ΠΑΝΕΠΙΣΤΗΜΙΟ ΜΑΚΕΔΟΝΙΑΣ

ΟΙΚΟΝΟΜΙΚΩΝ ΚΑΙ ΚΟΙΝΩΝΙΚΩΝ ΣΠΟΥΔΩΝ

ΔΙΑΤΜΗΜΑΤΙΚΟ ΠΡΟΓΡΑΜΜΑ ΜΕΤΑΠΤΥΧΙΑΚΩΝ ΣΠΟΥΔΩΝ ΣΤΗΝ ΟΙΚΟΝΟΜΙΚΗ ΕΠΙΣΤΗΜΗ

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ΕΠΙΜΕΛΕΙΑ: **ΠΑΡΓΙΑΝΑΣ ΧΡΗΣΤΟΣ**

ΕΠΙΒΛΕΠΩΝ ΚΑΘΗΓΗΤΗΣ: **ΚΩΝΣΤΑΝΤΑΤΟΣ ΧΡΗΣΤΟΣ**

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CONTENTS

ABSTRACT

In this dissertation we examine how an environmental tax policy interacts with quality choices. We consider a model where the consumption of a given quality produces both private and external benefits, the two types of benefits being positively correlated. We consider two different cases. In the first, the environmental tax is set taking into account both its long run effect on quality choices and its short run effect on prices. In the second, only the latter effect is taken into account, as is done in many cases. It turns out that results of the two models are completely different which in turn implies that environmental policy may be misleading when its effects on quality choices are not taken into account.

The first of the aforementioned cases is examined using a model where the regulator chooses the tax level at the first stage, firms choose their qualities at the second and compete in prices at the third (Model A). In order to examine the second case we use a model where the firms choose their quality during the first stage, the regulator imposes a tax at the second stage, and firms compete in prices at the third (Model B).

Several conclusions come out from our study: social welfare and taxes are higher when the regulator plays first. On the other hand, profits and both products environmental quality are higher when firms play before the regulator. Despite the higher environmental quality of both products in model B, total environmental damage is bigger in that model since quantities consumed are larger.

The regulator's environmental preferences are also very important. When the regulator cares more about the environment, optimal taxes are higher and the environmental problem abates, but the market distortion problem worsens: prices go up and quantities are reduced.

Finally, we examine the regulator's time consistency. We find that if the regulator could play twice, he would have no incentives to change the tax, since he could only marginally improve social welfare. Thus, we can say that the regulator is time consistent and the model that dominates is the long run model.

1. INTRODUCTION

Recently, people's awareness concerning the environment has increased substantially and as a result, environmental protection has now become a priority for governments. Following intense negotiations during the past decade, 128 countries finally reached on agreement and signed the Kyoto protocol in 2005. Its main target is the reduction of CO_2 emissions in the developed countries. Although the agreed reduction may not mean much for the environment, it is considered as a good start towards further reduction in the future.

In this work we examine the role of environmental policy, in the presence of imperfect competition and endogenous quality choices. We consider two different cases. In the first, the environmental tax is set taking into account both its long run effect on quality choices and its short run effect on prices. In the second, only the latter effect is taken into account, as is done in many cases. It turns out that results of the two models are completely different which in turn implies that environmental policy may be misleading when its effects on quality choices are not taken into account.

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The dissertation is organised in the following way: chapter 2 contains the theoretical background, chapter 3 reviews the available environmental policy instruments, chapter 4 presents the model and its main results, and chapter 5 concludes.

2. THEORETICAL BACKGROUND

Before reviewing the environmental policy instruments it is useful to examine their theoretical background. In this chapter we analyse the concept of sustainability, which allows us to understand what should be the real target of environmental policy, and that of the tragedy of commons which shows why it is not easy to fight the environmental problem.

Sustainability is quite important and so we have to examine further its definition. As generally understood, it is a kind of obligation towards future generations. If defined as an obligation to leave the world exactly as we found it, it is, perhaps, unfeasible and likely not even desirable since it would imply no further use of mineral resources, no more construction or development in infrastructures, etc. Perhaps a more appropriate definition of sustainability is that of an 'obligation to conduct ourselves so that we leave to the future the option or the capacity to be as well-off as we are.' In thinking about sustainability, we have to take into account not only the resources that we use and those we leave behind, but also the environmental quality, the productive capacity and the technological knowledge. Sustainability should not require that any particular species of fish, for example, be preserved: our analysis must also account for substitutability on the production side. We know that usually, in the production of any particular output one kind of input can be substituted for another. There is no reason for our society to feel guilty about using up aluminium as long as we leave behind a capacity to perform the same or analogous function using other kinds of material. If we leave behind the capacity to create welfare, then we have sustainability even if we destroy some resources.

People who care for the environment are trying to find a way to avoid the evils of pollution without abandoning any of the privileges they now enjoy. They think that the problem will be solved technologically by replacing for example the polluting existing fuels with other fuels which are friendly to the environment. Hardin (1968), argues that such a problem can not be solved technologically. The environmental problem, according to Hardin, has many similarities with the tragedy of commons.

The tragedy of commons develops in this way. There is a pasture open to all. There are many herdsmen and each of them can keep as many cows on the commons as he wants. As a rational being, each herdsman seeks to maximize his gain, and more or less consciously, he asks 'what is the utility to me of adding one more animal to my heard'? This utility has one negative and one positive component. The positive component is a function of the profit of one animal. Since the herdsman receives all the proceeds from the sale of the additional animal, the positive component of his utility is nearly +1. The negative component is a fraction of the overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all the herdsmen, the negative utility for a particular decision making herdsman is only a fraction of -1. Net utility is therefore positive and the rational herdsman adds another and another animal to his herd. This is the tragedy of commons: each man decides to increase his herd without limit in a world that is limited.

The tragedy of the commons reappears in problems of pollution. Here it is not a question of taking something out of the commons, but of putting something in – sewage into water and dangerous fumes into the air. The calculations of utility are much the same as before. The rational man finds that his share of the cost of the wastes he discharges into the commons is less than the cost of purifying his wastes before releasing them. Since this is true for everyone, no one will purify his wastes before releasing them. Individuals find it easier to drop litter than find a bin and so they impose costs on their local communities. In our days, it has been recognised that the developed nations look like the shepherds in Hardin's model with many more cows on the common, in terms of their CO_2 emissions, than their less developed neighbours. If developing nations cut, or even stabilize, emissions it would decrease their ability to generate wealth and deal with the problems of poverty and increasing population. In each of these cases the benefits are gained by few, while the costs are shared between much more parts. This is the essence of the tragedy of commons model.

