ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SOCIAL SCIENCES

OPTIMAL ENVIRONMENTAL POLICY IN DIFFERENT MARKET STRUCTURES UNDER COOPERATIVE AND COMPETITIVE R&D

Master Thesis by

Ilker UMUR, B.Sc

Department: Management Science and Engineering

Programme: Economics

NOVEMBER 2006

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Ilker UMUR

(412021009)

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Supervisor : Assoc. Prof. Dr. M. Özgür KAYALICA

Members of the Examining Committee : Prof. Dr. Benan Zeki ORBAY

Assoc. Prof. Dr. Ensar YILMAZ

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ISTANBUL TEKNIK ÜNIVERSITESI ★ SOSYAL BILIMLER ENSTITÜSÜ

FARKLI PIYASA YAPILARINDA ISBIRLIKÇI VE REKABETÇI AR&GE ALTINDA OPTIMAL ÇEVRE POLITIKASI

Yüksek Lisans Tezi

Ilker UMUR

(412021009)

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Tez Danismani : Doç. Dr. M. Özgür KAYALICA

Diger Jüri Üyeleri : Prof. Dr. Benan Zeki ORBAY

Doç. Dr. Ensar YILMAZ

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PREFACE

Today environmental issues have started to sound the alarm siren. It is possible to interpret this alarm as an invitation not only for society as a whole but also for people as an individual to show the essential sensitivity to the environmental issues. From the beginning of 1980s, economists have interested intensively with environmental issues and its impact on economic activities. Due to the importance to find a panacea for an efficient use of limited resources, the inevitability of the integration of economics into policy fields has been put on the agenda. Based on such a sense, the purpose of this study is to clarify the relationship between environmental policy, environmental technology and market structure.

Initially, I would like to express my particular appreciations to my supervisor Assoc. Prof. Dr. M. Özgür KAYALICA for his guidance and support.

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Bu arastirma optimal çevre politikasi yönetimini farkli pazar yapilarinda, Cournot ve Bertrand, teknolojik tasma ve ürün farklilasmasinin oldugu isbirlikçi ve rekabetçi çevresel Arastirma ve Gelistirme (Ar-Ge) altinda analiz etmektedir. Emisyon yogunlugunu azaltici Ar-Ge ve farklilastirilmis ürünün söz konusu oldugu duopol durumunda üç asamali teorik oyun teorisi dikkate alinmistir. Birinci asamada hükümet emisyon vergisi ve Ar-Ge sübvansiyonu belirler. Ikinci asamada firmalar emisyon vergisini ve Ar-Ge sübvansiyonunu veri alip eszamanli olarak Ar-Ge seviyelerini belirler. Üçüncü asamada ise iki durum analiz edilmektedir. Birinci durumda Cournot rekabeti altinda firmalar diger her seyi veri olarak alip üretim seviyelerini kararlastirir. Bununla beraber, ikinci durumda ise Bertrand rekabeti altinda firmalar diger her seyi veri olarak alip fiyat seviyelerini kararlastirir..

Her iki pazar yapisinda emisyon vergisinin marjinal hasardan az oldugu gösterilmistir. Bununla birlikte, ürün farklilasmasi yeterli derecede az oldugunda emisyon vergisi Bertrand rekabetinde marjinal hasara esitlenmektedir. Ar-Ge sübvansiyonu konusuna gelince, fiyat rekabetinde sübvansiyon her zaman pozitiftir. Miktar rekabetinde ise sübvansiyon ürün farklilasmasina ve teknolojik tasmaya dayanmaktadir; isbirlikçi Ar-Ge altinda sübvansiyon daima pozitiftir. Rekabetçi Ar-Ge ortaminda eger ürün farklilasmasi parametresi yeterince yüksek ve teknolojik tasma yeteri kadar düsükse, optimal sübvansiyon negatif olabilir. Aksi takdirde optimal sübvansiyon pozitiftir.

SUMMARY

This paper analyses optimal environmental policy rule in different market structures, Cournot and Bertrand, under cooperative and competitive environmental R&D when technologic spillover and product differentiation exist. A three-stage game theoretic model is considered in a differentiated product duopoly where R&D is emission intensity reducing. In the first stage, the regulator (government) determines emission tax and R&D subsidy. In the second stage, given the emission tax and R&D subsidy firms choose their R&D level simultaneously. In the third stage, two cases are analyzed. In the first case, firms choose their output levels taking everything else as given under Cournot competition. In the second case, however, firms choose their price levels taking everthing else as given under Bertrand competition.

It is demonstrated that emission tax is lower than marginal damage in both market structure. Nonetheless, if product differentiation is sufficiently low, emission tax is equal to marginal damage in Bertrand competition. With regard to R&D subsidy, under price competition subsidy is always positive. Under quantity competition, subsidy depends on product differentiation and technologic spillover; subsidy is always positive under cooperative R&D. Under competitive R&D if product differentiation parameter high enough and technologic spillover parameter is sufficiently low, optimal subsidy could be negative. Otherwise, optimal subsidy is positive

.

1. INTRODUCTION

Since last two decades, environmental problems have increased rapidly. In the beginning of 1980s, it was realized that quantity and quality of available natural resources determine economic and social development in the long run. A change in perception in turn leads economic agents to alter their behaviour. Political parties and some employers' organisations shift their main concern by putting the environment above work and income in their priority list. In addition, in parallel with this consciousness economists attend environmental issues (Dietz et. al., 1991).

Environmental policy has become one of the most important parts of the applied policy and theory. "It is well known that from the economists' point of view, environmental policy is a case of analysing externalities and market failure issue thoroughly examined in microeconomic theory" (Xepapadeas, 1997).

Regarding this frame on the one hand, firms provide many different products in a large range or services to society. However, firms impose a cost on society by polluting the air, water, and land. Governments (regulators) overcome negative externality by imposing some regulation (emission tax, emission standards, quotas etc). They give subsidy to encourage firms to undertake environmental R&D as well. Concerning such strategies, a firm might respond by decreasing output level or by renovating its technology associated with production methods. Embracing Research Joint Venture (RJV) formation, the thesis weighs the probability of forming RJV under the umbrella of firms and its implications over firms.

This aspect of the thesis is assumed to bring in an insight regarding firms' strategic behaviours. Game theory, in this respect, would serve as a brilliant tool to scrutinize strategic situations where players (firms) choose different actions in an attempt to maximize their returns while government tries to maximize welfare.

This work aims to contribute to the literature by comparing optimal environmental policy in two different markets' conducts when firms produce differentiated products and embrace competitive and cooperative environmental R&D.

This study includes five chapters. After providing a background in the introduction in chapter one, chapter two examines the fundamentals of environmental economics and the effects of the environmental technology as well. Moreover, previous studies about this subject are overviewed. In chapter three, a theoretical model which is used to examine our purposes is presented. The model consists of two main parts; Bertrand case and Cournot case. In chapter four, these two cases are compared. Finally in the last chapter, the results are underlined.

2. LITERATURE REVIEW

2.1. Theoretical Framework

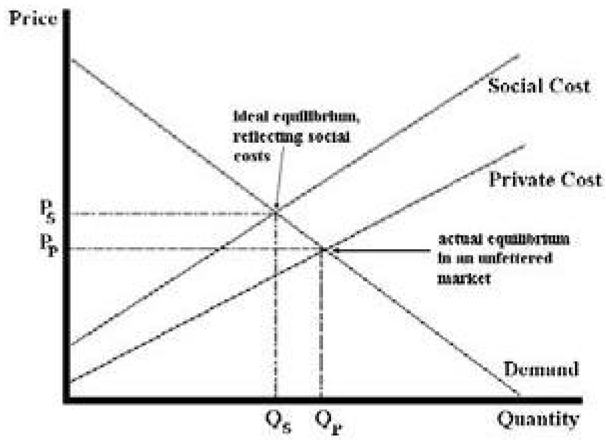
Economic investigation of environmental policy is based on the idea that effects of destructive economic activities on the environment constitute an externality. For the precision of this thesis, externality concept should be clarified. What is externality? Externality is explained in Deardorff's Glossary of International Economics (2006) as the following: “An effect of one economic agent's actions on another, such that one agent's decisions make another better or worse off by changing their utility or cost. Beneficial effects are positive externalities; harmful ones are negative externalities.” A firm imposes a cost on society by polluting the air, water and land. The firm that owns the factory has an economic incentive to use labour or steel to the limit that it can productively employ, because those inputs are costly to the firm. Those labour and steel, which are used up in a given factory, can be assessed as a cost. This cost is internalized by the firm due to the fact that the firm has to pay for those inputs. The cost society of having some of its labour and steel used up in a given factory is internalized by the firm, because it has to pay for those inputs. Nonetheless, the firm does not have economic incentive to internalize externality of pollution.

In fact, environmental problems are due to the variance derived in between the private cost and social cost. There cannot be trade-off between environment and the production of goods under laissez- faire conditions. In this respect, it is important to recognise market failure due to externality.

Conventional pollution externality leads firms to overproduce. That’s first market failure[1]. Figure 2.1 below points out the effects of a negative externality. Vertical

[1] It should be stated that second product market failure is caused by imperfect competition. This in turns leads to too little output.

distance between the two supply curves indicates a difference between the marginal private cost and marginal social cost. The marginal private cost is less than the marginal social cost. In addition, it is supposed that social benefit equals to individual benefit.



Source: Wikipedia [4]

Figure 2.1: Supply & Demand Curves with External Costs

If the consumers take into consideration only their own private cost, they will end up at price $\mathbf{P_p}$ and quantity $\mathbf{Q_p}$, instead of the more efficient price $\mathbf{P_s}$ and quantity $\mathbf{Q_s}$. These latter reflect the idea that the marginal social benefit should equal the marginal social cost. That is to say production should be increased only if the marginal social benefit exceeds the marginal social cost. As a result, a free market is inefficient; as at the quantity $\mathbf{Q_p}$, the social benefit is less than the societal cost. Hence; society as a whole would be better off if the goods between $\mathbf{Q_p}$ and $\mathbf{Q_s}$ had not been produced. The problem is that people are buying and consuming too much.

There is a dilemma of societal communication and coordination to balance benefits and costs. This discussion also indicates that a competitive market is incapable of

[4] The figure has been retrieved from World Wide Web: URL

http://en.wikipedia.org/wiki/Image:Negative_externality.jpg solving pollution problem. If one of the firms decides to internalize external costs, this firm faces higher costs than those of competitors and is likely to exit the market. This situation points out that collective solution is needed; such as government intervention for restricting pollution.

The rest of this section would try to reflect different revisions of the issue with an aim to bring in an extent standpoint.

According to Pigou (1938) the social optimal level can be attained by using policy instruments. He has explained his opinion in his works “The Economics of Welfare”. In terms of his approach, the divergence between private and social costs can be made up by imposing either a tax on emission which creates environmental damages or another equivalent measure.

There is a classical example in which there is a factory generating smoke that has harmful effect on individual living nearby. According to Pigou (1938), the factory is responsible for damage; therefore, a tax should be imposed so as to reduce smoke level and environmental damage. This approach has been dared by Coase (1960). As said by Coase (1960), an optimal agreement on the level of environmental externality can be reached without any regulation. This approach is based on bargaining among pollutant and the victims of pollutions. In the example of Coase, the factory by generating pollution harms the farmer. The factory is voluntary to pay the farmer to get right of polluting because of the fact that the factory has to obtain farmer’s permission. Thus, the farmer may accept this payment in order to suffer damage implied by emissions. The optimal solution can be achieved by private negotiation. In this respect, Coase Theorem requires the existence of a well defined and enforceable property rights. In this theorem, there are only two parties and no transaction costs, which existence can prevent private bargaining. However, necessary assumptions for making the theorem valid have been found insufficient regarding the majority of environmental problems. That’s why Coase Theorem cannot be an alternative to environmental policies which are predicated on Pigovian approach (Xepapadeas, 1997).

Environmental policy tries to response the internalization of the cost of environmental degradation. Environmental policy instruments can be separated into two main groups:

a) Economic instruments (Subsidy, charge system, deposit refund system, tradable emission permits etc.)

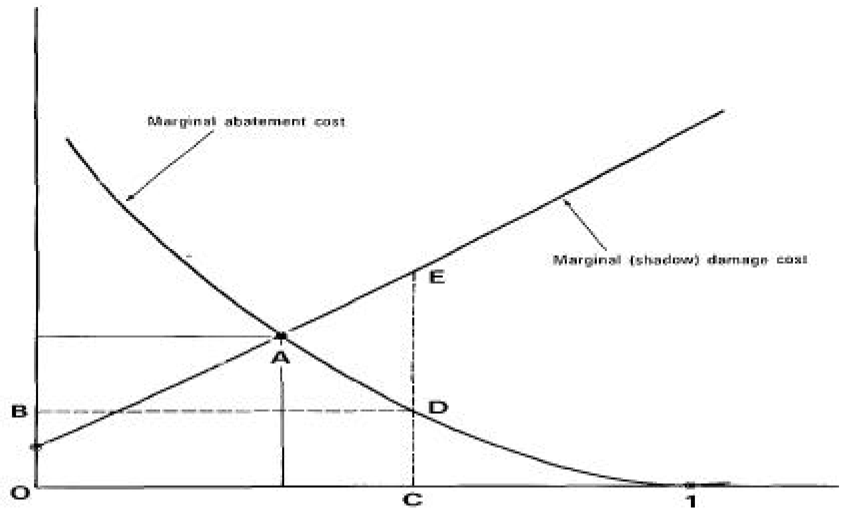
b) Regulations (Standards, emission quotas, negotiations etc.)

Polluters control themselves by regarding consumption of environmental input or regulators (governments) impose limit for pollution. The relative efficiency of different policy instruments depends on specific considerations such as the regional extent of the problem, the number of pollution sources, the easiness of monitoring, the importance of transaction costs and the pervasiveness of other market distortions (Nicolaisen et al., 1991). The firms generally respond to environmental policy in different ways; by decreasing their output level or by changing production methods to decrease emission's level.

On the contrary, some economists embrace the opinion of environmental responsibility instead of environmental taxation. One of the pioneering papers written by Bazin et al. (2004) has stated that degree of the responsibility affects environmental quality; and high degree of responsibility could be used instead of taxation. According to this paper, the fact that polluters pay a tax leads to reveal this idea: "Since I pay, I can consume and thus pollute".

As a counter argument, also as widely held opinion, is the following: when polluters do not pay their environmental cost, this means environmental thievery and thus thievery of social welfare. In terms of Bithas (2006), environmental responsibility is necessary to form environmental behaviour; it is part of efficient environmental policy as well. But it is not enough to impede environmental thievery.

Going back to previous argument, to internalize negative externality thanks to environmental policy for the firms, marginal damage cost is equal to or greater than marginal abatement cost (Figure 2.2). Optimal point of emission level is where marginal abatement cost is equal to marginal damage cost. At this point, an increase in abatement equals to the gains reduced from emissions. When marginal abatement cost is less than marginal damage cost, it leads to an excessive emission level (such as point B). In this situation, CE shows total environmental damage. The amounts to CD are internalized by the pollutants. But, the amounts to DE of environmental damage are not internalized.



Emission as a fraction of uncontrolled

(laissez-faire) level

Source: Economics and environment/ a survey of issues and policy options by Joa Nicolaisen et al. (1991)

Figure 2.2: Abetment cost and damage function

According to Schwartz and Clements (1999) "From an economic perspective, main purpose of subsidies is to reallocate resources, that is, to alter economic activity and behaviour to achieve an outcome that is more desirable from what would occur otherwise. Hence, arguments for subsidies are often based on some concept of efficiency or economic justice". On the other side, it can not be said that all subsidies are corrective in nature even if when subsidies create more desirable outcome. Compensating market imperfections is one of the reasons for using subsidies.

Subsidies is applied to case where markets do not share out resources efficiently because of the fact that owner of these resources cannot reap their full return (i.e. free rider problem). Subsidies must be paid for. Thus, it is important that subsidies are effective (i.e. reach their intended target group) and realize a given aim at minimum cost.

Subsidies are important elements for environmental policy on the subject of environmental technology. They are the main tools of innovation policy as well. In the Netherlands, empirical studies show that subsidies have a windfall gain for applicants (Kemp, 2000). Thus, it is important that subsidies should be given only if the adaptation of cleaner technology entails high costs or causes competitive disadvantage owing to more lax regulation in other country. The question "What about the effectiveness of subsidies for the development of environmentally preferable technologies?" is asked and debated by Kemp. He has studied the question with using econometric analysis on the effectiveness of thermal insulation subsidies which are given by National Insulation Program. The conclusion has approved that there is only weak a positive relationship between the subsidy for thermal home improvement and the diffusion of thermal insulation technologies. Some empirical examples are given and it is pointed out that in the Netherlands, subsidies have limited effect on environmental technology. It is underlined the conclusion of some works which have showed that innovator invest environmental technology when they believe market exist for the new technology. Investment decision is taken irrespectively of subsidies. But also it has been emphasized that it has not been studied systematically.

Firms undertake R&D with the intention of reaching desired emission level by reducing either production cost or abatement cost. Namely there are two types of R&D: production R&D and environmental R&D. In this work, environmental R&D has been taken into consideration. When governments (regulators) impose environmental policies to reduce emissions and environmental damage, which burdens extra cost for firms, costs increase while outputs decrease. Thus, strict environmental policy doesn't adequately induce the firms to undertake environmental R&D. Firms can form collaboration before undertaking R&D. It is called research joint venture (RJV).

