoretical model. Therefore, our experimental results not only do show that introducing criminal enforcement consistently improves compliance under the different elicitation methods but also that the number of complying subjects slightly increases under the *hot* treatment, significantly increases under the *cold* treatment and strongly increases under the lottery treatment.

Having observed these quantitative differences in the three elicitation methods, we also investigated whether these differences could be explained through gender differentiation or group effect. Our experimental results show that only under the *hot* treatment, some effects deriving from gender differentiation can be observed regarding females. The number of female subjects that chooses to be compliant in the first step game (9 subjects out of 12), in fact, sharply decreases in the second treatment (2 subjects out of 12). No gender and group differentiations emerges, instead, under both the *cold* treatment and the lotteries, where it is confirmed that the introduction of DOJ improves the number of complying subjects.

3.8 CONCLUSIONS

Criminal enforcement has always been perceived as a very important tool in deterring anti-social behaviour. However, one of the main criticisms of criminal enforcement is that often civil liability provides sufficient mechanisms of deterrence without involving expensive and protracted litigation costs (Hoffman, 1992). Some critics have also noted that criminal enforcement does not lead to optimal deterrence because prosecutors are often accused of choosing cases arbitrarily based largely on political motivations (Lazarus, 1995). Our first set of experimental findings may support such criticism as they show that it is possible to protect the environment without having to resort to criminal prosecutions. Our results, in fact, provide a first empirical validation of the theoretical outcomes obtained in the first game theory model by supporting the argument that it is more efficient to let the EPA resolve the cases internally (administratively) rather than refer them to the Department of Justice for civil or criminal prosecution. From our experimental test it emerges that the intervention of the DOJ acts merely as an additional enforcement cost which, in turn, might reduce the probability of conducting inspections by the EPA without affecting the probability of firm's compliance.

Moreover, the second set of experimental results (relative to the model in which EPA and DOJ are assumed to be characterized by different motivations on the conduction of their respective enforcement decisions) were obtained by making use of different experimental procedures in laboratory. More precisely, we calculate the probability of compliance by letting subjects play the two experimental treatments that correspond to the two games proposed in the theoretical model above - i.e. treatment without the DOJ and treatment with the

DOJ – under *cold* condition, *hot* condition and pairwise choice lotteries.

Standard economic theory assumes implicitly that preferences do not depend on the elicitation procedure and are stable over time. In accordance with this view, we find that the three elicitation methods employed do not seem to affect subjects responses qualitatively, but there is a significant quantitative difference in terms of number of observations across the three treatments. So, while in our experiments subjects' behaviour is generally internally consistent in the sense that there are no differences in results derived from *cold*, *hot* and lottery methods, some differences are noticeable in the number of observations collected. Under both *hot* and *cold* treatments some nodes of the game are not reached and then several observations are lost. More specifically, the *hot* treatment provides the smallest amount of data; the lottery experimental design provides, on the contrary, the biggest number of observations.

The overall experimental findings lead to somewhat mixed considerations in terms of environmental policy implications. The first experimental results may suggest that enhancing criminal enforcement programs would not necessarily strengthen deterrence since criminal fines might not be able to give polluters the adequate incentives to prevent environmental crimes. Criminal enforcement may, indeed, reduce the effectiveness of enforcement policies. On the other side, the second experimental results show that criminal enforcement enhances deterrence by improving firms' compliance.

On the whole, the results allow us to say also that an environmental approach in which the choice of the enforcement strategy is randomized can be successful in encouraging firms' compliance. One of the main implications of our results in terms of environmental policy suggestions is that the EPA and the DOJ, even though they jointly operate towards a better environmental quality, should not share the same objective functions but should keep and perceive them separately.

Figure 3.1 Strategic game between firm and EPA in extensive form

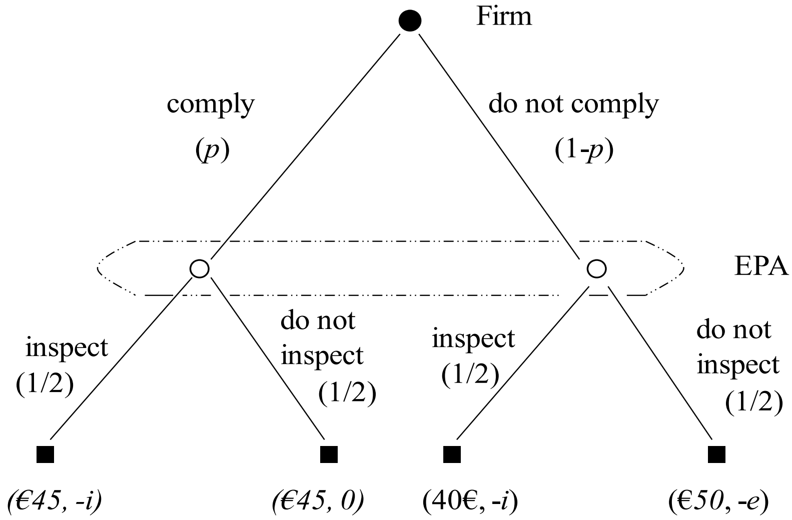


Figure 3.2 Strategic game between firm, EPA and DOJ in extensive form

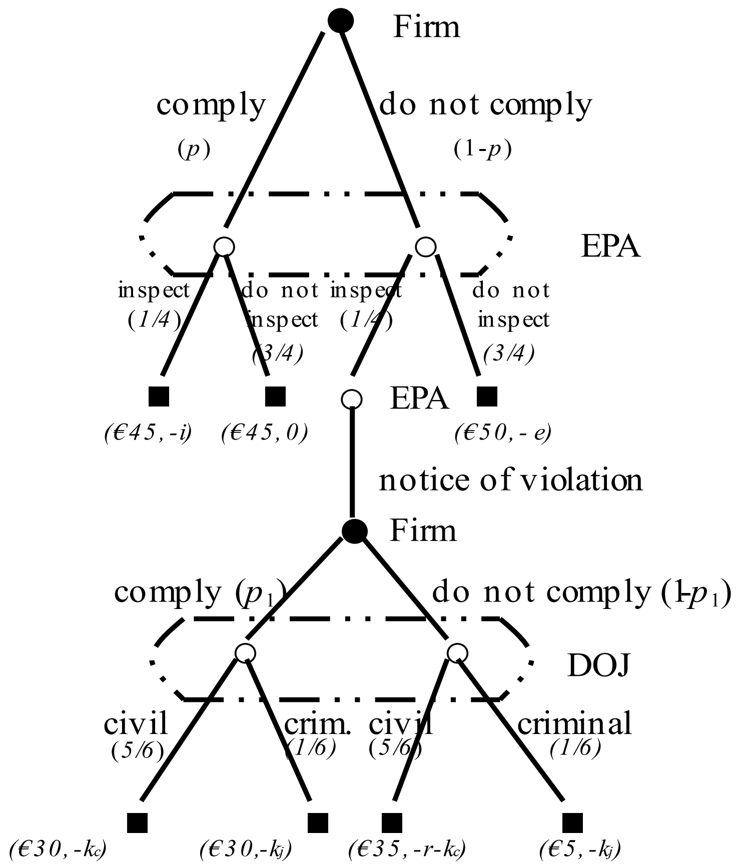


Table 3.1 Gambles of all games – summary table (first experiment)

Pairwise choice gambles	Left gamble						Right Gamble					
€	*5*	*30*	*35*	*40*	*45*	*50*	*5*	*30*	*35*	*40*	*45*	*50*
Gamble 1	0	0	0	0	1	0	0	0	0	0.5	0	0.5
Gamble 2	0	0	0	0	1	0	0	0.25	0	0	0	0.75
Gamble 3	0	0	0	0	1	0	0.05	0	0.2	0	0	0.75
Gamble 4	0	0.25	0	0	0	0.75	0.05	0	0.2	0	0	0.75

Figure 3.3 Gambles of the game between firm and EPA

Lottery A **Lottery B**

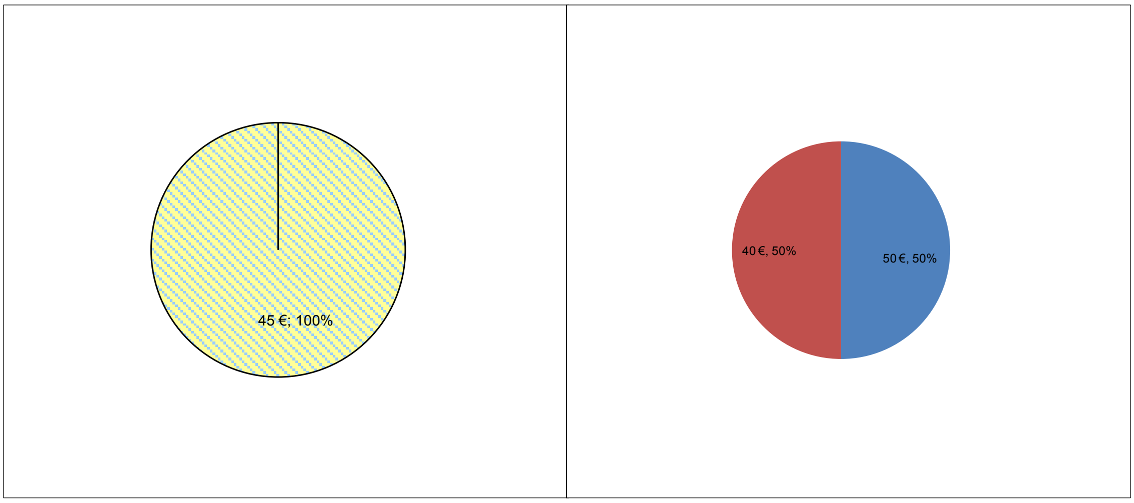


Figure 3.4 Strategic game between firm and EPA in extensive form

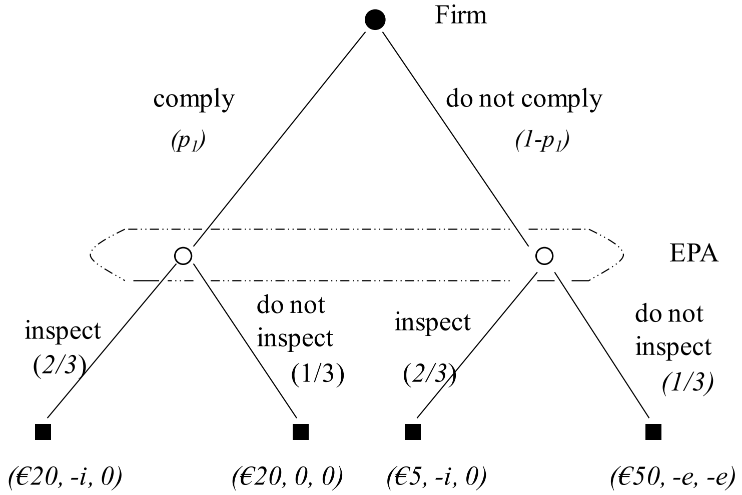


Figure 3.5 Strategic game between firm, EPA and DOJ in extensive form

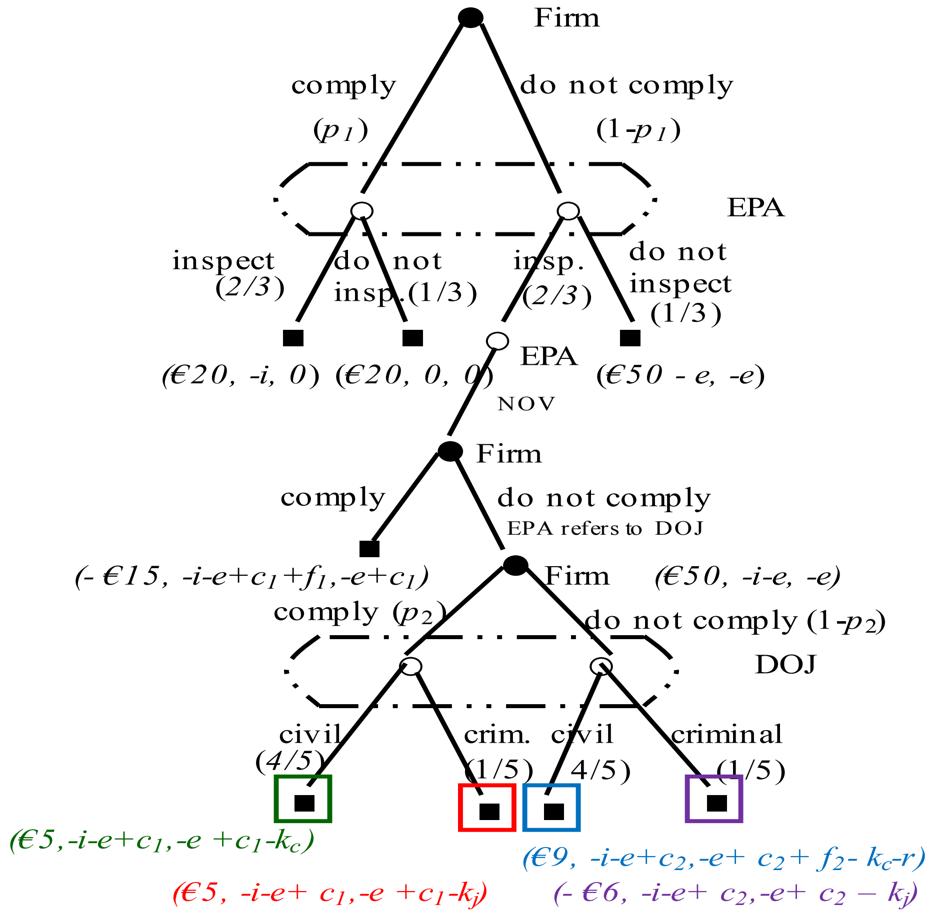


Table 3.2 Gambles of all games – summary table (second experiment)

Pairwise choice gambles	Left gamble						Right Gamble					
€	*-15*	*-6*	*5*	*9*	*20*	*50*	*-15*	*-6*	*5*	*9*	*20*	*50*
Gamble 1	0	0	0	0	1	0	0	0	0.66	0	0	0.33
Gamble 2	0	0	0	0	1	0	0.66	0	0	0	0	0.33
Gamble 3	0	0	0	0	1	0	0	0.18	0	0.49	0	0.33
Gamble 4	0.66	0	0	0	0	0.33	0	0	0.66	0	0	0.33
Gamble 5	0.66	0	0	0	0	0.33	0	0.18	0	0.49	0	0.33
Gamble 6	0	0	0.66	0	0	0.33	0	0.18	0	0.49	0	0.25