Hardin suggests various ways to solve the problem. One is privatisation: to create ownership also creates an incentive to manage the resource and prevent over-use. Although this is theoretically possible for some resources (such as National Parks overused by too many visitors) for others it is more difficult (for example the atmosphere). Rather than 'exhorting individuals to behave responsibly and then relying on their consciences to make them behave as unrealistic', Hardin instead advocates for 'mutual coercion, mutually agreed upon', that is, encouragement backed up by sanctions, including legal ones.

3. ENVIRONMENTAL POLICY

The presence of harmful environmental externalities which take the form of environmental pollution generated by the industrial sector of the economy and the environmental pollution that may come from consumers reassures specific policy measures: the three major approaches to environmental policy are command and control, economic instruments, and information strategies.

3.1. COMMAND AND CONTROL

The basic characteristic of the command and control approach is that the government directly dictates the behaviour of every firm that pollutes the environment. There are two main types of command and control regulation: performance standards and design standards.

In the former case, the regulator defines an emission limit for the firm which in turn adjusts its output or/and abatement in order to comply with the limit. A performance standard has the advantage of leaving the firm the freedom to comply by either reducing output or increasing abatement. The main disadvantage is that it requires individual monitoring and knowledge of compliance costs. Letting $\bar{e}$ be the maximum allowable emission for the firm, the latter chooses output and abatement in order to:

$$\max_{q,a} \; q \cdot p - c(q,a)$$

$$\text{s.t.}\; e = \bar{e}\,,\; e = s(q,a)$$

On the other hand, when there is a design standard the regulator requires the use of a specific technology. Design standard is usually used when emission monitoring is expensive or technically unfeasible. Let $\bar{a}$ be the minimum required abatement to use the specific design. The problem for the firm in this case is:

$$\max_{q,a} \; q \cdot p - c(q,a)$$

$$\text{s.t. } a = \bar{a}$$

Although by choosing the emission target and the abatement level both a performance standard and a design standard lead to the same emission level, the output-abatement combinations are different in the two cases: output is lower and abatement higher in the performance standard case.[1] This reveals the qualitative difference between the two approaches. The performance standard is more flexible since it allows the firm to achieve the emission standard by either reducing its output or increasing its abatement. Such a substitution is impossible under the design standard.

As a policy instrument, command and control can have some advantages and is widely used. Its main advantage is that measures can be introduced quickly in response to emerging problems and set out clear and fair rules that affect all parts equally. However, it also has disadvantages. Firms, comply only partially in the licence conditions because regulation gives no incentive to invest in pollution reduction beyond the legal limit. In the long run there is no change in firms' behaviour since there is no incentive to use a different kind of technology, friendlier to the environment.

3.2. ECONOMIC INSTRUMENTS

Economic policy instruments can overcome the incentive disadvantage of command and control regulation by providing a more flexible and potentially more efficient means to encourage polluters to reduce their polluting behaviour. The most common environmental economic policy instruments are: emission taxes, subsidies, output taxes and emissions permits.

Economic policy instruments provide an incentive for firms to reduce emissions by making technological improvements, since they have the effect of internalizing external costs and so, making the polluter bear the cost of the environmental damage. This is the practical application of the 'polluter pays' principle.

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[1] See Xepapadeas (1997) pp. 24-26

On the other hand, economic instruments can be problematic if the activity being taxed meets basic needs or makes a significant contribution to the quality of life of economically disadvantaged groups. Economic instruments that raise the price of water, food or energy, for example, will have a proportionally greater effect on lower income groups than on more wealthy consumers. The basic starting point in economics for the prescription of pollution taxation is the concept of 'market failure'. This means that the market fails to include the costs of pollution, which are not internalised, and the allocation of resources does not take place according to Pareto optimality criteria. In what follows we analyse every instrument in more detail.

3.2.1 Emission taxes

The polluting firms internalize external social damages if they are confronted with an emission tax per unit of waste released in the environment. The tax rate must be equal to marginal social damages. We assume that the firms choose how much they will produce and the amount of abatement they undertake, and the tax is imposed on the resulting emissions. The firm solves the problem:

$$\max_{q,a} p \cdot q - c(q,a) - t \cdot e,$$

where $e = s(q,a)$. The optimal tax in this case is $t = d$, where d is the marginal social environmental damage. In the absence of market distortions such tax leads to the social optimal emission level. This price incentive for emission control is the 'Pigouvian' tax.

3.2.2. Emissions reduction subsidies

A subsidy scheme involves payments to the firm for reducing emissions below a given level. The firm here solves the problem:

$$\max_{q,a} p \cdot q - c(q,a) + v(\bar{e} - e),$$

where $e = s(q,a)$, $\bar{e}$ is the maximum allowable emission level, and v is the subsidy per unit reduction of emissions below $\bar{e}$.

Since the firm's objective function under the subsidy scheme differs from the corresponding objective function under taxes only by a constant, a subsidy equal to marginal social damages evaluated at the optimal emission level will enforce firms to emit at the social optimum. Although taxes and subsidies offer the same marginal incentives for emission reductions, they differ with respect to their effect on long run pollution. This is because they have different impact on firms' long run entry-exit decisions. The Pigouvian tax leads to a reduction in the industry size, while a subsidy leads to an increase in the industry size relative to the unregulated equilibrium. It is possible that the increase in the industry size under the subsidy scheme lead to even an increase of total emission in the long run (Baumol and Oates 1988)

3.2.3. Output or product taxes

Output or product taxes are taxes imposed on products that are environmentally harmful either when used in production or when consumed. While often confused with Pigouvian taxes, output taxes differ from the latter in that they are imposed on output rather than on emissions. Pigouvian and output taxes are equivalent if there is a one-to-one correspondence between output level and emissions. While prices and quantities are more easily observable and verifiable, verification of emissions levels is very costly. So it is easier to impose a commodity tax/subsidy policy, relative to a Pigouvian tax/subsidy on emissions.

Many papers consider output tax/subsidy policies rather than emission tax/subsidy policies. Petrakis *et al.* (2004) considers a model with two firms which produce two differentiated goods and compete in prices. In this model consumption generates two types of damages: damage to the individual consumer and an environmental externality. One good causes no damage at all and it is called the clean good, while the other, called the dirty good, generates damages both to the consumer using it and to the society. There are also two groups of consumers, those that have perfect knowledge of the negative effect of the dirty good's consumption and those that have no knowledge at all. The utility of informed consumers is:

$$U_j = (a+\theta_{cj})q_c + (a-\theta_{dj})q_d - \frac{1}{2}(q_c^2 + q_d^2 + 2\cdot g\cdot q_c \cdot q_d),$$

where $j=i,n$ stands for informed and uninformed consumers, while $\theta_{cn} = \theta_{dn} = 0$.