As stated by Caloghirou et al. (2003), joint venture has been defined by OECD "as activities in which the operations of two or more firms are partially, but not totally, functionally integrated in order to carry out activities in one or more of the following areas: i) buying or selling operation; ii) natural resource exploration, development and/or production operations; iii) research and development operations; and iv) engineering and construction operations". Even though there are lots of collaborations' forms, most of them are related to technological subjects. According to Caloghirou et al. (2003), there are many works on RJVs. Two of the reasons of these works are explained in the following:

1) Growing willingness of firms to engage in cooperative R&D, which is considered as a contradiction to the idea that R&D constitutes the centre of the firms spirit,

2) RJVs are one of the applications fields for policy. If regulator perceives that RJVs are restricting the competition, it imposes policy to prevent this collaboration. Whereas policy encourages to RJVs when regulator believes the cooperation is not an obstacle to the conditions of competitive markets.

RJV can be considered as a strategic behaviour among firms. RJV raises the benefit of R&D. Veugeler (1998) clarifies RJV's several advantages, which are in favour of firm, in the following: Sharing of costs/risks, access to partner's know-how/markets/products, efficiency enhancements, economies of scale in production/distribution/R&D, synergy effects from exchanging/sharing complementary know-how, competitive considerations, monitor/control partner's technology/markets/products, influence other alliance activities (pre-emption, followers), influence competitive structure, government policy (industrial, trade & competition policy), subsidies for co-operation, local content and anti-trust.

Anti-trust or competition laws are defined in Wikipedia Web Encyclopedia as "laws whose state purpose is the promotion of economic and business competition by prohibiting anti-competitive behaviour and unfair business practises".

Röller et al. (1997) asked question in their works as "why firms form research joint venture?" This work underlines two main reasons in the economics literature.

(i) Internalising the spillovers associated with R&D

(ii) Cost saving by sharing R&D costs.

Internalising spillovers is an effective way to overcome free-rider problem. Firms are less incentive and spend less on RJV owing to free rider behaviour. If firms form RJV with choosing R&D investment level cooperatively to maximize joint venture, spillovers are internalised and these result leads to an optimal R&D investment and raise welfare. Cost sharing also is powerful incentive as it fallows firm to pool their resources and avoid wasteful duplication. (Firms within an industry may be pursuing the same invention, using the same method and thus replicating effort). It is showed that RJVs affect market structure and market power. Moreover, large firms have less incentive to form RJV with smaller firms to increase market power. Hence, industry becomes increasingly asymmetric. In this regards, RJV may raise competitive concerns. One of the conclusions is that if firms produce similar products, they do not tend to form RJV.

Jaffe et al. (2002) has examined the relationship between technological change and environmental policy. There are two results:

1) Environmental effects on society and on economic activity are affected by the rate and the direction of technological change.

2) Environmental policy interventions generate new restraints and incentives, which affect technological development.

A development of environmental technology reduces the cost of pollution abatement and thus pollution. Environmental health is improved as well. This is a static story. But in fact there are dynamic stories between environmental policy and technology. Policies reduce pollution at present, and induce firms to invest in new technologies for the future. Development of technology changes cost/benefit analysis.

Environmental policies take this dynamic interaction into consideration. The static model does not consider the fact that technology is not free (Jaffe et al., 2004).

At this point, to understand RJV better, it should be focused on R&D market failures. There are three R&D market failures:

1) Firms take into consideration their profits more than total surplus, which in turn leads to too little R&D.

2) If one of the firms gets new technology, it does not want to share it with the other firm in the same industry. Hence, there occurs too little R&D once more.

3) Firms try to be the first to introduce new technology and therefore to capture all private benefits. This leads to over-investment in R&D.

If there is uncontrolled information leakage (spillover), firms acting independently will not internalize owing to spillover. This is called spillover effect. Thus, in the situation where there is enough (high) spillover, firms tend to under invest R&D.

As Katsoulacos et al. (1999) mentions, firms cope with R&D market failure through RJV. Hence, they take R&D decision cooperatively. They handle not only spillover effect but also second and third R&D failures. But RJV is incapable of overcoming first R&D failure.

Environmental policy may induce firms to innovate either by adopting existing environmental appropriate technology or by accomplishing more and newer R&D. Even in this situation, environmental policy should consider external effect induced by innovation, market distortions in R&D market, free riding induced by R&D spillover and benefit & cost of R&D cooperation (Carraro and Metcalf, 2000).

According to Ulph (1999), it can be divided five the review related about RJV:

i) Performance of RJVs ii) RJVs size and membership iii) Interaction between RJVs and product market competition iv) The evaluation of RJVs and RJV policy v) Innovation and competition.

2.2. An Overview and Review of Previous Studies

Chiou and Hu (2001) have examined the firms' strategic behaviour under emission tax. In their paper, three types of environmental RJV are considered:

1) R&D cartelization in which firms choose R&D efforts to maximize the joint profit.

2) RJV competition in which firms share the R&D fruits to maximize their own profits.

3) RJV cartelization in which firms share R&D fruits and maximize the joint profit.

Supposed by the model of this paper, there are two firms that produce homogenous product. These firms generate pollution. There are two different games. In the first game, a duopoly is examined without environmental RJV. The game includes two stages. In the first stage, the firms choose their pollution abatement level. In the second stage, they choose their output level. In the second game, there are three general types of RJV. The first type of RJV is the R&D cartelization. In the first stage of the second game, the two firms coordinate in the environmental abatement level in order to maximize their joint profit although there is no spillover of the abatement technology. In the second stage, the two firms engage in Cournot quantity competition. The second type of RJV is the RJV competition. In the first stage involving this type of RJV, the two firms spread abatement technology to each other in order to maximize their own profits; but not to attain joint profit. In the second stage, the two firms engage in Cournot quantity competition. The third type of RJV is the RJV cartelization; that is, in the first stage, the two firms share abatement technology each other in order to maximize the joint profit. Finally, in the second stage, the two firms engage in Cournot quantity competition.

This paper shows that environmental RJV doesn't always improve the social welfare; because the firms in RJV cartelisation reduce their output level and environmental R&D level to maximize joint profits. In addition, such a cartelisation can be regarded as a social optimal when spillover is sufficiently high. Because of the fact that there is free-riding effect, an environmental RJV competition with high enough spillover coefficient will bring the lowest social surplus. A RJV cartelization has a negative impact on the total output, on per output abatement and on social surplus. However, a RJV cartelization with a high rate of environmental technological spillover maximizes social-surplus. Thus, antitrust law enforcers should pay attention whether the members of an environmental RJV are substantially sharing environmental innovations or not. Moreover they should allow joint profit maximization to eliminate the free-riding effect. In many countries, R&D cooperation is supported under antitrust laws, which effects in promoting R&D and production efficiency exceed the inefficiency resulting from the reduction in competition.

Greenlee (2005) has studied RJV in empirically studies. It is underlined that principal benefit of RJV is accessing to the innovation venture partners. This leads to reduce cost. RJV's structure and spillovers affect directly partner's behaviours. When spillovers are low and joint venture membership is small, members increase R&D expenditure which is used for getting greater sales volume. Additionally benefit of the new innovations is not transmitted too largely to rivals or to partners. When spillover or number of participants increase, individual research affects overspread largely, so this in turn leads to smaller cost advantages. Thus, participant in venture invests less in R&D. But participant benefits from increased level of effective R&D thanks to sharing with additional firms. It is also found that sharing information is better for welfare than joint venture that maximizes joint profit. Under the circumstance spillovers are low, R&D sharing venture improve welfare. When there is single industry wide joint venture, it improves social welfare by increasingly total effective R&D. If there are several competing joint ventures, any collaboration reduces R&D.

Chen (2005) has examined the relation between RJV and financial structure. If cost reduction due to R&D is uncertain, the use of strategic debt in RJV competition induces the firm to high effort for in R&D. When the firms use debt, their R&D effort and output level increases. Because the firms would like to cover debt obligation through producing more and capturing a bigger market share. The use of debt weakens free rider problem. The firms do not have intensive to trick; whereas they make effort to cope with free rider problem because of strategic debt.

Furthermore, each firm's profit is less owing to higher R&D expenditure and lower market price than in the unleveraged industry although production cost is reduced and free rider problem is weakened when the firms use debt.

In the presence of asymmetries between firms, how do the firms choose their collaboration partners? And how is important the technology of competitor? Atallah (2005) has tried to find the answers of these questions. When firms choose their partner, they consider spillover and cost differences. A firm wants to form collaboration with the most efficient firms, if low spillover exists. Cost difference between firms increases between firms; efficient firms prefer to collaborate with the most efficient firm among remaining firms. Whereas, in the situation of high spillovers, a firm prefers to remain out of collaboration but if cost differentiation is sufficiently low, firms tend to collaborate. It is also attained that larger firms with high technologic capabilities profit from R&D cooperation.

Katsoulacos and Ulph (1998) have obtained some conclusions related about RJV. Principals of them are:

i) Cost reduction is the most important reason to form RJV(eliminating duplication effort)
ii) If products are very close substitute or firms are so willingness to share information. Cost considerations tend to be dominant factor
iii) RJV might close one lab to prevent from facing very competitive situation when both firms discover.
iv) RJV may keep both of labs to get benefit of maximum when firms are different but complementary industries.
v) Eliminating needless duplication and diminishing returns of R&D expenditure are cost reasons for having two labs.

Chiroleu-Assouline et al. (2003) has compared different instruments (emission tax, emission standards and auctioned permits) of environmental policy according to the incentives for innovation and embracing of new technology when environmental technology and imperfect competition exist. In this works, it is assumed that regulator knows market structure and emission level of the each firm but it is unconscious about consequence of research effort. The other assumption involves the permits to pollute, which are auctioned by government. The firms are mindful about how many permits they need with innovation or without innovation. They are also aware of the fact that the price of the permits is determined by the perfectly competitive of permits market. They have found that emission tax reduces total pollution but the innovation does not always induce to reduce pollution. If the firms adopt innovation, there are two effects for firms; decreasing in emission by reducing emission coefficient (direct effect) and reduction of environmental cost which brings on decrease production cost. This in turns increases production and emissions (indirect effect). These two effects depend on emission tax. If there are excessive taxes with innovation, pollution reduction is smaller for the situation where innovation exists than the situation on the contrary. It is underlined that three policy arguments can not be ranged on the subject of incentive to innovate, the size of innovation, acceptability of environmental policy and total welfare. Ranking depends on for a given criteria.

Montero (2002) has studied whether or not there is any difference regarding incentive to invest in environmental R&D under different market structure and environmental policy instruments.(emission standards, emission tax, tradable permits and auctioned permits). The model of the firm has two stages. In the first stage, firms choose their R&D level; in the second stage they choose their output. It is assumed that there two symmetric firms and limit of the emission level is determined exogenously. Firms' products are strategic substitutes in Cournot competition while they are strategic complements in Bertrand competition. One of the conclusions points out that standards, emission tax or auctioned permits can procure the most incentive to invest R&D in Cournot competition. As for Bertrand competition, either tax or auctioned permits provide the most incentives. If markets are perfectly competitive, permits and emission standards have lower incentives than tax. It is emphasized that under Cournot competition, if products are strategic substitutes, under tradable permits regulation, firms have an incentive to under-invest in R&D. If firms are in auctioned permit regulation, the firms may have incentive to over-invest in R&D.

Lee (1999) has tried to find the answer of the question that is "What is the optimal output tax for polluting oligopolistic firms?" In this work, it is assumed market structure is determined endogenously,-free entry- firms are identical and products are homogenous. He has found that optimal tax under imperfect competition could be less than, equal to or greater than marginal external damage depending on curve of market demand. This conclusion is explained in that way; equilibrium number of firm could be below or above social optimum. For correcting this distortion, emission tax would be greater or less than marginal external damage. The study has emphasized that optimal tax equal to marginal external damage for symmetric oligopolists when market demand is linear.

Poyago-Theotoky (2000) has approached the relationship between environmental policy and innovation by using the argument of willingness. The firms commit more environmental R&D, sacrifice their profit and reduce production. This is qualified Voluntary Approach (V.A.). In this work, she assumed there exists duopoly and closed economy. The firms which are identical produce homogeny product. To answer the question of "What is the relation between ER&D and non-cooperative R&D and how do these formations have performance relatively in terms of environmental innovation and social welfare?" it is used three-stage game. In first stage, firms decide whether they or not form R&D organisation, in the second stage the regulator set environmental tax (as a tool of environmental policy) and in the last stage firms compete in market.

It has been attained that environmental innovation is greater in ERC than in independent R&D in the case of relatively small damage, whereas large damage opposite is true. This conclusion holds for comparison of social welfare. As for environmental tax, it is greater in the situation of independent R&D than in ERC for small damage. If there exists a large damage, the ranking is opposite.

David (2004) has compared voluntary agreement (V.A.) and emission tax as an environmental policy under Cournot competition. The regulator offers a contract to firms to limit their emission by determining specific level. The firms accept or reject. If firm refuse they must pay emission tax. While the regulator is determining emission level, he takes into consideration social welfare maximization. V.A. do not affect output always leads to higher abatement than tax. V.A. lets the firms avoid tax payment; thus marginal production cost is reduced compared to the tax. That's means higher output, hence consumer surplus is always higher with the V.A. V.A. lets the firms to obtain higher profit compared to tax depends on the level of threat. Nonetheless, it can not be said emission level. Because on the one hand, V.A. causes more abatement than tax on the other hand it causes higher output and higher emissions.

Beath et al. (1998) has studied the relation between spillovers and R&D. It is showed that the effect of the spillover on the R&D depends on how significant the spillover is and what type of research is pursued. According to this study, RJV always gets a large amount of cost reduction than the independent firms and as a result spend more on R&D but, in every situation, the amount of R&D spending per unit of cost reduction lower in RJV than non cooperative R&D thanks to elimination needless duplications. In this study, R&D is separated as two stages for examining effect of the diminishing returns correct. In the first stage firms incur expenditure that will generate new knowledge while in the second stage this knowledge is engaged to reduce unit costs. In the first stage, firms determine how many labs they use. If there is a single research path, the RJV operates one lab in order to eliminate needless duplication. If there are complementary research paths, the number of labs (one or two) depend the stage of the R&D process in which diminishing returns happen. They found that RJV operates both labs when diminishing returns occur at the first stage (creation of knowledge), whereas it will be indifferent related about the number of the labs when diminishing returns occur in the second stage (Cost reduction); because, it is proportionally more difficult to invent new technologies. It economizes a lot on physical inputs.

In the work of Poyago-Theotoky (1999), it is compared R&D competition and R&D cooperation (RJV) when spillovers are endogen. There are two identical firms which produce homogeny products and undertake cost reducing R&D. The model includes three stages. In the first stage, firms decide their R&D expenditure, in the second stage; firms decide how much of the knowledge created in the first stage and the last stage they compete in Cournot competition. The firms share full information and maximize RJV profit in RJV. To conclude, total output and the profits of the firms are higher in R&D cooperation than in R&D competition. That means consumer surplus, producer surplus and consequently welfare is more in RJV than in R&D competition. It is underlined that in the case of R&D competition, when spillover equal to zero, the profits of the firm will maximum as well. Because, positive spillover reduces rival's unit cost and increases its market share, hence reduces its own profitability.

Albrecht (1999) has compared several environmental policy instruments including emission tax, voluntary agreement, grandfather and auctioned permits in terms of the incentive to invest in environmental R&D. There are two sectors, polluting firms which are not identical –different marginal abatement cost-and investing firms in R&D. It has into taken considerations the decision to innovate and the marketing of the resulting innovations as endogenous. It is assumed as well that firms want to invest in innovation if the cost of innovation does not exceed a critical value which is determined the discounted profits from innovation. If the polluters are ready to pay more the price of technology, they buy and install new technology. The quantity of solving technologies depends on the effective need to reduce emission. Thus, the effects of environmental policy instruments on firms are important. If emission target is strict, that's in turns to force the polluters to obtain new technologies which are presented by innovators. He has attained that the market created by emission tax is always more important than the market created by tradable permits. Because Tradable permits aim only to reduce emission .Moreover, it is highlighted that emission taxes is the most incentive instrument to invest in environmental R&D.

Yun et al. (2000) have studied several type R&D organisation including independent R&D, R&D coordination, R&D consortium and RJV in terms of technologic improvement and social welfare. In the situation of independent R&D, each firm chooses their R&D level to maximize its profit. In the case of R&D coordination firms do not share research input – output information, only corporate in deciding their R&D level. As for R&D consortium the firms share their research input – output but determine their R&D level independently. Finally, in RJV the firms share research input – output and maximize joint profit. There are two kinds of externality; positive (spillover and output sharing) and negative (input sharing). Input and output sharing are given exogenously. The analysis is performed two stage model of duopolistic competition. In the first stage, firms choose their R&D organisation and at the last stage they compete in output market. In this paper, it has been attained that either independent R&D or R&D consortium can be more effective in terms of R&D investment than R&D coordination or RJV. But it could not be stated any dominance uniquely of any form of R&D organisation which depends on spillovers, degree of competition and input-output sharing rate of R&D consortium and RJV. Such as, if the product market is competitive, independent R&D is superior to any R&D organisation. Nonetheless, if competition is weak, cooperative R&D regime may be preponderance according to technologic improvement and social welfare. In particular, when input sharing rate is relatively high, R&D consortium will be dominant to RJV.

