Innovation Prizes

For Environmental R&D in Presence of Lobbyism

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Til Papa

Preface

I would like to thank my inspiring supervisor Mads Greaker for giving me the opportunity to develop his idea and investigating innovation prizes. I am very grateful to my dearest sensei Gry Tengmark Østenstad for all her support and guidance. I am thankful to Oslo Centre for Research on Environmentally friendly Energy (CREE) for awarding me their scholarship. I look forward to further research on the topic of environmental R&D at the Department of Economics, UiO. Thanks to the best study group, you know who you are.

Thanks to the giants.

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Abstract

Recent contributions in the environmental literature seem to suggest that incentives to environmental research is lower than incentives to ordinary research, arguing in favor for additional support for environmental R&D. Their arguments are based on the conjecture of the commitment problem. Since the government influences incentives implicitly through their environmental policy, they may be tempted to expropriate rents from the successful innovation with strategic taxation. In this thesis I analyze whether the incentives to environmental R&D is systematically lower, due to both the appropriability problem and the commitment problem. Secondly I investigate how an inducement prize to environmental innovations can remedy these market failures. My conclusion on the standard commitment problem confirm the results in Greaker and Hoel (2011) where a ranking of incentives is arbitrary, depending on parameter values. This gives no reason to frequently use of innovation prizes to environmental R&D. I therefore expand the analysis and introduce a political disturbance, investigating whether this gives a specific ranking. It turns out that intermediate disturbance gives a distinct underprovision of environmental R&D. For this special case innovation prizes will restore the optimal level of incentives. The thesis contains of a historical introduction and a discussion of innovation prizes as an inducement mechanism for environmental R&D.

Summary

In this thesis I discuss ex ante inducement prizes as an instrument for promoting innovation, with special focus on environmental R&D. The question is whether we can prove by economic theory that environmental research should be prioritized in R&D support programs. The model in this thesis is based on a working paper by Greaker and Hoel (2011), where they show that a comparison of envionmental R&D and ordinary market good R&D gives no specific ranking. I expand their model my including an aspect of political economy to investigate how an extended commitment problem could be solved by an innovation prize. My conclusion is a possible ranking for intermediate political disturbance.

From the literature on innovation economics the under-provision of R&D rises from the appropriability problem. Knowledge is a public good with no boundaries on its consumption. Every innovator contributes to the common pool of knowledge. This positive externality is not taken into account by innovators, resulting in too little knowledge creation. Since knowledge and ideas easily spill between sectors, the innovator is not able to extract the total gain from her invention, decreasing further motivation to invest in R&D. The appropriability problem is the justification for governmental interference and support of research.

In the sector of environmental research the demand for new green technology is created indirectly through the emission tax, and hence the incentives to invest in environmental R&D. Literature on political economy has showed that policies tend to be inefficient over time. Current politicians do not manage to bind their actions when no outside institution enforces such commitments. The results from Greaker and Hoel (2011) depends crucially on timing of governmental intervention. If the innovator act after the environmental policy is implemented the government would be tempted to influence the spread of the innovation by strategic taxation. The innovator sets a price on her innovation, named a license fee, as best response to the policy. The government is therefore able to put a downward pressure on the fee by lowering the tax. The intention is to maximize welfare, but the result is decreasing incentives. This is refereed to as the expropriation problem, a concurrent issue with the commitment problem.

In the case of environmental R&D the commitment problem amplify the appropriability problem, craving for an investigation of the effect on incentives. Based on

these market failures one can argue in favor of additional support to environmental R&D. Greaker and Hoel (2011) aim to compare the incentives to R&D in a general model set up, investigating whether there exist specific differences in the incentives to invest in ordinary market good R&D compared to environmental R&D. If there are systematic differences, it justifies a diversion in R&D support programs.

The question is whether the appropriability problem is superior in the case of environmental R&D due to the commitment problem. Greaker and Hoel (2011) state that no systematic ranking of the different R&D incentives is possible, hence no particular reason for additional support to environmental R&D. My hypothesis is that the incentives to environmental R&D is larger than market good R&D, and I will investigate whether I can find a special scenario where this holds. It turns out not to be as clear as first thought.

This thesis' extension is to include an aspect of political disturbance. I introduce interest groups that influence the taxation decision of the government with the aim of protecting private profit. The welfare maximizing government, or equivalent the benevolent social planner, suffers from "weakness of will", setting the policy with a biased welfare objective. The underlying reason for investigating this special case is an impression of a weak environmental policy where the global emission tax is too low. The aspect of political disturbance give me a model with an extended commitment problem.