The regulator imposes a tax t on the dirty good. The firm that offers the dirty good solves the following maximization problem:

$$\max_{p_d} \pi_d = (p_d - t - c_d)[\mu \cdot q_{di} + (1-\mu) \cdot q_{dn}]$$

Where c_d is the marginal cost of the dirty good, q_{di} is the quantity of the dirty good that is consumed by the informed consumer, q_{dn} is the quantity of the dirty good that is consumed by the uninformed consumer, and μ is the percentage of informed consumers.

As expected, prices of both goods are higher after imposing the tax and the higher the tax rate, the more of the clean and less of the dirty good is consumed by both groups of consumers. There is, however, a problem due to the fact that the regulator cannot distinguish between the two groups of consumers: the tax rate being common for all consumers is set at a higher (lower) for the informed (uninformed) consumers relative to the social optimum, since the informed already take into account part of the externality as their individual damage. This means that at the equilibrium, the informed (uninformed) consumers purchase less (more) than their optimal quantity of the dirty good. Since the dirty good imposes external damages in addition to individual damages, the inability of the regulator to distinguish between the two groups of consumers allows uninformed consumers to partially free ride.

Bansal and Gangopadhyay (2001) considers a model with output tax/subsidy policies in order to show how these policies affect the clean up levels. In their model two firms produce a physically homogenous good x and they play two-stage game. In the first stage they choose the clean up levels and in the second stage they choose prices. Consumers derive utility from the polluting good x and a composite good, money. Each consumer buys only one unit of x. Consumers are environmentally conscious. They are willing to pay a higher price for x, if it is environmentally better. Production of the homogenous composite good has no environmental impact. For a consumer buying both the composite good and x the utility is given by:

$$U = y + I[u + \theta(y)e_i - p_i] - Z,$$

where y is the money endowment, u is the utility derived from one unit of x, e_i is the clean up level of firm i from which the consumer buys the good x, at price p_i, Z is the aggregate level of pollution. The component I is zero when the consumer does not purchase x, and 1 in the case of purchase; $\theta(y)$ is marginal willingness to pay for quality. Total pollution Z depends on clean up levels and the amount of production and consumers treat Z as a public bad and so Z does not affect individual actions.

We assume that $e_1 \geq e_2$. Let θ_1 be a consumer indifferent between buying quality 1 and 2, and θ_2 be a consumer who is indifferent between buying quality 2 or none at all: $\theta \cdot e_1 - p_1 = \theta \cdot e_1 - p_2 \Rightarrow \theta_1 = \dfrac{p_1 - p_2}{e_1 - e_2}$, and if $\theta \geq \theta_1$ will buy from firm 1. $\theta_2 = \dfrac{p_2}{e_2}$, and if $\theta_2 < \theta < \theta_1$ will buy from firm 2. With no tax, profits are: $\Pi_i = a_i p_i$, where $a_i(e_1, e_2, p_1, p_2)$ and a is the demand for each good. With uniform tax/subsidy: $\Pi_i(t_i) = (1 - t_i)a_i p_i$, where t_i is the tax rate on product i. When $t>0$, t corresponds to a tax and when $t<0$ to a subsidy.

In this setting, the authors find that the imposition of a uniform *ad valorem* tax on all firms reduces the clean up levels adopted by them. On the other hand, an *ad valorem* subsidy improves the adopted clean up levels.

A discriminatory subsidy policy rewards the cleaner firm and leaves the other firm unaffected. On the other hand a discriminatory tax policy punishes the dirtier firm and exempts the cleaner firm. They show that the average clean up levels increase with a policy that rewards good producers and fall with a policy that punishes the dirtier producers. They also find that a discriminatory *ad valorem* subsidy unambiguously improves aggregate welfare whereas a discriminatory *ad valorem* tax policy may reduce aggregate welfare.

Cremer and Thisse (1999) studied the provision of environmental quality in imperfectly competitive markets. They considered a vertical differentiation model where there is a continuum of consumers whose types are identified by θ which is distributed over $[\underline{\vartheta},\vartheta]$ with $\underline{\vartheta}>0$. Each consumer either buys one unit of the differentiated commodity or does not participate at all in the market. If he does not buy then his utility is zero. The indirect utility of a consumer of type θ who buys a good of quality q at price p is given by:

$$V_\vartheta(p,q,q^\alpha)=\vartheta q+\gamma\vartheta q^\alpha+y-p,$$

where y is consumers' income, q^α is the average quality over all consumers.

There is an infinite number of potential firms that play a three stage game: first, firms decide whether or not to enter, second, they choose quality and finally they choose prices. Marginal production cost of firm i is independent of quantity but is strictly increasing and convex in quality. There is also a strictly positive but arbitrarily small entry cost F.

Cremer and Thisse (1999) showed that the market will tend to underprovide environmental quality. They come to the following main results: First, a commodity tax may have a significant impact on the market structure. Actually it tends to increase the number of active firms. Second, through its impact on market structure, a commodity tax may be welfare-improving, even though quality creates a positive externality. Finally, a commodity tax may bring an equilibrium that is close to a Pareto-efficient allocation.

3.2.4. Coexistence of taxes

Moving from partial to general equilibrium analysis a new issue arises with Pigouvian taxes: since they coexist with other taxes in the economy their full impact becomes more complicated to assess. Two new issues must now be taken into account.

The first is to determine the optimal emission tax in the presence of other distortionary taxes in the economy, like commodity taxes. Regarding this problem, Bovenberg and Goulder (1996) consider a model which includes as inputs labour, one 'dirty' and one 'clean' intermediate input, and one 'dirty' and one 'clean' consumption good, with individual utility depending on private consumption, environmental quality and public consumption. They find that the optimal taxes of the 'dirty' intermediate input and consumption good are equal to marginal environmental damages divided by the marginal cost of public funds. This cost depends on the distortionary tax on labour and the uncompensated wage elasticity of labour supply, and is expected to exceed unity. Thus, the optimal emission tax in the presence of distortionary labour taxes is less than marginal damages. The choice of an optimal emission tax lower than environmental damages can, therefore, be regarded as an efficient environmental protection instrument.

The second problem relates to whether the cost of emission taxes is reduced when tax revenues are used to lower existing distortionary taxes. As noted in Pearce (1991) the use of environmental taxes to reduce distortionary taxes could result in two benefits. The first benefit is the environmental protection while the second relates to the distortionary cost of the tax system. This is analyzed in the double dividend theory. Three effects are present when an environmental tax is imposed. The first is the emission reduction, also called the 'Pigouvian' effect, and it is always positive. The second, which is positive too, is the revenue effect which reflects welfare gains from reducing other distortionary taxes. The third, which is negative, is the interdependence effect, which reflects the likely increase of pre-existing tax distortions due to the introduction of environmental taxes that also create extra costs. The extra costs are the losses of revenue and efficiency in labour and capital markets if environmental taxes discourage employment and investment. The second and the third effect work in different directions. When the revenue effect exceeds the interdependence effect we have a case of double dividend in the strong form. On the other hand we have double dividend in the weak form when the interdependence effect exceeds the revenue effect.