"What can be said related to different market structures in terms of price, and welfare?". Hackner (1999) has tried to answer this question. He allows product vertical and horizontal product differentiation. But firms have the same marginal cost of production. He has attained that Cournot price is higher than Bertrand price regardless of goods are complement or substitutes. Namely, welfare is always higher under price competition. In addition, Cournot profit is higher than Bertrand profits; whereas when products are complements, the conclusion is opposite. If there are n firms instead of two, when goods are complements and quality difference are large, low quality firms will charge higher prices under Bertrand competition than under

Cournot competition. If goods are substitutes, high quality firms might earn higher profits under Bertrand competition than under Cournot competition. He has underlined that if the model extent from two firms to n firms, the difference under two competitions disappears. Thus, in this situation, it is not clear which type of competition is more efficient.

Symeonidis (2002) has compare Bertrand case and Cournot case in a differentiated oligopoly with spillover. He has emphasized that it exists two types of differentiations; vertical and horizontal differentiation. First is due to product R&D. It implies quality differentiation and affects directly gross consumer surplus by increasing product qualities. On the other hand horizontal differentiation indicates substantiality. In the model, there are two firms which produce differentiated products. It has been described two stage game. In first stage firms choose their product R&D level and in the last stage they determine their prices or quantities. As for conclusion which has been obtained, comparative advantage depends on R&D spillover and product differentiation. R&D expenditure, price and firm's profits are always higher under Cournot model than under Bertrand model. Moreover, output, consumer surplus and total welfare are higher in the case of Bertrand than in the case of Cournot if either R&D spillovers are weak or products are sufficiently differentiated. If R&D spillovers are strong and products are not too differentiated, output, consumer surplus and total welfare are lower in price competition than quantity competition.

Poyago-Theotoky (2003) has examined the effect of the degree of product differentiation and optimal environmental policy in Cournot competition and in Bertrand competition. As an environmental policy analzed in this paper, subsidy and emission tax are utilized on environmental R&D. The model of the paper consists of three stages. At the first stage, the government sets emission tax and environmental R&D subsidy. At the second stage, firms choose their environmental R&D level simultaneously. At the last stage, they set output or price taking as a given emission tax and R&D subsidy. This paper has showed that the emission tax is always lower than marginal damages in Cournot competition while the emission tax is generally lower than marginal damages in Bertrand Competetion. In addition, Cournot emission tax is always lower than Bertrand emission tax. The case of nearly homogeneous products indicates that the emission tax is equal to marginal damages with price competition. Moreover, subsidy depends on the degree of product differentiation. In terms of this work's alaysis, the optimal policy mix consists of an emission tax and a R&D subsidy. Furthermore this paper has reached the fact that if there is constrain such as linear marginal damage, the second-best tax under Bertrand competition always exceeds the second-best tax under Cournot competition.

A similar comparison for the case of the R&D subsidy reveals that whether the R&D subsidy is higher or lower in quantity or price competition depends crucially on the degree of product differentiation and on initial emissions.

Poyago-Theotoky and Petrakis (2002) have showed that when emission tax is determined exogenously, the optimal R&D subsidy can be negative depending on the degree of environmental damage and spillover parametre. Also this paper has indicated that welfare, in the case of R&D cooperation, is lower than welfare in the case of R&D subsidisation. The model of the paper is non-tournament in which there are duopoly firms producing homogenous goods under constant returns and also in which there is R&D spillover. Two different games exist. In the first game, there are three stages; at the first stage the government sets subsidy rate. At the second stage, firms choose their abatement level and how much to spend in cost reducing R&D. At the last stage, firms compete in product market by choosing their output level. Coming to the second game, subsidy doesn't exist; firms cooperate by choosing their cost reducing R&D level in order to maximize joint profits. However, they compete in product market. It is assumed that the firms generate pollution as a by product and technology policy is exogeneous, namely emission tax is fixed.

The paper handled by Poyago-Theotoky and Petrakis (1999) has focused on the impact of two different policies; R&D subsidy and R&D cooperation in a duopoly model with cost reducing R&D, spillovers and abatement. Shortly, it can be said that the aim of this paper is to demystify the debate about which policy is better than the other. For investigating the aim which is determined, they have used two differents model. In the first game, government sets R&D subsidy, firms choose their abatement level and firms compete in product market respectively. In the second game, firms cooperate in cost reducing R&D to maximize joint profit and compete in product market. It has been assumed that firms generate pollution as a by product, emission tax is endogenous, firms produce homogenous product. It has showed that R&D subsidy can be negative.This depends on spillover and environmental damage. The other conclusion is that welfare in the case of R&D is lower than in the case of R&D subsidization.

Katsoulacos et al. (1996) have examined that the optimal policy is a combination of R&D subsidy and emission tax when the firms generate pollution and technologic spillover exist. In the model of this paper, there are environmental R&D spillovers, pollution generating duopoly firms acting under Cournot competition and homogenous product. According to this work, the optimal tax is less than marginal damages while the subsidy depends on the deviation between emission taxes and marginal damages. It has been underlined that the firms have incentive to undertake environmental R&D only if there exists emission tax. They have found that when spillovers are sufficiently small, the optimal subsidy may be negative and when emission tax increases, output level decreases while abatement expenses increase. This work has highlighted three causes of the environmental R&D undertaken privately to deviate from social optimal R&D: i) firms do not consider consumer surplus, so they produce suboptimal output ii) Environmental spillover iii) Strategic effect. Firms tend to over-invest in environmental R&D so as to increase their market share. If the first two factors dominate over the third, optimal subsidy is positive. If spillover is small, the strategic effect dominates, and then negative subsidy should be necessary.

Poyago-Theotoky (2005) has studied the importance of environmental R&D, which is directed towards emission reduction of harmful pollutants, and which are associated with social welfare. The firms undertake R&D expenditure for reducing their emission level before the regulator sets emission tax. Namely, there is voluntary approach for firms to reduce emissions. Regulator follows time-consistent policy. The study has focused on two different regimes related to R&D organisation:

1) Independent R&D;

2) Environmental R&D cartel.

Moreover, it has been assumed that there are spillovers in the R&D process so that a firm can benefit from the R&D effort of its rival at no cost to itself. Due to the negative externality, firms tend to over produce. So, government impose emission tax to prevent this market failure. Market structure is duopolistic. In the model, there are two scenarios. In the first scenario, there are three stages game. At the first stage, firms opt their environmental R&D level non-cooperatively; at the second stage, regulator sets emission tax; and at the last stage, firms compete in the market by choosing their output level. In the second scenario, firms form environmental R&D cartel at the first stage only; other stages remain the same.

This work has come to the conclusion that in the case of environmental R&D cartel (ERC), when environmental damage is low, environmental R&D is higher compared to independent R&D. If environmental damage is high, the conclusion is the opposite. The same proposition can be said about social welfare. Furthermore, this paper has paid attention to the fact that if there are n-firms in the market, which affects deeply relation of between environmental policy and the organisation of environmental R&D. Furthermore, this paper has paid attention to the fact that if there are n-firms in the market, which affects deeply the relation between environmental policy and the organisation of environmental R&D, free-rider problem would be more severe. Therefore, ERC would make more effort on environmental R&D.

Roy Chowdhruy (2002) has analyzed the interaction between environmental policy, market structure and level of the pollution. He has considered duopoly market structure where the firms endogenously decide to form joint venture. In this paper market structure is determined endogenously .Due to pollution, government imposes emission tax, which creates abatement cost for the firms. It is assumed that one firm supplies capital while the other supplies labour in joint venture. In the model, there are two stages. At the first stage, firms decide whether to choose Cournot competition or joint venture formation. Joint venture can be formed only if two firms choose it. At the second stage, in the case of Cournot, firms simultaneously choose their output level; however, in the case of joint venture case; firms choose simultaneously the level of input supply for the joint venture. Then, the government determines optimal tax.

Two components of joint venture have been analyzed; synergy and moral hazard. If two firms form joint venture, it leads to cost reduction due to synergy. Moreover, two advantages of the joint venture have been mentioned; gain from synergy and avoiding loss of rents. As for moral hazard, when the capital and labour supply reach big amount in joint venture, it's impossible to control these labour and capital flows. Also that cannot be at the contract. The firms begin to pay attention more on their own profit than on joint venture. Thus, free rider problem appears which leads to less level of input supply than optimum. The conclusion of this work can be summarized as the following; the pollution level depends on market structure and government regulation. If government policy is strict, Cournot competition is better than joint venture formation regarding the pollution. If the government policy is weak, joint venture formation is better than Cournot competition. Furthermore, if the synergetic effect is large, strict regulation causes an increase on the level of pollution, which leads to regime switch from joint venture to Cournot competition. For a given market structure, the optimal tax is less than marginal social damage. If the industry is not excessively polluting, by means of manipulating emission tax the first best outcome can be realized (under joint venture formation). If the industry is polluting, second best tax might or might not be equal to the optimal tax under either joint venture or Cournot competition.

Katsoulacos et al. (1999) has analyzed the impact of environmental policy on the performance of environmental RJV. In this paper, it has been examined that how environmental policy affects environmental innovation when the firms form environmental RJV. Especially it has focused on a comparison made between the impact of environmental policy on innovative performance of RJV and non-cooperative equilibriums. In the model, two firms are considered which generate pollution by producing dirty goods. Due to environmental externality, government imposes emission tax. In line with the model, information sharing is determined endogenously besides the numbers of the lab operated endogenously. There are seven-stage in the game;

1) *Government decides whether or not to allow RJV.*

2) *If RJVs are allowed, firms choose whether or not to form one.*

3) *Firms choose the number of labs to operate.* At this stage, if the two firms act non-cooperatively, each of them operates their own independent lab. If they form a RJV; then, at stage 3, they can choose either to continue to operate one lab each, or to operate a single combined lab.

4) *Firms choose the amount of R&D to do in each lab.* At this stage, the amount of R&D is determined by the lab conditional on the probability to discover a new technology.

5) *Conditioning on the outcome of the R&D decisions*. Firms choose whether or not to share information. This stage depends on stage 4. There are three possibilities for the outcome of stage 4.

6) *The government sets environmental taxes t00, t10, t11 conditioning on the technology that each firm has as a result of the outcomes of stages 4 and 5.* In this stage, three possible situations appear depending on which technology the firms each has.

7) *Firms choose output in a non-cooperative Cournot Equilibrium.*

In this stage, the firms choose their output level non-cooperatively under Cournot competition.

This game has been solved by backward induction. The conclusions can be expressed as the following: Due to the failure to make the right-information-sharing decisions, to operate the right number of labs – so have excessive duplication of effort and due to incorrect R&D decisions taken through under- or over-investment, welfare losses appear. Furthermore, it has been shown that;

a) Information-sharing is more likely when damage occurs and taxes are low.

b) When damage is low, RJVs perform better in R&D decision-making than it does under the non-cooperative equilibrium. This situation depends on two reasons. Firstly, since the returns to R&D are high, they are more likely to avoid the risk of needless duplication. Secondly, the loss occurred from under-investment of the RJV is smaller than the loss occurred from over-investment in the non-cooperative equilibrium.

c) As damage rises, the under-investment of the RJV increases and the over-investment in the non-cooperative equilibrium falls. A questionable conclusion is that RJVs do better than non-cooperative organisation when environmental damage is low; but when environmental damage is high, RJV is worse.

Oladunjoye (2005) has examined two environmental policies (subsidy and tax) under competitive R&D and under cooperative R&D organisation in a heterogeneous product market. According to the model, the firms generate pollution and face tax on emission at a rate per unit of emission in a duopoly structure and the government gives a subsidy to encourage the firms to invest in environmental R&D. There are technologic spillover and product differentiation. The model includes three stage game. In the first stage, the regulator sets a tax on emission at a rate per unit of emissions and subsidizes R&D at a rate s per unit of R&D investment. In the second stage, the firms choose their level of R&D simultaneously. In the final stage, they choose their output under Cournot competition taking the emission tax and subsidy as given by the regulator. What have been compared are the optimal emission taxes, subsidies and social welfare under both R&D arrangements.

This work has demonstrated the fact that the second-best emission tax is less than marginal damages under both environmental R&D. In addition, on the one hand, the subsidy has also been found to be strictly positive under cooperative R&D. Though, under competitive R&D it is only positive for high spillovers. On the other hand, if spillover is low, subsidy is negative. Under the assumption of exogenous emissions tax and constant marginal damage shows that, for sufficiently low spillovers, optimal subsidy under cooperative ER&D should be greater than under competitive environmental R&D. This result also holds for high spillovers and highly differentiated products. This will discourage free riding on R&D investments among firms and it helps to reduce emission costs. Such a reduction leads to an increase on R&D levels, which minimize emissions and helps correct output market failure.

However, optimal subsidy under cooperative R&D should be less than what is obtained under competitive environmental R&D for high spillovers and less differentiated products.

Using numerical computation, for sufficiently low product substitutability, optimal emission tax under environmental R&D cooperation should be less than optimal emissions tax under competitive environmental R&D; while the subsidy under cooperative environmental R&D should be more than the subsidy under competitive environmental R&D, which may be negative for low environmental R&D spillover. This will encourage the coordination of environmental R&D investments among firms while the subsidy helps to lessen environmental R&D expenditure. Thus, a decrease on expenditure gives way to an increase on environmental R&D levels that helps to correct output market failure. For sufficiently low spillover effects and high product differentiation, optimal emission tax under environmental R&D cooperation should also be lower than the optimal emission tax under environmental R&D competition; while the optimal subsidy under environmental R&D cooperation should be higher than the optimal subsidy under environmental R&D competition. However, the reverse is correct for sufficiently high spillovers and high product differentiation.

To conclude, regardless of the degree in product differentiation, if spillover is small, environmental R&D cooperation is socially desirable. Nevertheless, if there is a high spillover effect and products are less differentiated, competitive R&D is socially desirable.

3. THE MODEL

In this model, a duopoly is considered as a market where firms sell differentiated products and compete either by setting quantities or by setting prices.

The firms face inverse demand function as shown by the following equation,

$$P = A - q_i - g.q_j \qquad \textbf{(1)}$$

or direct demand function as indicated by the subsequentequation:

$$q_i = \left[\frac{1}{(1-g^2)}\right].\left[A.(1-g) - P_i + g.P_j\right] \qquad \textbf{(2)}$$

where i, j = 1, 2, i.≠j and $A \phi 0$. Parameter γ indicates the degree of product differentiation and $0 \leq g \leq 1$. The fact that y is close to zero $(g \to 0)$ represents perfectly differentiated goods and local monopolist firms. If g gets close to one $(g \to 1)$, the goods become very similar (in the limit they become homogeneous). We assume that unit production costs, *c*, are constant while there are no fixed costs and normalizing unit costs by setting *c* equals to zero. The firms generate pollution by producing.

Emission per unit output

$$e_i = e_0 - z_i - b.z_j \qquad \textbf{(3)}$$

i = 1, 2, i ? j, where zi represents firm i's environmental R&D level which is directed towards emission reduction of harmful pollutants and e_0 represents initial emissions per unit of output. Additionally, β shows the degree of technological spillover between the firms.

$0 \leq b \leq 1$ and it is assumed that $e_0 \geq z_i + b.z_j$ for any z_i and z_j. Environmental R&D expenditure for firm i, $R = 0{,}5.d.z_i^2$ **(4)**

z_i represents firm i's environmental R&D level. The firm i has to spend an amount R to reach environmental technological level z_i. The symbol of δ captures the relative efficiency of environmental R&D. It should not be ignored that environmental R&D cost function indicates diminishing returns to environmental R&D.

Total emissions can be figured as the following

$$E = \sum_i e_i . q_i = \left(e_1 . q_i + e_2 . q_j \right) \qquad \textbf{(5)}$$

To make clear the symbols, it should be said that D represents environmental damage and equals to $D = \left(e_1 . q_i + e_2 . q_j \right) f$ where f represents marginal disutility. The government has also environmental policy tools; emission tax and subsidy. Due to pollution caused by firms' production, government imposes emission tax at a rate t per unit of emission. Futhermore, government gives subsidy at a rate s per unit of R&D investment so as to encourage the firms to invest in environmental R&D.

In this model a three stage game is considered in a differentiated product duopoly where R&D is emission intensity reducing. In the first stage, the regulator (government) determines emission tax and R&D subsidy. In the second stage, given the emission tax and R&D subsidy firms choose their R&D levels simultaneously. In the third stage, two cases are analyzed. In the first case, firms choose their output levels taking everything else as given under Cournot competition. In the second case; however, firms choose their price levels taking everything else as given under Bertrand competition.