My aim is to compare the incentives in a laissez-faire R&D scenario to the incentives to environmental R&D with lobbyism. The model is as general and basic as possible, increasing the relevance of my results. My findings for a general commitment problem follows the result in Greaker and Hoel; no special ranking of incentives to market good R&D and environmental R&D with a benevolent planner is possible. But in case of the extended commitment problem the incentives to environmental R&D is systematically lower for intermediate influence of lobby groups. The result breaks if we look at the two extreme cases with either total lobbyism or no influence.

When incentives to environmental R&D is sufficiently lower than to market goods R&D, I show how an inducement prize may restore the social optimal level of incentives. This result argues in the favor for diverse R&D support with additional inducement to the sector of environmental R&D.

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1 Introduction

There is broad consensus about the need of drastic change in the way societies produce goods and generate energy if we shall combat climate change and reach the 2° target, agreed on at the Copenhagen Accord. The ambitious objective is to prevent dangerous anthropogenic interference with the climate system and this thesis is meant to contribute to the literature on how to accomplish this.

In the latest report by Intergovernmental Panel on Climate Change (IPCC) the panel state that continued emissions of greenhouse gases (GHG) will cause further global warming. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions (IPCC 2013). IPCC recommend a 50% reduction by 2050, and a reduction of 100% by 2100 from the GHG level in 2010.

In the *science* article "Advanced Technology Paths to Global Climate Stability: Energy for a Green House Planet" researchers from diverse fields argue that climate change is an energy problem, and currently we lack the technology to reach the goal set by UNFCCC:

> Arguably, the most effective way to reduce CO_2 emissions with economic growth and equity is to develop revolutionary changes in the technology of energy production, distribution, storage and conversion (Hoffert et. al. 2002, page 981).

In other words, a possible solution to climate change could be a technological revolution. Hoffert et. al. (2002) further claims that a stabilization of carbon dioxide will require research on alternative energy sources for the coming decades: "We conclude that a broad range of intensive research and development is urgently needed to produce technological options that can allow stabilization and economic development" (page 981). The world is in need of a technological breakthrough and radical inventions in alternative energy sources to prevent climate change.

Economic theory has showed that research and development (R&D) is underprovided in the private market as a result of positive externalities from knowledge spillovers. In environmental economics this market failure interacts with the additional negative externality from emissions. This complicates the analysis of innovation policies. Should we adopt policies that corrects for the environmental externality or a policy that corrects the knowledge externality? Or are there sufficient policies that can correct for both? A complete understanding of the interaction between the two externalities and how these can be mitigated by governmental policy is truly pertinent f pushing the forthcoming technological breakthrough and solving the problem of climate change.

The patent system is implemented to deal with the externality of knowledge spillovers. Additional instruments to induce R&D as subsidies and grants are used by the government to accompany the patent system. This thesis will explore a less common inducement mechanism, namely innovation prizes. I will analyze whether prizes solve the commitment problem and whether they are especially suited to stimulate environmental R&D in suboptimal surroundings due to lobbyism and governmental "weakness of will".

2 Economics of innovation

Technological progress is a result of ideas and innovation. Schumpeter has been declared the founder of innovation theory in economics (Hall and Rosenberg 2010). In the book *The Theory of Economic Development* (1934) Schumpeter forwarded the idea of "creative destruction" by innovations. He argued that innovation is a necessary condition for economic development. To stimulate innovation the government needs to support innovators with credit funding (Schumpeter 2008). Without entrepreneurs we would have a stagnating economy (Sweezy 1943). Schumpeter divided the process into three phases; invention, development and diffusion. This is referred to as the Schumpeterian trilogy of the technology process. The first stage involves discovery and creation of new ideas. In the second stage these ideas are developed, and at last the new product is sold and spread in the market.

Research and development (R&D) is a headline that includes fundamental research, applied research and experimental development in both governmental and private sector. The term R&D incorporates the first stages of the innovation process including the creation and development of ideas. R&D consists of systematic and creative investigation, using knowledge to identify new applications and discoveries (Grupp 1998). This includes both the development of new products, and improvements of existing goods.

After Schumpeter and his study of the technological process several theoretical directions of innovation theory has been developed, all based on Schumpeter's contribution. The literature on innovation theory is concerned with the underprovision of innovation due to knowledge spillovers. Laffont and Tirole (1996) contributed to the canon by looking at the interaction of the patent institution and the emission policies in context of pollution control. This thesis will follow in this direction, pointed out by the Laffont and Tirole article and include the perspective of environmental economics into the field of innovation to study R&D policies.

2.1 Knowledge externalities

Knowledge is a public good, characterized by being non-rivalrous and non-excludable. There are no boundaries on its consumption. One agent's use does not affect the access of others. Knowledge is available everywhere, and preventing others from using it is almost impossible. A new idea is difficult to control and hold exclusive. Once it is revealed in the market it will leak and be easily copied (Foray 2004).