The presence of a double dividend, especially in the strong form, is especially appealing to policy makers since it implies that environmental taxes could be introduced without any cost and therefore there is no need to justify them in terms of uncertain environmental benefits. Theoretical and empirical research do not seem however to support the idea of a double dividend in its strong form. In fact, the double dividend hypothesis holds only in the weak form.

3.2.5. The Coasian approach

In the previous section a number of policy instruments were examined which, when applied, could lead to the social optimal pollution level. This approach can be regarded as the traditional one. According to this approach the divergence between private and social costs can be solved by imposing a tax on the party that creates the environmental damage, or by imposing other equivalent measures. In the classical example of a factory generating smoke that has harmful effects on individuals living nearby, the Pigouvian tradition would support the decision to make the owner of the factory liable for the damages created by the smoke and impose on him a tax that varies with smoke.

In a different approach, Coase argues that there are parties in the economy that generate pollution which harms other parties. The only thing that the government should do, according to Coase, is to properly define the property rights over clean air. This approach leads to bargaining processes among the parties in order to reach an optimal agreement on the level of the environmental externality. This optimal agreement can lead to a Pareto optimal solution without any need for regulation. The Coasian approach is, however, of limited relevance to most of the major pollution problems. Since most cases of air and water pollution, for example, involve a large number of polluters and/or victims, the likelihood of a negotiated resolution of the problem is small. Transactions costs are too large to permit a Coasian resolution of most major environmental problems.

3.2.6. Tradable emission permits

These disadvantages can be avoided with the introduction of tradable emissions permits. This economic instrument is, perhaps, the only 'Coasian' instrument that can be used. Tradable emission permits represent a system of tradable property rights for environmental pollution. A tradable permits system involves the determination of a total level of allowable emissions and the distribution of the emission allowances to the firms. After their initial distribution, permits can be traded. The equilibrium in the permit market is equivalent to the Pigouvian tax equilibrium. The competitive equilibrium permit price is equal to the marginal environmental social damages.

Factories can trade emissions permits among themselves. Those who find it easy to reduce emissions will have surplus permits, which can be sold to competitors who are less able to cut their pollution. The regulator can issue permits in one of two ways. The first is grandfathering, which recognises the rights of established industries, which are granted permits, based on their emission levels prior to the introduction of the trading system. The alternative is to auction permits each year to the highest bidders. The advantage of the tradable permit system is that it allows the regulator to cut, year by year, the total amount of pollution produced by steadily decreasing the number of permits in the system.

3.3. INFORMATION STRATEGIES FOR POLLUTION CONTROL

The first phase of pollution control involved applying command and control policies. Over time, however, it became clear that these traditional regulatory approaches to pollution control were excessively costly in some circumstances and not able of achieving the stipulated goals in others.

In response to these deficiencies, the second phase of pollution control focused on market-based approaches. These approaches have both added flexibility and improved cost-effectiveness to pollution control policy. Even the addition of market-based approaches, however, has not fully solved the problem of pollution regulation. Neither staffs nor budgets are adequate for the task of regulating all of the potentially harmful substances that are emitted by firms and households. Often, these difficulties are compounded by the problems associated with designing, implementing, monitoring and enforcing market-based regulations.

Phase three involves investment in the provision of information as a mean for making the community an active member in the regulatory process. The information strategies involve public and/or private attempts to increase the availability of information on pollution to workers, consumers, shareholders and the public. Provision of greater information may either complement or replace traditional regulation strategies. Information strategies target the use of market forces in order to achieve efficient pollution control.

The starting point for thinking about information approaches to pollution control is the Coase theorem. Coase pointed out that pollution control situations have certain symmetry. Inefficient pollution imposes costs on victims which exceed the costs of controlling that pollution. In other words the marginal benefits of pollution control exceed the marginal costs. The existence of inefficient pollution damage therefore provides a motivation for the victims to take corrective action, even in the absence of any such incentives by the polluters. The list of victims can be very large, much larger than originally thought, including, besides the traditional categories of those harmed directly by the pollution, those who may be disturbed by it even if they are not directly affected. Information about environmental risks is asymmetrically distributed. In a typical case the best knowledge about emission profiles is held by the polluters and/or regulators, not the victims. Furthermore the polluters do not want to share the information with victims in the absence of outside pressure to do so. However, even if information on emissions is provided, this may not be sufficient for the victims to understand how serious the risk they face is.

In the next few pages are analyzed the types of pollution, the different types of settings, because each of them has different characteristics and needs to be examined separately, and the functions that a typical information strategy involves, according to Tietenberg.

There are two broad pollution types: product pollution and process pollution. Pollution can arise either from the consumption or use of products (product pollution) or the production of those products (process pollution). Examples of the former include the consumption of foods contaminated with pesticides, the use of aerosol sprays which are harmful for the ozone, driving cars etc. Examples of the latter include water pollution from pulp and paper factories, air pollution from steel factories, hazardous waste pollution from chemicals plants, radiation from nuclear power plants, etc.

There are four specific settings. Each of them should be examined separately because of their different characteristics: the household setting, the consumption setting, the employment setting and the community setting.

The household setting: indoor pollutants, though increasingly recognized as significant contributors to human health problems, have not traditionally been addressed by conventional regulation. Two classic examples of dangerous indoor pollutants are radon gas and lead paint. Radon gas is colourless and it tends to enter homes from the ground or through water supply. The homeowners have full information and so they have three choices. They can decide not to control; they can undertake some control; or they can attempt to solve the problem by selling the house to someone else. For the first two choices, homeowner incentives are compatible with efficiency, because those who would bear the damage and those who would pay for the control are in the same household. The third choice, however, leads to a possible inefficiency. The cheapest solution may well be selling the house to an unsuspecting buyer, thereby passing any control costs to them. The role of the government here is clear. It seems necessary to assume that only full information transfers of property take place. An informed buyer should reduce the offer price by an amount that reflects the cost of controlling the radon or lead.

The consumption setting: this is the situation of product pollution in which damage goes directly on those consuming the product. An example is fruit or vegetables with residues of pesticides. Here there is a case where the polluter and the victim are different. Since consumers and producers are linked by the purchase decision, pollution inflicted on consumers is not necessarily an externality. Consumers who are aware that a product is exposing them to an environmental risk can either avoid purchasing it or purchase it only at a lower price. The problem here is that the market will not necessarily supply the necessary amount of information about the risk. Hence, to assure that consumers are fully informed there is a need for government intervention. If the environmental risk is so large that rational consumers would not purchase the product, the government typically bans it. In the case that the environmental risk exceeds the benefits of the product for some consumers but not for others, product labelling should provide the needed information. In addition, the government should inform consumers so that they can understand what the label implies about the product.