Figure 3.6 Gambles of the game between firm and EPA

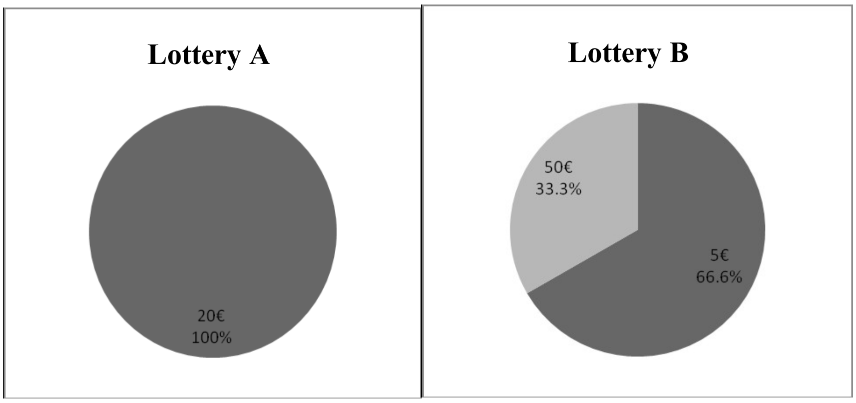


Figure 3.7 Subjects' behaviour in the game between firm and EPA- results

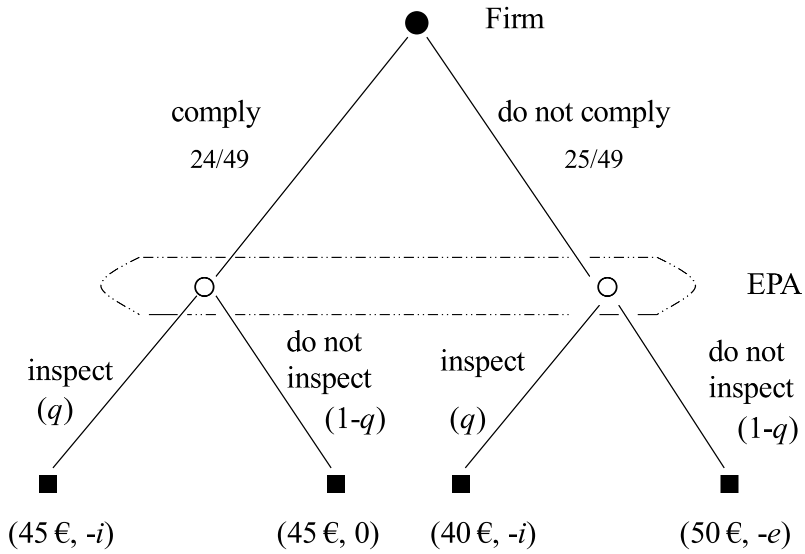


Figure 3.8 Subjects' behaviour in the game between firm, EPA and DOJ - results

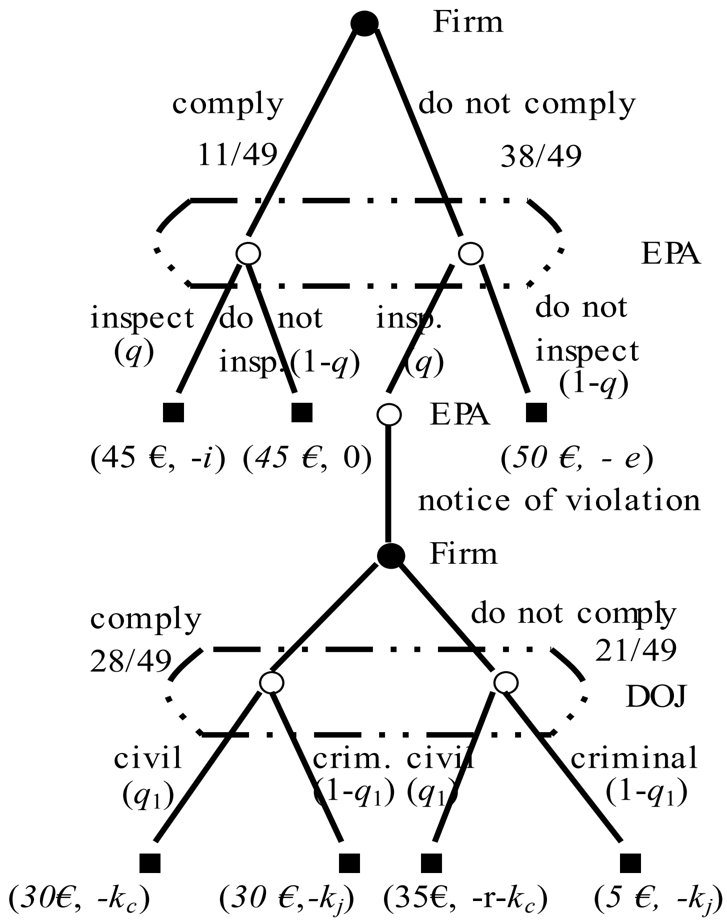


Figure 3.9 Strategic game between firm and EPA under hot method- results

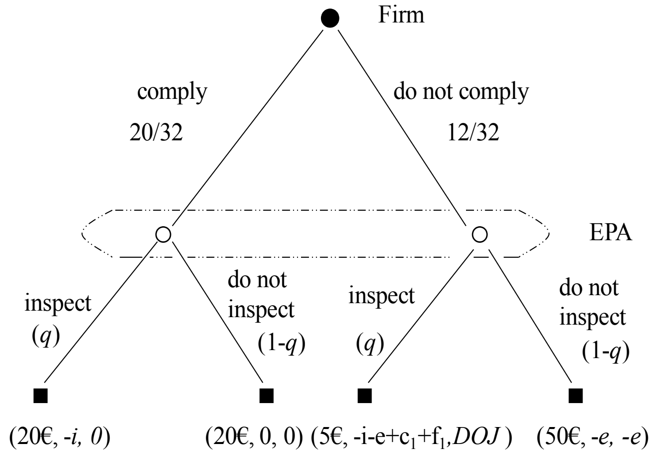


Figure 3.10 Strategic game between firm and EPA under cold method-results

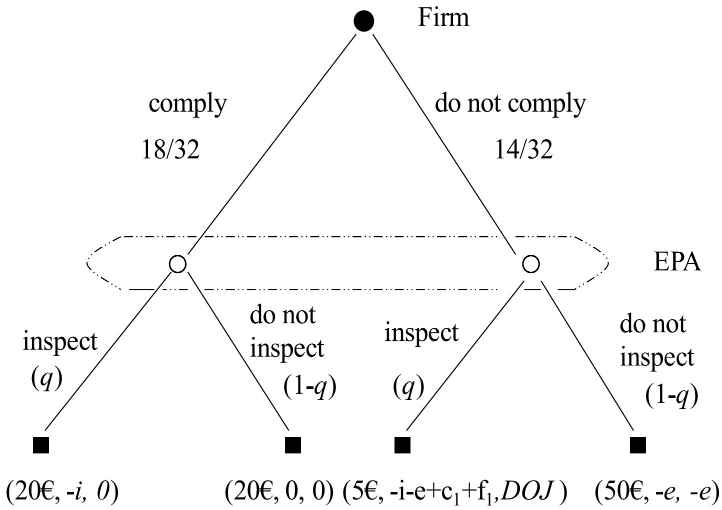


Figure 3.11 Strategic game between firm and EPA under lotteries method-results

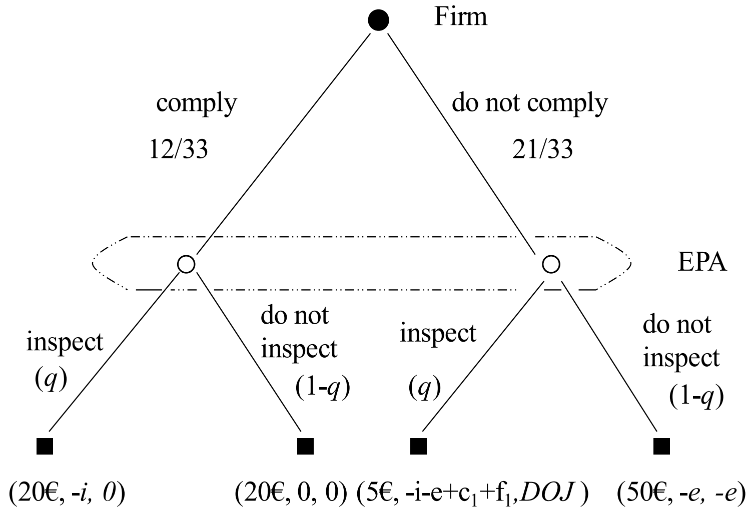


Figure 3.12 Strategic game between firm, EPA and DOJ under hot method-results

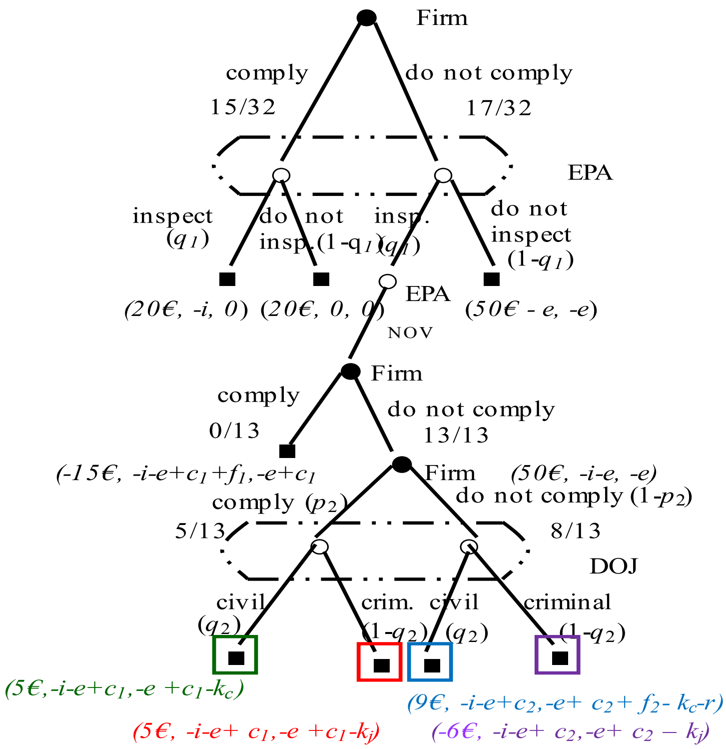


Figure 3.13 Strategic game between firm, EPA and DOJ under cold method-results

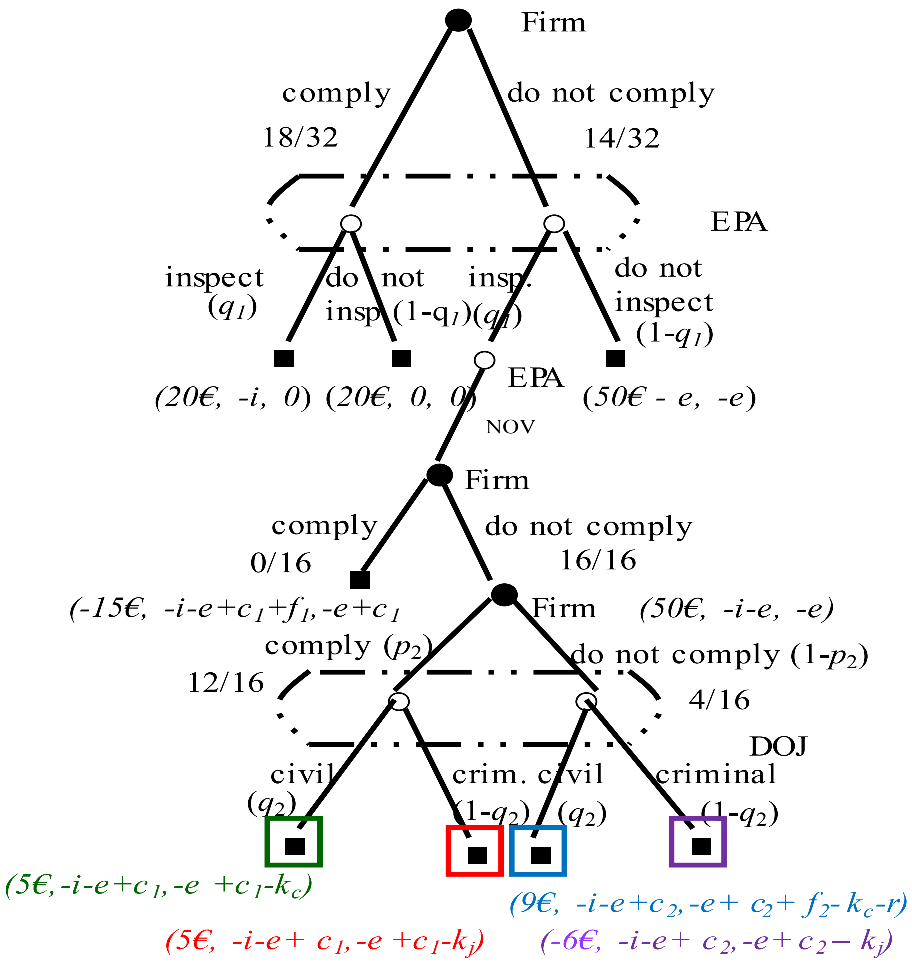
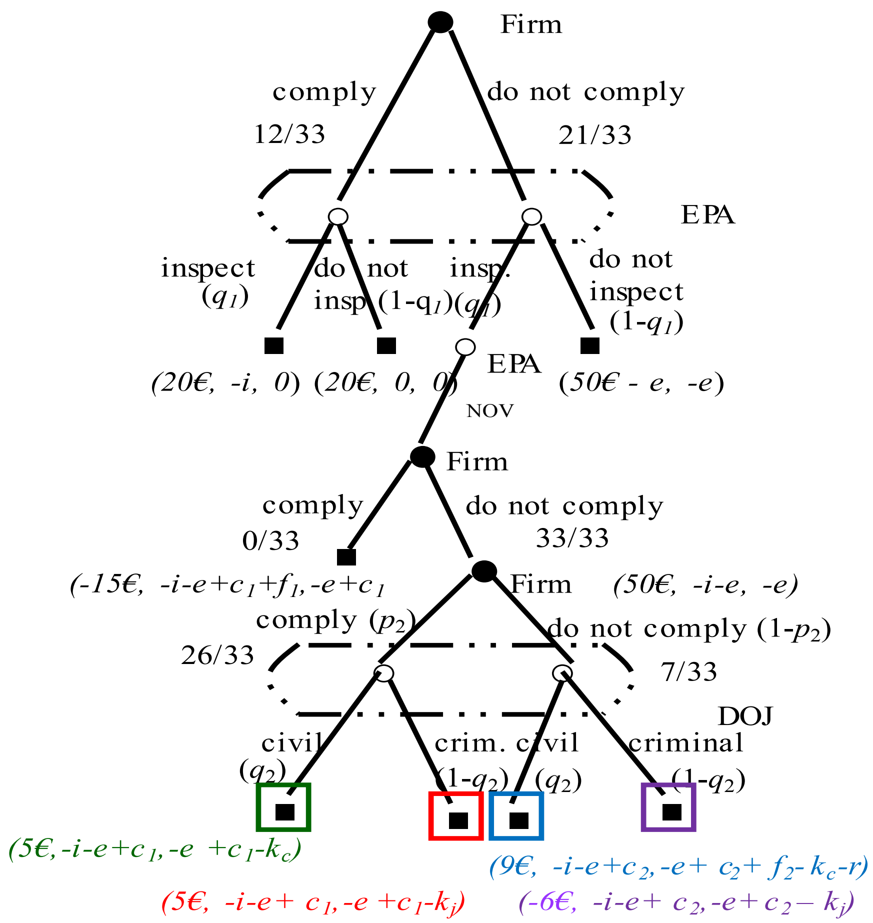


Figure 3.14 Strategic game between firm, EPA and DOJ under lotteries method- results



APPENDIX: EXPERIMENTAL INSTRUCTIONS (ORIGINALLY IN ITALIAN)

In this appendix, we report the instructions that we used for the treatments played.

Instructions for participating to the experiment (these instructions are the same for both experiments).

Welcome and thank you for having accepted to participate at this experiment. You will receive €5 for participating. Please, carefully read the following instructions that are identical for every participant.

During the experiment you are not allowed to talk with any of the other participants. If you will not respect this rule you will be excluded from the experiment and you will not receive any payment.

If you have any question, please, raise your hand and wait that one of the experimenters will come close to you to respond to your answer.

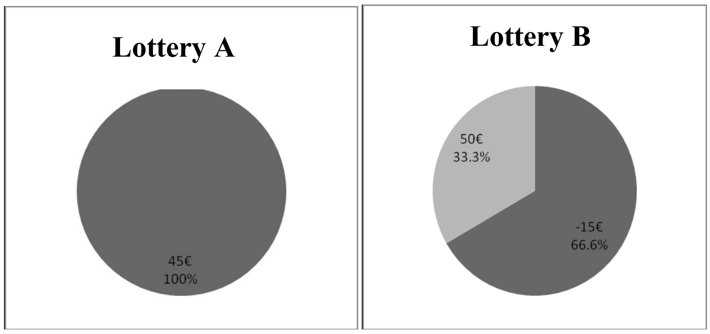
What you will earn will depend partly by your choices and partly by the case. You will earn €5 for being here plus the half of the overall amount you will gain during the experiment will be paid cash directly at the end of the experiment.

FIRST EXPERIMENT

Information on the experiment

In this part of the experiment you will see four pairwise choice gamble lotteries, as follows.

For every pairwise lottery you will have to specify if you prefer to play lottery A or lottery B.

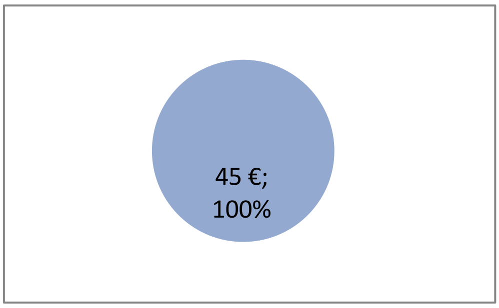


If you choose lottery A you will receive €75 with certainty, if you choose lottery B you will receive €50 with 75% of probability and €100 with 25% of probability. You will find ten pairwise choice lotteries: your task is to choose for every pair of lotteries if you prefer lottery A or lottery B.

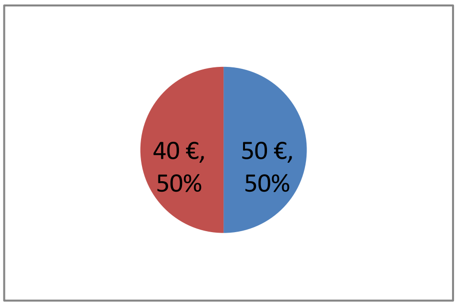
Turn page and begin the experiment!

1.

Lottery A

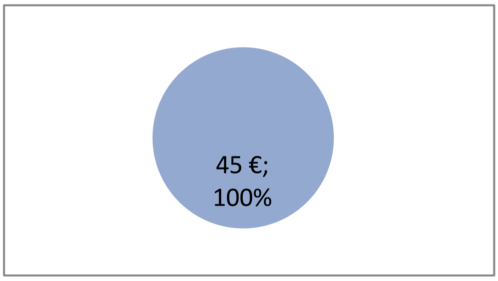


Lottery B

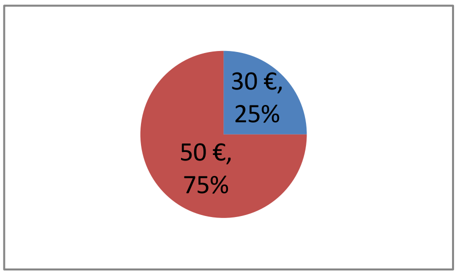


2.

Lottery A

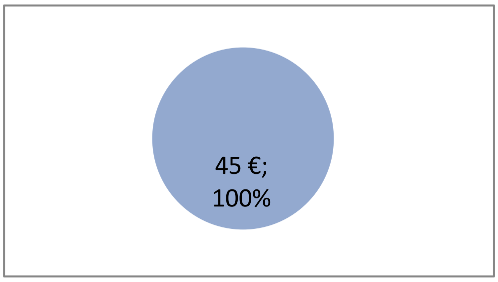


Lottery B

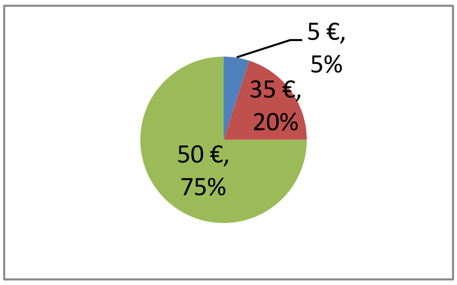


3.