3.1. COURNOT CASE

3.1.1. Under Competitive R&D

3.1.1.1. Stage 3

Given the policy scheme (t,s) announced by the governments and the choice of R&D effort in emission reduction z_i, firm i maximizes following profit by choosing its output level;

$$p_i = P.q_i - t.e_i.q_i - (1-s).0.5.d.z_i^2 = (A - q_i - g.q_j).q_i - t.e_i.q_i - (1-s).0,5.d.z_i^2 \qquad \textbf{(6)}$$

The first order condition is obtained as follows,

$$\frac{\partial p_i}{\partial q_i} = A - 2.q_i - g.q_j - t.e_i = 0 \Rightarrow q_i = \frac{A - t.e_i - g.q_j}{2} \qquad \textbf{(7)}$$

The reaction functions are obtained as follows,

$$q_i = \frac{A - t.(e_0 - z_i - b.z_j) - g.q_j}{2} \qquad \textbf{(8a)}$$

$$q_j = \frac{A - t.(e_0 - z_j - b.z_i) - g.q_i}{2} \qquad \textbf{(8b)}$$

Solving simultaneously eq.(8a) and (8b) Cournot-Nash eq.output levels are obtained as follows,

$$q_i^* = \frac{(2-g).(A - t.e_0) + (2 - g.b).t.z_i + (2.b - g).t.z_j}{4 - g^2}, \ \{i, j\} = \{1,2\}, \ i \neq j \qquad \textbf{(9)}$$

q_i^* is Cournot-Nash Equilibrium output

$p_i = q_i^{\,2} - 0,5.(1-s).d.z_i^{\,2}$ p_i is overall profit.[5] **(10)**

3.1.1.2. Stage 2

In the second stage firm i taking the subsidy on R&D as given will max second stage profit by choosing z_i.[6]

$$p_i = q_i^{\,2} - 0,5.(1-s).d.z_i^{\,2}$$

The first order condition is obtained as follows,

$$\frac{\partial p_i}{\partial z_i} = 0 \Rightarrow 2.q_i.\frac{\partial q_i}{\partial z_i} - (1-s).d.z_i = 0$$

In the symmetric equilibrium $z_i = z_j = z_{ccomp}$, the solution related to R&D effort can be expressed in the following way;[7]

$$z_{ccomp} = \frac{2.t.(2-g.b).(2-g).(A-t.e_0)}{\Omega_{ccomp}} \qquad \textbf{(11)}$$

where $\Omega_{ccomp} = \left[(1-s).d.(4-g^2)^2 - 2.t^2.(2-gb).(2-g).(b+1)\right]$

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[5] See in the appendix (A1)

[6] The second order condition requires $2.t^2(2-g.b)^2 \ \pi \ (1-s).d.(4-g^2)^2$ while the stability condition is satisfied for

$2.t^2(2-g.b).(b+1).(2-g) \ \pi \ (1-s).d.(4-g^2)^2$ or $\Omega_{ccomp} \ \phi \ 0$

[7] The expressions for the differentiations are in the appendix (A4)

It is presumed that $(A - t.e_0) \succ 0$ and

$$(1-s).d.(4-g^2)^2 - 2.t^2.(2-g.b).(2-g).(b+1) \succ 0$$

In the symmetric equilibrium,output level can be expressed in the following way,

$$q_{ccomp} = \frac{(A - t.e_0) + t.z_{ccomp}.(b+1)}{2+g}$$

Regarding the model, it should be noted that ;

- If $t = 0 \Rightarrow z_{ccomp} = 0$. Namely, firms undertake emission reduction only if governmnet impose taxes for emission. However, in this presumption R&D subsidies are not taken into account. Thus, positive environmental tax functions as an incentive for the firms to undertake R&D.
- $\frac{\partial z_{ccomp}}{\partial s} = \frac{2.t.d.(2-g.b).(2-g).(A-t.e_0).(4-g^2)^2}{\Omega_c^{\ 2}} \succ 0$ The equation expressed in figures implies an increase in the subsidy which will lead to an increase in env R&D.
- $\frac{\partial q_{ccomp}}{\partial s} = \frac{t.(b+1).\frac{\partial z_{ccomp}}{\partial s}}{2+g}$ The equation in question indicates the fact that an increase on R&D subsidy will give rise to production as well.
- $\frac{\partial q_{ccomp}}{\partial t} = -\frac{e_0 - z_{ccomp}.(b+1)}{2+g} + \frac{(b+1).t}{2+g}.\frac{\partial z_{ccomp}}{\partial t}$ Change in tax has two effects on output: direct and indirect effect. An increase in tax has not only a direct negatif effect but also has an indirect positive effect on output. While

the first term represents direct effect, the second term symbolizes indirect effect. At this point the quesiton that comes into mind is: Which effect dominates the other? In general, it is expected that direct effect will dominate ultimately. So, $\frac{\partial q_{ccomp}}{\partial t}\ \pi\ 0$

Substituting eq (11) into eq (9) , in the symmetric equilibrium output and price for given s and t can be shown in the following equation:

$$q_{ccomp} = \frac{(A - t.e_0)}{2+g} + \frac{2.t^2.(b+1).(2-g).(2-g.b).(A-t.e_0)}{(2+g).\Omega_{ccomp}} \quad \textbf{(12)}$$

and using eq. (1),

$$P_{ccomp} = A - q_{ccomp} - g.q_{ccomp} = A - (1+g).q_{ccomp} \quad \textbf{(13)}$$

3.1.1.3. Stage 1

In Dixit (1979) and Singh and Vives (1984), each firm has produced differentiated good and they have supposed that there is representative consumer whose preferences for consumption of the two goods q_1, q_2 and numeraire good M is described as utility function; [8]

$$U(q_1, q_2) = A_1.q_1 + A_2.q_2 - \frac{q_1^{\ 2} + 2g.q_1.q_2 + q_2^{\ 2}}{2} + M \quad \textbf{(14)}$$

The term M stands for the consumption of goods other than good 1 and good 2. By horizontal differentiation; it means that brands are not formally ranked among all

[8] The inverse demand functions are derived from the utility function.
$\frac{\partial U(q_i, q_j)}{\partial q_i} = A - q_i - g.q_j = P_i, \{i, j\} = \{1,2\}$, i ≠ j

consumers given equal prices because of the variety of preferences. When goods are substitutes, the degree of substitutability could be interpreted in terms of horizontal product differentiation. On the other hand, vertical differentiation is referred to quality differentiation usually characterized by consumers' willingness to pay .For vertical differentiation goods, brands are uniformly ranked by all consumers. That is higher quality is preferable. A_i measures quality in vertical sense. Other things equal, an increase in A_i increases marginal utility of consuming good i. Thus utility is quadratic in the consumption of q goods and linear in the consumption of other goods,

$$U(q_i, q_j) = A.(q_i + q_j) - \frac{q_i^{\ 2} + 2.g.q_i.q_j + q_j^{\ 2}}{2} + M \qquad \textbf{(15)}$$

$$W = U(q_i, q_j) - 0{,}5d\,(z_i^{\ 2} + z_j^{\ 2}) - D \qquad \textbf{(16)}$$

In equation above, the social welfare is determined total surplus minus R&D cost minus environmental damage. In a symmetric equilibrium $e_{ccomp} = e_0 - (1 + b)z_{ccomp}$ and the social welfare becomes,

$$W_{ccomp} = 2.A.q_{ccomp} - (1 + g).q_{ccomp}^{\ 2} - d.z_{ccomp}^{\ 2} - 2e_{compc}q_{ccomp}f \qquad \textbf{(17)}$$

The government maximize W_{ccomp} by choosing both t and s. The first order condition requires that $\frac{\partial W_{ccomp}}{\partial t} = \frac{\partial W_{ccomp}}{\partial s} = 0$, so

$$\frac{\partial W_{ccomp}}{\partial t} = 0 \Rightarrow 2.A.\frac{\partial q_{ccomp}}{\partial t} - 2.q_{ccomp}.(1+g).\frac{\partial q_{cccomp}}{\partial t} - 2.z_{cccomp}.d.\frac{\partial z_{ccomp}}{\partial t} - 2.e_{ccomp}f.\frac{\partial q_{ccomp}}{\partial t} - 2.f..q_{ccomp}.\frac{\partial e_{ccomp}}{\partial z_{ccomp}}.\frac{\partial z_{ccomp}}{\partial t} = 0 \qquad \textbf{(18)}$$

$$\frac{\partial W_{ccomp}}{\partial s} = 0 \Rightarrow 2.A.\frac{\partial q_{ccomp}}{\partial s} - 2.(1+g).q_{ccomp}.\frac{\partial q_{ccomp}}{\partial s} - 2.d.z_{ccomp}.\frac{\partial z_{ccomp}}{\partial s} - 2.f.e_{ccomp}.\frac{\partial q_{ccomp}}{\partial s} - 2.f.q_{ccomp}.\frac{\partial e_{ccomp}}{\partial z_{ccomp}}.\frac{\partial z_{ccomp}}{\partial s} = 0 \qquad \textbf{(19)}$$

The optimal policy combination $\left(t_{ccomp}, s_{ccomp}\right)$ is, [9]

$$t_{ccomp} = f - \frac{q_{ccomp}}{e_{ccomp}} \tag{20}$$

Parallel to what is expected , the second best tax is below marginal damage.

$$s_{ccomp} = 1 - \frac{2.t_{ccomp}.\left(2 - g.b\right)}{f.\left(4 - g^{2}\right).\left(b + 1\right)} \tag{21}$$

As it is supposed, second best emission tax should be below marginal damage. It is well known that a corrective tax on polluting activities equals to marginal social damage internalizes the social cost of firms' negative externalities. But this situation exists when a regulator has full information and the externality generating industry is competitive.

Because of the interaction between over production due to pollution externality and under production owing to market power, optimal emission tax is less than marginal social damage. (Output-distortion effect) The internalization of externality burden constitutes an extra cost; the firm decreases its output, which in turn leads to higher prices. As a result, it can be stated that consumers are affected by two factors in negative means: increasing price level and negative externality.

The optimal subsidy depends on the degree of product differentiation and on spillover parameter. Another result obtained in this model indicates the fact that subsidy increases when the deviation between emission tax and marginal pollution damage increases.

If the firms take into account of their interests, they under-invest in environmental R&D. (the undervaluation effect) In this case, the regulator (government) impose positive subsidy to encourage the firm for investing in environmental R&D. Thus, subsidy should be positive. At this point subsidy plays role to help correct the suboptimal environmental R&D. In addition, Inasmuch as there is technological spillover, it could be asserted a question of free-rider effect. The firms can not

[9] All steps are presented in the appendix (A18) and (A19)

internalize the externality appeared from spillover. Hence, the firms will under-invest in environmental R&D.

When social returns exceed private ones, R&D is secured as positive and an under investment in R&D can be expected. On the one hand, firms get positive subsidy by undertaking under-investment on R&D; on the other hand, they maximize their profit by minimizing their R&D expenditure.

It could be stated that spillover parameter is low and product differentiation parameter is high optimal subsidy is negative .In the expression of subsidy, the term of $\frac{2.t.(2-g.b)}{(4-g^2).(b+1)}$ reflects strategic effect. If the strategic effect dominates the output distortion effect ,the subsidy could be negative. In this situation, the firms want to capture all benefits of being the first firm to introduce the new technology. Hence,the firms would over-invest in environmental R&D

3.1.2. Under Cooperative R&D

It is analyzed that the situation in that firms act cooperatively at the stage R&D (stage 2) only. Accordingly, firms set their R&D cooperatively to maximize joint first stage profit while competing in the third stage. In addition, Research Joint Venture (RJV) is considered. Furthermore, it is admitted that within RJV there exists full information sharing of research result and spillover is set its max value (β = 1). Finally,last stage of the game is solved in the same way as it has been done in the case of competitive R&D.

3.1.2.1. Stage 3

Given the policy scheme (t,s) announced by the governments and the choice of R&D effort in emission reduction z_i, firm i maximizes following profit by choosing its output level;

$$p_i = P.q_i - t.e_i.q_i - (1-s).0,5.d.z_i^2 = (A - q_i - g.q_j)q_i - t.e_i.q_i - 0,5.(1-s).d.z_i^2 \qquad \textbf{(6)}$$

The first order condition is obtained as follows,

$$\frac{\partial p_i}{\partial q_i} = A - 2.q_i - g.q_j - t.e_i = 0 \Rightarrow q_i = \frac{A - t.e_i - g.q_j}{2} \qquad \textbf{(7)}$$

The reaction functions are obtained as follows,

$$q_i = \frac{A - t.(e_0 - z_i - z_j) - g.q_j}{2} \quad \textbf{(22a)}$$

$$q_j = \frac{A - t.(e_0 - z_j - z_i) - g.q_i}{2} \quad \textbf{(22b)}$$

Solving simultaneously eq. (22a) and eq. (22b) Cournot-Nash eq.output levels are obtained as follows,

$$q_i^* = \frac{A - t.e_0 + t.z_i + tz_j}{2 + g} \quad , \{i, j\} = \{1,2\}, \mathrm{i} \neq \mathrm{j} \quad \textbf{(23)}$$

q_i^* is Cournot-Nash Equilibrium output

3.1.2.2. Stage 2

In the second stage the firms taking the subsidy on R&D as given will max second stage profit by choice z_i.

$$p_{rjv} = (p_i + p_j) = q_i^2 - 0{,}5.(1-s).d.z_i^2 + q_j^2 - 0{,}5.(1-s).d.z_j^2 \quad \textbf{(24)}$$

The first order condition is obtained as follows,

$$\frac{\partial p_{rjv}}{\partial z_i} = 0 \Rightarrow 2.q_i.\frac{\partial q_i}{\partial z_i} + 2.q_j.\frac{\partial q_j}{\partial z_i} - (1-s).\partial.z_i = 0 \quad \textbf{(25)}$$

$\frac{\partial p_{rjv}}{\partial z_i} = \frac{\partial p_{rjv}}{\partial z_j} = 0$ which in symmetric equilibrium $z_i = z_j = z_{ccoop}$, the solution related to R&D effort can be expressed in the following way, [8]

$$z_{ccoop} = \frac{4.t.(A - t.e_0)}{(2+g)^2(1-s).d - 8.t^2} = \frac{4.t.(A - t.e_0)}{\Omega_{ccoop}} \qquad \textbf{(26)}$$

where $\Omega_{ccoop} = (2+g)^2.(1-s).d - 8.t^2$

In the symmetric equilibrium,output level can be expressed in the following way,

$$q_{ccoop} = \frac{A - t.e_0 + 2.t.z_{ccoop}}{2+g}$$

It should be noted that ,

- $t = 0 \Rightarrow z_{ccoop} = 0$ It means that if emission is not taxed, firms will not invest in environmental R&D.

[8] All steps are presented in the appendix (A23)

- $\dfrac{\partial z_{ccoop}}{\partial s} = \dfrac{4.t.(2+g)^2.d.(A-t.e_0)}{\Omega_{ccoop}{}^2} \phi 0$ That means when emission tax is given, an increase in subsidy is observed which will in turn lead to an increase in environmental R&D.

- $\dfrac{\partial q_{ccoop}}{\partial s} = \dfrac{2.t}{2+g}.\dfrac{\partial z_{ccoop}}{\partial s} \phi 0$ That indicates if subsidy on R&D increases, production will also increase.

If (26) is substituted into (23), the following equation is found;

$$q_{ccoop} = \frac{A-t.e_0}{2+g} + \frac{8.t^2.(A-t.e_0)}{(2+g).\left[(2+g)^2.(1-s).d - 8.t^2\right]} \qquad \textbf{(27)}$$

$$P_{ccoop} = A-(1+g).q_{ccoop} \qquad \textbf{(28)}$$

3.1.2.3 Stage 1

The government would like to maximize welfare by choosing t and s. In a symmetric equilibrium $e_{ccoop} = e_0 - (1+b)z_{ccoop}$ and the social welfare becomes,

$$W_{ccoop} = 2.A.q_{ccoop} - (1+g).q_{ccoop}{}^2 - d.z_{ccoop}{}^2 - 2e_{ccoop}q_{ccoop}f \qquad \textbf{(17)}$$

The first order condition requires that $\dfrac{\partial W_{ccoop}}{\partial t} = \dfrac{\partial W_{ccoop}}{\partial s} = 0$,

$$\frac{\partial W_{ccoop}}{\partial t} = 0 \Rightarrow 2.A.\frac{\partial q_{ccoop}}{\partial t} - 2.q_{ccoop}.(1+g).\frac{\partial q_{ccoop}}{\partial t} - 2.z_{ccoop}.d.\frac{\partial z_{ccoop}}{\partial t} - 2.e_{ccoop}f.\frac{\partial q_{ccoop}}{\partial t} - 2.f.q_{ccoop}.\frac{\partial e_{ccoop}}{\partial z_{ccoop}}.\frac{\partial z_{ccoop}}{\partial t} = 0 \quad \textbf{(29)}$$

$$\frac{\partial W_{ccoop}}{\partial s} = 0 \Rightarrow 2.A.\frac{\partial q_{ccoop}}{\partial s} - 2.(1+g).q_{ccoop}.\frac{\partial q_{ccoop}}{\partial s} - 2.d.z_{ccoop}.\frac{\partial z_{ccoop}}{\partial s} - 2.f.e_{ccoop}.\frac{\partial q_{ccoop}}{\partial s} - 2.f.q_{ccoop}.\frac{\partial e_{ccoop}}{\partial z_{ccoop}}.\frac{\partial z_{ccoop}}{\partial s} = 0 \quad \textbf{(30)}$$

The optimal policy combination (t_{ccoop}, s_{ccoop}) is [9]

$$t_{ccoop} = f - \frac{q_{ccoop}}{e_{ccoop}} \quad \textbf{(31)}$$

$$s_{ccoop} = 1 - \frac{2.t_{ccoop}}{(2+g).f} \quad \textbf{(32)}$$

It is showed that the emission tax is less than marginal damage. This result is the same with emission tax with expression under competitive R&D. If eq (32) is taken into consideration, it can be revealed that subsidy is always positive. The regulator encourages the firms to coordinate and eliminate duplication of efforts while completely internalizing R&D spillover. This in turn leads to more efficient use of their resources.