The employment setting: the employment setting provides a very different set of interactions between polluters and victims. Employers typically control the overall production process, which includes decisions about the toxicity of the substances employees face. However, employees have at least some control over their actual exposure to risk. Employees will seek wage increases to compensate for the risk and the employer must choose how much to invest in risk reduction. All of this, however, depends on fully informed workers and employers. Individual employees are unlikely to be willing to undertake the cost of acquiring information about the risk and employers do not have an incentive to inform their workers about environmental risks. Here the role of the government and/or labour organizations is important.

The community setting: from an economic point of view, the most difficult setting for pollution information involves situations where the polluter and the victim have no relationship. The relationship between polluters and their neighbouring communities provides a good example of this problem. While the victims still have an incentive to take action against environmental risk, here the role of the government is, perhaps, even more important than in any of the other settings.

In each of the above different settings, an information strategy can be useful. The typical information strategy involves four separate functions. First, it is important for the government to establish mechanisms for discovering environmental risks. Environmental risks will normally be detected only after some investment in information is made by the government. People should be informed so that they can recognize where there is environmental danger.

Second, it should be assured that the available information is reliable. Information has both a quantity and quality dimension. Effective risk communication requires that the necessary information be reliable as well as available. Inaccurate or partial information can be worse than no information, if it promotes either a false sense of security or unjustified fears. Accurate information can be promoted by standardizing the method of collection and by assuring significant penalties for those who give incorrect information.

Third, the government should spread properly the available information. The necessary information must reach the victims in a usable form. Transparency is the key to assuring the availability of useful information. In practice this means that the information must be in a form that can be used by the community, and the community must have access to it.

Finally, once the information about an environmental risk is generated, the next step is to define what can be done with it. In product market, consumers may choose less environmentally harmful products. In the capital markets owners of shares of common stock in polluting firms may decide to invest in companies with a greener record, either for moral reasons or because they believe that environmentally benign firms will ultimately face fewer clean up costs and will therefore be more competitive.

Garcia-Gallego and Georgantzis studies the incentives of manufactures to invest in persuasive advertising aiming at increasing the consumers' willingness to pay for a more ecological product. It considers a duopoly model of vertical differentiation, where the two firms, *a* and *b*, sell two products which are identical in all other aspects, except for their performance with respect to the natural environment. The product's environmental qualities are assumed to be respectively S_a and S_b, with $S_a > S_b$, implying that firm *a* has a greener product. They also assume that firm *a* is the greener one. The population of potential consumers is *M*. Each consumer *i* maximize his utility U_i, demanding a maximum of one unit of the product from firm *j* whose product quality and price satisfy:

$$U_i = \max\{R + v_i \cdot S_a - P_a, R + v_i \cdot S_b - P_b, 0\}$$

where $R>0$ is the utility enjoyed by the consumer from consuming a unit of the product before environmental considerations are taken into account and

v_i is a consumer specific parameter indicating consumer *i's* marginal willingness to pay for a unit improvement of the environmental quality of a product, which is uniformly distributed along the interval $[m,n]$, where $m>0$ and $n>m$, with density *d*. Moreover, it is assumed that $L=n-m$.

For a pair of prices (P_a, P_b) which are not too different from each other, there will be a critical consumer i_0, whose environmental consciousness parameter v_0, makes him indifferent between buying from the less ecological or from the more ecological manufacturer: $v_0 S_a - P_a = v_0 S_b - P_b \Rightarrow v_0 = \frac{P_a - P_b}{S_a - S_b}$. All consumers with $v < v_0$ buy the less green product, while the opposite holds $\forall \ v > v_0$ buy more green. The profit functions are: $\Pi_a = (P_a - c)\, q_a$, $\Pi_b = P_b\, q_b$, where c is the extra cost paid for greener product. Firms set prices to maximize profits and here we have Bertrand – Nash equilibrium. They concentrate on three types of advertising:

1) advertising which increases equally the environmental consciousness of all consumers, without affecting consumer heterogeneity,

2) advertising which increases more the willingness to pay of those consumers who were already willing to pay more, thereby increasing consumer heterogeneity,

3) advertising which increases more the willingness to pay of those consumers who were initially willing to pay less, thereby decreasing consumer heterogeneity.

They arrive at the conclusion that firm *a* always benefits from advertising of type 1 and 2, but the result is ambiguous from advertising of type 3. On the other hand firm *b's* profits are always reduced from advertising of type 1 and 3, while advertising of type 2 has ambiguous results. They also observe that only the second type of advertising increases both product prices. The first type of advertising will increase the price of the ecological product and decrease the price of the less ecological one. Advertising of the third type increases competition between the two firms by decreasing consumer heterogeneity. Thus, equilibrium prices will decrease in the presence of this type of advertising.

Petrakis *et al.* (2004) examines the case where the regulator decides to improve the situation by informing consumers about the negative effects of consuming the dirty good. The regulator targets a fraction of consumers depending on the cost of sending the information. Consumers who receive the information take into account the individual damage that the consumption of the dirty good imposes on them. Since the government does not know the true type of each consumer it targets all consumers. One result of this policy is that the firm producing the dirty good decreases its price while the firm producing the clean good increases its price relative to the unregulated equilibrium. Contrary to the case of taxation, where the tax has a positive effect on both prices, in the case of information provision the price of the clean good is higher but the price of the dirty good is lower. Another result is the decrease of consumed quantity of the dirty good and the increase of consumed quantity of the clean good, relative to the unregulated case.

4. THE MODEL

4.1. GENERAL ASSUMPTIONS

Assume that there are two firms, 1 and 2, each of them producing a variant of a good and competing in prices. Each variant, besides its particular consumption properties is also distinguished for its environmental quality, v_i, i=1,2; $v_h > v_l$, h,l=1,2 , $l \neq g$, implies that product h is environmentally friendlier than product l. The cost of each producer is:

$$C_i = cq_i + \frac{k}{2}v_i^2, \; i=1,\, 2, \quad c,\, k>0, \qquad (1)$$

where q_i, $i=1,2$ represent the quantity of each firm's product. This means that total cost consists of two parts, variable cost (cq_i) and fixed cost. The former is assumed to be the same for the two firms and for simplicity also equal to zero. The latter is increasing in the environmental quality of each good.