Lottery A

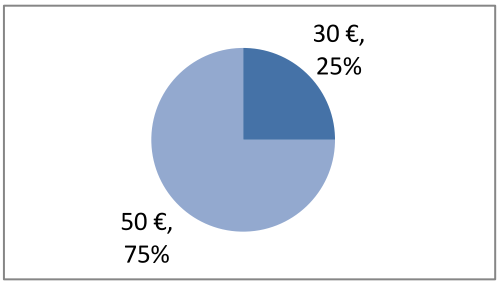


Lottery B

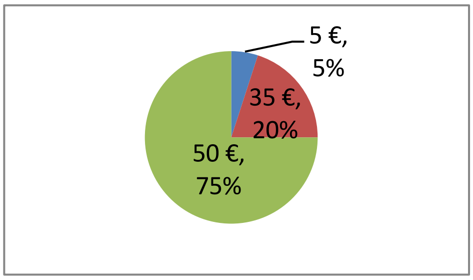


4.

Lottery A



Lottery B



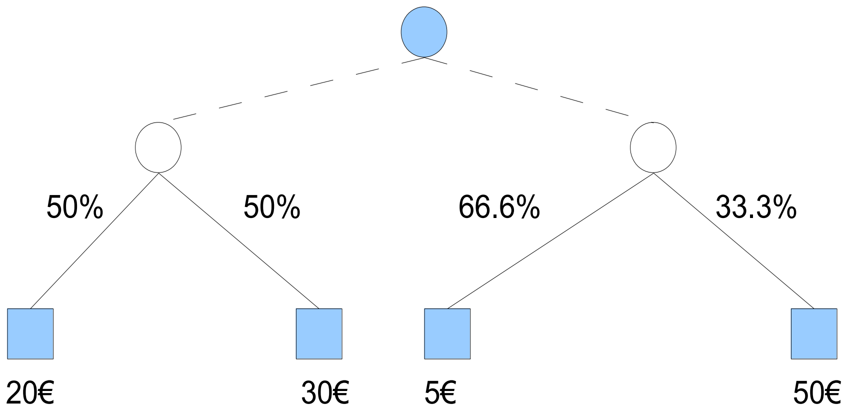
SECOND EXPERIMENT

Information on the experiment

The experiment is made of three independent parts. Your choices in each part would not influence in any way the outcomes that you will reach in the successive parts. You will be paid only for one of the three parts which will be randomly determined at the end of the experiment. Therefore, you should try to be as more accurate as possible in every part of the experiment since your profit will depend only by one of the three parts.

Information on Part 1 (cold)

In this part of the experiment you will see two figures (called trees) as the one presented below.



In the above presented tree, as example, starting from the dark circle (called node) you should choose whether to move on the right or on the left side of the tree. To identify your choice, you have to underline with your pen one of the two dotted lines. If you choose left, you will play a lottery where you could win €20 with 50% of probability or €30 with 50% of probability. If you choose right, you will play a lottery where you could €5 with 66.6% of probability or €50 with a probability of 33.3%.

In the trees presented in this first part, you should make a decision every time you reach a node followed by dotted lines.

Turn page and start your experiment.

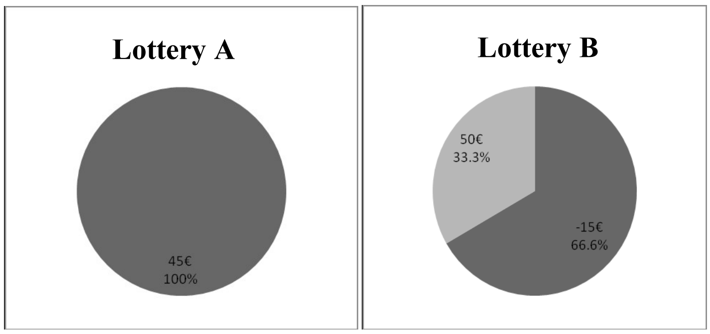
Information on Part 2 (hot)

The second part of the experiment is identical to part one, but now every time you make a decision, underlining a dotted line, you have to raise your hand to call one of the experimenters that are in the classroom to know how to proceed.

Information on Part 3 (lottery)

In this part of the experiment you will see six pairwise choice gamble lotteries, as follows.

For every pairwise lottery you will have to specify if you prefer to play lottery A or lottery B.

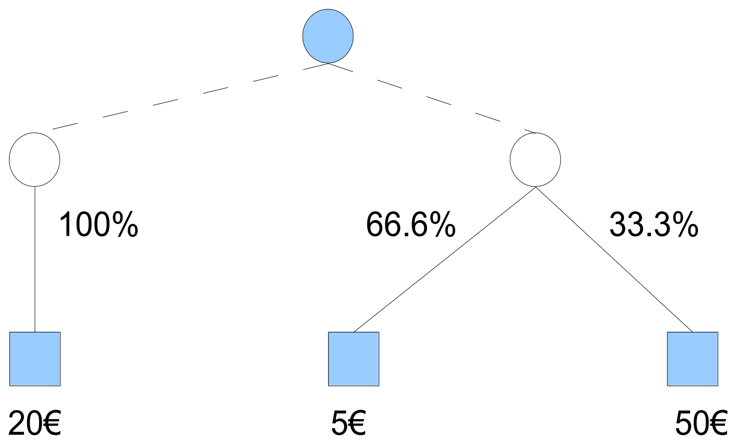


If you choose lottery A you will receive €75 with certainty, if you choose lottery B you will receive €50 with 75% of probability and €100 with 25% of probability. You will find ten pairwise choice lotteries: your task is to choose for every pair of lotteries if you prefer lottery A or lottery B.

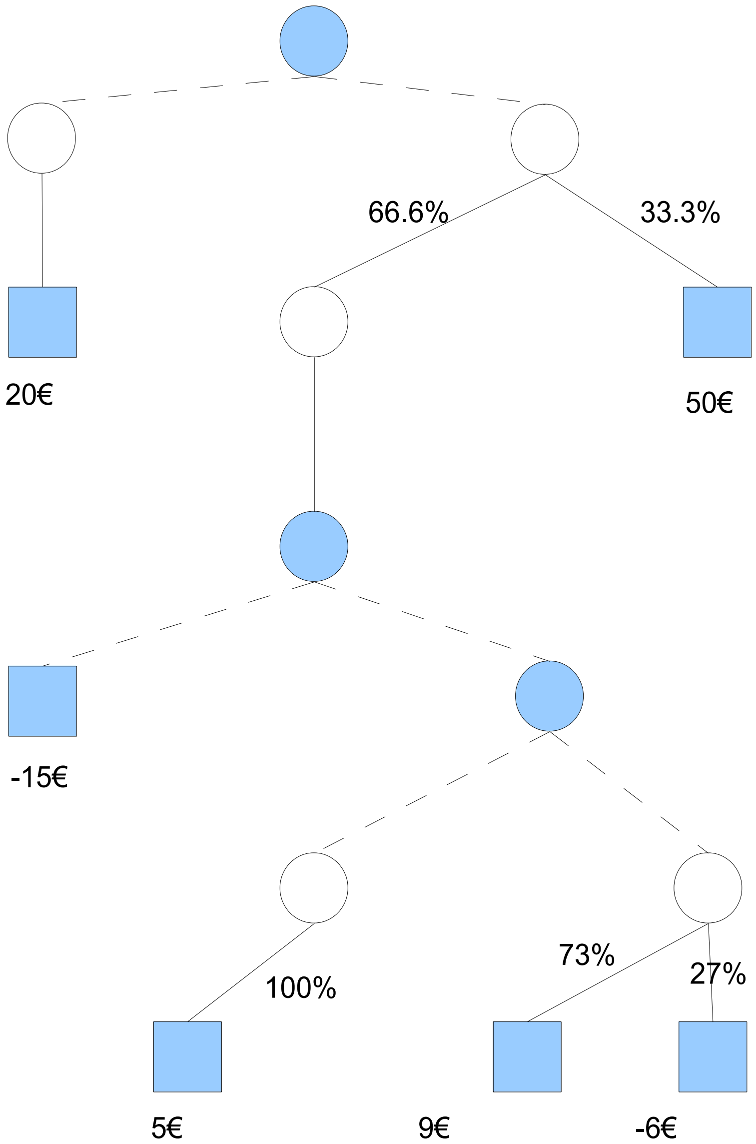
Turn page and begin the experiment!

Game Trees (under both *cold* and *hot* procedures)

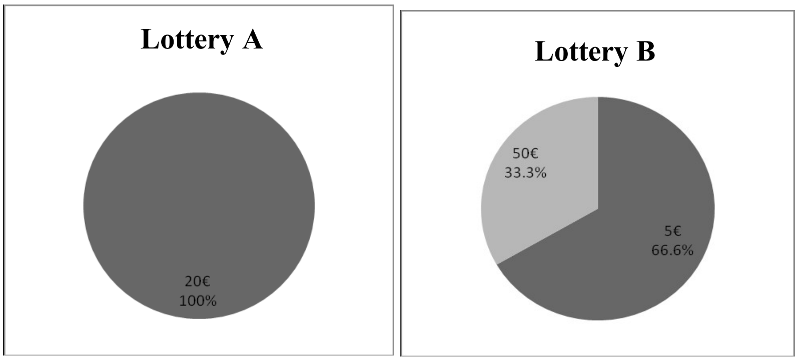
Game Tree 1



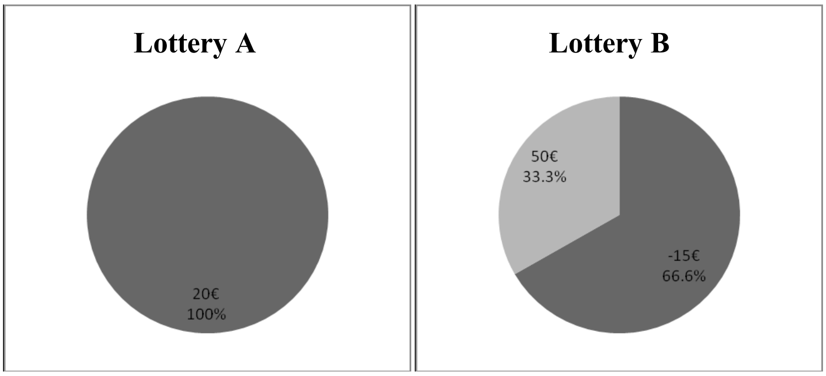
Game Tree 2



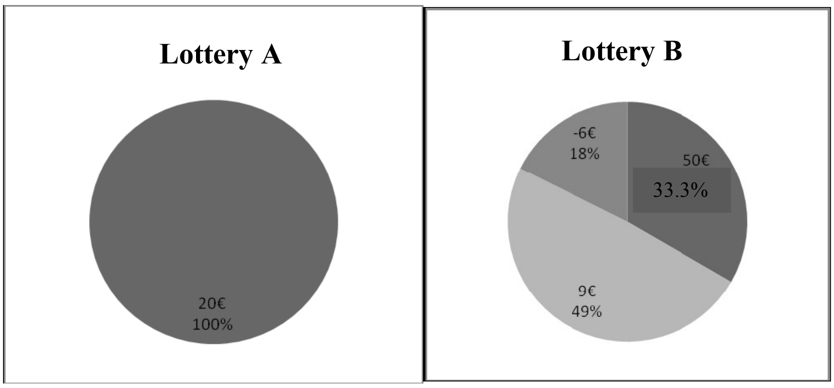
1.


Lottery A
20€
100%
Lottery B
50€
33.3%
5€
66.6%

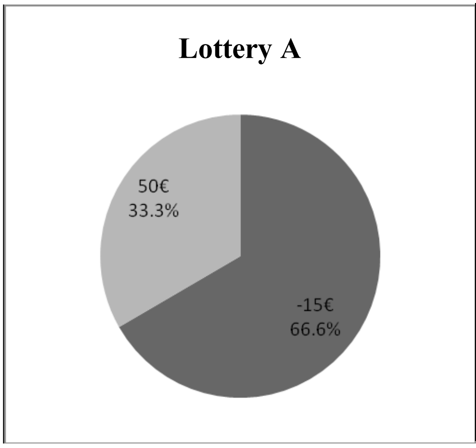
2.

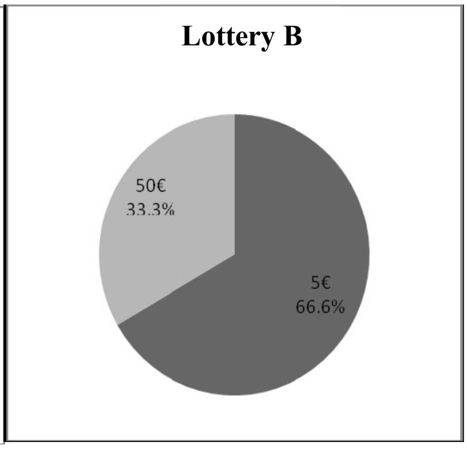

Lottery A
20€
100%
Lottery B
50€
33.3%
-15€
66.6%

3.

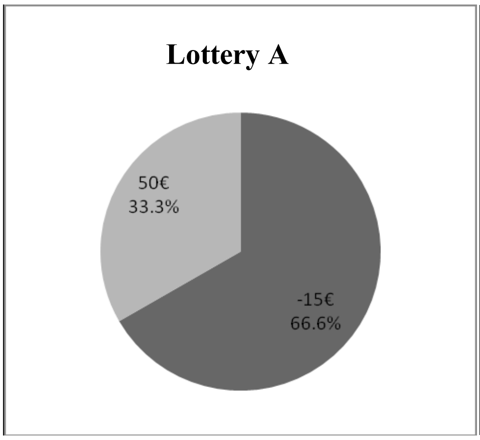

Lottery A
20€
100%
Lottery B
-6€
18%
50€
33.3%
9€
49%

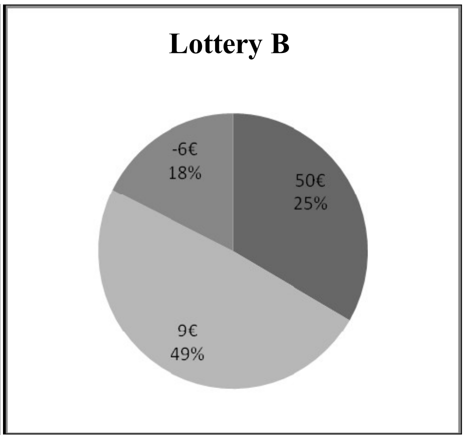
4.


Lottery A
50€
33.3%
-15€
66.6%

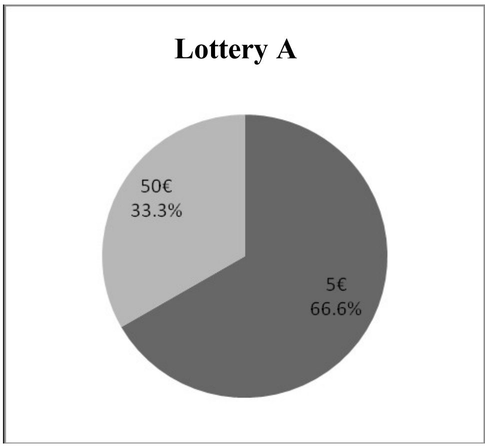

Lottery B
50€
33.3%
5€
66.6%

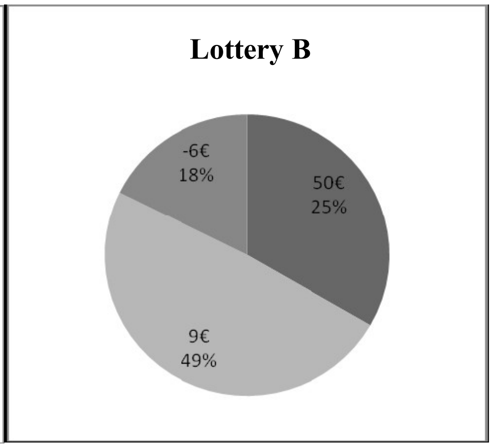
5.


Lottery A
50€
33.3%
-15€
66.6%


Lottery B
-6€
18%
50€
25%
9€
49%

6.


Lottery A
50€
33.3%
5€
66.6%


Lottery B
-6€
18%
50€
25%
9€
49%

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CHAPTER FOUR

ENFORCEMENT AND AIR POLLUTION: AN ENVIRONMENTAL JUSTICE CASE STUDY

4.1 INTRODUCTION

Environmental justice is a movement that emerged in the United States in the 1980s[39] and has become a concern in the U.S. federal policy agenda in the early 1990s. In 1994, in fact, environmental justice was institutionalized at federal level through an Executive Order[40] which focused attention on human health and environmental conditions in low-income and minority communities. The key concept of environmental justice issues is that low-income groups and ethnic minorities bear disproportionate environmental burdens, in the form of polluted air and water, unsafe jobs, under-enforcement of environmental laws, etc. (Ringquist, 1997; Evans and Kantrowitz, 2002).

As argued by Ringquist and Clark (1999), environmental equity involves an equal distribution of environmental risk across all social classes, races and geographic areas. The concept of environmental equity is substantially similar to environmental justice, with the only difference that the latter has a stronger nuance in terms of environmental policy. Environmental justice, thus, deals mainly with the question of whether disadvantaged population groups, such as racial and socioeconomic minorities, are disproportionately exposed to pollution and whether demographic composition influences the amount of pollutants. However, while environmental groups continue to focus their attention on

[39] More exactly, the environmental justice movement was launched in 1982, when residents of Warren County (North Carolina) protested the construction of a hazardous waste landfill in their predominantly African-American community.

[40] Title VI of the Civil Rights Act of 1964 prohibits discrimination on the basis of race, color, or national origin. Environmental justice as a national policy goal was first through Executive Order 12898.

environmental justice problems, the evidence from empirical studies has been ambiguous. There is no general agreement on whether minorities or disadvantaged population groups are exposed to more pollution, and if so which minorities (racial, age, socioeconomic) are more at risk.

In the United States it has been widely shown that socioeconomic status and ethnicity are associated with exposures to environmental hazards (Brown, 1995; Arora and Cason, 1999). In particular, minorities and people with low income often tend to live closer to contaminated sites, thus suffering more than the general population from adverse environmental risks. Contrary to the United States, as far as we know in Italy the impact of socioeconomic factors on environmental outcomes has been rarely studied. Empirical analyses on Italian data with focus on social inequalities in exposures to traffic emissions have only been done with regard to the city of Rome (Forastiere *et al.*, 2007), and on waste generation and landfill diversion (Mazzanti *et al.*, 2009).