[9] All steps are presented in the appendix (A38) and (A39)

This fact can be regarded as vital due to the fact that social returns exceed private returns. On the one hand, firms get positive subsidy by making under investment on R&D; on the other hand, they maximize their profit by minimizing their R&D expenditure. Explicitly, the firms consider their private benefits more than social benefits.

3.2. BERTRAND CASE

3.2.1. Under Competitive R&D

Direct demand function,

$$q_i = \left[\frac{1}{\left(1-g^2\right)}\right].\left[A.(1-g) - P_i + g.P_j\right] \qquad \textbf{(2)}$$

To facilitate comparasion with the Cournot case, k will be used to show emission tax and v will be employed to illustrate subsidy. Hence,

3.2.1.1. Stage 3

Each firm maximizes following profit by choosing their appropriate price level.

$$p_i = P.q_i - k.e_i.q_i - 0{,}5.(1-v).d.z_i^{\,2} \qquad \textbf{(33)}$$

The first order condition is obtained as follows,

$$\frac{\partial p_i}{\partial P_i} = 0 \Rightarrow \frac{\lfloor A.(1-g) - 2.P_i + g.P_j + k.e_i \rfloor}{1-g} = 0 \Rightarrow \tag{34}$$

The reaction functions are obtained as follows,

$$P_i = \frac{A(1-g) + g.P_j + k.(e_0 - z_i - b.z_j)}{2} \quad \text{Reaction Function for firm i} \tag{35a}$$

$$P_j = \frac{A.(1-g) + g.P_i + k.(e_0 - z_j - b.z_i)}{2} \quad \text{Reaction Function for firm j} \tag{35b}$$

Solving simultaneously eq.(35a) and (35b) equilibrium price level is obtained as follows,

$$P_i^* = \frac{(2+g).[A.(1-g) + e_0.k] - k.(g+2.b).z_j - k.(2+b.g).z_i}{4-g^2}, \{i, j\} = \{1,2\}, \text{i} \neq \text{j} \tag{36}$$

By using eq.(2) and (35a) into eq(33), maximum overall profit is obtained as follows

$$p_i = \frac{(P_i - k.e_i)^2}{1-g^2} - 0{,}5.(1-v).d.z_i^2 \tag{37}$$

3.2.1.2. Stage 2

Firm i taking the subsidy on R&D as given will maximize second stage profit by choosing its R&D level.[10]

$$p_i = \frac{(P_i - k.e_i)^2}{1-g^2} - 0{,}5.(1-v).d.z_i^2 \qquad \textbf{(37)}$$

The first order condition is obtained as follows,

$$\frac{\partial p_i}{\partial z_i} = 0 \Rightarrow \frac{2.(P_i - k.e_i).\left(-k.\frac{\partial e_i}{\partial z_i} + \frac{\partial P_i}{\partial z_i}\right)}{1-g^2} - (1-v).d.z_i = 0 \qquad \textbf{(38)}$$

In the symmetric equilibrium $z_i = z_j = z_{bcomp}$; the solution related to R&D effort can be expressed in the following way,[11]

$$z_{bcomp} = \frac{2.k.(A - k.e_0).(2-g^2 - b.g)}{\Omega_{bcomp}} \qquad \textbf{(39)}$$

where $\Omega_{bcomp} = (1+g).(1-v).(4-g^2).(2-g).d - 2.k^2.(b+1).(2-g^2-b.g)$

[10] The second order condition requires $2.k^2(2-g^2-g.b)^2 \; \pi \; (1-v).d\,(1-g^2).(4-g^2)^2$ while the stability condition is satisfied for $2.k^2(2-g^2-g.b).(b+1) \; \pi \; (1-v).d\,(1+g).(4-g^2)(2-g)$

[11] All steps are presented in the appendix (A42)

In the symmetric equilibrium, price level can be expressed in the following way,

$$P_{bcomp} = \frac{[A.(1-g) + e_0.k] - k.(1+b).z_{bcomp}}{2-g}$$

It should be stated that;

- k = 0 then $z_{bcomp} = 0$ The formula implies that if emissions are not taxed, firms will not invest in environmental R&D.

- $\dfrac{\partial z_{bcomp}}{\partial v} = \dfrac{2.k.(A-k.e_0).(2-g^2-b.g).(1+g).(4-g^2)^2.(2-g).d}{\Omega_{bcomp}{}^2} \phi\ 0$ Thus, an increase in subsidy leads to an increase in R&D.

- $\dfrac{\partial P_{bcomp}}{\partial v} = \dfrac{-k.(b+1).(2+g).\dfrac{\partial z_{bcomp}}{\partial v}}{4-g^2} \pi\ 0$ The formula implies the fact that if subsidy increases, price will decrease. This situation points an opposite effect than Cournot.

In the symmetric equilibrium,output level can be expressed in the following way

$$q_{bcomp} = \frac{A - P_{bcomp}}{1+g} = \frac{A - k.e_0 + k.z_{bcomp}.(b+1)}{(2-g).(1+g)}$$

$$\frac{\partial q_{bcomp}}{\partial k} = -\frac{e_0 - (b+1).z_{bcomp}}{(2-g).(1+b)} + \frac{k.(b+1)}{(2-g).(1+b)}.\frac{\partial z_{bcomp}}{\partial k}$$

It would be practical to stress that a change in tax has two effects on output: direct and indirect effect. An increase in tax has a direct negative effect on output. Nonetheless, it has an indirect positive effect on output as well. In this regard, first term represents direct effect, second term represents indirect effect. At this point, the model focuses on the following question: Which effect dominates the other? In general, it is expected that direct effect will dominate ultimately. Hence , $\frac{\partial q_{bcomp}}{\partial k} \pi 0$.

By substituting eq (39) into (36), price level for the given k and v is formulated in the following symmetric equilibrium:

$$P_{bcomp} = \frac{A.(1-g)+e_0.k}{2-g} - \frac{2.k^2.(A-k.e_0).(b+1).(2-g^2-b.g)}{(2-g).\Omega_b} \qquad \textbf{(40)}$$

$$q_{bcomp} = \frac{1}{1+g}.\left[A - \frac{A.(1-g)+e_0.k}{2-l} + \frac{2.k^2.(A-k.e_0).(b+1).(2-g^2-bg)}{(2-g).\Omega_b}\right] \qquad \textbf{(41)}$$

3.2.1.3. Stage 1

In this section government (regulator) sets up v and k so as to maximize welfare that is defined as total surplus minus R&D cost minus environmental damage.

$$U(q_i, q_j) = A.(q_i + q_j) - \frac{q_i^{\ 2} + 2g.q_i.q_j + q_j^{\ 2}}{2} + M \qquad \textbf{(42)}$$

$$W = U(q_i, q_j) - 0{,}5.d(z_i^{\ 2} + z_j^{\ 2}) - D \qquad \textbf{(43)}$$

In a symmetric equilibrium $e_{bcomp} = e_0 - (1+b)z_{bcomp}$ and the social welfare becomes,

$$W_{bcomp} = 2.A.q_{bcomp} - (1+g).q_{bcomp}^{\ 2} - d.z_{bcomp}^{\ 2} - 2e_{bcomp}q_{bcomp}f \qquad \textbf{(44)}$$

The first order condition requires that $\frac{\partial W_{bcomp}}{\partial k} = \frac{\partial W_{bcomp}}{\partial v} = 0$,

$$\frac{\partial W_{bcomp}}{\partial k} = 0 \Rightarrow 2.A.\frac{\partial q_{bcomp}}{\partial k} - 2.q_b.(1+g).\frac{\partial q_{bcomp}}{\partial k} - 2.z_{bcomp}.d.\frac{\partial z_{bcomp}}{\partial k} - 2.e_{bcomp}.f.\frac{\partial q_{bcomp}}{\partial k} - 2.f.q_{bcomp}.\frac{\partial e_{bcomp}}{\partial z_{bcomp}}.\frac{\partial z_{bcomp}}{\partial_{kcomp}} = 0 \qquad \textbf{(45)}$$

$$\frac{\partial W_{bcomp}}{\partial v} = 0 \Rightarrow 2.A.\frac{\partial q_{bcomp}}{\partial v} - 2.(1+g).q_{bcomp}.\frac{\partial q_{bcomp}}{\partial v} - 2.d.z_{bcomp}.\frac{\partial z_{bcomp}}{\partial v} - 2.f.e_{bcomp}.\frac{\partial q_{bcomp}}{\partial v} - 2.f.q_{bcomp}.\frac{\partial e_{bcomp}}{\partial z_{bcomp}}.\frac{\partial z_{bcomp}}{\partial v} = 0 \qquad \textbf{(46)}$$

The optimal policy combination $\left(k_{bcomp}, v_{bcomp}\right)$ is,[12]

$$k_{bcomp} = f - (1-g)^2 \,.\, \frac{q_{bcomp}}{e_{bcomp}} \tag{47}$$

$$v_{bcomp} = 1 - \frac{2.k_{bcomp}.\left(2 - b.g - g^2\right)}{\left(4 - g^2\right).f.(b+1)} \tag{48}$$

Analyzing the equations stated above, it can be posited that second best emission tax should be below marginal damages. Eq (64) shows that emission tax is affected directly by product differentiation degree. When γ is close to zero, $k \, \pi \, f$; whereas, when γ is close to one, $k = f$. The figure points out that emission tax equals to marginal damage (first best rule). This situation could exist in perfectly competitive market. This conclusion remind Bertrand Paradox.[13]

Beside eq. (64), eq (65) shows that the subsidy cannot be negative. Furthermore, when the deviation between emission tax and marginal pollution damage increases, subsidy also increases.

Note that, when $g = 0$ the goods are independent so that each firm acts like a local monopoly. As a result, the emission tax and the R&D subsidy are the same in both Cournot and Bertrand Competition.

[12] All steps are presented in the appendix (A61) and (A62)
[13] Despite of the fact that firms are market power, price equals to marginal cost when products are homogenous.

3.2.2. Under Cooperative R&D

At R&D stage (Stage 2), the firms acting cooperatively are examined. From this perspective firms set their R&D cooperatively to maximize joint first stage profit while they compete in the third stage. In the stage 2, Research Joint Venture (RJV) is considered. Furthermore, within the RJV there exists full information sharing of research result and spillover is set its max value ($\beta = 1$).

Last stage of the game is solved in the same way as it has been done in the case of competitive R&D.

3.2.2.1. Stage 3

Each firm maximizes following profits by choosing their price level.

$$p_i = P.q_i - k.e_i.q_i - 0{,}5.(1-v).d.z_i^{\;2} \qquad \textbf{(49)}$$

The first order condition is obtained as follows,

$$\frac{\partial p_i}{\partial P_i} = 0 \Rightarrow \frac{\lfloor A.(1-g) - 2.P_i + g.P_j + k.e_i \rfloor}{1-g} = 0 \Rightarrow \qquad \textbf{(50)}$$

The reaction functions are obtained as follows,

$$P_i = \frac{A.(1-g) + g.P_j + k.(e_0 - z_i - z_j)}{2} \quad \text{Reaction Function for firm i} \qquad \textbf{(51a)}$$

$$P_j = \frac{A.(1-g)+g.P_i+k.(e_0-z_j-z_i)}{2} \text{ Reaction Function for firm j} \quad \textbf{(51b)}$$

Solving simultaneously eq.(51a) and eq. (51b) equilibrium price level is obtained as follows,

$$P_i^* = \frac{A.(1-g)+e_0.k-k.z_j-k.z_i}{2-g}, \quad \{i, j\} = \{1,2\}, \text{ i} \neq \text{j} \quad \textbf{(52)}$$

By using eq.(2) and (51a) into eq(49), it is obtained maximum overall profit:

$$p_i = \frac{(P_i-k.e_i)^2}{1-g^2} - 0{,}5.(1-v).d.z_i^{\ 2} \quad \textbf{(53)}$$

3.2.2.2. Stage 2

The firms taking the subsidy on R&D as given will maximize second stage profit by choosing their R&D level.

The objective function of the RJV can be expressed in the following way,

$$p_{rjv} = p_1 + p_2 = \frac{(P_i-k.e_i)^2}{1-g^2} + \frac{(P_j-k.e_j)^2}{1-g^2} - 0{,}5.(1-v).d.z_i^{\ 2} - 0{,}5.(1-v).d.z_j^{\ 2} \quad \textbf{(54)}$$

The first order condition is obtained as follows,

$$\frac{\partial p_{rjv}}{\partial zi}=0\Rightarrow\frac{2.\left(P_i-k.e_i\right).\left(k.\frac{\partial e_i}{\partial z_i}+\frac{\partial P_i}{\partial z_i}\right)}{1-g^2}+\frac{2.\left(P_j-k.e_j\right).\left(k.\frac{\partial e_j}{\partial z_j}+\frac{\partial P_j}{\partial z_i}\right)}{1-g^2}-\left(1-v\right).d.z_i=0 \quad \textbf{(55)}$$

In the symmetric equilibrium, $z_i=z_j=z_{bcoop}$, the solution related to R&D effort can be expressed in the following way,[14]

$$z_{bcoop}=\frac{4.k.\left(1-g\right).\left(A-e_0.k\right)}{\left(1+g\right).\left(2-g\right)^2.\left(1-v\right).d-8.k^2.\left(1-g\right)} \quad \textbf{(56)}$$

In the symmetric equilibrium, price level can be expressed in the following way,

$$P_{bccop}=\frac{A.\left(1-g\right)+e_0.k-2k.z_{bcoop}}{2-g}$$

Note that;

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[14] All steps are presented in the appendix (A66)

- $k = 0$ then $z_{bcoop} = 0$ That means if emissions are not taxed, firms will not invest in environmental R&D.

- $\dfrac{\partial z_{bcoop}}{\partial v} = \dfrac{4.k.(A - k.e_0).(1-g^2).(2-g)^2.d}{\Omega_{bcoop}} \phi\ 0$ Thus; if subsidy increases, it will lead to an increase in R&D.

- $\dfrac{\partial P_{bcoop}}{\partial v} = \dfrac{-2.k.\dfrac{\partial z_{bcoop}}{\partial v}}{2-g} \pi\ 0$ The formula explains the fact that if subsidy increases, price will decrease. This situation indicates an opposite effect than Cournot.

By substituting eq (56) into (52), price level for the given k and v is formulated in the following symmetric equilibrium;

$$P_{bcoop} = \frac{A.(1-g) + e_0.k}{2-g} - \frac{8.k^2.(1-g).(A - e_0.k)}{(2-g).\Omega_{bcoop}} \quad \textbf{(57)}$$

$$q_{bcoop} = \frac{1}{1+g}.\left[A - \frac{A.(1-g) + e_0.k}{2-g}\right] + \frac{8.k^2.(1-g).(A - e_0.k)}{(2-g).\Omega_{bcoop}} \quad \textbf{(58)}$$

3.2.2.3. Stage 1

In this section governments (regulator) set up v and k in order to maximize welfare that is defined as total surplus minus R&D cost minus environmental damage.

$$U(q_i, q_j) = A.(q_i + q_j) - \frac{q_i^{\ 2} + 2g.q_i.q_j + q_j^{\ 2}}{2} \qquad \textbf{(59)}$$

$$W = U(q_i, q_j) - 0{,}5.d\,(z_i^{\ 2} + z_j^{\ 2}) - D \qquad \textbf{(60)}$$

In a symmetric equilibrium $e_{bcoop} = e_0 - (1+b)z_{bcoop}$ and the social welfare becomes,

$$W_{bcoop} = 2.A.q_{bcoop} - (1+g).q_{bcoop}^{\ \ 2} - d.z_{bcoop}^{\ \ 2} - 2e_{bcoop}q_{bcoop}f \qquad \textbf{(61)}$$

The first order condition requires that $\frac{\partial W_{bcoop}}{\partial k} = \frac{\partial W_{bcoop}}{\partial v} = 0$,

$$\begin{aligned}\frac{\partial W_{bcoop}}{\partial k} = 0 \Rightarrow\ & 2.A.\frac{\partial q_{bcoop}}{\partial k} - 2.q_{bcoop}.(1+g).\frac{\partial q_{bcoop}}{\partial k} - 2.z_{bcoop}.d.\frac{\partial z_{bcoop}}{\partial k} - \\ & 2.e_{bcoop}.D'.\frac{\partial q_{bcoop}}{\partial k} - 2.D'.q_{bcoop}.\frac{\partial e_{bcoop}}{\partial z_{bcoop}}.\frac{\partial z_{bcoop}}{\partial k} = 0\end{aligned} \qquad \textbf{(62)}$$

$$\begin{aligned}\frac{\partial W_{bcoop}}{\partial v} = 0 \Rightarrow\ & 2.A.\frac{\partial q_{bcoop}}{\partial v} - 2.(1+g).q_{bcoop}.\frac{\partial q_{bcoop}}{\partial v} - 2.d.z_{bcoop}.\frac{\partial z_{bcoop}}{\partial v} - \\ & 2.D'.e_{bcoop}.\frac{\partial q_{bcoop}}{\partial v} - 2.D'.q_{bcoop}.\frac{\partial e_{bcoop}}{\partial z_{bcoop}}.\frac{\partial z_{bcoop}}{\partial v} = 0\end{aligned} \qquad \textbf{(63)}$$

The optimal policy combination $\left(k_{bcoop}, v_{bcoop}\right)$ is[15]

$$k_{bcoop} = f - \left(1 - g^{\,2}\right).\frac{q_{bcoop}}{e_{bcoop}} \qquad \textbf{(64)}$$

$$v_{bcoop} = 1 - \frac{2.k_{bcoop}\left(1 - g\right)}{\left(2 - g\right).f} \qquad \textbf{(65)}$$

Handling the equations stated above, it can be claimed that second best emission tax should be below marginal damages due to negative externality of pollution. Eq (83) shows that emission tax is affected directly by product differentiation degree. When γ is close to zero, $k \; \pi \; f$ whereas when γ is close to one $k = f$. The figure points out that emission tax equals to marginal damage (first best rule). This situation could exist in perfectly competitive market.