Consumers utility depends on the consumption of each available variant and of the numéraire good Y. The representative consumer's utility is given by the following utility function:[2]

$$U = (a+v_1)q_1 + (a+v_2)q_2 - \frac{1}{2}(q_1^2 + q_2^2 + 2gq_1q_2) + Y \quad a>0,\; 0<g<1, \qquad (2)$$

The utility function in *(2)* exhibits a taste for variety. When $v_1=v_2$, for $g=1$ products 1 and 2 are completely homogeneous and the only thing that matters is their total quantity consumed. On the other hand, when $g=0$ there is no substitutability at all between the two products. The presence of v_1, v_2 in the individual utility function implies that consumers care about environmental quality.[3] The maximum possible quality, which implies zero damages, is assumed to be $\bar{v}$. Firms' choice of environmental quality is $v_i \leq \bar{v}$, $i=1$,2. The smaller is v_i, the lower is the utility consumers enjoy from product I, as it is evidence from *(2)*, and the higher the

[2] The models that are analyzed here are based on Petrakis at al (2004).

[3] The presence of v may either be due to the fact that the consumer is aware about the environmental problem his consumption creates, or because environmental quality may be positively correlated with some desirable product characteristics. For instance, organic vegetables may be healthier and at the same time environmentally friendlier. Either explanation does not change the interpretation of our results.

marginal environmental damage, defined as $d = n(\bar{v} - v_i)$, where n is a technological parameter. All consumers can see v_1 and v_2, which means that they have full knowledge of the effect the environmental quality, has on them.[4] When $v_1 \neq v_2$, there is an element of vertical differentiation between the two goods in the model.

Finally, the regulator maximizes the social welfare function:

$$SW = U - n(\bar{v} - v_1)q_1 - n(\bar{v} - v_2)q_2 - \frac{k}{2}(v_1^2 + v_2^2), \quad n, \bar{v} > 0, \tag{3}$$

where $TD = (\bar{v} - v_1)q_1 + (\bar{v} - v_2)q_2$ is the total environmental damage that is caused by the production of the good. The bigger the difference $\bar{v} - v_i$, the greater the marginal environmental damage of the good. When $v_i = \bar{v}$ good i does not harm the environment at all.

The regulator may levy an environmental tax on the two goods. Since there are market imperfections, it is expected that the optimal tax attempts to simultaneously correct for both the external environmental damage and market imperfections. In what follows we consider two three-stage games. In the first game the regulator imposes a tax or subsidy at the first stage, at the second stage the two firms choose the environmental quality of their product, and at the third stage the two firms compete in prices. In the second game, environmental quality is chosen at the first stage, the regulator imposes a tax or subsidy at the second stage, and at the third stage the two firms compete in prices.

4.2. THE PRICING STAGE

We start by examining the third stage which is similar in the two models. Maximizing *(2)* yields the demand functions for the two goods:

$$q_i = \frac{a(1-g) + v_i - gv_j + gp_j - p_i}{1-g^2}, \tag{4}$$

[4] Petrakis *et al* (2004) assumes that this knowledge is imperfect and there is a fraction of informed consumers and a fraction of uninformed consumers. Uninformed consumers cannot see v_1 and v_2, in the utility function and so, they behave as if they obtain the same utility from the consumption of both goods.

where $i, j=1, 2$ and $i \neq j$.

The profit functions for the two firms, *1* and *2*, are:

$$\Pi_i = (p_i - t_i) q_i(p_i) - \frac{k}{2} v_i^2, \; k>0 \tag{5}$$

where t is the tax that the regulator imposes on each firm. Maximizing each of the above functions with respect to its corresponding price yields the reaction functions:

$$p_i = \frac{a(1-g) + t_i + v_i - g v_j}{2} + \frac{g p_j}{2}. \tag{6}$$

Solving the above system yields equilibrium prices:

$$p_i = \frac{a(2-g-g^2) + 2t_i + g t_j + 2v_i - g^2 v_i - g v_j}{4-g^2}. \tag{7}$$

Substituting the prices back into the demand and profit functions yields quantities and profits as function of qualities:

$$q_i = \frac{a(2-g-g^2) - (2-g^2)t_i + g t_j + 2v_i - g^2 v_i - g v_j}{4 - 5g^2 + g^4}, \tag{8}$$

$$\Pi_i = \frac{[a(2-g-g^2) - 2t_i + g^2 t_i + g t_j + (2-g^2) v_i - g v_j]^2}{(4-g^2)^2 (1-g^2)}. \tag{9}$$

Notice that: $\frac{\partial q_i}{\partial t_i} < 0$ and $\frac{\partial p_i}{\partial t_i} > 0$, as expected, which means that when taxation is higher the quantity of the good is lower and its price is higher because the cost is higher.

4.3. MODEL A *(t-v-p)*

In this model the regulator imposes a tax in the first stage, thus affecting both environmental quality choices and prices. In other words this model focuses on both the short run effect (price choice) and the long run effect (quality choice) of a tax.

At the second stage both firms maximize their profit functions *(9)* in order to choose the quality of their product. This yields reaction functions in the (v_1, v_2) space, from which equilibrium qualities as functions of taxes and other parameters are obtained:

$$v_i = v_i(a, g, k, t_1, t_2). \tag{10}$$

The exact expression for v_i is too complex and offers little intuition, it is, therefore, relegated into the appendix (see Appendix A). One can verify the following properties: $\frac{\partial v_i}{\partial t_i} < 0$ and $\frac{\partial v_i}{\partial t_j} > 0$, which implies that an increase in the rate of taxation on a product reduces that product's quality. This happens because t is not a function of v, which means that the regulator gives firms no incentive to increase the environmental quality of their product, and, at the same time, a higher tax reduces marginal revenue. Substituting optimal *v's* back into *(2)* and *(3)* yields the indirect utility $V = V(a, g, k, t_1, t_2)$, and social welfare function $SW = SW(a, g, k, n, \bar{v}, t_1, t_2)$ respectively. At the first stage, the regulator maximizes the latter in order to choose, in the first stage, the tax or subsidy to be imposed on each firm:

$$t_i^* = t_i^*(a, g, n, \bar{v}, k). \text{ (See Appendix A)} \qquad (11)$$

Having obtained the optimal tax rates, we substitute them into the expressions in *(10)* in order to obtain equilibrium qualities:

$$v_i^* = v_i^*(a, g, n, \bar{v}, k). \text{ (See Appendix A)} \qquad (12)$$

4.4. MODEL B *(v-t-p)*

In this model, the regulator does not take into account the fact that the tax affects quality choices in the long run. Instead, he focuses only on the short run effects of tax which are the effects on prices.