This chapter aims to cover this gap in the empirical literature by investigating whether income and the ethnic and social composition of population in Italy may have a role in explaining air emissions. The analysis is conducted at the provincial level[41] to investigate the existence of provincial differences in the determination of environmental pollution. Air pollution emissions data (from 2005 data) were combined with data from the latest available Italian Census (the 2001 Italian Census). The main objective of this chapter is twofold: first we assess whether the economic characteristics (such as income levels, percentage of foreigners, percentage of children, etc.) of provinces help to explain the level of emissions in the air; secondly, we test the social inequality hypothesis linked to air pollution. The results obtained show no evidence of environmental inequity against the foreign component of the population but provide evidence that releases are higher in provinces with higher percentage of both children and female-headed households. These first results imply that, in Italy, environmental injustices are more likely to be observed in terms of social conditions that in terms of racial

[41]In Italy, a province is an administrative sub-division of a region, which is an administrative sub-division of the State. A province consists of several administrative sub-divisions called "comune". Italy was divided into 103 provinces at the time we collected our data; as of 2011, there are 110 provinces. Provinces are equally distributed on the territory between north west, north east, centre and south, even though the level of urbanization is higher in the northern part of the country.

discrimination.

The environmental justice issue is closely linked to the enforcement issue. In fact, the enforcement of environmental quality regulations is an important element of any environmental policy: only a coherent and homogeneous enforcement of laws guarantees the inexistence of social or ethnic inequalities in exposure to environmental risk. In order to account for the enforcement issue, we consider the number of pending proceedings in the courts located in the Italian provinces as a measure of the inefficiency of law enforcement. Arguably pollution will be lower in provinces with efficient courts and efficient enforcement, since long trials are likely to postpone the timing of punishment (Becker, 1968) and this could be an important factor inducing firms to commit illegal activities.

The remainder of the chapter is organized as follows. Section two presents a review of the key conceptual issues that are addressed by the environmental justice literature. Section three presents the theoretical framework. In sections four and five, respectively, the model specifications and the datasets used in the analysis are discussed, while in section six the results from the estimations are presented. Section seven concludes with some final considerations in which are discussed, in particular, the potential implications (if any) between enforcement of air emissions regulation and low-income groups in Italy.

4.2 KEY REFERENCES IN LITERATURE

The relationship between the distribution of environmental pollution and the population characteristics has been studied by a substantial body of literature. In the next two sections, the main U.S. and E.U. empirical contributions on this issue are reviewed.

4.2.1 U.S. EMPIRICAL EVIDENCE

In the United States, the pioneering study on race and environmental quality *Toxic Wastes and Race in the United States* was conducted by the United Church of Christ's (UCC) Commission for Racial Justice (1987). Race is found to be the most significant variable associated with the location of hazardous waste sites since communities with the greatest number of hazardous waste facilities had the highest composition of racial and ethnic population. The study also found that three out of every five African Americans lived in communities with abandoned toxic waste sites and that 60 percent of African Americans lived in communities with one or more waste sites.[42] Twenty years after the release of *Toxic Wastes and Race*, the recent results by Bullard *et al.* (2010) are still very similar to the findings from 1987. They confirm that significant racial and socioeconomic disparities persist today since Hispanics or African Americans are concentrated in neighbourhoods with the greatest number of hazardous waste facilities.

Over the last two decades, environmental justice literature has grown very rapidly. However, mixed evidences were obtained by various studies. Numerous studies document inequities in the spatial distribution of environmental quality (e.g., Bullard, 1983; Bullard and Wright, 1987, 1989; Goldman, 1991; Nieves and Nieves, 1992; Hamilton, 1993, 1995) and many others find limited support for the existence of environmental inequities (e.g., Anderton *et al.*, 1994; Been and Gupta, 1997). Anderton *et al.* (1994) and Been and Gupta (1997) use binary response models to analyze plant location decisions, comparing neighbourhoods with industrial plants to neighbourhoods without a plant. Anderton *et al.* (1994), using the 1980 U.S. census data and employing multivariate regression techniques to investigate environmental equity in the demographics of dumping, find that education and occupation, but not race, are significant indicators of waste facilities in a region. Been and Gupta (1997) using 1990 U.S. census data investigated, through multivariate techniques, whether waste facilities were placed in minority communities or minorities moved in afterwards. They obtain mixed evidence on environmental inequities: while waste disposal sites proved to be correlated with race and income, neither the percentage of poor nor the percentage of African Americans were significant factors in deciding the siting of waste sites.

Mohai and Bryant (1992) reviewed fifteen various environmental inequity studies conducted between 1971 and 1992 and concluded that nearly all the

[42] More precisely, the report found that zip code areas with one hazardous waste facility had twice the nonwhite population (24%) than those without such facilities, and that communities with more than one waste facility had an average 38% of nonwhite population (the national average nonwhite population was 16%.).

studies showed evidence of inequities, based on income and race, in the distribution of environmental hazards. The fifteen studies varied substantially in terms of geographic areas considered. About half of the studies focused on a single urban area, while the rest focused on a region, an aggregation of urban areas, or the U.S. as a whole. Eleven of the studies examined the distribution of air pollution, four examined the distribution of solid or hazardous waste facilities, while one focused on toxic fish consumption. The scale and the statistical methods employed cannot always be determined from the Mohai and Bryant review. They also suggest that factors such as housing discrimination and the location of jobs may have led poor and racial minorities to move closer to hazardous facilities due to the cheapest available housing and potential job opportunities.

More recently, Cory and Rahman (2009) studied the association between income, race and hazardous levels of arsenic concentrations in Arizona and found no supporting evidence that selective enforcement of the arsenic standard could disadvantage minority or low-income groups. They use data on arsenic water concentration and socioeconomic data from 2000 U.S. Census. Out of 359 zip-code areas, 121 were found to be exposed to arsenic levels greater than the maximum level of arsenic allowed in water, while the other 238 were not exposed. They use logistic regression models to estimate the relationship between the likelihood of arsenic contamination at zip-code level and its associated demographic and economic characteristics. The dependent variable is arsenic exceedance in respect to the maximum level and the explanatory variables are the following: percent of white population, percent of black population, percent of Hispanic population, percent of minority (black and Hispanic population), per capita family income, average value of house and average income per household. If a particular zip-code had average arsenic concentration greater than the maximum limit allowed it was assigned the value of 1, otherwise it was assigned the value of 0. Their results support the conclusion that selective enforcement of arsenic standard is unlikely to have disadvantaged minority or low-income groups in Arizona.

In another work, however, Aradhyula *et al.* (2006) found the existence of disproportionate environmental risk in low-income and minority communities for the Phoenix metropolitan area in Arizona. Using data from 1990 and 2000 U.S. Census and from the Toxic Release Inventory (TRI),[43] they estimate a simultaneous equations model to explain jointly firms' siting decisions and minorities' decision to move. Their results suggest two main conclusions. First, there is a positive and highly significant relationship between TRI exposure and minority communities. Second, the presence of a TRI facility increased the minority share in a community by nearly 10%.

As a matter of fact, notwithstanding the U.S. well-established literature, there is still significant disagreement whether race and social class generate environmental inequities in the United States. This is partially explained by the sensitivity of Environmental Justice results to the type of contaminant considered, its geographical location, and the spatial unit of analysis.

4.2.2 E.U. Empirical Evidence

The environmental justice debate is only beginning to develop at the European Union level. This approach can be dated from the drafting of the UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, adopted at the Fourth Ministerial Conference in the *"Environment for Europe*" process in Aarhus (1998). In its Article 1, the Convention states as an objective to "guarantee the rights of access to information, public participation in decision-making, and access to justice in environmental matters in accordance with the provisions of this Convention."

However, especially in the U.K. the environmental justice debate has started to expand by integrating environmental issues and social justice perspective. In Europe, in fact, the majority of the empirical studies took place in U.K. In England and Wales, McLeod *et al.* (2000) investigate the relationship

[43] The U.S. Toxics Release Inventory is a database compiled and maintained by the EPA since 1981. Over 75,000 companies are required to report their emissions to the EPA by chemical and amount released. So through the TRI the EPA collects data on toxic chemical releases and waste management activities.

between particulate matter (PM_{10})[44], nitrogen dioxide (NO_2) and sulphur dioxide (SO_2), and a vector of socioeconomic indicators. They found that higher social classes were more likely to be exposed to greater air pollution. In contrast, Brainard *et al.* (2002) found that the level of NO_2 and carbon monoxide (CO) in Birmingham was higher in communities with a greater proportion of black people and deprived classes. They found that the average carbon monoxide and nitrogen dioxide emissions for districts with poor populations are higher than in wealthy ones. The averages of these pollutants were also higher among districts with high proportion of blacks than among more white districts. Wheeler and Ben-Shlomo (2005) also found that air quality is poorer among households of low social class. More recently, social inequalities in NO_2 levels in Leeds were confirmed by Namdeo and Stringer (2008) at the detriment of poorer groups. Naess *et al.* (2007) using a number of socioeconomic indicators (income, education, living in a flat or in a crowded household) showed that in Oslo (Norway) the most deprived areas were exposed to higher particulate matter emission levels. In contrast, no association between nitrogen dioxide emission levels and education or occupation was found in a cohort of Norwegian men.

Environmental inequalities were explored also in Helsinki (Finland) by Rotko *et al.* (2000) and Rotko *et al.* (2001): levels of NO_2 decreased with a higher level of education. Much greater contrasts in exposure were observed between socio-economic groups for men than for women, both for NO_2 and $PM_{2.5}$. In Sweden, two studies showed evidence of social inequalities related to NO_2. Stroh *et al.* (2005) found that the strength of the association between the socio-economic status and NO_2 concentrations varied considerably between cities. In another

[44] Particulate matter of solid or liquid matter suspended in the atmosphere; PM_{10} particles (<10 μm) and $PM_{2.5}$ particles (<2.5 μm) are of major health and environmental concern. Fine particulates (PM_{10} and $PM_{2.5}$) together with nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and benzene are part of the Air Quality Strategy (AQS) (DETR 2000) developed in response to the 1995 Environment Act and the EU Air Quality Framework Directive (96/62/EC). Each of these pollutant can have potential effects on health. Short-term and long-term exposure to ambient levels of particulate matter are associated with respiratory and cardiovascular illness and mortality as well as other ill-health effect (DEFRA, 2007; World Health Organization, 2005; Committee On the Medical Effects of Air Pollutants, 2007). At high levels NO_2 causes inflammation of the airways. Long term exposure may affect lung function and respiratory symptoms (DEFRA, 2007). Carbon monoxide substantially reduces capacity of the blood to carry oxygen to the body's blocking important biochemical reactions in cells (DEFRA, 2007). SO_2 causes constriction of the airways of the lung. Benzene is a recognized human carcinogen (DEFRA, 2007).

study, Chaix *et al.* (2006) found that children from areas with low neighbourhood socio-economic status were more exposed to NO_2 both at home and at school.

Four other European studies explored social inequalities related to air pollution. In Rijnmond (Netherlands), according to Kruize *et al*. (2007), lower income groups live in areas with higher levels of NO_2 than greater income groups. In Germany, Schikowski *et al*. (2008) revealed the existence of a social gradient with higher PM_{10} exposures among subjects with less than 10 years of schooling than among those with higher education. By contrast, in Rome, Forastiere *et al.* (2007) found that the higher social classes appear to reside in areas with high traffic emissions. This disparity is even stronger when socio economic status rather than income is considered. Havard *et al.* (2009), using a French deprivation index (Havard *et al.* 2008), found that in Strasbourg the mid-level deprivation areas were the most exposed to NO_2, PM_{10} and CO.

From this review, it is clear that in Europe the empirical literature that investigates the relationship between exposure to environmental pollution and socio-economic status is a relatively novel topic compared to the USA. European studies (similarly to the U.S. literature) also generate mixed findings regarding exposure disparities. Italy is one of the less investigated countries. In what follows we aim to cover this gap by trying to establish the existence or not of environmental injustices.

4.3 THEORETICAL FOUNDATIONS

The environmental justice literature has its own theoretical roots in the "inverse U" relationship, commonly referred to as the *Environmental Kuznets Curve* (EKC), which suggests that the level of per capita income has a negative effect on environmental quality measured by the levels of pollution, but, beyond a certain level, per capita income has a positive effect on environmental quality. A crucial issue becomes the existence of a turning point in the relationship between income and pollution. The EKC assumes that the relationship between environment and income might be similar to that suggested by Kuznets (1955) between income inequality and economic development. Since the pioneering works by Grossman and Krueger (1991, 1993, 1995) on the environmental Kuznets curve, there has been a large amount of both theoretical and empirical studies.[45] A comprehensive review of the literature on EKC is provided by Brock and Taylor (2005) whose analysis aims to underline how a non-monotonic inverted U-shaped curve may emerge from the relationship between income and pollution emissions.

The so-called environmental justice approach aims to expand the structural factors assumed to drive the environmental Kuznets curve relationship, in order to better integrate economic and social issues with environmental issues. Ethnic diversity and race have been the most significant variables which have been neglected in empirical studies (for example, Cole *et. al.* 1997; Selden and Song, 1994) on the EKC, but that have started to be used by the environmental justice literature to investigate the possible causal relationship between income inequalities and pollution levels. The EKC function usually takes the form $E_{it} = \alpha + \beta Y_{it}/pop + \gamma(Y_{it}/pop)^2 + \varepsilon$ (Stern and Common, 2001) where E is environmental degradation, Y is real income, pop is population, ε is an error term, i is location, t is time and α, β and γ are parameters to be estimated.

Grossman and Krueger (1994) argue that knowledge of the shape of the relationship between environment and income could help policy makers in improving or developing new environmental policies. However, as de Bruyn *et al.* (1998) point out, studies on EKC are based on reduced-form models. This means that the endogenous variable (environmental quality) is expressed only as a function of predetermined variables, and no indication about the direction of causality (whether growth affects the environment or vice versa) is known. As stated by Cole *et. al.* (1997, p. 401) reduced-form relationship "reflect correlation

[45] In particular, Grossman and Krueger analyse the EKC through the discussion of three different mechanisms: scale effect, composition effect and technique effect. Scale effect shows that even if the structure of the economy and technology does not change, an increase in production will result in an increase of pollution and environmental degradation. Thus, economic growth through scale effect has a negative impact on the environment. On the other hand, the authors argue that composition effect may have a positive impact on the environment. Pollution increases in the earlier stages of development, while in the later stages of development pollution decreases as the economic structure moves towards services and light manufacturing industries. Therefore, composition effect could lower environmental degradation through this change in the structure of production. Finally, technique effect captures improvements in productivity and adaptation of cleaner technologies, which will lead to an increase in environmental quality.

rather than causal mechanism".

To motivate this empirical analysis, we adopt the theoretical framework developed by Hamilton (1995) in which he puts forward three alternative explanations to account for the pollution patterns examined in environmental justice studies: *i)* pure discrimination related to race/gender, *ii)* the Coase Theorem, and *iii)* the theory of collective action (Olson, 1965).

Under the race/gender discrimination hypothesis, facility operators are assumed to look at the racial composition of communities surrounding polluting facilities and decide to locate or increase releases in areas with higher concentrations of minority or low-income groups. Hence, race is perceived to be a factor behind such decisions, that prevails compared to other economic factors (i.e., costs, efficiency) that would be of greater importance to a rational profit-maximizing firm. Mohai and Bryant (1992) have identified a number a possible relationships between race/gender composition and facilities' siting decisions, such as *(a)* lower costs of doing business (due to the availability of lower land values and lower incomes in minority communities); *(b)* lack of conflict in poor areas due to weak political power or insufficient community resources; and *(c)* limited mobility of minorities due to poverty and housing discrimination.

The second explanation applies the standard version of the Coase theorem, suggesting that, in a world without transaction costs, a polluting firm will locate (or increase pollution) in areas in which the releases will cause the least damage. Looking for the lowest damage can be translated, from the polluting firm's perspective, in locating in areas where potential compensation demands (i.e., for adverse health impacts and property loss caused by exposures to pollution) and liability costs are expected to be lower. Areas with higher incomes and property values will increase the potential damages from releases in an area, so polluting firms will attempt to conduct these activities in areas with low income residents and associated lower property values.

Finally, under the last explanation, firms may decide to increase releases in minority and poor communities areas because they face less (political) collective actions. In an ideal Coasean world, the "victim" would be able to negotiate compensation directly with the polluter. However, the compensation demands, in reality, are typically negotiated at community level through the political process. This could lead to results that appear similar to the pure race/gender discrimination hypothesis: firms will decide to locate or increase releases in areas where they face the lowest political opposition to their actions. To the extent that minority communities are less likely to be politically active, then these communities will be more likely to experience higher levels of pollution.

These alternative theories predict that certain variables should explain pollution levels. The race/gender discrimination hypothesis tests whether factors such as the race and the gender composition of the population predict releases. The Coase theorem hypothesis tests whether economic factors such as income levels and unemployment rates explain releases. The political/collective action tests whether the political activity of local residents influences environmental quality. Factors such as age, education and the number of households with children are expected to influence the incentives to undertake political actions (Filer, Kenney and Morton, 1993).

4.4 MODEL SPECIFICATIONS

The main objective of this work is to test whether air releases generated by the industrial sector could be explained using socio-economic-and demographic variables. However, a methodological issue that arises in the environmental justice literature is that regressing pollution levels on demographic characteristics can introduce endogeneity problems. In fact, when investigating if pollution amounts may be determined by a number of factors such as income, gender, education levels and other demographic variables, it must be considered that firms may be attracted to locate in minority and low-income areas (Hamilton 1993, 1995), but also some groups (minorities or low-income) may choose to live in or nearby polluted areas for social or economic reasons (e.g., cheaper rents) or other social factors. Hence, there is a problem of reverse causality,[46] due to the fact that

[46] Reverse causality is one of the main sources of endogeneity problems. Been (1994) also points out this endogeneity problem and resolves it by using pre-siting demographic data (i.e., data from before the industrial plants were built). Ringquist (1997) uses a control variable approach by controlling for housing prices; Gray and Shadbegian (2004) use instrumental variables.