[15] All steps are presented in the appendix (A85) and (A86)

REFERENCES

Albrecht, J., 1999. Policy Instruments and Incentives for Environmental R&D: A Market-Driven Approach, *University of Ghent, CEEM*, 2-24.

Retrieved: 17 May 2006, from World Wide Web: URL

http://www.feem.it/NR/rdonlyres/FFD8E874-FDCA-43D8-8034-EE2F67B3FB24/586/17992.pdf

Atallah, G., 2005. Partner Selection in R&D Cooperation, *Scientific Series*, Number: 24, 1-32.

Bazin, D., Ballet, J. and Touahri, D., 2004. Environmental Responsibility versus Taxation, *Ecological Economics*, **Volume 49**, Issue: 2, 129-134.

Beath, J., Poyago-Theotoky, J. A. and Ulph, D., 1998. Organization Design and Information-Sharing in a Research Joint Venture with Spillovers, *Bulletin of Economic Research*, **Volume 50**, Number: 1, 47-59.

Bithas, K., 2006. The Necessity for Environmental Taxes for the Avoidance of Environmental Thievery. A Note on the Paper "Environmental responsibility versus taxation", *Ecological Economics*, **Volume 56**, Issue 2, 159-161.

Caloghirou, Y., Ioannides, S. and Vonortas, N. S., 2003. Research Joint Ventures, *Journal of Economic Surveys*, **Volume 17**, No 4, 541-570.

Carraro, C. and Metcalf, G. E., 2000. Behavioral and Distributional Effects of Environmental Policy: Introduction, *Discussion Papers Series*.

Retrieved: 23 April, 2006, from World Wide Web: URL

http://ase.tufts.edu/econ/papers/200011.pdf

Chen, H-C., 2005. RJV Competition and Financial Structure, *Department of Financial Operations, National Kaohsiung First University of Science &Technology*, 1-23.

Retrieved: 18 April, 2006, from World Wide Web: URL

http://www.nchu.edu.tw/~Fin/content/meeting/2002tfaconference/conferencePDF/C4/C4-2%20Chen,%20H.pdf

Chiou, J-R. and Hu, J-L., 2001. Environmental Research Joint Ventures under Emission Taxes, *Environmental and Resource Economics*, **Volume 20**, 129-146.

Chiroleu-Assouline, M., Ragot, L. and Schubert, K., 2003. Incentive to Innovate in a Clean Technology under Monopolistic Competition: A Comparison of Policy Instruments, 1-25.

Retrieved: 09 May, 2006, from World Wide Web: URL

http://eurequa.univ-paris1.fr/membres/chiroleu/pdf/Innovation.pdf

D'aspremont C., Jacquemin, A.,1998 Cooperative and noncooperative R&D in duopoly with spillovers. *American Economic Review* , 78, 1133-1137

David, M., 2004. Regulating a Polluting Oligipoly: Emission Tax or Voluntary Agreement, *Institute National de la Recherce Agronomiquue, Joint Research Unit in Public Economic*, 1-38.

Deardorff, A. V., 2006. Deardorff's Glossary of International Economics.

Retrieved: 12 February, 2006, from World Wide Web: URL

http://www.library.northwestern.edu/collections/polisci/economics_finance.html

Dietz, F. J., van der Ploeg, F. and van der Straaten, J., 1991. Environmental Policy and the Economy, *North-Holland*, Amsterdam

Dixit, A., 1979 A model of duopoly suggesting a theory of entry barriers, *Bell Jornal of Economics*, 10,20-32

Greenlee, P., 2005. Endogenous Formation of Competitive Research Sharing Joint Ventures, *The Journal of Industrial Economics*, **Volume LIII**, Number: 3, 355-391.

Hackner, J., 1999. A Note on Price and Quantity Competition in Differentiated Oligopolies, *Department of Economics, Stockholm University*, 1-9.

Jaffe, A. B., Newell, R. G. and Stavins, R. N, 2002. Environmental Policy and Technological Change, *Environmental and Resource Economics*, **Volume 22**, 41-69.

Jaffe, A. B., Newell, R. G. and Stavins, R. N, 2004. A Tale of Two Market Failures: Technology and Environmental Policy, *Ecological Economics*, **Volume 54**, 164-174.

Retrieved: 19 March, 2006, from World Wide Web: URL

http://ksghome.harvard.edu/~rstavins/Papers/JNS_Ecological_Economics.pdf

Katsoulacos, Y. and Ulph, D., 1998. Endogenous Spillovers and The Performance of Research Joint Ventures, *The Journal of Industrial Economics*, **Volume XLVI**, 333-357.

Katsoulacos, Y., Xepapadeas, A. and Carraro, C., 1996. Environmental Policy and Market Structure, *Kluwer Academic Publishers*, Netherlands

Katsoulacos, Y., Ulph, A. and Ulph, D., 1999. The Effects of Environmental Policy on the Performance of Environmental RJVs, *NBER Working Paper Series*, **7301**, 1-44.

Retrieved: 27 March, 2006, from World Wide Web: URL

http://www.nber.org/papers/w7301.pdf

Kemp, R., 2000. Technology and Environmental Policy-Innovation Effects of Past Policies and Suggestions for Improvement, *OECD Proceedings Innovation and the Environment*, Paris, 35-61.

Lee, S-H., 1999. Optimal Taxation for Polluting Oligopolists with End Market Structure, *Journal of Regulatory Economics*, **Volume 15**, 293-308

Montero, J-P., 2002. Market Structure and Environmental Innovation, *Journal of Applied Economics*, **Volume V**, Number: 2, 293-325.

Nicolaisen, J., Dean, A. and Hoeller, P., 1991. Economics and the Environment: A Survey of Issues and Policy Options, *OECD Economic Studies*, **Volume 16**, Spring, 7-43.

Oladunjoye, O., 2005. Optimal Environmental Policy in a Heterogeneous Product under Research and Development Competition and Cooperation, *University of Guelph, Department of Economics*, L24, Q50, Q55, 1-32.

Retrieved: 10 February, 2006, from World Wide Web: URL

http://www.iaee.org/en/students/papers/OlusegunOladunjoye.pdf

Petrakis, E. and Poyago-Theotoky, J., 1999. Technology Policy in an Oligopoly with Spillovers and Pollution, *Department of Economics, University of Crete*, 1-28.

Poyago-Theotoky, J. A., 1999. A Note on Endogenous Spillovers in a Non-Tournament R&D Duopoly, *Review of Industrial Organization*, **Volume 15**, 253-262

Poyago-Theotoky, J. A., 2000. Voluntary Approaches and the Organization of Environmental R&D, *School of Economics, University of Nottingham*, 1-13.

Poyago-Theotoky, J. A., 2003. Optimal Environmental Taxation, R&D Subsidization and the Role of Market Conduct, *Finnish Economic Papers*, **Volume 16**, Number 1, Spring, 15-26.

Retrieved: 13 March, 2006, from World Wide Web: URL

http://www.taloustieteellinenseura.fi/fep/articles/f2003_1b.pdf

Poyago-Theotoky, J. A, 2005. The Organisation of R&D and Environmental Policy, *Journal of Economic Behaviour & Organization*, **Volume xxx**, 1-13.

Poyago-Theotoky, J. A. and Petrakis, E., 2002. R&D Subsidies versus R&D Cooperation in a Duopoly with Spillovers and Pollution, *Australian Economic Papers*, **Volume 41**, Issue 1, 37-52.

Roy Chowdhury, I., 2002. Joint Ventures, Pollution and Environmental Policy, *National Institute of Public Finance and Policy*, H23, L13, 1-30.

Retrieved: 08 March, 2006, from World Wide Web: URL

http://www.nipfp.org.in/working%20paper%5Cwp31.pdf

Röller, L-H., Tombak, M. M., and Siebert, R., 1997. Why Firms Form RJV: Theory and Evidence, *Social Science Research Center*, 1-39.

Schwartz, G. and Clements, B., 1999. Government Subsidies, *Journal of Economic Surveys,* **Volume 13**, No: 2, 119-147.

Singh, S., and X.Vives 1984 Price and quantity competition in a differentiated duopoly, *RAND Journal of Economics*, 15 , 546-554.

Symeonidis, G., 2002. Comparing Cournot and Bertrand Equilibria in a Differentiated Duopoly with Product R&D, *Department of Economics, University of Essex*, 1-25.

Ulph, D., 1999. Competition, Innovation and Research Joint Ventures, *Department of Economics, University College London*, 1-33.

Veugelers, R., 1998. Collaboration in R&D: An Assessment of Theoretical and Empirical Findings, *De Economist*, **Volume 146**, Number 3, 419-443.

Yun, K-L., Park, Y-S. and Ahn, B-H., 2000. Spillover, Competition and Better R&D Organization, *The Japanese Economic Review*, **Volume 51**, Number: 3, 448-461.

Xepapadeas, A., 1997. Advanced Principle in Environmental Policy, Edward Elgar Publishing, 1-15.

Wikipedia Encyclopedia, 2006.

Retrieved: 05 June, 2006, from World Wide Web: URL

http://en.wikipedia.org/wiki/Anti-trust

APPENDIX A

Derivation of Expression (10)

$$p_i = P.q_i - t.e_i.q_i - (1-s).0.5.d.z_i^2 = (A - q_i - g.q_j).q_i - t.e_i.q_i - (1-s).0,5.d.z_i^2 \Rightarrow$$

$$p_i = (A - q_i - g.q_j - t.e_i).q_i - (1-s).0,5.d.z_i^2 = K.q_i - (1-s).0,5.d.z_i^2$$

where $K = A - q_i - g.q_j - t.e_i$

Substituting eq.(7) into K

$$K = A - g.q_j - t.e_i - \frac{A - t.(e_0 - z_i - b.z_j) - g.q_j}{2} = \frac{A - t.e_i - g.q_j}{2} = q_i \Rightarrow$$

$$p_i = q_i^2 - 0,5.(1-s).d.z_i^2 \qquad \textbf{(A1)}$$

Derivation of Expression (11)

The first order condition is ;

$$\frac{\partial p_i}{\partial z_i} = 0 \Rightarrow 2.q_i.\frac{\partial q_i}{\partial z_i} - (1-s).d.z_i = 0 \qquad \textbf{(A2)}$$

From eq (9) $$\frac{\partial q_i}{\partial z_i} = \frac{(2 - g.b).t}{4 - g^2} \quad \textbf{(A3)}$$

In the symmetric equilibrium, $z_i = z_j = z_{ccomp}$, substituting eq (A3) and eq(9) into eq (A2),

$$\frac{\partial p_i}{\partial z_{ccomp}} = 2.t.(2-g.b).\frac{(2-g).(A-t.e_0)+(2-g.b).t.z_{ccomp}+(2.b-g).t.z_{ccomp}}{(4-g^2)^2} = (1-s).d.z_{ccomp} = 0$$

$$\frac{\partial p_i}{\partial z_{ccomp}} = 2.t.(2-g.b).(2-g).(A-t.e_0) = \left[(1-s).d.(4-g^2)^2 - 2.t^2.(2-g.b).(2-g.b+2.b-g)\right]z_{ccomp}$$

$$\frac{\partial p_i}{\partial z_{ccomp}} = 2.t.(2-g.b).(2-g).(A-t.e_0) = \left[(1-s).d.(4-g^2)^2 - 2.t^2.(2-g.b).(2-g).(b+1)\right].z_{ccomp}$$

$$z_{ccomp} = \frac{2.t.(2-g.b).(2-g).(A-t.e_0)}{\Omega_{ccomp}} \qquad \textbf{(A4)}$$

where $\Omega_{ccomp} = \left[(1-s).d.(4-g^2)^2 - 2.t^2.(2-gb).(2-g).(b+1)\right]$

Derivation of Expression of (20) and (21)

$$\frac{\partial W_{ccomp}}{\partial t} = 0 \Rightarrow 2.A.\frac{\partial q_{ccomp}}{\partial t} - 2.q_{ccomp}.(1+g).\frac{\partial q_{ccomp}}{\partial t} - 2.z_{ccomp}.d.\frac{\partial z_{ccomp}}{\partial t} -$$
$$2.e_{ccomp}.f.\frac{\partial q_{ccomp}}{\partial t} - 2.f.q_{ccomp}.\frac{\partial e_{ccomp}}{\partial z_{ccomp}}.\frac{\partial z_{ccomp}}{\partial t} = 0$$

$$\frac{\partial W_{ccomp}}{\partial t} = 0 \Rightarrow \left[2.A - 2.q_{ccomp}.(1+g) - 2.e_{ccomp}.f.\right].\frac{\partial q_{ccomp}}{\partial t} -$$

$$\left(2.d.z_{ccomp} + 2.f.q_{ccomp}.\frac{\partial e_{ccomp}}{\partial z_{ccomp}}\right).\frac{\partial z_{ccomp}}{\partial t} = 0 \qquad \textbf{(A5)}$$

Using eq(3) $\frac{\partial e_{ccomp}}{\partial z_{ccomp}} = -(1+b)$ and **(A6)**

$$\frac{\partial q_{ccomp}}{\partial t} = \frac{-e_0 + (b+1).z_{ccomp} + (b+1).t.\frac{\partial z_{ccomp}}{\partial t}}{2+g}$$

If it is substituted eq.(3) into previous eq. it is attained ,

$$\frac{\partial q_{ccomp}}{\partial t} = \frac{-e_{ccomp}}{(2+g)} + \frac{t.(b+1)}{2+g}.\frac{\partial z_{ccomp}}{\partial t} \qquad \textbf{(A7)}$$

Substituting eq.(A7) and eq (A6) into (A5) it is reached,

$$\frac{\partial W_{ccomp}}{\partial t} = 0 \Rightarrow \left[2.A - 2.q_{ccomp}.(1+g) - 2.e_{ccomp}.f.\right].\left[\frac{-e_{ccomp}}{(2+g)} + \frac{t.(b+1)}{2+g}.\frac{\partial z_{ccomp}}{\partial t}\right] -$$

$$\left(2.d.z_{ccomp} - 2.f.q_{ccomp}.(b+1)\right).\frac{\partial z_{ccomp}}{\partial t} = 0$$

and using eq (13) it is attained,

$$\frac{\partial W_{ccomp}}{\partial t} = \frac{-e_{ccomp}.(2.P_{ccomp} - 2.f.e_{ccomp})}{2+g} +$$
$$\left[(2.P_{ccomp} - 2.f.e_{ccomp}).\frac{(b+1).t}{2+g} + [-2.z_{ccomp}.d + 2.f.q_{ccomp}(b+1)]\right].\frac{\partial z_{ccomp}}{\partial t} = 0 \qquad \textbf{(A8)}$$

In addition,

$$\frac{\partial W_{ccomp}}{\partial s} = 0 \Rightarrow 2.A.\frac{\partial q_{ccomp}}{\partial s} - 2.(1+g).q_{ccomp}.\frac{\partial q_{ccomp}}{\partial s} - 2.d.z_{ccomp}.\frac{\partial z_{ccomp}}{\partial s} -$$
$$2.f.e_{ccomp}.\frac{\partial q_{ccomp}}{\partial s} - 2.f.q_{ccomp}.\frac{\partial e_{ccomp}}{\partial z_{ccomp}}.\frac{\partial z_{ccomp}}{\partial s} = 0 \qquad \textbf{(A9)}$$

eq (A6) and equ (13) substitute in to eq (A9) and some arrangement it is obtained,

$$\frac{\partial W_{ccomp}}{\partial s} = 2.(P_{ccomp} - f.e_{ccomp}).\frac{\partial q_{ccomp}}{\partial s} + 2.[-d.z_{ccomp} + f.q_{ccomp}.(b+1)].\frac{\partial z_{ccomp}}{\partial s} \qquad \textbf{(A10)}$$

Using $\frac{\partial q_{ccomp}}{\partial s} = \frac{(2-g.b).t.\frac{\partial z_{ccomp}}{\partial s} + (2.b-g).t.\frac{\partial z_{ccomp}}{\partial s}}{4-g^2} \Rightarrow$

$$\frac{\partial q_{ccomp}}{\partial s} = \frac{t.(2-g).(b+1)}{4-g^{2}} . \frac{\partial z_{ccomp}}{\partial s} \qquad \textbf{(A11)}$$

substituting eq (A11) into eq (A10) it is reached,

$$\frac{\partial W_{ccomp}}{\partial s} = \left[\frac{2t.(2-g).(b+1).(P_{ccomp} - f.e_{ccomp})}{4-g^{2}} + 2.\left[-d.z_{ccomp} + f.q_{ccomp}.(b+1)\right]\right] . \frac{\partial z_{ccomp}}{\partial s} = 0 \; \textbf{(A12)}$$

It should be kept in mind that , $\frac{\partial z_{ccomp}}{\partial s} \phi \ 0$, so

$$\frac{2.t.(2-g).(b+1).(P_{ccomp} - f.e_{c})}{4-g^{2}} + 2.\left[-d.z_{ccomp} + f.q_{ccomp}.(b+1)\right] = 0 \qquad \textbf{(A13)}$$

When eq (A13) and (A8) are analyzed, it is found that

$$2.P_{ccomp} - 2.f.e_{ccomp} = 0 \Rightarrow P_{ccomp} = f.e_{ccomp} \qquad \textbf{(A14)}$$

From eq (A13) and eq (A14) the subsequent equation is obtained;

$$f.q_{ccomp}.(b+1) = d.z_{ccomp} \qquad \textbf{(A15)}$$

Eq (A14) and eq (A15) show the structure of the optimal policy scheme.