Firstly we substitute optimal prices from *(7)* into the utility and social welfare function, and this yields:

$$V = V(a, v_1, v_2, g, t_1, t_2) \text{ (See Appendix B)} \qquad (13)$$

$$SW = SW(a, v_1, v_2, g, n, \bar{v}, t_1, t_2) \text{ (See Appendix B)} \qquad (14)$$

In order to find the optimal tax or subsidy the regulator maximizes the social welfare, equation *(14)* which yields:

$$t_i = -a + ag - v_i + gv_j + 2n\bar{v} - ng\bar{v} - 2nv_i + ngv_j, \qquad (15)$$

where *i, j=1, 2* and $i \neq j$. As expected, as the environmental quality increases the environmental tax decreases, that is $\frac{\partial t_i}{\partial v_i} < 0$.

Substituting taxes into the demand functions (equation *(8)*), yields the profit functions:

$$\Pi_i = \frac{(-a(1-g)+gv_j+n(\bar{v}-g\bar{v}+gv_j-v_i)-v_i)^2}{1-g^2} \qquad (16)$$

The two firms maximize their profit function and the system of the first order conditions from *(16)* yields optimal qualities:

$$v_1 = v_2 = \frac{2(1+n)(a-n\bar{v})}{(1+g)k-2(1+n)^2} \qquad (17)$$

The two qualities are equal in this case because the two firms are symmetric. Finally, we substitute qualities into equation *(15)* in order to obtain the optimal tax rates:

$$t_1 = t_2 = \frac{a((-1+g^2)k-2n(1+n))+n((2+g-g^2)k-2(1+n))\bar{v}}{(1+g)k-2(1+n)^2} \qquad (18)$$

4.5. RESULTS

Table 1 reports simulation results of models A and B (see the corresponding columns), for selected values of the parameters. SW represents the social welfare, v is the environmental quality, t is the tax per unit of product, p is the price of the good, q is the quantity that each firm produces and Π is the total profits of each firm.

As we can see (see Table 1) *SW* is higher in model A than in model B which means that *SW* is higher when the regulator plays first in the three stage game. On the other hand the profits are higher in the second model, which means that firms prefer to commit to a product quality before the regulator imposes the tax. Moreover, both the environmental quality and the total quantity consumed are higher in model B, while prices and taxes are higher in model A.

The C column presents results of a hybrid model: firms choose qualities before taxes are chosen (like in model B) but instead of choosing their profit maximizing quality they choose the quality dictated by model A. Comparing models A and C one can say that model C is like a four-stage model with the following order of moves: stages 1 and 2 are like in model A and stages 3 and 4 like in model B, *i.e.,* at the first stage the regulator chooses a tax rate, at the second stage firms choose their quality level, at the third stage the regulator re-considers his tax choice and at the last stage both firms set their price. This of course raises questions, regarding the regulator's credibility when setting a tax rate at the beginning of the game. If we compare *SW* in model A and model C we observe that the difference in taxes between these models is sometimes significant while the difference in *SW* is almost zero. This means that the regulator indeed changes the tax during the third stage in model *(t-v-t-p)* but that only decreases total environmental damage, and, on the other hand, does not affect *SW* at all, so, it is quite difficult to say that the tax in model A is time inconsistent. The regulator chooses tax by maximizing *SW* and so we can say that the regulator does not have any incentives to change the taxation ex-post because this change does not affect *SW*.

Let us now reconsider the role of *n*. We have assumed that n is an exogenous technological parameter. Another very interesting interpretation of *n* is as a parameter that shows how important is the environmental problem for the regulator.[5] We can say that *n* is a weight, which reveals the regulator's preferences about the environment. We observe that the social welfare function can be separated in two parts: the first is net utility from consumption $(U - \frac{k}{2}(v_1^2 + v_2^2))$, while the second is related to the environmental externality $Td = (\bar{v} - v_1)q_1 + (\bar{v} - v_2)q_2$. The environmental part is weighted with *n* and the other part with *1*. When *n=1*, the two parts are weighted equally, when *n>1*, the environmental problem prevails, while when *n<1* the net utility from consumption prevails.

We find that when $n \leq 1$, i.e. the environmental externality is less important for SW than utility from consumption, environmental damage is lower when the tax is imposed after qualities have been chosen, and higher when the tax is imposed first. Moreover, in this case total environmental damage is higher, as expected, compared to any other case. We also observe that when *n* decreases, taxes are decreased, and because of this, prices are getting lower, while consumed quantities, total environmental damage and profits are getting higher in both A and B models. Finally,

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[5]By the definition of marginal environmental damage, $d = n(\bar{v} - v_i)$, *n* converts products' quality into environmental damage. Thus, *n* is determined either by science and is exogenous, or in the absence of such complete definition it should be determined by the government.

the product quality in model A increases, while that in model B decreases, although the quality in model B is always higher than that of model A.

Furthermore, the role of g is quite important as well. When g decreases the firm's market power increases and so does the market distortion, therefore, we expect that the regulator focuses more on this problem. As we can see from the simulations, this happens, since, when g decreases, taxes are decreased, and become subsidies in many cases, in both models. Because of this, environmental quality, consumed quantities, and profits are increased, while prices are decreased in both A and B models, and so, the market distortion problem is getting smaller. SW is increased in model A, but it is decreased in model B, while total environmental damage is increased in both models.

Finally, k affects the cost of producing better quality, so when k is lower, the production of the quality is cheaper, with the result that v is increased. SW is getting higher in the first model, but it is getting lower in the second model while total environmental damage is getting higher in both models because the consumed quantity has increased.

	g=0.7, n=1, k=15			*g=0.5, n=1, k=15*			*g=0.3, n=1, k=15*		
	A	B	C	A	B	C	A	B	C
SW	1052	744	1054	1222	741	1224	1450	635	1454
v	1.5	9	1.5	1.9	11	1.9	2.3	13.9	2.3
t	3.3	-6.6	5.5	-6	22	-3	-17	-41	-13
p	16.7	10	18.5	16	8	18	15.2	6	17.6
q	26.3	34.2	25.3	30	41	29	36.2	52	34
Π	353	599	326	700	1284	639	1196	2477	1077
Td	973	744	935	1105	741	1057	1279	635	1213

	g=0.7, n=0.5, k=15			*g=0.5, n=0.5, k=15*			*g=0.3, n=0.5, k=15*		
	A	B	C	A	B	C	A	B	C
SW	1585	1403	1585	1822	1562	1824	2139	1750	2141
v	1.8	7.1	1.8	2.26	8.3	2.26	2.7	10	2.7
t	-8	-11	-6.7	-20	-25	-17	-31	-40	-29
p	7.9	6.4	9	7.5	5.8	8.8	7	5	8.6
q	31	35	31	36.4	41.6	35.6	42	50	41
Π	512	650	490	996	1302	950	1666	2275	1580
Td	576	459	563	646	486	631	736	500	717