(a) firms can decide to locate in a minority or low-income area, or *(b)* minority and low-income groups decide to live in polluted areas.

We collected some of the measures that have been employed in prior environmental justice studies and, in order to minimize possible bias due to this endogeneity problem, we developed our investigation through two steps of analysis. In the first step, in a standard ordinary least-squares linear regression, per-capita income is estimated as a function of a vector of fairly standard variables (the set of explanatory variables comprise different classes of population's ages, sex, different types of levels of education, entrepreneurial spirit, and geographical dummies). Predicted values from this regression are then used in the second step where an ordered probit is used to address the extent to which socio-economic factors influence air pollution levels.

Moreover, the values of the explanatory variables are observed at their 2001 Census values: thus, the 2001 socio-economic characteristics are used to explain air releases in 2005 (see Arora and Cason, 1999, on the use of lagged explanatory variables to avoid endogeneity bias). Hence, in our estimation model, we assume that the socio-economic conditions (pre-determined economic and demographic provincial data observed at time *t*) take some time (a four-years time lag) to exhibit their effects on the levels of air pollution (observed at time *t+1*).

Equation 4.1 presents the first auxiliary linear ordinary least-squares regression of per-capita income. Each of the variables will be discussed in more detail in the following sections.

(4.1)

$$pcincome = \alpha + \beta_1 pcenterpr + \beta_2 infrastructure + \beta_3 females + \beta_4 age15to34 + \beta_5 age35to49 + \\ + \beta_6 unidegree + \beta_7 lowsecschool + \beta_8 primschool + \beta_9 noedu + \beta_{10} north + \beta_{11} centre + \varepsilon_i$$

We, then, substitute the obtained predicted values of income in the second step of analysis (equation 4.2), where we estimate a standard ordered probit model (Greene, 2003) in which explanatory variables are used to predict the probabilities of being exposed to different levels of pollution emissions as shown below:

(4.2)

$$y_i^* = \beta_0 + \beta_1 \log pcincomehat + \beta_2 \log pcincomehat^2 + \beta_3 \log pcasia + \beta_4 \log pcafr + \\ + \beta_5 \log pcfemhead + \beta_6 \log children + \beta_7 \log elders + \beta_8 \log pendingproceedings + e$$

We will now discuss in more details the two-steps model here introduced and all variables will be properly defined.

4.4.1 Income Regression Analysis

The first step focuses on identifying the factors which are related to the determination of per-capita income. An OLS regression is estimated (for the year 2001) using equation 4.1, where *pcenterpr* is the number of registered firms at provincial level every 100 people, *infrastructure* is an indicator of the transportation infrastructure level, *females* is the number of population which is female, *age15to34* is the number of population aged between 15 and 34 years old, *age35to49* is the number of population aged between 35 and 49 years old, *unidegree* is the number of people with an undergraduate university degree, *lowsecschool* is the number of people with low secondary school diploma, *primschool* is the number of people with only primary school, *noedu* is the number of people with no education at all, *north* is a geographical dummy variable representing the Northern Italian provinces, *centre* is a geographical dummy variable representing the Central Italian provinces. Table 4.4 shows the results of coefficients and t-statistics.

4.4.2 Air Pollution Regression Analysis

This second step of analysis aims to identify the demographic characteristics that could explain the distribution of the levels of air pollution. To accomplish this objective, in the ordered probit regression the dependent variable (air pollution emissions) is categorized into four levels and is coded 1 for low air emissions, 2 for medium-low air emissions, 3 for medium-high air emissions and 4 for high emissions.[47] To measure socioeconomic status, we use the variable

[47] The standard ordered probit is built around a latent regression of the form $y^* = x'\beta + \varepsilon$ where x is the vector of explanatory variables, β is the vector of estimated parameters, and ε is the error term, which is assumed to be normally distributed across observations and is normalized with the mean and variance of zero and one, with cumulative distribution denoted by $\Phi(\cdot)$ and density function denoted by $\phi(\cdot)$. The air pollution data, y, are related to the underlying latent variable y^*, through cut offs points or thresholds μ_n, where $n = 1 \ldots 3$. The probabilities are the followings: $Prob(y = n) = \Phi(\mu_n - \beta' x) - \Phi(\mu_{n-1} - \beta' x)$, $n = 1 \ldots 3$, where $\mu_0 = 0$ and $\mu_3 = +\infty$ and $\mu_1 < \mu_2 < \mu_3$ are defined as three thresholds between which categorical responses are estimated; ordered probit

(*lpcincomehat*), the logarithm of the predicted income values; we also considered the quadratic specification of the same variable (*lpcincomehat2*) which allows us to capture the presence of an inverse U-shaped relation between income and pollution. Regarding ethnic groups characteristics, the percentage of African population (*pcafr*) and the percentage of Asian population (*pcasia*) are used. The percentages of children and of family households with a female as the head of the household are considered to be groups that could suffer from possible environmental discrimination. As mentioned above, we control for a measure of law enforcement (*pending proceedings*). Table 4.5 include the coefficients, their standard errors and *z*-ratios.

A multitude of different statistical approaches are employed in the environmental justice analysis, depending on the nature of the dependent variable. Multivariate analysis (for example, Been and Gupta, 1997; and Pastor *et al.* 2001), as well as logit (for example, Cory and Rahman, 2009; Hamilton, 1995; or Brooks and Sethi, 1997, where the dependent variable, i.e. the level of exposure to pollution levels, assumes the value of 1 if there was an increase of exposure in the zip code and 0 otherwise) and probit models (Ringquist, 1997; Aradhyula *et al.*, 2006) are used.

The advantage of the ordered probit model is that the marginal effects allow us to determine the impact of each explanatory variable (e.g., ethnicity, income and minorities) on the probability of each level of air pollution emissions. Even though this ranking approach to measure the amount of pollution has not been widely used in previous environmental justice studies, there are some precedents for using an ordered probit analysis. Sadd *et al*. (1999) estimate an ordered logit model on Los Angeles neighbourhoods. They constructed a dependent variable ordered according to the level of assumed health hazard, which takes a value of 0 if the tract has no air release, a value of 1 if it has an air release that does not contain carcinogen compounds, and a value of 2 if it contains carcinogen air release. Forastiere *et al.* (2007), in their investigation of the

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estimation will give the thresholds μ and parameters β. The thresholds μ show the range of the normal distribution associated with the specific value of the dependent variable; the parameters β represent the effect of changes in explanatory variables on the underlying scale. The marginal effects show how the probability of air pollution releases change with a small unit change in the explanatory variables.

relationship between exposure to traffic emissions and socioeconomic conditions in Rome, grouped air pollution (i.e., particulate matter emissions, PM_{10}) into four categories: low, mid-low, mid-high, and high emissions, using the 20th, 50th, and 80th percentiles as cut-off points.

To build our dependent variable in the ordered probit regression, beside using air pollution emissions raw data and simply aggregating together the fourteen different pollutants, we also defined a province-level index of air pollution. In order to do that, following Brooks and Sethi (1997),[48] we use Threshold Limit Values (TLVs) in order to adjust for toxicity: *"A threshold limit value is the amount of airborne concentration in mg/m^3 of a substance to which a worker may be repeatedly exposed for a normal 8-hour workday and a 40-hour workweek without adverse health effect"* (Brooks and Sethi, 1997: 236).

We employed both the Italian threshold limit values established by law for ambient pollution (D.P.C.M. 28/3/83,[49] D.P.R. 203/88,[50] D.Lgs. 351/99[51]) and the U.S. threshold values (see Table A2, in appendix) using the GESTIS-Substance Database which contains information for the safe handling of hazardous substances and other chemical substances at work.[52] In the U.S., the major providers of the Occupational Exposure Limits are the American Conference of Governmental Industrial Hygienists (ACGIH)[53], the Occupational Safety and Health Administration (OSHA), and the National Institute of Occupational Safety and Health (NIOSH). We considered the limit values released and enforced by the U.S. OSHA that sets workplace standard; where the OSHA threshold limit values were not available, we used the U.S. National Institute of Occupational Safety and

[48] Brooks and Sethi (1997) created a weighted toxicity index using Threshold Limit Values (TLV), combined with a distance function, to develop an exposure measure for each U.S. zip code.
[49] Decree of the President of the Council of Ministers.
[50] Decree of the President of the Italian Republic.
[51] Decree Law.
[52] The database provides an overview of the limit values from various E.U. member States, Canada (Québec), and the United States as of 2010. The GESTIS-Substance Database is maintained by the Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA, Institute for Occupational Safety and Health of the German Social Accident Insurance).
[53] The ACGIH is a professional organisation of occupational hygienists from universities or governmental institutions. The list of TLVs includes more than 700 chemical substances and physical agents, as well as dozens of biological exposure indices for selected chemicals. ACGIH threshold values do not have a legal force in the USA, but they are only recommendations. OSHA defines regulatory limits. However, ACGIH threshold values are a very common base for setting TLVs in the USA and in many other countries. ACGIH exposure limits are in many cases more protective than OSHA's (http://www.acgih.org).

Health (NIOSH)[54] values.

For example, under the Italian environmental law, sulphur dioxide has a threshold limit value of 80μg/m^3 (D.P.R. 203/88) into ambient air, while nitrogen dioxide has a limit value of 40μg/m^3 (D.P.R. 203/88). Thresholds available from the U.S. OSHA define, instead, the maximum concentration mg/m^3 of a substance to which a worker may be repeatedly exposed for a normal 8-hour workday and a 40-hour workweek without adverse health effects. For example, arsenic has a threshold limit value of 0.2 mg/m^3, while chromium has a threshold limit value of 1mg/m^3.

For the purpose of aggregating pollutants, our air pollution index was constructed in the following way. Let E^i_j define the emission of pollutant j from province i, and let T_j denote the threshold limit value associated with substance j. Then, the toxicity-weighted aggregated level of air pollution in province i is defined as: $AP^i = \sum_j \frac{E^i_j}{T_j}$. This procedure provides us with a measure of emission for each province, which represents our dependent variable in the ordered probit model. So, for every province in our data set, the sum of the fourteen hazardous substances considered, weighted by their associated threshold limit values (under both Italian and U.S. regulations), was calculated. This procedure allows us to get a more accurate measure of emissions for each Italian province.

On the basis of the different threshold limit values available, we were able to formulate nine different specifications of the dependent variable, that is: 1) E: raw data on emission levels; 2) NE: normalized raw data on emission levels; 3) zE: standardized raw data on emission levels;[55,56] 4) AWE: data on emission levels divided by the U.S. threshold limit values; 5) NAWE: normalized data on emission levels divided by the U.S. threshold limit values; 6) zAWE: standardized

[54] The U.S. National Institute of Occupational Safety and Health publishes recommended exposure limits (RELs) which OSHA takes into consideration when promulgating new regulatory exposure limits (http://www.osha-slc.gov/SLTC/pel/index.html). NIOSH's documents and threshold limit values list are available at http://www.cdc.gov/niosh/database.html.

[55] Standardization and normalization are the re-scaling techniques most frequently used to better compare a sample. To normalize the data, we used the following command on STATA: su E, meanonly gen NE = (E-r(min))/(r(max)-r(min)), where r(min) and r(max) are respectively the minimum and the maximum values of the data.

[56] To standardize the data, we use the formula $z = (x - \mu)/\sigma$ where x is the observation to be standardized, μ is the mean of the population, σ is the standard deviation of the population.

data on emission levels divided by the U.S. threshold limit values; 7) IWE: data on emission levels divided by the Italian threshold limit values; 8) NIWE: normalized data on emission levels divided by the Italian threshold limit values; 9) zIWE: standardized data on emission levels divided by the Italian threshold limit values. Except for the three specifications of the dependent variable in which the data are standardized and for the specifications where U.S. threshold limit values are employed, the remaining four specifications (E, NE, IWE and NIWE) yield very similar results both in terms of their statistical significance and of the signs of coefficients.

4.5 DATA

In order to assess whether air emissions are influenced by socioeconomic status at the Italian provinces level, and whether social inequalities are linked to air pollution, data from the latest available 2001 Census by the Italian Statistical Agency (ISTAT) are used (see Table A1 in the appendix), in which both socio-demographic characteristics (sex, age, type of family, nationality) and socio-economic variables (educational degree) are observed. These data are merged with data available at provincial level on household income (Istituto Tagliacarne).

4.5.1 THE ISPRA DATABASE

With regard to the environmental data, some papers in the literature use proximity to dangerous facilities as a proxy for environmental risk, [e.g. Anderson *et al.* (1994), Been (1994), Boer *et al.* (1997), Oakes *et al.* (1996), Pollock and Vittas (1995)] whereas other studies use actual pollution emissions levels [see Brooks and Sethi (1997), Daniels and Friedman (1999), Gray and Shadbegian (2004), Morello-Frosch *et al.* (2004), Ringquist (1997)]. In our analysis, given the lack of more disaggregated data, it was not possible to document the proximity and the exposure of poor and minority communities to sources of industrial air pollution. We are aware of the fact that the use of too broad a scale or unit of analysis has been discouraged (Anderton *et al.* 1994), but the most disaggregated available Italian data are only at provincial level.

We use the information on air pollution provided by the Italian Institute for Environmental Protection and Research (ISPRA)[57] which is responsible for the National Emission Inventory. The ISPRA dataset includes data on air emissions in all the Italian provinces (103 provinces distributed over 20 regions). This is a comprehensive database that collects all emission estimates of the major pollutants including greenhouse gases, ozone precursors, benzene, particulate matters, heavy metal and polycyclic aromatic hydrocarbon. The national inventory is reported to the European Commission at the national aggregated level, but it is calculated at the regional level and then disaggregated at the provincial level. In the "*Disaggregation of the National Inventory 2005*" Report, data related to the disaggregation of the emissions of the national inventory at the provincial level are available, divided by activity according to the SNAP (Selected Nomenclature for Air Pollution) classification.[58] The SNAP classification consists of the following 11 groups of activities: 1) combustion in energy and transformation industry; 2) non-industrial combustion plants; 3) combustion in manufacturing industry; 4) production processes; 5) extraction and distribution of fossil fuels; 6) solvent and other product use; 7) road transport; 8) other mobile sources and machinery; 9) waste treatment and disposal; 10) agriculture; 11) other sources.

We use data relative only to macro-sector 1 (combustion in energy and transformation industry), macro-sector 3 (combustion in manufacturing industry) and macro-sector 4 (production processes), since we want to base our analysis on air pollution emissions released by the industrial sector and not also from agriculture or road, air, or sea transportation. Descriptive statistics relative to the fourteen contaminants selected for this analysis are provided in table 4.1. Air

[57] ISPRA is the Institute for Environmental Protection and Research established by Italian Law 133/2008. The Institute performs the functions of three former institutions: APAT (Agency for Environmental Protection and Technical Services), ICRAM (Central Institute for Applied Marine Research), INFS (National Institute for Wildlife).

[58] This classification includes all activities which are considered relevant for atmospheric emissions. The ISPRA database is characterized by three different typologies of emissions: area, point and linear sources. For area emissions (emissions from sources distributed on the territory) a direct measurement is not feasible, and it is necessary, therefore, to estimate them from statistical data and specific emission factors. The approach that ISPRA has applied is based on a linear relation between source activity and emission, following this relation: $E_i = A * FE_i$, where: Ei = emission of the pollutant i (g year^{-1}); A = activity indicator (i.e. produced amount, fuel consumption, etc.); FEi= emission factor for the pollutant i (i.e., $g\ t^{-1}$ of product, kg/kg of solvent, g inhabitant^{-1}).

pollution emissions are expressed in megagrams: the average level of air releases is 3.532.766 megagrams with a minimum value of 13.1997 megagrams (Prato) and a maximum value of 2.86 megagrams (Rome). The average per-capita air emission levels, instead, is 7.14 megagrams with a minimum value of 0.57 megagrams (Prato) and a maximum value of 41.04 (Taranto). Figure 4.1.1 and figure 4.1.2 (at the end of the chapter) show, respectively, air emission levels and per-capita emission levels for the first twenty most polluted provinces.

4.5.2 INDEPENDENT VARIABLES

The primary source for the demographic data used in this analysis is derived from the Italian Census 2005 Population and Housing by the Italian Statistical Agency. The variables selected and their summary statistics are provided in table 4.2. All tables are reported at the end of the chapter.

The independent variables were chosen according to the most commonly used in environmental justice studies. Additional variables, such as the entrepreneurial spirit, the infrastructural endowment and the efficiency of the judicial system constitute an improvement upon previous studies.

Demographic data

Age/sex/race

In the first step of analysis (ordinary least square regression - OLS), following the traditional and conventional estimation of the Mincer (1958; 1974) equation, we regress income on a set of independent variables which include age, gender, educational attainment and geographical dummy variables. More specifically, the distribution of income among different working age group population is examined. The independent variable *age* (grouped into ranges of 5 years each) is categorized into two groups of age, namely (i) age range from 15 to 34 years and (ii) age range from 35 to 49 years. Another independent variable employed is *female* (percentage of population which is females) to examine female-based variations in the distribution of households income.

In the second step of analysis (ordered probit regression), *children* (percentage of population less than six years old) and *elders* (percentage of population more than 65 years old) are also examined as they are assumed to be inherently more susceptible to air pollution (Greenberg, 1993; Chaix *et al.*, 2006). Regarding racial characteristics, the percentage of *African* residents and the percentage of *Asian* residents are used. Moreover, the percentage of family households with a *female as the head of the household* is considered to be a group that could suffer from possible environmental discrimination (Arora and Cason, 1999).