Eq (A14) connotes that price equals to marginal environmental damage per unit of output.

Eq (A15) says that the marginal R&D cost equal marginal saving from R&D in environmental damage because $f.q_{ccomp} = -\frac{\partial e_{ccomp}}{\partial z_{ccomp}}.f.q_{ccomp}$

At the optimal policy combination (t*, s*), it is expected that the firms' first order conditions must satisfy the optimum condition identified above.

From eq (7) $q_i = \frac{A - t.e_i - g.q_j}{2} \Rightarrow q_{ccomp} = A - (1+g).q_{ccomp} - t.e_{ccomp} \Rightarrow$

$$P_{ccomp} = q_{ccomp} + t.e_{ccomp} \qquad \textbf{(A16)}$$

F.o.c of the second stage:

$$2.q_i.\frac{\partial q_i}{\partial z_i} - (1-s).d.z_i = \frac{2.q_{ccomp}.t.(2-gb)}{4-g^2} - (1-s).d.z_{ccomp} = 0 \qquad \textbf{(A17)}$$

From eq (A14) and eq (A16) , the optimal emission tax is obtained as the following;

$$P_{ccomp} = q_{ccomp} + t.e_{ccomp} \Rightarrow f.e_{ccomp} = q_{ccomp} + t.e_{ccomp} \Rightarrow t^* = f - \frac{q_{ccomp}}{e_{ccomp}} \qquad \textbf{(A18)}$$

In addition, using eq.(A15) and eq.(A17), the optimal subsidy is attained as the following,

$$\frac{2.q_{ccomp}.t.(2-g.b)}{4-g^2} = (1-s).f.q_{ccomp}.(b+1) \Rightarrow s^* = 1 - \frac{2.t.(2-g.b)}{f.(4-g^2).(b+1)} \qquad \textbf{(A19)}$$

Derivation of Expression of (26)

$$\frac{\partial p_{rjv}}{\partial z_i} = 0 \Rightarrow 2.q_i.\frac{\partial q_i}{\partial z_i} + 2.q_j.\frac{\partial q_i}{\partial z_j} - (1-s).\partial.z_i = 0 \tag{A20}$$

From eq (9),it is attained eq. (A21),(A22),

$$\frac{\partial q_i}{\partial z_i} = \frac{(2-g).t}{4-g^2} = \frac{t}{2+g} \tag{A21}$$

$$\frac{\partial q_i}{\partial z_j} = \frac{t}{2+g} \tag{A22}$$

If it is substituted eq. (A21),(A22) into eq. (A20), it is found,

$$\frac{\partial p_{rjv}}{\partial z_i} = 0 \Rightarrow 2.q_i.\frac{t}{2+g} + 2.q_j.\frac{t}{2+g} - (1-s).\partial.z_i = 0$$

In the symmetric equilibrium $z_i = z_j = z_{ccoop}$ and substituting (23),

$$\frac{4.q_{ccoop}.t}{2+g} = (1-s).d.z_{ccoop} = \left(\frac{4.t}{2+g}\right).\left(\frac{A - t.e_0 + 2.t.z_{ccoop}}{2+g}\right) \Rightarrow$$

$$z_{ccoop} = \frac{4.t.(A - t.e_0)}{(2+g)^2(1-s).d - 8.t^2} = \frac{4.t.(A - t.e_0)}{\Omega_{ccoop}} \quad \textbf{(A23)}$$

where $\Omega_{ccoop} = (2+g)^2.(1-s).d - 8.t^2$

Derivation of Expression of (31) and (32)

$$\frac{\partial W_{ccoop}}{\partial t} = 0 \Rightarrow 2.A.\frac{\partial q_{ccoop}}{\partial t} - 2.q_{ccoop}.(1+g).\frac{\partial q_{ccoop}}{\partial t} - 2.z_{ccoop}.d.\frac{\partial z_{ccoop}}{\partial t} - 2.e_{ccoop}.f.\frac{\partial q_{ccoop}}{\partial t} - 2.f.q_{ccoop}.\frac{\partial e_{ccoop}}{\partial z_{ccoop}}.\frac{\partial z_{ccoop}}{\partial t} = 0 \quad \textbf{(A24)}$$

$$\frac{\partial W_{ccoop}}{\partial t} = 0 \Rightarrow [2.A. - 2.q_{ccoop}.(1+g). - 2.e_{ccoop}.f].\frac{\partial q_{ccoop}}{\partial t} - \left[2.z_{ccoop}.d + 2.f.q_{ccoop}.\frac{\partial e_{ccoop}}{\partial z_{ccoop}}\right].\frac{\partial z_{ccoop}}{\partial t} = 0 \quad \textbf{(A25)}$$

From eq (3) ,it is reached $e_{ccoop} = e_0 - z_{ccoop} - b.z_{ccoop} = e_0 - 2.z_{ccoop}$

Using $\frac{\partial e_{ccoop}}{\partial z_{ccoop}} = -2$ **(A26)** and $\dfrac{\partial q_{ccoop}}{\partial t} = \dfrac{-e_0 + 2.z_{ccoop} + 2.t.\dfrac{\partial z_{ccoop}}{\partial t}}{2+g}$. When it is substituted eq (3), it is obtained

$$\frac{\partial q_{ccoop}}{\partial t} = \frac{-e_{ccoop}}{2+g} + \frac{2.t.}{2+g}\frac{\partial z_{ccoop}}{\partial t} \qquad \textbf{(A27)}$$

Substitute (A27) and (A26) into (A25),it is found

$$\frac{\partial W_{ccoop}}{\partial t} = 0 \Rightarrow \left[A - q_{ccoop}(1+g).-e_{ccoop}.f\right].\left[\frac{-e_{ccoop}}{2+g} + \frac{2.t.}{2+g}\frac{\partial z_{ccoop}}{\partial t}\right] - \left[z_{ccoop}.d - 2.f.q_{ccoop}\right].\frac{\partial z_{ccoop}}{\partial t} = 0 \Rightarrow$$

and using eq (28), it is secured

$$\frac{\partial W_{ccoop}}{\partial t} = \frac{-e_{ccoop}}{(2+g)}.\left(P_{ccoop} - e_{ccoop}.f\right) + \left[\frac{2.t.\left(P_{ccoop} - e_{ccoop}.f\right)}{2+g} - d.z_{ccoop} + 2.f.q_{ccoop}\right].\frac{\partial z_{ccoop}}{\partial t} = 0 \qquad \textbf{(A28)}$$

In addition,

$$\frac{\partial W_{ccoop}}{\partial s}=0\Rightarrow 2.A.\frac{\partial q_{ccoop}}{\partial s}-2.(1+g).q_{ccoop}.\frac{\partial q_{ccoop}}{\partial s}-2.d.z_{ccoop}.\frac{\partial z_{ccoop}}{\partial s}-$$
$$2.f.e_{ccoop}.\frac{\partial q_{c}}{\partial s}-2.f.q_{ccoop}.\frac{\partial e_{ccoop}}{\partial z_{ccoop}}.\frac{\partial z_{ccoop}}{\partial s}=0 \qquad \textbf{(A29)}$$

$$\frac{\partial W_{ccoop}}{\partial s}=0\Rightarrow\left[A-(1+g).q_{ccoop}-f.e_{ccoop}\right]\frac{\partial q_{ccoop}}{\partial s}+$$
$$\left[-d.z_{ccoop}.\frac{\partial z_{ccoop}}{\partial s}+f.q_{ccoop}.\frac{\partial e_{ccoop}}{\partial z_{ccoop}}\right].\frac{\partial z_{ccoop}}{\partial s}=0 \qquad \textbf{(A30)}$$

From eq.(23) ,it is attained $\frac{\partial q_{ccoop}}{\partial s}=\frac{2.t}{2+g}.\frac{\partial z_{ccoop}}{\partial s}$ **(A31)**

Substitute eq (A26) ,eq (28) and eq (A31) into eq (A29) and some arrangement,it is obtained

$$\frac{\partial W_{ccoop}}{\partial s}=\left[\frac{2.t.(P_{ccoop}-f.e_{ccoop})}{2+g}-d.z_{ccoop}+2.f.q_{ccoop}\right].\frac{\partial z_{ccoop}}{\partial s}=0 \qquad \textbf{(A32)}$$

$\frac{\partial z_{ccoop}}{\partial s}\ \phi\ 0$ (stage 2 has been already shown), so

$\left[\frac{2.t.(P_{ccoop}-f.e_{c})}{2+g}-d.z_{ccoop}+2.f.q_{ccoop}\right]$. must be equal to zero. **(A33)**

From eq (A28) and (A33)

$$P_{ccoop} - f.e_{ccoop} = 0 \Rightarrow P_{ccoop} = f.e_{ccoop} \quad \textbf{(A34)}$$

From eq (A33) and (A34)

$$-d.z_{ccoop} + 2.f.q_{ccoop} = 0 \Rightarrow d.z_{ccoop} = 2.f.q_{ccoop} \quad \textbf{(A35)}$$

Eq (A34) and eq (A35) determine the structure of the optimal policy. Eq (A34) states that price equals to marginal environmental damage per unit of output.

Eq (A35) brings clarification to the fact that marginal R&D cost equals to marginal saving in environmental damage from R&D due to $2.f.q_{ccoop} = -f\dfrac{\partial e_{ccoop}}{\partial z_{ccoop}}.q_{ccoop}$

At the optimal policy combination (t*, s*), the firms' first order conditions must satisfy the optimum condition identified above.

In the symmetric equilibrium;

$$q_{ccoop} = A - (1+g).q_{ccoop} - t.e_{ccoop} \Rightarrow P_{ccoop} = q_{ccoop} + t.e_{ccoop} \quad \textbf{(A36)}$$

F.o.c of the second stage eq (25)

$$4.t.q_{ccoop} = (2+g).(1-s).d.z_{ccoop} \quad \textbf{(A37)}$$

Using(A34) and (A36),it is obtained

$$f.e_{ccoop} = q_{ccoop} + t.e_{ccoop} \Rightarrow t_{ccoop}{}^{*} = f - \frac{q_{ccoop}}{e_{ccoop}} \qquad \textbf{(A38)}$$

Using (A35) and (A37), it is reached

$$4.t.q_{ccoop} = 2.(2+g).(1-s).f.q_{ccoop} \Rightarrow s_{ccoop}{}^{*} = 1 - \frac{2.t}{(2+g).f} \qquad \textbf{(A39)}$$

APPENDIX B

Derivation of Expression of (39)

$$p_i = \frac{(P_i - k.e_i)^2}{1-g^2} - 0{,}5.(1-v).d.z_i^{\,2} \qquad \textbf{(A39)}$$

The first order condition,

$$\frac{\partial p_i}{\partial z_i} = 0 \Rightarrow \frac{2.(P_i - k.e_i).\left(-k.\frac{\partial e_i}{\partial z_i} + \frac{\partial P_i}{\partial z_i}\right)}{1-g^2} - (1-v).d.z_i = 0 \qquad \textbf{(A40)}$$

From eq (36), $\frac{\partial P_i}{\partial z_i} = \frac{-k.(2+b.g)}{4-g^2}$ and from eq (3), $\frac{\partial e_i}{\partial z_i} = -1$. If it is used this eq. into eq.(40),

$$\frac{\partial p_i}{\partial z_i} = 0 \Rightarrow \frac{2.(P_i - k.e_i).\left(k + \frac{-k.(2+b.g)}{4-g^2}\right)}{1-g^2} - (1-v).d.z_i = 0$$ and some arrangement,

$$\frac{\partial p_i}{\partial z_i} = 0 \Rightarrow 2.(P_i - k.e_i).\left[k.(4-g^2) - k.(2+b\,g)\right] = (1-v).(1-g^2).(4-g^2).d.z_i \qquad \textbf{(A41)}$$

If it is substituted eq (36) and eq (3) into eq. (A41)

In the symmetric equilibrium; $z_i = z_j = z_{bcomp}$, it is obtained,

$$\frac{\partial p_i}{\partial z_{bcomp}} = 0 \Rightarrow \begin{bmatrix} A.(1-g).(2+g)+e_0.k.(2+g)-e_0.k.(4-g^2)-k.z_{bcomp}.(g+2).(b+1)- \\ k.z_{bcomp}.(4-g^2).(b+1) \end{bmatrix}.$$

$$[+4.k-k.g^2-k.(2+b.g)] = (1-v).(1-g^2).(4-g^2)^2 d.z_{bcomp}$$

$$\frac{\partial p_i}{\partial z_{bcomp}} = 0 \Rightarrow 2.k.(A-k.e_0).(2-g^2-b.g) = [(1-v).(1+g).(4-g^2).(2-g).d-2.k^2.(b+1).(2-g^2-b.g)]z_{bcomp}$$

some arrangement it is reached,

$$z_{bcomp} = \frac{2.k.(A-k.e_0).(2-g^2-b.g)}{\Omega_{bcomp}} \qquad \textbf{(A42)}$$

where $\Omega_{bcomp} = (1+g).(1-v).(4-g^2)^2(2-g).d-2.k^2.(b+1).(2-g^2-b.g)$

Derivation of Expression of (47) and (48)

$$\frac{\partial W_{bcomp}}{\partial k} = 0 \Rightarrow 2.A.\frac{\partial q_{bcomp}}{\partial k} - 2.q_{bcomp}.(1+g).\frac{\partial q_{bcomp}}{\partial k} - 2.z_{bcomp}.d.\frac{\partial z_{bcomp}}{\partial k} - 2.e_{bcomp}.f.\frac{\partial q_{bcomp}}{\partial k} - 2.f.q_{bcomp}.\frac{\partial e_{bcomp}}{\partial z_{bcomp}}.\frac{\partial z_{bcomp}}{\partial k} = 0 \qquad \textbf{(A43)}$$

Using eq. (3)

$$\frac{\partial e_{bcomp}}{\partial z_{bcomp}} = -(1+b) \tag{A44}$$

When it is substituted eq. (A44) into eq. (A43)and some arrangement it is attained,

$$\frac{\partial W_{bcomp}}{\partial k} = 0 \Rightarrow \left[2.A. - 2.q_{bcomp}.(1+g) - 2.e_{bcomp}.f\right]\frac{\partial q_{bcomp}}{\partial k} + \left[-2.z_{bcomp}.d. + 2.f.q_{bcomp}.(b+1)\right].\frac{\partial z_{bcomp}}{\partial k} = 0 \tag{A45}$$

Using $q_{bcomp} = \frac{(A - P_{bcomp})(1-g)}{1-g^2} = \frac{A - P_{bcomp}}{1+g}$ eached following eq.,

$$\frac{\partial q_{bcomp}}{\partial k} = -\frac{1}{1+g}.\frac{\partial P_{bcomp}}{\partial k} \tag{A46}$$

Using eq (36) and eq (3),obtained

$$\frac{\partial P_{bcomp}}{\partial k} = \frac{e_{bcomp}}{2-g} - \frac{k.(b+1)}{2-g}.\frac{\partial z_{bcomp}}{\partial k} \tag{A47}$$

Substituting eq (A47) into eq (A46) it is secured,

$$\frac{\partial q_{bcomp}}{\partial k} = -\frac{1}{1+g}.\left[\frac{e_{bcomp}}{2-g} - \frac{k.(b+1)}{2-g}.\frac{\partial z_{bcomp}}{\partial k}\right] \tag{A48}$$

Substituted . eq (A48) into eq (A45) it is found,

$$\frac{\partial W_{bcomp}}{\partial k}=0\Rightarrow-\frac{1}{1+g}.\left[2.A.-2.q_{bcomp}.(1+g)-2.e_{bcomp}.f\right].\left[\frac{e_{bcomp}}{2-g}-\frac{k.(b+1)}{2-g}.\frac{\partial z_{bcomp}}{\partial k}\right]$$
$$+\left[-2.z_{bcomp}.d.+2.f.q_{bcomp}.(b+1)\right]\frac{\partial z_{bcomp}}{\partial k}=0\Rightarrow$$

$$\frac{\partial W_{bcomp}}{\partial k}=\frac{-e_{bcomp}.(P_{bcomp}-f.e_{bcomp})}{(1+g).(2-g)}+$$
$$\left[(P_{bcomp}-f.e_{bcomp}).\frac{(b+1).k}{(1+g).(2-g)}+\left[-z_{bcomp}.d+f.q_{bcomp}(b+1)\right]\right].\frac{\partial z_{bcomp}}{\partial k}=0 \qquad \textbf{(A49)}$$