	g=0.7, n=2, k=25			g=0.5, n=2, k=25			g=0.3, n=2, k=25		
	A	B	C	A	B	C	A	B	C
SW	262	108	263	305	39	305	362	-166	363
v	0.4	4.8	0.4	0.5	6	0.5	0.7	8	0.7
t	31	19	32	26	8	28	20	-7	23
p	38	30	39	37	27	38	37	23	38
q	13	20	12	15	25	14	18	34	17
Π	87	212	80	174	493	157	298	1082	263
Td	1026	1232	982	1185	1420	1124	1398	1617	1313

	g=0.7, n=1, k=25			g=0.5, n=1, k=25			g=0.3, n=1, k=25		
	A	B	C	A	B	C	A	B	C
SW	1005	890	1005	1154	988	1155	1353	1099	1355
v	0.8	4.5	0.8	1	5.4	1	1.3	6.5	1.3
t	5.3	0.5	6.6	-3	-10	-2	-13	-23	-11
p	18	15	19	17	14	18	17	13	18
q	25	28	24	28	33	28	33	40	32
Π	321	428	307	625	861	592	1042	1516	979
Td	961	890	939	1092	988	1063	1264	1099	1225

	g=0.7, n=0.5, k=25			g=0.5, n=0.5, k=25			g=0.3, n=0.5, k=25		
	A	B	C	A	B	C	A	B	C
SW	1537	1449	1537	1757	1635	1757	2047	1873	2048
v	1	3.9	1	1.3	4.5	1.3	1.6	5.3	1.6
t	-6.8	-8.7	-6	-17	-20	-16	-28	-33	-27
p	8.7	8	9.4	8.6	7.2	9.3	8.3	7.3	9.1
q	30	32	30	35	37	34	40	44	40
Π	482	551	469	926	1076	900	1526	1813	1478
Td	582	528	574	656	585	647	753	653	741

Table 1: Numerical results for selected values of the parameters.

5. CONCLUSIONS

In this dissertation, after a brief literature review, we examined how a tax policy affects the environmental problem when quality choice is endogenous. Several conclusions came out from our study. First, social welfare is higher when the regulator imposes the tax before qualities are chosen. Second, the environmental quality of the two products is higher when qualities are chosen before the tax. Third, the optimal tax is higher when the regulator plays first and because of this, the environmental problem diminishes. Notice that, while the environmental problem is reduced, market distortion will be increased by the tax. We are facing here a typical second best problem where the regulator needs to correct two problems with one policy instrument. The value of n, the importance of the environmental problem in the social welfare function, becomes now of paramount importance. As n gets larger, the regulator cares more about the environment, the taxes are increased and the environmental problem abates, but the market distortion problem enlarges, since prices are increased and quantities are decreased.

We also examined the regulator's time consistency. We find that if the regulator could play twice, he would have no incentives to change the tax, since he could only marginally improve social welfare. Thus, we can say that the regulator's choice is time consistent and the model that dominates is the long run. If the regulator's choice is time inconsistent, firms would know that, and so, they would choose the quality that they chose in the short run model. In that case firms and the regulator would play model B which means lower social welfare.

Several assumptions need to be relaxed in this model. First, instead of assuming equal marginal costs for the two firms one could assume that these costs are different for the two firms. Second, instead of assuming that all consumers are affected by v_1, v_2, we could assume that a fraction of them either cannot see v_1, v_2, either is not affected by them. Finally, in this model t_i is not a function of v_i, i.e. the regulator does not give to firms any incentives to increase the quality of their product. Perhaps a model with $t_i = t_i(v_i)$ could give some useful results and calls for further work on this model.

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APPENDIXES

APPENDIX A

Equation *(10)*:

$$v_i = -(2(-2+g^2)(a(-4+g^2(2-6k)+8k-4gk+g^3k+g^4k)-(-2+g^2)(2+(-4+g^2)k)t_1$$
$$-g(-4+g^2)kt_2))/(16(1-2k)^2+g^6(4-13k)k+g^8k^2-16g^2(1-5k+7k^2)+g^4(4-32k+60k^2))$$

Equation *(11)*:

$$t_i = (a(g^6k+g^4(2-9k-4n)-16(k+2n)+4g^2(-1+6k+6n))-$$
$$(-4+g^2)(2(-2+g^2)+(-2+g)^2(1+g)(2+g)k)nv)/$$
$$(16(-1+k-2n)+g(16k+g(8+(1+g)(-8+g^2)k-4(-6+g^2)n)))$$

Equation *(12)*:

$$v_i = (2(-4+g^2)(-2+g^2)(a-nv))/$$
$$(16gk-8g^3k+g^5k+g^4(k-4n)-8g^2(-1+k-3n)+16(-1+k-2n)$$

APPENDIX B

Equation *(13)*:

$$V=(-2a^2(2+g)^2(3-5g+2g^2)+(4-3g^2)t_1^2+4t_2^2-3g^2t_2^2-8gt_2v_1+4g^3t_2v_1-12v_1^2+ 9g^2v_1^2-2g^4v_1^2+8t_2v_2-6g^2t_2v_2+2g^4t_2v_2+16gv_1v_2-6g^3v_1v_2-12v_2^2+9g^2v_2^2-2g^4v_2^2 +2t_1(4v_1-3g^2v_1+g^4v_1-g^3(t_2-2v_2)-4gv_2)+2a(-1+g)(2+g)^2((-1+g)(t_1+t_2)- (-3+2g)(v_1+v_2)))/(2(-4+g^2)^2(-1+g^2))$$

Equation *(14)*:

$$SW=\frac{1}{2}(\frac{1}{4-5g^2+g^4}(2n(v-v_1)(a(-2+g+g^2)-(-2+g^2)t_1-gt_2-2v_1+g^2v_1+gv_2)) -k(v_1^2+v_2^2)+\frac{1}{4-5g^2+g^4}(2n(v-v_2)(a(-2+g+g^2)+g(-t_1+v_1)+(2-g^2)(t_2-v_2))) +(-2a^2(2+g)^2(3-5g+2g^2)+(4-3g^2)t_1^2+(4-3g^2)t_2^2-8gt_2v_1+4g^3t_2v_1-(12-9g^2 +2g^4)v_1^2+8t_2v_2-6g^2t_2v_2+2g^4t_2v_2+16gv_1v_2-6g^3v_1v_2-12v_2^2+9g^2v_2^2-2g^4v_2^2+2t_1 (v_1(4-3g^2+g^4)-g^3(t_2-2v_2)-4gv_2)+2a(-1+g)(2+g)^2((-1+g)t_1-(1-g)t_2-(-3 +2g)(v_1+v_2)))/((-4+g^2)^2(-1+g^2)))$$