Education

In the OLS regression, educational levels are considered as determinants of income and are classified into four categories corresponding to the International Standard Classification of Education: university degree, lower secondary education, primary education and no education at all.

Income

The Tagliacarne Institute and the Union of Italian Chambers of Commerce provide the data related to real household disposable *income* per capita in each province.

Territorial variables

In the OLS regression, we introduced two geographical dummy variables to reflect the territorial subdivision of Italy (Bagnasco, 1977): *North Italy* (comprehensive of North-eastern and North-western Italian provinces) and *Central Italy*. The dummy South Italy is left out as reference.

Other independent variables

In the OLS regression, two additional variables are included: provincial *entrepreneurial spirit* (number of registered firms every 100 people at the province level) and the level of *infrastructure* present in each province, measured as an indicator of the transportation infrastructure endowment (Guiso, Sapienza and Zingales, 2004). These data were drawn from the yearly report of data and social indicators on quality of life performed by the leading Italian financial newspaper, *Il Sole 24 Ore*.[59]

[59] *Il Sole 24 Ore* publishes this annual report on quality of life every year since 1989. The 103 Italian provinces are ranked according to a summary indicator of their quality of life constructed collecting official statistical data. The final quality of life indicator is based on 36 social indicators related to six main areas: consumption and wealth, labor and business, environment and services, justice efficiency and criminality, population, leisure. Even though the statistical robustness of

In the ordered probit regression, the demographic and economic data are implemented with the variable *pending proceedings* which is a measure of the inefficiency of law enforcement in terms of number of pending trials in each province (data collected from "*Il Sole 24 Ore*").[60] Pending proceedings have risen to almost 9 millions in the last few years in Italy, two thirds of which belong to the criminal sector, while the remaining are civil ones. Trial and appeal delays and the large number of pending proceedings are one of the major problems associated with the inefficiency of justice in Italy.

By merging the above described environmental, demographic and economic data we produced a database that can contribute to extremely exiguous literature on environmental justice studies in Italy.

Table 4.2 provides the descriptive statistics for the economic and the demographic variables: these measures are the independent variables in our regressions. Average per capita income is in million liras; average income is 14.675 which varies from a minimum of 9.104 (province of Caltanissetta) to a maximum of 20.613 (province of Milan). Entrepreneurial spirit reflects the number of registered firms; the average number of firms on the territory is 23.970 with a minimum value of 9.85 (province of Vibo Valentia) and a maximum value of 37.93 (province of Verbania). The maximum value of the infrastructural index belongs to Trieste while its minimum value is 443 and belongs to Sondrio. On average, 10% of the population has an undergraduate university degree with a minimum value of almost 7% (province of Prato) and a maximum value of almost 18% (Rome). On average 35.8% of the population has a lower secondary school diploma, with a minimum value of 26.4% (Rome) and a maximum value of 45.7% (Bolzano). On average 1.2% of the population have no education at all, with a minimum value of 0.3% (Sondrio) and a maximum value of almost 3.6% (Crotone). About 0.27% of the population is Asian with a minimum value of 0.015% (Enna) and a maximum value of 2.09% (Prato). About 0.64% of the population is African with a minimum value of 0.07% (Taranto) and a maximum

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these rankings is often criticized (Lun *et al*,. 2006; Vitali and Merlini, 1999), the results of the *Il Sole 24 Ore* report it constitutes a very regular collection and analysis of data on quality of life.

[60] The data on the number of pending proceedings by the *Il Sole 24 Ore* is an elaboration of the data released by the Italian Ministry of Justice.

value of 2.19% (Modena). The average number of family households with a female as the head of the household is 11.7% with a minimum value of 7.7% (Nuoro) and a maximum value of 20.1% (Savona). The average percentage of children is 5.2 with a minimum value 3.69 (Ferrara) and a maximum value of 7.35 (Naples). On average, the 19.8% of the population is composed by elders with a minimum value of 12.5% (Naples) and a maximum value of 25.9% (Savona). The average number of pending proceedings is 41.14 every thousand people, but there is a high variability among the provinces. Some provinces have a number of 9.5 (Lecco) or 11.44 (Trento) pending proceedings, others go as high as 132.96 (Messina) or 158.06 (Reggio Calabria) per thousand people.

Table 4.3 reports the cross-correlations between the various socio-economic variables and the environmental variable. Limiting our comments on the strength of the relationship between the main independent variables of interest and the dependent variables, we can observe that there is a quite high collinearity between some of the independent variables. In particular there is a high positive correlation between the following independent variables: (i) between the number of firms and per-capita income (r = 0.84) and between the number of firms and North (r = 0.7); (ii) a high negative correlation between per-capita income and no education (r = - 0.73); (iii) a fairly high positive correlation between per-capita income and North (r = 0.6); (iv) there is also collinearity between the number of pending proceedings and North (r=0.71). However, given the model specifications presented in section 4.4, there is no high correlation between any of the independent variables that might pose a serious specification problem of collinearity.

4.6 RESULTS

4.6.1 INCOME REGRESSION ANALYSIS - RESULTS

In the first OLS regression, the dependent variable is per-capita income and is regressed over the above specified set of explanatory variables. Table 4.4 presents the OLS regression's results (obtained using STATA/SE 9.0). Overall, this model performs well in explaining the dependent variable with an R-squared value of 84.29%. Among all the independent variables, the entrepreneurial spirit (number of firm) and the infrastructure endowment have the strongest effect on per-capita provincial income level. Note that the coefficients on age classes are both statistically significant. The sign of the coefficient on people aged between 15 and 34 is negative, while the one on people aged between 35 and 49 is positive, suggesting that income profiles rise with age (experience). These outcomes are not new in literature. Gomez and Hernandez de Cos (2008), in fact, examined the role of the age structure of the population as a determinant of economic growth and they found that productivity peaks during the working ages of 35 and 54 when "*the balance between formal education and experiential human capital reaches its optimum*".

The coefficient on female participation to the determination of per-capita income is negative but it is not statistically significant. Almost all the education variables (except the lower secondary school diploma) are significant in explaining per-capita provincial income. We find that higher levels of education (undergraduate university degree) are positively related to per-capita provincial income; consistently, no education at all has a statistically significant and negative impact on per-capita income. Our findings also suggest that geography (Northern and Central Italian provinces) has a positive and significant effect on per-capita provincial income (relative to Southern provinces). Hence, population age, educational attainment and geographic factors seem to matter in explaining the variability of per-capita income across Italian provinces.

4.6.2 AIR POLLUTION REGRESSION ANALYSIS - RESULTS

Table 4.5 reports the results of the ordered probit model. For convenience we report in full details the results associated only to one specification of the independent variable (i.e., raw data). It should be noted that when the dependent variable is ordered, estimated parameters do not reflect a unit change of an independent variable on probability; thus, the estimated coefficients in an ordered probit have no direct interpretation. For this reason, we also calculate the associated marginal effects (see Greene, 2003, p. 738, for a discussion of calculating marginal effects). These can be interpreted as the change in the probability of attaining different levels of air pollution emissions as a result of a unit change in each explanatory variable. Notice that the sum of the marginal effects equals zero. The signs on the marginal effects of the significant variables do not remain constant: more specifically, in the third and the fourth air pollution categories, *Pr*(Y=3: medium-high emissions) and *Pr*(Y=4: high emissions), the statistically significant variables have opposite signs compared to the first and the second air pollution categories. In the fourth scenario, for example, a 1% increase in income is associated with a 35.92% increase in the probability of attaining high emission levels.

Tables from 4.5.1 to 4.5.5 report the marginal effects that each explanatory variable has on the four scenarios of air pollution – that is the impact that an increase of one unit of the explanatory variables has on the probability of attaining, respectively, low, medium low, medium high and high air pollution emissions. From table 4.5.4, the *income* variables (in their logarithmic linear and quadratic specifications) are both statistically significant, showing that an increase in income translates to an increase in the probability of attaining high levels of air pollution emissions. Moreover, the statistical significance of the squared term for income and its negative relationship with the dependent variable, allow us to identify an inverse U-shaped relationship between income and air releases. The interpretation of this environmental Kuznets curve is that an increase in economic activity leads to a higher probability of attaining high levels of air pollution, but beyond a turning point, as income increases further, the demand for a cleaner environment reduces the level of pollution. This outcome implies that in the richest Italian provinces industrial firms are more likely to invest in technology and innovation and to control air pollution.

We can notice that the percentages of Asian and African foreigners are never, in the four scenarios, statistically significant. Hence, the results provide no support for the contention that ethnicity could be associated with a disparate-impact discrimination for environmental harm. The results, however, indicate that a 1% increase in the number of family households with a female head translates into a 0.49% increase in the probability of attaining high levels of air pollution emissions: so, these estimates suggest that air releases are greater, on average, in provinces with greater proportion of female-headed households. The results for children are somewhat similar: a 1% increase in the percentage of resident children translates into an increase by 1.6 percentage points in the probability of attaining high levels of air pollution emissions. Those are key results: greater concentrations of females as household heads and of children are likely to be associated with increased levels of air pollution.

We can notice that the sign of the coefficient of judicial inefficiency is positive (although this variable is not statistically significant), implying that an increase in judicial inefficiency is associated with an increase in the probability of having high releases. In other words, provinces with high judicial inefficiency are more likely to experience more releases than provinces with lower judicial efficiency. We were motivated to refine the model and to capture potential interactions (which are the product of two independent variables) in influencing air pollution. To account for this, we tried out several possible interactions of judicial inefficiency with other explanatory variables but the only interaction term which was statistically significant (and improved the estimation results) was that between *pending proceedings* and *children* (hence, pending proceedings*children was included as an additional independent variable).[61] Intuitively, the interaction term reflects the possibility that the result could be influenced by this particular independent variables' combination.

The model incorporating the interaction is:

(4.3)

$$y_i^* = \beta_0 + \beta_1 \log pcincomehat + \beta_2 \log pcincomehat^2 + \beta_3 \log pcasia + \\ + \beta_4 \log afr + \beta_5 \log pcfemhead + \beta_6 \log children + \beta_7 \log elders + \\ + \beta_8 pendingproceedings + \beta_9 pendingproceedingschildren + e$$

Similar to the previous estimation model, the same explanatory variables remain significant and the levels of statistical significance of all the estimated coefficients improve overall. In table 4.6, the results of the ordered probit model with the interaction term are provided. Tables from 4.6.1 to 4.6.5 report the marginal effects that each explanatory variable has on the four scenarios of air

[61] The following interactions were also tried out: *pendingproceedings*incomehat, pendingproceedings*incomehat2, pendingproceedings*pcfemhead, pendingproceedings*pcasia, pendingproceedings*pcafr* .

pollution. The statistical significance of the income variables improves and the signs are confirmed, again validating the existence of an inverse U-shaped relationship between income and air releases. The key result from this model is, however, that pending proceedings not only are statistically significant but also that the interaction term shows a statistically significant impact on air releases.

When the variable pending proceedings is present in the regression also interacted with the proportion of children, its overall sign is given by the sum of the coefficients of the variable itself plus the product between the interaction coefficient and the proportion of children in each province. For instance, when the coefficient of pending proceedings is 5.66 and the interaction coefficient is -3.12, the overall effect will depend on the proportion of children in the province. If this proportion in a certain province is 0.10 (i.e., 10%), the net effect in this province is given by [5.66 – (3.12 * 0.10) = (5.66 - 0.312) = 5.348]; if the proportion of children in another given province is 0.20 (i.e., 20%), the net effect in this other province would be [5.66 – (3.12*0.20)= (5.66- 0.624) = 5.036], and, thus, the overall effect would be always positive even though it decreases at the increasing of the proportion of children.

From our results, therefore, an increase of judicial inefficiency (weaker law enforcement) is associated with an increase in the probability of air releases. The interaction term suggests that an increase of judicial inefficiency in the provinces with higher proportions of children leads to a decrease in the probability of having high levels of air pollution, even though the net effect is always positive.

More specifically, if we look at table 4.6.4, a 1% increase in the number of pending proceedings translates into a 1.6 percentage points increase in the probability of attaining high levels of air pollution emission. In general, therefore, it seems that wherever law enforcement is weak, firms pollute more implying that enforcement of law does matter, other conditions being equal, to explain air pollution. However, further investigation needs to be done to clarify the interpretation of the interaction between the effects of judicial inefficiency and the proportion of children.

We employed all the alternative model specifications (although the results are not reported in full detail) to estimate the same ordered probit models reported above for the five other alternative specifications of the dependent variable, as explained in section 4.4.2. Our results are substantially confirmed in both ordered probit models (with and without the interaction variables), in terms of statistical significance and coefficient signs, when using normalized raw data (NE) and when using Italian threshold limit values for ambient air pollution (in both forms, normalized and not normalized data), as one can see from tables 4.7 to 4.8.1. However, when using U.S. threshold limit values for hazardous substances, all the independent variables lose their statistical significance. So, while the estimated coefficients on some specifications of the dependent variable (i.e.: E, NE and IWE) were definitely robust (see table 4.9), on the remaining alternative specifications (NIWE, AWE and NAWE) they do not perform well under the same set of explanatory variables.

4.7 CONCLUSIONS

This chapter presents a reduced form statistical analysis on the relationship between air pollution and socioeconomic characteristics across the Italian provinces. Our approach uses the level of air pollution emissions (fourteen types of pollutant substances from the industrial sector), released by industrial plants in 2005 as the measure of environmental quality, merged with 2001 data on socio-demographic characteristics at provincial level. The main objective is to ascertain whether income, ethnicity and gender composition of the population can help explain releases and whether environmental injustice arguments can be identified in Italy.

The estimates obtained by the ordered probit models indicate that an increase in income by one unit is expected to increase the probability of higher levels of air pollution releases, that is releases increase with income, but our estimates are also consistent with an inverse U-shaped environmental Kuznets curve: once income exceeds a turning point, air pollution decreases with increasing income.

Our search for environmental injustice finds evidence that releases tend to be higher in provinces with high concentration of females as households' head and with high concentration of children. Our findings do not allow identifying any environmental discrimination based on ethnicity suggesting that environmental justice issues are not likely in Italy to be perceived in racial and ethnic terms but in terms of social categories and gender composition.

We find also that greater judicial inefficiency (or lenient law enforcement) is associated with higher levels of pollution. This result suggests that a better implementation, all through the territory, of the local enforcement of environmental laws can play an important role in creating the conditions for better relationships between firms and judicial institutions improving, thus, the overall environmental quality.

Extension of the work and future research. Data on Italian air emissions releases are available for the years 1990, 1995, 2000 and 2005, so it would be possible, for future research, to use a panel data analysis using also the penultimate 1991 Italian Census data and the imminent release of the 2011 Census data. In the present chapter, a cross-section regression was run on 2005 pollution emissions data. Estimating other cross-section regressions for each year would allow us to check for structural changes over time in the relationship between the variables, under both fixed effects and random effects.

One of the main limitations of the ISPRA dataset is that it is not possible to obtain information on the compliance trends and on the enforcement activities in each province. It would be desirable to have access to more detailed data sets on the number of inspections conducted by enforcement authorities, on compliance levels and on the implications of the different penalty means. The lack of accurate and incomplete information does not allow policymakers to understand how the Italian system of enforcing environmental laws work and what reforms may be needed.

Another interesting investigation for future research can be to estimate separate air pollution regressions for the local and the global pollutants. Sulphur dioxide (SO_2), carbon monoxide (CO) and nitrogen monoxide (NOX) are three major local air pollutants whereas carbon dioxide (CO_2) is the major global pollutant. With regard to the relationship between pollutants and income, while in the literature there is a general agreement on the existence of an inverted-U curve for local pollutants, there is less consensus on the shape of the curve for global pollutants (Lopez, 1994; Meers, 2000). Treating differently local and global pollutants, thus, might add important further insights into the empirical and theoretical debate.

Another area of improvement of the present work could be the measurement of the dependent variable. We examine toxicity (by employing threshold limit values), but risk exposure is not covered in this analysis: instead of using actual pollution levels, the use of spatial analysis using Geographical Information System (GIS) would allow to use proximity from hazardous facilities as a proxy for environmental risk.

Finally, concerning on the use of instrumental variables, instead of performing a two-steps regression model it may be useful to estimate the model in a single step. Modeling an ordered probit with instrumental variables in one single step, however, cannot be run by STATA software. We leave the programming of this model as our future task to be solved.

Table 4.1 Descriptive statistics of the air pollutants that compose the dependent variable in the ordered probit regression

Pollutants - descriptive statistics (N = 103 provinces)					
pollutants	mean	median	standard deviation	minimum value	maximum value
*sulphuric dioxide**	8557.90	1990.71	17423.36	0.303	96385.52
*nitrogen oxides**	8980.24	3946.46	11918.65	14.60	54407.96
*carbon monoxide***	16963.46	9025.16	38034.08	1502.72	376509.9
*carbon dioxide****	3493031	1848533	4561720	129135.4	2.85e+07
*nitrous oxide**	1381.87	848.42	2176.10	112.85	20518.56
*ammonia***	3847.59	2224.30	4817.7	14.25	28817.56
*arsenic*****	363.38	107.35	894.59	0.56	8076.338
*chromium***	508.68	185.51	810.91	0.65	4481.793
*copper***	405.63	126.35	1524.76	3.53	15151.66
*mercury***	69.95	34.18	138.26	1.58	1076.05
*nickel**	1332.13	564.34	1978.39	3.64	13554.87
*lead**	1943.42	695.85	4622.00	0.83	42187.82
*selenium**	109.11	30.93	215.34	0.36	1665.048
*benzene**	153.64	114.53	140.91	16.82	917.8066
total air emissions	3532766	1863494	4606910	131997.8	2.86e+07
per-capita air emiss.	7.140	4.468	8.137	0.5792	41.04

Notes: *substance measured in micrograms; **substance measured in milligrams; ***substance measured in megagrams; ****substance measured in nanograms. In the ordered probit regression analysis, all the different measurement units were converted into megagrams.