In addition,

$$\frac{\partial W_{bcomp}}{\partial v}=0\Rightarrow 2.A.\frac{\partial q_{bcomp}}{\partial v}-2.(1+g).q_{bcomp}.\frac{\partial q_{bcomp}}{\partial v}-2.d.z_{bcomp}.\frac{\partial z_{bcomp}}{\partial v}-$$
$$2.f.e_{bcomp}.\frac{\partial q_{bcomp}}{\partial v}-2.f.q_{bcomp}.\frac{\partial e_{bcomp}}{\partial z_{bcomp}}.\frac{\partial z_{bcomp}}{\partial v}=0 \qquad \textbf{(A50)}$$

Subs eq (A44) into eq (A50) and some arrangement it is reached,

$$\frac{\partial W_{bcomp}}{\partial v}=0\Rightarrow\left[A.-(1+g).q_{bcomp}-f.e_{bcomp}\right].\frac{\partial q_{bcomp}}{\partial v}+\left[-d.z_{bcomp}+f.q_{bcomp}.(b+1)\right].\frac{\partial z_{bcomp}}{\partial v}=0 \qquad \textbf{(A51)}$$

Using $q_{bcomp}=\frac{(A-P_{bcomp}).(1-g)}{1-g^{2}}=\frac{A-P_{bcomp}}{1+g}$ it is found,

$$\frac{\partial q_{bcomp}}{\partial v} = -\frac{1}{1+g} . \frac{\partial P_{bcomp}}{\partial v} \qquad \textbf{(A52)}$$

Using eq. (36)

$$\frac{\partial P_{bcomp}}{\partial v} = -\frac{k.(b+1).(2+g)}{4-g^{2}} . \frac{\partial z_{bcomp}}{\partial v} \quad \text{and} \qquad \textbf{(A53)}$$

Subs. eq.(A53) into eq. (A52) ,it is reached

$$\frac{\partial q_{bcomp}}{\partial v} = \frac{k.(b+1)}{(2-g).(1+g)} . \frac{\partial z_{bcomp}}{\partial v} \qquad \textbf{(A54)}$$

If it is substituted. eq (A54) into eq.(A51) and some arrangementit is attained,

$$\frac{\partial W_{bcomp}}{\partial v} = 0 \Rightarrow \left[A. - (1+g).q_{bcomp} - f.e_{bcomp}.\right] \frac{k.(b+1)}{(2-g).(1+g)} . \frac{\partial z_{bcomp}}{\partial v} +$$
$$\left[-d.z_{bcomp} + f.q_{bcomp}.(b+1)\right] \frac{\partial z_{bcomp}}{\partial v} = 0 \Rightarrow$$

$$\frac{\partial W_{bcomp}}{\partial v} = \left[\frac{k.(b+1).\left(P_{bcomp} - f.e_{bcomp}\right)}{(1+g).(2-g)} + \left[-d.z_{bcomp} + f.q_{bcomp}.(b+1)\right]\right] . \frac{\partial z_{bcomp}}{\partial v} = 0 \qquad \textbf{(A55)}$$

$\frac{\partial z_{bcomp}}{\partial v} \phi\ 0$, so

From eq(A55) $\left[\frac{k.(b+1).(P_b - f.e_{bcomp})}{(1+g).(2-g)} + \left[-d.z_{bcomp} + f.q_{bcomp}.(b+1)\right]\right]$ must be zero **(A56)**

From eq (A49) and (A56)

$A-(1+g).q_{bcomp} - f.e_{bcomp} = 0$ using eq.(1), $P_{bcomp} = e_{bcomp}.f$ **(A57)**

From (A55) and (A57)

$-d.z_{bcomp} + f.q_{bcomp}.(b+1) = 0 \Rightarrow d.z_{bcomp} = f.q_{bcomp}.(b+1)$ **(A58)**

Based on the equations in question, it can be said that eq (A57) and eq (A58) determine the structure of the optimal policy.

As regards this optiamal policy, eq (A57) demonstrates that price equals to marginal environmental damage per unit of output.

Eq. (A58) connotes the fact that marginal R&D cost equals to marginal saving in environmental damage from R&D because of $2.f.q_{bcomp} = -f.\left(\frac{\partial e_{bcomp}}{\partial z_{bcomp}}\right).q_{bcomp}$

At the optimal policy combination (k*, v*), the firms' first order conditions must satisfy the optimum condition identified above.

In the symmetric equilibrium;

F.o.c of Stage 3 from eq.(34) $\frac{A.(1-g) - 2.P_i + g.P_j + k.e_i}{1-g} = 0 \Rightarrow$

$P_{bcomp} = A.(1-g) - (1-g).P_{bcomp} + k.e_{bcomp}$ **(A59)**

Stage 2 f.o.c from eq(38)

$$2.(P_{bcomp} - k.e_{bcomp}).\left[-k.(2+b.g) + 4.k - k.g^2\right] = (1-g^2).(1-v).(4-g^2).d.z_{bcomp}$$

From eq(A59) $P_{bcomp} = A.(1-g) - (1-g).P_{bcomp} + k.e_{bcomp} = (1-g^2)q_{bcomp} + k.e_{bcomp}$

substitute this eq into above

$$2.k(-2+b.g+g^2).q_{bcomp} = (1-g).(4-g^2).d.z_{bcomp} \quad \textbf{(A60)}$$

From eq (A57) and eq (A59)

$$e_{bcomp}.f = A.(1-g)-(1-g).P_{bcomp}+k.e_{bcomp} \Rightarrow k_{bcomp}{}^{*} = f-(1-g)^2.\frac{q_{bcomp}}{e_{bcomp}} \quad \textbf{(A61)}$$

From eq (A58) and eq (A60)

$$2.k.(-2+b.g+g^2).q_{bcomp} = (1-v).(4-g^2).f.q_{bcomp}.(b+1) \Rightarrow$$

$$v_{bcomp}{}^{*} = 1-\frac{2.k.(2-b.g-g^2)}{(4-g^2).f.(b+1)} \quad \textbf{(A62)}$$

Derivation of Expression of (56)

$$\frac{\partial p_{rjv}}{\partial zi} = 0 \Rightarrow \frac{2.(P_i-k.e_i).\left(k.\frac{\partial e_i}{\partial z_i}+\frac{\partial P_i}{\partial z_i}\right)}{1-g^2}+\frac{2.(P_j-k.e_j).\left(k.\frac{\partial e_j}{\partial z_j}+\frac{\partial P_j}{\partial z_i}\right)}{1-g^2}-(1-v).d.z_i = 0 \quad \textbf{(A63)}$$

From eq (52),

$$\frac{\partial P_i}{\partial z_i} = \frac{-k}{2-g} \quad \textbf{(A64)}$$

$$\frac{\partial P_j}{\partial z_i} = \frac{-k}{2-g} \quad \textbf{(A65)}$$

Subs eq.(A65) and eq.(A64) and and from eq (3), $\frac{\partial e_i}{\partial z_i} = \frac{\partial e_j}{\partial z_j} = -1$ into eq.(A63) and some arrangement it is obtained

$$\frac{\partial p_{rjv}}{\partial z_i} = 0 \Rightarrow \frac{2.(P_i - k.e_i).\left(k + \frac{-k}{2-g}\right)}{1-g^2} + \frac{2.(P_j - k.e_j).\left(k + \frac{-k}{2-g}\right)}{1-g^2} - (1-v).d.z_i = 0 \Rightarrow$$

$$\frac{\partial p_{rjv}}{\partial z_i} = 0 \Rightarrow 2.k\left(P_i - k.e_i + P_j - k.e_i\right) = (1+g).(2-g)(1-v).d.z_i = 0$$

In the symmetric equilibrium, $z_i = z_j = z_{bcoop}, b = 1$ and also subs. eq. (52) and eq (3), it is found following equation,

$$\frac{\partial p_{rjv}}{\partial z_{bcoop}} = 0 \Rightarrow 2.k\left[2.A(1-g) - 2.e_0.k.(1-g) + 4.k.z_{bcoop}.(1-g)\right] = (1+g).(2-g)^2(1-v).d.z_{bcoop} = 0$$

$$z_{bcoop} = \frac{4.k.(1-g).(A - e_0.k)}{(1+g).(2-g)^2.(1-v).d - 8.k^2.(1-g)} \quad \textbf{(A66)}$$

Derivation of Expression of (64) and (65)

$$\frac{\partial W_{bcoop}}{\partial k}=0 \Rightarrow 2.A.\frac{\partial q_{bcoop}}{\partial k}-2.q_{bcoop}.(1+g).\frac{\partial q_{bcoop}}{\partial k}-2.z_{bcoop}.d.\frac{\partial z_{bcoop}}{\partial k}- \\ 2.e_{bcoop}.f.\frac{\partial q_{bcoop}}{\partial k}-2.f.q_{bcoop}.\frac{\partial e_{bcoop}}{\partial z_{bcoop}}.\frac{\partial z_{bcoop}}{\partial k}=0 \quad \textbf{(A67)}$$

Using eq.(3) , $\frac{\partial e_{bcoop}}{\partial z_{bcoop}}=-2$ **(A68)**

Substitute eq (A68) into eq(A67) and some arrangement following expression is attained,

$$\frac{\partial W_{bcoop}}{\partial k}=0 \Rightarrow \left[2.A-2.q_{bcoop}.(1+g)-2.e_{bcoop}.f\right]\frac{\partial q_{bcoop}}{\partial k}+ \\ \left[-2.z_{bcoop}.d.+4.f.q_{bcoop}\right]\frac{\partial z_{bcoop}}{\partial k}=0 \quad \textbf{(A69)}$$

Using $q_{bcoop}=\frac{(A-P_{bcoop}).(1-g)}{1-g^2}=\frac{A-P_{bcoop}}{1+g}$, reached following equation,

$$\frac{\partial q_{bcoop}}{\partial k}=-\frac{1}{1+g}.\frac{\partial P_{bcoop}}{\partial k} \quad \textbf{(A70)}$$

Using $\frac{\partial P_{bcoop}}{\partial k}=\frac{e_0}{2-g}-\frac{2.z_{bcoop}}{2-g}-\frac{2.k}{2-g}.\frac{\partial z_{bcoop}}{\partial k}$ and using eq.(3), it is found

$$\frac{\partial P_{bcoop}}{\partial k}=\frac{e_{bcoop}}{2-g}-\frac{2.k}{2-g}.\frac{\partial z_{bcoop}}{\partial k} \quad \textbf{(A71)}$$

Subs.eq (A71) into eq (A70)

$$\frac{\partial q_{bcoop}}{\partial k}=-\frac{1}{1+g}.\left[\frac{e_{bcoop}}{2-g}-\frac{2.k}{2-g}.\frac{\partial z_{bcoop}}{\partial k}\right] \quad \textbf{(A72)}$$

and subs.eq (A72) into eq (A69)

$$\frac{\partial W_{bcoop}}{\partial k}=0 \Rightarrow (-1).\left[P_{bcoop}-e_{bcoop}.f\right].\frac{1}{1+g}.\left[\frac{e_{bcoop}}{2-g}-\frac{2k}{2-g}.\frac{\partial z_{bcoop}}{\partial k}\right]+\left[-z_{bcoop}.d.+2.f.q_{bcoop}\right].\frac{\partial z_{bcoop}}{\partial k}=0$$

$$\frac{\partial W_{bcoop}}{\partial k}=\frac{-e_{bcoop}.\left(P_{bcoop}-f.e_{bcoop}\right)}{(2-g).(1+g)}+$$
$$\left[\left(P_{bcoop}-f.e_{bcoop}\right).\frac{2.k}{(2-g).(1+g)}+-z_{bcoop}.d+2.f.q_{bcoop}\right].\frac{\partial z_{bcoop}}{\partial k}=0 \quad \textbf{(A73)}$$

In addition,

$$\frac{\partial W_{bcoop}}{\partial v}=0 \Rightarrow 2.A.\frac{\partial q_{bcoop}}{\partial v}-2.(1+g).q_{bcoop}.\frac{\partial q_{bcoop}}{\partial v}-2.d.z_{bcoop}.\frac{\partial z_{bcoop}}{\partial v}-$$
$$2.f e_{bcoop}.\frac{\partial q_{bcoop}}{\partial v}-2.f.q_{bcoop}.\frac{\partial e_{bcoop}}{\partial z_{bcoop}}.\frac{\partial z_{bcoop}}{\partial v}=0 \quad \textbf{(A74)}$$

subs eq (A68) and some arrangement,

$$\frac{\partial W_{bcoop}}{\partial v}=0 \Rightarrow \left[A-(1+g).q_{bcoop}-f.e_{bcoop}\right].\frac{\partial q_{bcoop}}{\partial v}+\left[-d.z_{bcoop}+2.f.q_{bcoop}\right].\frac{\partial z_{bcoop}}{\partial v}=0 \quad \textbf{(A75)}$$

Eq (A53) for $b=1$, $\frac{\partial P_{bcoop}}{\partial v}=-\frac{2.k}{2-g}.\frac{\partial z_{bcoop}}{\partial v}$ **(A76)**

Subs. (A76) into (A52) it is found

$$\frac{\partial q_{bcoop}}{\partial v}=\frac{2.k}{(1+g).(2-g)}.\frac{\partial z_{bcoop}}{\partial v} \quad \textbf{(A77)}$$

If it is Substituted. eq (A77) into eq (A75) it is obtained ,

$$\frac{\partial W_{bcoop}}{\partial v}=\left[\frac{2.k.\left(P_{bcoop}-f.e_{bcoop}\right)}{(2-g).(1+g)}+-d.z_{bcoop}+2.f.q_{bcoop}\right].\frac{\partial z_{bcoop}}{\partial v}=0 \quad \textbf{(A78)}$$

It should be kept in mind that $\frac{\partial z_{bcoop}}{\partial v} \phi \ 0$, so

$$\left[\frac{2.k.\left(P_{bcoop}-f.e_{bcoop}\right)}{(2-g).(1+g)}+-d.z_{bcoop}+2.f.q_{bcoop}\right] \text{ must be zero.} \quad \textbf{(A79)}$$

From eq (A79) and eq (A73);

$$P_{bcoop}=e_{bcoop}.f \quad \textbf{(A80)}$$

From eq (79) and eq (A80)

$$d.z_{bcoop} = 2.f.q_{bcoop} \qquad \textbf{(A81)}$$

Eq (A80) and eq (A81) show the structure of the optimal policy.

Eq (A80) states that price equals to marginal environmental damage per unit of output.

Eq (A81) indicates that marginal R&D cost equals to marginal saving in environmental damage from R&D because of $2.f.q_{bcoop} = -f.\frac{\partial e_{bcoop}}{\partial z_{bcoop}}.q_{bcoop}$

According to the optimal policy combination (k*, v*), it is expected that the firms' first order conditions must satisfy the optimum condition identified above.

F.o.c of the stage 3, from eq (50) : $\frac{A.(1-g)-2.P_{bcoop}+g.P_{bcoop}+k.e_{bcoop}}{1-g} = 0 \Rightarrow$

$$P_{bcoop} = A.(1-g) - P_{bcoop}.(1-g) + k.e_{bcoop} \qquad \textbf{(A82)}$$

F.o.c of the stage 2, eq (A64) and eq (A65) substitute into eq (55):

$$2.(P_i - k.e_i).\frac{k - \frac{k}{2-g}}{1-g^2} + 2.(P_j - k.e_j).\frac{k - \frac{k}{2-g}}{1-g^2} = (1-v).d.z_i \Rightarrow$$

$$4.k.(P_{bcoop} - k.e_{bcoop}) = (1+g).(2-g).(1-v).d.z_{bcoop} \qquad \textbf{(A83)}$$

From eq (A80) and eq (A82),

$$e_{bcoop}.f = A.(1-g) - P_{bcoop}.(1-g) + k.e_{bcoop} \Rightarrow k.e_{bcoop} = e_{bcoop}.f - (1-g).(A - P_{bcoop}) \Rightarrow$$

$$k_{bccop}{}^{*} = f - (1-g^{2}).\frac{q_{bcoop}}{e_{bcoop}} \qquad \textbf{(A84)}$$

Substitute eq (A82) into eq (A83).

$$4.k\left[(1-g).q_{bcoop}\right] = (2-g).(1-v).d.q_{bcoop} \qquad \textbf{(A85)}$$

From eq (A81) and eq (A85) also with some arrangement it is attained,

$$4.k\left[(1-g).q_{bcoop}\right] = (2-g).(1-v).2.f.q_{bcoop} \Rightarrow$$

$$2.k.(1-g) = (2-g).(1-v)f \Rightarrow (2-g).f.v = f.(2-g) - 2.k.(1-g) \Rightarrow$$

$$v_{bcoop}{}^{*} = 1 - \frac{2.k(1-g)}{(2-g).f} \qquad \textbf{(A86)}$$

ABOUT THE AUTHOR

Ilker UMUR was born in 1978 in Mudurnu. After graduating from Bolu Ataturk Lisesi he received his Bachelor of Science degree in Mechanical Engineering from Istanbul Technical University in 2002. Since September 2002, he has been attending to the Master of Science degree in Economics at Istanbul Technical University.