Figure 4.1 Air pollution emissions for the first twenty most polluted Italian provinces (in millions megagrams)

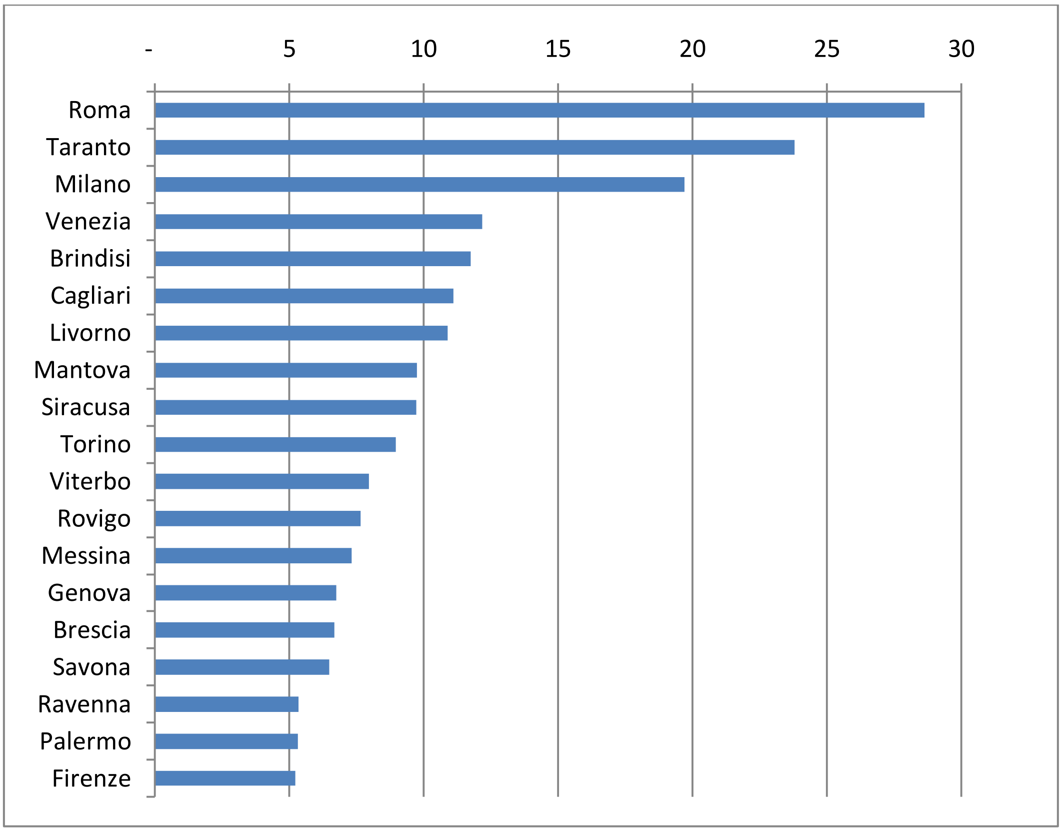

Figure 4.2 Per-capita air emissions levels for the first twenty most polluted provinces (per-capita megagrams)

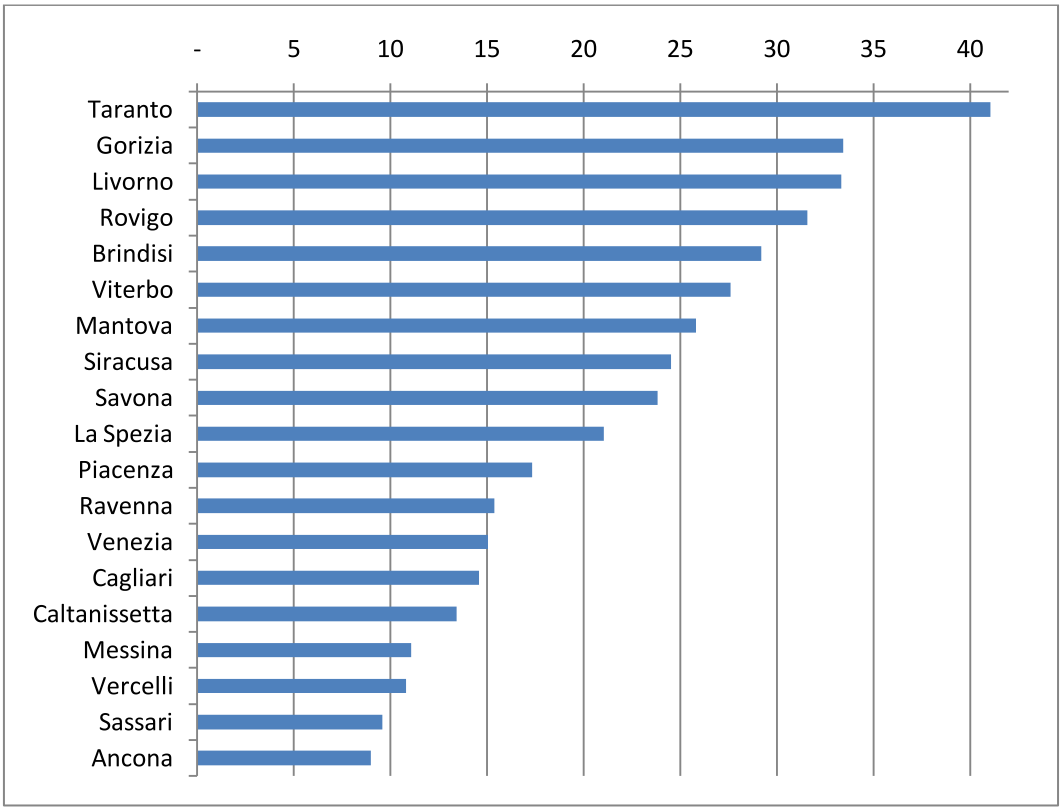

Table 4.2. Independent variables descriptive statistics (N = 103 provinces)

Variable	mean	standard deviation	minimum value	maximum value
pcincome	14675.68	3024.42	9104.12	20613.52
entrepreneurial spirit	23.970	4.964	9.85	37.93
infrastructure	556.902	81.927	443	1000
females	247242	271537.8	39886	1696080
age15to34	90399.67	101921.6	12641	678961
age35to49	93498.53	106050.4	14172	714986
pcunivdegree	0.105	0.022	0.067	0.178
pclowsecschool	0.358	0.035	0.264	0.457
pcprimschool	0.116	0.022	0.046	0.161
pcnoedu	0.012	0.007	0.002	0.035
pcasia	0.0027	0.0031	0.00015	0.020
pcafr	0.0064	0.0048	0.0007	0.021
pcfemhead	0.117	0.023	0.077	0.201
children	5.27	0.75	3.69	7.35
elders	19.84	3.09	12.52	25.91
pendingproc	41.146	29.107	9.55	158.06

Note: The variables used in logs in the regression are presented in their original levels.

Table 4.3. Independent variables descriptive statistics – Correlation matrix (N = 103 provinces)

	pcemissions	pcincome	# firms	infrastructure	females	age15~34	age35~49	pcunidegree	pclowsec	pcprimary	pcnoedu	Pcasia	pcafr	pcfemhead	pcchildren	pcelders	pendingproc	north	centre
pcemissions	1																		
pcincome	0,050	1																	
# firms	0,087	0,848	1																
infrastructure	0,027	0,203	0,113	1															
females	-0,079	0,141	0,117	0,447	1														
age15~34	-0,082	0,167	0,156	0,427	0,993	1													
age35~49	-0,077	0,219	0,193	0,416	0,990	0,993	1												
pcunidegree	-0,089	-0,127	-0,204	0,468	0,463	0,392	0,414	1											
pclowsec	0,055	0,127	0,216	-0,250	-0,228	-0,157	-0,190	-0,794	1										
pcprimary	-0,185	-0,520	-0,560	-0,363	-0,269	-0,277	-0,310	-0,220	0,185	1									
pcnoedu	-0,085	-0,738	-0,758	-0,041	0,004	-0,036	-0,071	0,354	-0,304	0,652	1								
pcasia	-0,014	0,461	0,453	0,110	0,304	0,338	0,357	-0,073	0,099	-0,157	-0,332	1							
pcafr	-0,063	0,528	0,567	-0,137	0,073	0,140	0,143	-0,375	0,335	-0,167	-0,375	0,536	1						
pcfemhead	-0,077	0,251	0,092	0,292	0,154	0,118	0,151	0,294	-0,346	-0,150	-0,068	0,189	-0,107	1					
pcchildren	-0,245	-0,600	-0,477	-0,022	0,257	0,267	0,200	0,140	-0,017	0,325	0,602	-0,098	-0,069	-0,150	1				
pcelders	0,144	0,626	0,509	0,019	-0,321	-0,337	-0,272	-0,092	-0,089	-0,308	-0,529	0,096	0,151	0,228	-0,875	1			
pendingproc	-0,031	0,443	0,506	-0,194	-0,099	-0,039	-0,032	-0,547	0,504	-0,340	-0,578	0,173	0,531	-0,274	-0,182	0,176	1		
north	0,116	0,643	0,704	0,061	0,019	0,077	0,088	-0,404	0,399	-0,481	-0,606	0,241	0,609	-0,120	-0,283	0,304	0,711	1	
centre	-0,039	0,162	0,068	-0,060	-0,019	-0,041	-0,010	-0,008	-0,156	0,010	-0,220	0,219	-0,084	0,336	-0,301	0,286	-0,172	-0,455	1

Table 4.4 First-step regression with OLS estimation - dependent variable: *per-capita income*

per-capita income (dep. variable)	coefficients	standard errors	t	P>|t|	[95% Conf. Interval]	
entrepreneurial spirit	214.36	72.960	2.94	0.004	69.43	359.28
infrastructure	4.99	1.563	3.20	0.002	1.88	8.09
females	-0.003	0.004	-0.66	0.512	-.012	0.006
age15to34	-0.032	0.015	-2.17	0.033	-.063	-0.002
age35to49	0.039	0.008	4.71	0.000	.022	0.05
university education	36452.35	16535.96	2.20	0.030	3605.69	69299
lower secondary school	1622.864	6213.95	0.26	0.795	-10720.4	13966.13
primary school	36152.43	8619.007	4.19	0.000	19031.84	53273.03
no education	-97931.4	27214.3	-3.60	0.001	-151989.3	-43873.53
North	3554.092	696.63	5.10	0.000	2170.30	4937.88
Centre	2415.81	508.23	4.75	0.000	1406.25	3425.36
_cons	-2663.83	3427.3	-0.78	0.439	-9471.80	4144.12
num. of observations = 103						
F(11, 91) = 79.69						
prob > F = 0.0000						
R-squared = 0.84						
Root MSE = 1269.1						

Table 4.5 Second-step regression with ordered probit estimation - dependent variable: *air pollution emissions* – specification: raw data (E)

air pollution emissions (dependent variable)	coefficients	standard error	z	P>|z	[95% Conf.	Interval]
lpcincomehat	123.11	63.30	1.94	0.052	-0.95	247.19
lpcincomehat2	-6.47	3.29	-1.96	0.050	-12.9	-0.011
lpcasia	-0.17	0.17	-0.96	0.339	-0.52	0 .17
lpcafr	-0.21	0.22	-0.95	0.340	-0.66	0.23
lpcfemhead	1.69	0.69	2.43	0.015	0.32	3.069
lchildren	5.51	1.93	2.85	0.004	1.72	9.30
lelders	2.73	1.65	1.65	0.098	-0.50	5.97
lpendingproceedings	0.26	0.28	0.93	0.350	-0.29	0.82
cut_1	601.25	305.05			3.35	1199.15
cut_2	602.06	305.06			4.14	1199.98
cut_3	602.87	305.07			4.93	1200.81
num. of observations = 103						
LR $chi^2(8)$ = 28.48						
prob > chi2 = 0.0004						
log likelihood = -128.53						
pseudo R2 = 0.099						

Table 4.5.1 Marginal effects of the ordered probit for *Pr* (Y =1: low air pollution emissions)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	-34.84	15.31	-2.28	0.023
lpcincomehat2	1.83	0.79	2.30	0.021
lpcasia	0.04	0.05	0.97	0.333
lpcafr	0.06	0.06	0.96	0.338
lpcfemhead	-0.48	0.20	-2.30	0.021
lchildren	-1.56	0.55	-2.83	0.005
lelders	-0.77	0.47	-1.63	0.102
lpendingproceedings	-0.07	0.08	-0.92	0.359

Table 4.5.2 Marginal effects of the ordered probit for *Pr* (*Y=2*: medium-low air pollution emissions)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	-14.26	8.78	-1.62	0.104
lpcincomehat2	0.75	0.45	1.64	0.102
lpcasia	0.019	0.021	0.91	0.364
lpcafr	0.025	0.027	0.91	0.361
lpcfemhead	-0.196	0.103	-1.90	0.058
lchildren	-0.639	0.304	-2.10	0.035
lelders	-0.316	0.216	-1.46	0.143
lpendingproceedings	-0.03	0.034	-0.90	0.369

Table 4.5.3 Marginal effects of the ordered probit for *Pr* (*Y=3*: medium high air pollution emissions)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	13.18	7.25	1.82	0.069
lpcincomehat2	-0.69	0.37	-1.83	0.067
lpcasia	-0.018	0.02	-0.92	0.359
lpcafr	-0.023	0.025	-0.92	0.359
lpcfemhead	0.181	0.099	1.82	0.069
lchildren	0.59	0.28	2.07	0.038
lelders	0.292	0.203	1.44	0.150
lpendingproceedings	0.028	0.032	0.88	0.381

Table 4.5.4 Marginal effects of the ordered probit for *Pr* (*Y=4*: high air pollution emissions)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	35.92	15.79	2.27	0.023
lpcincomehat2	-1.89	0.82	-2.30	0.021
lpcasia	-0.05	0.05	-0.97	0.334
lpcafr	-0.06	0.06	-0.96	0.338
lpcfemhead	0.49	0.21	2.31	0.021
lchildren	1.60	0.56	2.86	0.004
lelders	0.79	0.48	1.64	0.101
lpendingproceedings	0.07	0.08	0.92	0.357

Table 4.5.5 Summary of marginal effects of significant variables for the ordered probit estimation (I) – dependent variable: *air pollution emissions* – specification: raw data (E)

Probability in air pollution levels	Coefficient	Marginal Effect
lpcincomehat		
	123.11	
Pr (Y=1)		-34.84
Pr (Y=2)		-14.26
Pr (Y=3)		13.18
Pr (Y=4)		35.92
lpcincomehat2		
	-6.47	
Pr (Y=1)		1.83
Pr (Y=2)		0.75
Pr (Y=3)		-0.69
Pr (Y=4)		-1.89
lpcfemhead		
Pr (Y=1)	1.69	
Pr (Y=2)		-0.48
Pr (Y=3)		-0.19
Pr (Y=4)		0.18
		0.49
lchildren		
Pr (Y=1)	5.51	
Pr (Y=2)		-1.56
Pr (Y=3)		-0.63
Pr (Y=4)		0.59
		1.60

*Notes:*Y =1: low air pollution; Y=2 : medium-low air pollution; Y=3: medium-high air pollution; Y=4: high air pollution.

Table 4.6 Ordered probit estimation with interaction variable - dependent variable: *air pollution emissions* – specification: raw data (E)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	153.58	65.45	2.35	0.019
lpcincomehat2	-8.06	3.41	-2.36	0.018
lpcasia	-0.16	.17	-0.93	0.354
lpcafr	-0.28	.23	-1.22	0.224
lpcfemhead	1.83	.70	2.58	0.010
lchildren	23.76	9.55	2.49	0.013
lelders	3.16	1.68	1.87	0.061
lpendingproceedings	5.65	2.77	2.04	0.041
*lpendproc*lchildren*	-3.12	1.59	-1.95	0.051
cut_1	780.39	319.84		
cut_2	781.22	319.86		
cut_3	782.04	319.87		
number of observations = 103				
LR chi2(9) = 32.37				
log likelihood = -126.58				
prob > chi2 = 0.0002				
pseudo R2 = 0.1134				

Table 4.6.1 Marginal effects of the ordered probit for *Pr*(*Y =1*: low air pollution emissions)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	-42.74	18.23	-2.34	0.019
lpcincomehat2	2.24	0.95	2.36	0.018
lpcasia	0.04	0.05	0.93	0.353
lpcafr	0.07	0.06	1.21	0.227
lpcfemhead	-0.50	0.20	-2.53	0.012
lchildren	-6.61	2.70	-2.45	0.014
lelders	-0.88	0.47	-1.84	0.065
lpendingproceedings	-1.57	0.77	-2.02	0.043
*lpendproc*lchildren*	0.86	0.44	1.94	0.053

Table 4.6.2 Marginal effects of the ordered probit for *Pr*(*Y* = *2*: medium-low air pollution emissions)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	-18.51	8.96	-2.07	0.039
lpcincomehat2	0.97	0.46	2.08	0.038
lpcasia	0.02	0.022	0.89	0.372
lpcafr	0.03	0.029	1.15	0.250
lpcfemhead	-0.22	0.11	-1.98	0.048
lchildren	-2.86	1.42	-2.01	0.044
lelders	-0.38	0.23	-1.64	0.101
lpendingproceedings	-0.68	0.38	-1.75	0.080
*lpendproc*lchildren*	0.37	0.22	1.70	0.090

Table 4.6.3 Marginal effects of the ordered probit for *Pr*(*Y* = *3*: medium high air pollution emissions)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	16.76	8.35	2.01	0.045
lpcincomehat2	-0.88	0.43	-2.02	0.044
lpcasia	-0.01	0.020	-0.89	0.374
lpcafr	-0.03	0.027	-1.14	0.256
lpcfemhead	0.19	0.10	1.90	0.058
lchildren	2.59	1.32	1.96	0.049
lelders	0.34	0.21	1.58	0.114
lendingproceedings	0.61	0.35	1.72	0.085
*lpendproc*lchildren*	-0.34	0.20	-1.68	0.093

Table 4.6.4 Marginal effects of the ordered probit for *Pr*(*Y* = *4*: high air pollution emissions)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	44.48	19.07	2.33	0.020
lpcincomehat2	-2.33	0.99	-2.35	0.019
lpcasia	-0.04	0.05	-0.93	0.354
lpcafr	-0.08	0.06	-1.21	0.227
lpcfemhead	0.53	0.20	2.53	0.011
lchildren	6.88	2.83	2.43	0.015
lelders	0.91	0.49	1.86	0.063
lpendingproceedings	1.63	0.81	2.01	0.045
*lpendproc*lchildren*	-0.90	0.47	-1.92	0.055

Table 4.6.5 Summary of marginal effects of significant variables for the ordered probit estimation (II) with interaction variable – dependent variable: *air pollution emissions* – specification: raw data (E)

Probability in air pollution levels	Coefficient	Marginal Effect
lpcincomehat		
	153.58	
Pr (Y=1)		-42.74
Pr (Y=2)		-18.51
Pr (Y=3)		16.76
Pr (Y=4)		44.48
lpcincomehat2		
	-8.06	
Pr (Y=1)		2.24
Pr (Y=2)		0.97
Pr (Y=3)		-0.88
Pr (Y=4)		-2.33
lpcfemhead		
Pr (Y=1)	1.83	
Pr (Y=2)		-0.50
Pr (Y=3)		-0.22
Pr (Y=4)		0.19
		0.53
lchildren		
Pr (Y=1)	23.76	
Pr (Y=2)		-6.61
Pr (Y=3)		-2.86
Pr (Y=4)		2.59
		6.88
lpendingproceedings		
Pr (Y=1)	5.65	
Pr (Y=2)		-1.57
Pr (Y=3)		-0.68
Pr (Y=4)		0.61
		1.63
*lpendproc*lchildren*		
Pr (Y=1)	-3.12	
Pr (Y=2)		0.86
Pr (Y=3)		0.37
Pr (Y=4)		-0.34
		-0.90

Notes: Y =1: low air pollution; Y=2 : medium-low air pollution; Y=3: medium-high air pollution; Y=4: high air pollution.

Table 4.7 Ordered probit estimation without interaction variable (dependent variable: *air pollution emissions* – specification: *NE* – normalized raw data)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	137.92	63.65	2.17	0.030
lpcincomehat2	-7.25	3.31	-2.19	0.029
lpcasia	-0.24	0.18	-1.37	0.169
lpcafr	-0.18	0.22	-0.82	0.414
lpcfemhead	1.76	0.70	2.51	0.012
lchildren	5.32	1.92	2.76	0.006
lelders	2.52	1.64	1.54	0.125
lpendingproceedings	.26	0.28	0.95	0.342
cut_1	671.13	306.72		
cut_2	671.96	306.74		
cut_3	672.79	306.75		
number of observations = 103				
LR chi2(8) = 31.26				
prob > chi2 = 0.0001				
log likelihood = -127.14				
pseudo R2 = 0.1095				

Table 4.7.1 Ordered probit estimation with interaction variable (dependent variable: *air pollution emissions* – specification: *NE* – normalized raw data)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	169.74	65.87	2.58	0.010
lpcincomehat2	-8.90	3.43	-2.60	0.009
lpcasia	-0.24	0.18	-1.35	0.176
lpcafr	-0.25	0.23	-1.08	0.278
lpcfemhead	1.90	0.71	2.68	0.007
lchildren	24.09	9.56	2.52	0.012
lelders	2.96	1.68	1.76	0.078
lpendingproceedings	5.81	2.77	2.10	0.036
*lpendproc**lchildren*	-3.21	1.59	-2.01	0.045
cut_1	857.67	321.90		
cut_2	858.52	321.92		
cut_3	859.37	321.93		
number of observations = 103				
LR chi2(9) = 35.37				
prob > chi2 = 0.0001				
log likelihood = -125.08				
pseudo R2 = 0.1239				

Table 4.8 Ordered probit estimation without interaction variable (dependent variable: *air pollution emissions* – specification: *IWE* – Italian threshold limit values)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	106.91	62.83	1.70	0.089
lpcincomehat2	-5.58	3.27	-1.71	0.088
lpcasia	-0.27	0.17	-1.55	0.121
lpcafr	0.04	0.22	0.20	0.839
lpcfemhead	1.68	0.68	2.46	0.014
lchildren	4.38	1.88	2.32	0.020
lelders	1.83	1.63	1.12	0.261
lpendingproceedings	0.01	0.28	0.04	0.966
cut_1	521.28	302.64		
cut_2	522.06	302.65		
cut_3	522.85	302.66		
number of observations = 103				
LR chi2(8) = 22.11				
prob > chi2 = 0.0047				
log likelihood = -131.71				
pseudo R2 = 0.0774				

Table 4.8.1 Ordered probit estimation with interaction variable (dependent variable: *air pollution emissions* – specification: *IWE* – Italian threshold limit values)

air pollution emissions (dependent variable)	Coefficients	Standard error	z	P>|z
lpcincomehat	135.42	64.90	2.09	0.037
lpcincomehat2	-7.06	3.38	-2.09	0.037
lpcasia	-0.27	0.17	-1.56	0.119
lpcafr	-0.004	0.22	-0.02	0.986
lpcfemhead	1.81	0.69	2.62	0.009
lchildren	22.21	9.51	2.34	0.020
lelders	2.33	1.67	1.40	0.163
lpendingproceedings	5.26	2.75	1.91	0.056
*lpendproc*lchildren*	-3.03	1.58	-1.92	0.055
cut_1	690.53	316.96		
cut_2	691.32	316.97		
cut_3	692.14	316.99		
number of observations = 103				
LR chi2(9) = 25.82				
prob > chi2 = 0.0022				
log likelihood = -126.58				
pseudo R2 = 0.0904				

Table 4.9 Comparison among ordered probit estimations with interaction variable across alternative specification of the dependent variable

air pollution emissions (dependent variable)	coefficients (dep. var.: *E*)	P>|z	coefficients (dep. var.: *NE*)	P>|z	coefficients (dep. var.: *IWE*)	P>|z
lpcincomehat	153.58	0.019	169.74	0.010	135.42	0.037
lpcincomehat2	-8.06	0.018	-8.90	0.009	-7.06	0.037
lpcasia	-0.16	0.354	-0.24	0.176	-0.27	0.119
lpcafr	-0.28	0.224	-0.25	0.278	-0.004	0.986
lpcfemhead	1.83	0.010	1.90	0.007	1.81	0.009
lchildren	23.76	0.013	24.09	0.012	22.21	0.020
lelders	3.16	0.061	2.96	0.078	2.33	0.163
lpendingproceedings	5.65	0.041	5.81	0.036	5.26	0.056
*lpendproc*lchildren*	-3.12	0.051	-3.21	0.045	-3.03	0.055

Note: dependent variable: *air pollution emissions* specifications: *E* – raw data; *NE* – normalized raw data and *IWE* – data weighted by the Italian threshold limit values.

APPENDIX: DATA SOURCES AND VARIABLES DESCRIPTION

TABLE A1 – Variable Description and Data Sources

Variable	Description	Source
air pollution emissions	data on air emissions in all the Italian provinces	ISPRA – Air Emissions Provincial Inventory – year 2005
per-capita income	natural logarithm of per-capita income at provincial level, year 2001	elaborated from Institute Tagliacarne – our calculation
entrepreneurial spirit	number of registered firm at provincial level	Il Sole 24 Ore - Quality of Life Report data- year 2001
infrastructure	transportation infrastructural index	Il Sole 24 Ore - Quality of Life Report data- year 2001
females	number of female component the population	ISTAT data Census data, 2001
age15to34	number of people aged between 15 and 34 years old	ISTAT data Census data 2001
age35to49	number of people aged between 35 and 49 years old	ISTAT data Census data 2001
pcuniversitydegree	percentage of the population which has an undergraduate university degree	elaborated from ISTAT data Census data 2001
pclowersecondaryschool	percentage of the population which has a lower secondary school diploma	elaborated from ISTAT data Census data 2001
pcprimaryschool	percentage of the population which has a primary school diploma	elaborated ISTAT data Census data 2001
pcnoeducation	percentage of the population which has a no education at all	elaborated ISTAT data Census data 2001
pcfemalehead	percentage of family households with a female as the head of the household	elaborated from ISTAT data Census data 2001

pcasia	percentage of Asian residents	elaborated from ISTAT data Census data 2001
pcafr	percentage of African residents	elaborated from ISTAT data Census data 2001
children	percentage of children < 6 years old	elaborated from ISTAT data Census data 2001
elders	percentage of people >65 years old	elaborated from ISTAT data Census data 2001
pending proceedings	number of civil proceedings pending at courts located in a province every thousand inhabitants	Il Sole 24 Ore – Quality of Life Report data- year 2001
territorial dummies: northern provinces, central provinces	the geographical distinction in the three macro-areas it has been done following the definition of ISTAT. - North-west and north-east regions comprehend: Liguria, Lombardia, Piemonte, Valle d'Aosta, Friuli Venezia Giulia, Emilia R., Trentino, Veneto. - Central regions: Toscana, Marche, Umbria, Lazio. -Southern regions: Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia, Sardegna, Sicilia.	ISTAT

TABLE A2 – Pollutants description and threshold limit values

In the following table the pollutants and their respective U.S. and Italian threshold limit values are reported

Table A2: threshold limit values

Code	Pollutant	U.S. TLVs – eight hours mg/m3	Italian laws on air pollution – eight hours
001	SO2 – sulphur dioxide	13	80 µg/m^{3*}
002	NOX – nitrogen monoxide	30	40 µg/m3
005	CO – carbon monoxide	55	10 mg/m^{3**}
006	CO2 – carbon dioxide	9000	100.000t/year***
007	N2O – nitrous oxide (NIOSH)	30	50 µg/m3
008	NH3 – ammonia	35	10 mg/Nm3
M01	As – arsenic	0,2	6 ng/m3****
M03	Cr – chromium	1	0,05 mg/m3
M04	Cu – copper	1	1 mg/m3
M06	Ni - nichel	1	0,1 µg/m^3
M07	Pb - lead	0,05	0,5 µg/m^3
M08	Se - selenium	0,2	0,2 µg/m^3
P11	Benz - benzene (NIOSH)	0,32	5 µg/m^3

Notes: *substance measured in micrograms; **substance measured in milligrams; ***substance measured in megagrams; ****substance measured in nanograms. In the ordered probit regression analysis, all the different measurement units were converted into megagrams.

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CHAPTER 5
CONCLUSIONS

This thesis develops both a theoretical and an experimental analysis (chapters 2 and 3) on environmental enforcement, and carries out an empirical investigation (chapter 4) on the issue of environmental justice. The present chapter discusses some further implications from the theoretical model and from the experimental and empirical analyses and puts forward some indications for possible future research directions.

In chapter 2 specific reference is made to the U.S. environmental enforcement structure as a case characterized by well-defined roles of institutions and by a longstanding application of administrative, civil and criminal enforcement procedures. The main aim of the chapter was to reinforce the importance of the strategic interactions between governmental institutions (enforcers) and the regulated community (firms).

During the last few decades, the enforcement toolbox of U.S. environmental regulators and institutions has been harshly criticized (see, for example, Abbot, 2005) for leaving too large amount of discretion, administrative and/or investigative, in the hands of the Environmental Protection Agency (EPA), and prosecutorial in the hands of the Department of Justice (DOJ). The U.S. EPA has been promoting enforcement activities on all fronts but especially on criminal actions[62]. Such a trend has come under criticism as it has been argued that the fear of being indicted may, in the long run, undermine environmental compliance thereby worsening both the relations between EPA and firms and environmental conditions (Gaynor and Lippard, 2002; Coffee, 1991; Green, 1997). Moreover, as noted by Firestone (2003), the decision about whether to enforce and what kind of enforcement action to undertake rests entirely in the discretion of the enforcer.

[62] U.S. EPA, *Compliance and Enforcement Annual Results* (various years).

This discretion implies that, rightly or wrongly, some cases are handled administratively, whereas very similar cases end up in the courts (Babbit, Cory, *et al.,* 2004).

These are the core reasons why the U.S. enforcement system has become the object of political, economic and environmental debate with regard to the possibility that environmental regulations are enforced selectively or arbitrarily. This, in turn, raises the issue of potentially inadequate enforcement, partly due to the regulatory competition between EPA and DOJ [e.g., Yeager (1991) on the Clean Water Act enforcement].

These considerations constitute the main motivation for developing specific models of environmental enforcement in chapter 2 of this thesis, in which the relationships between EPA and DOJ, that have traditionally been treated as independent of each other, are investigated in a strategic game together with firms. This part of research centres around the question on how firms, EPA and DOJ can interact, given their respective objective functions, to increase regulatory compliance and to choose the best enforcement strategy that could lead to increased environmental quality. Two game theory models are developed, i) a model in which EPA's and DOJ's enforcement decisions are made under the same objective function, and ii) a model in which EPA and DOJ are assumed to not share the same objective function. In both models, firms' compliance decisions are analyzed as well as the institutional enforcement decisions (in terms of strategy to adopt) and their effects on firms' choices. These models may assist regulators and enforcers in environmental policy development and decision-making, by contrasting the impact of alternative enforcement strategies.

The main result of the first theoretical model (where EPA and DOJ share the same objective function) shows that it is more efficient to let the EPA solve the cases administratively rather than refer them to the Department of Justice for civil or criminal prosecution. This may suggest that increasing the scope of criminal enforcement programmes would not necessarily strengthen deterrence since criminal fines might not be able to give polluters adequate incentives to prevent environmental crimes. In the context of the model employed, criminal enforcement may, indeed, reduce the effectiveness of enforcement policies. This result is particularly relevant considering that both in the United States and in the European Union environmental regulators have recently been actively reviewing how to extend criminal sanctions in terms of their scale and scope to enhance deterrence (U.S. Senate, 2003; House of Commons, 2005; European Commission, 2007).

One of the main results of the second theoretical model (under the assumption that EPA's and DOJ's objective functions are different), however, is that criminal enforcement can enhance deterrence by improving firms' compliance. In terms of environmental policy implications, our result suggests that, even though EPA and DOJ should work in coordination, in order to maximize the level of compliance by the firms they should act independently of each other without sharing the same objective function.

Overall, a defence of the U.S. environmental enforcement system is provided, suggesting that, contrary to the prevailing consensus in the literature (Sunstein *et al.,* 2002) that a consistent and predictable enforcement is preferable, a discretionary enforcement may generate higher compliance (Baker *et al.*, 2004). Another important point of our results is that EPA and DOJ engage in strategic interaction in their environmental enforcement behaviour. It is shown that not only do they influence each other in their enforcement decisions, but they also impact on decisions by the firms and increase (under certain circumstances) the probability of compliance.

Chapter 3 discusses the experimental approaches performed to test the theoretical findings of the two game theoretic models developed in chapter two. Both experimental validations fully agree with the theoretical results thus confirming the importance of the strategic interactions between enforcers and firms. The results can have notable policy implications concerning the optimal choice of enforcement strategies.

While motivated by and intended to analyze the enforcement of environmental regulations, the game theory models developed in the present thesis are applicable to other contexts that entail relationships between different enforcement institutions. For example, they can be applied to analyze enforcement options and players' behaviour in financial crime areas, such as tax law enforcement, money laundering, *etc*.

One possible way to extend this study for future research could be to develop dynamic game theory models where players can learn how to play over time and can update their beliefs by learning how to play based on their past experiences and acquired knowledge of the other players' actions and their payoffs.

Moreover, the patterns of the different enforcement strategies considered in the game theory models are based on the conventional enforcement system mostly applied in the U.S.; it would be interesting, in a future research, to extend this analysis to game theoretical models for Europe, where the environmental enforcement institutional mechanisms are different.

Chapter 4 presents an environmental justice empirical analysis on the relationship between income, demographic characteristics and concentrations of air industrial pollutants within the Italian provinces. Within a law and economics approach, environmental justice and enforcement of laws are strictly related. If environmental laws and regulations are uniformly and equally enforced, they do protect all groups in society, including minority and low-income populations. In general, the enforcement of environmental laws has environmental justice implications embedded within it.

Two general conclusions can be drawn from the empirical results. First, the estimates obtained indicate that air pollution releases increase with income, but they are also consistent with an inverse U-shaped environmental Kuznets curve: once income exceeds a turning point, air pollution decreases with increasing income. Second, there is some evidence that air releases tend to be higher in provinces with high concentration of females as households' head and with high concentration of children. Since the findings do not point to environmental discrimination on the basis of ethnicity, this suggests that environmental justice issues in Italy are not likely to manifest themselves along racial and ethnic terms but instead in terms of social categories and gender composition.

We also find that judicial inefficiency (a measure of the inefficiency of law enforcement) is associated with higher levels of pollution. In terms of policy implications, this result suggests the need to strengthen, all through the territory, the local enforcement of environmental laws in order to possibly reduce the negative effects of ambient air pollution.

A possible development of this study for future analysis is that as more data (Italian Census data) will become available the research can move in a more dynamic direction and check whether, over time, consistent results will continue to emerge. The study of the links between public health and the location of industrial plants or waste treatment facilities is another possible way to extend the analysis in order to help supporting public policy decisions and minimize public health impacts. It would also be useful to extend the study to other environmental variables (water and/or waste pollution) and to develop a more comprehensive analysis of the social aspects and environmental concerns. An area that warrants further investigation is the analysis of the behaviour of Italian enforcement authorities. One challenge here is that it might be difficult to obtain information on the number and on the frequency of inspections and of other enforcement actions for air or water pollution, given the fragmentation of the Italian enforcement system among several institutional authorities.

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