One way of visualizing the externality following the properties of a public good is to think that all new ideas are built on old knowledge. Then each additional innovation increases the pool of knowledge. Every innovator will contribute to the pool of knowledge as long as the expected profits of an idea are positive. The social loss occurs when the innovator does not take into account the positive spillover effect on other firms (Stiglitz 2014), resulting in too little knowledge creation compared to the socially optimal level. Innovation is therefore under-provided in a market free from governmental interference, the laissez-faire market.

There will often exist diverse uncertainties in the field of R&D. The innovator does not necessarily know whether the innovation will be successful, how large the cost of production will be or the future demand of the product. In the industry of ideas researchers have minor chance of gathering all surplus from their inventions. Ideas are easily copied and the spill of knowledge is almost impossible to prevent. Since the social surplus is not equal to the private value of knowledge, an externality is created. This is known as the appropriability problem. Appropriability concerns the innovator's ability to harvest all return from her invention. Imitations and involuntary flow of knowledge between innovating firms decrease the expected return and thus also the incentives to innovate.

2.2 R&D policies

To remedy the knowledge externality, governmental intervention is a necessity. The patent system is implemented to correct for this market failure. Patents provide the innovator with property rights to her private developments. There are three types of "intellectual property"; copyright, trademarks and the patent system. When an innovator holds a patent she becomes a monopoly supplier of the invention. In economic theory a monopolist has the opportunity to charge a price higher than the marginal cost of production. As a result, a smaller quantity of the product is sold to a higher price than optimal. Each patent is therefore given with limited duration to shorten monopoly activity. The patent system is introduced to remedy an externality, but simultaneously an additional deadweight loss is created.

Boldrin and Levine (2008) raises a controversial question whether the patent system have any positive effect on the innovation decision at all. They give examples of how patents may slow the development of further knowledge and stagnating competition. Intellectual property rights may be mistakenly identified as a necessary evil that fosters innovation. Boldrin and Levine claim instead that patents are an unnecessary evil: "(. . .) there is no evidence that intellectual monopoly achieves the desired purpose of increasing innovation and creation, it has no benefits" (page 11). They support this daring conclusion by arguing that the positive short run effects will be exceeded in the long run, because patents make innovations more costly and discourage competitors to enter. They base their findings on empirical evidences from the continued extension of patent protection in US, Europe and Japan.

To supplement the existing patent system, several inducement mechanisms are available to the government. Research grants, subsidies and public research at universities and academies are common instruments. These supplements are necessary for inducing development of non-patentable ideas and utilize the positive externalities from R&D.

Under a stereotypical grant process the government has to make assumptions based on limited information about the innovators' risk and subsidize the effort of the innovating firm regardless of success (Newell and Wilson 2005). When innovators do not bear the risk of failure the incentives to efficient research may decrease. "For example, if failure does not cost them anything, researchers might solicit contracts or grants even when they know that their efforts have little chance of success" (page

9). The result is inefficient allocation of grants making this type of supplementary R&D policy sub optimal. However, an overall goal of funded research is not always to develop finite and completed outcomes, but to subsidize basic research with a wider range such that the pool of knowledge expands. When the knowledge base increases the diffusion of new information is pushed and knowledge spillovers is maximized.

The different aspects mentioned above of how supplementary R&D policies affects innovation indicates the importance of adjusted policies to the diverse sectors of R&D. Commercial research and product development might need a different and more specified type of inducement policy than basic research. Inducement prizes is a mechanism that distinguishes from grants and patents in numerous ways. Where grants are given early in the R&D process no matter outcome, prizes are only rewarded in case of success. Where patentable ideas must satisfy the conditions by the patent law office, a prize can be rewarded to specific research addressing special innovation challenges in areas where patents do not perform well. Prize competitions provide a change in the way innovation is financed and contribute to the governmental toolbox of inducement mechanisms.

3 Inducement prizes

This thesis will analyze inducement prize competitions. Innovation contests generate incentives to innovate that differ substantially from the patent system. The prize funder[1] announces the victory conditions and the monetary size of the prize ex ante. The prize is not necessary a cash transfer. It could be a medal, a contract or another type of honor. In this thesis only monetary transfers are considered. The funder chooses the winning party after the contest. Often such competitions last for several years either with a stated deadline, or they are valid until a winning solution arrives.

The possibility of winning encourages innovators to participate in the competition. Innovators must bear the up-front research expenditures. This implies that participants must hold the necessary financials before the competition, and could be a potential disadvantage. Costs and expenditures are not reimbursed, this may rule out small firms and individual researchers that have good ideas but no funding.

[1]The prize funder could either be the government, a firm or a wealthy person.

On the other hand, an innovator would also need funding to develop patentable inventions. This means that prize competitions does not exclude existing innovators. The prize funder only pay if the solution requested was developed, avoiding the sunk costs in case of unsuccessful research.

An essential distinction between innovation prizes, as described in this thesis and other rewards, is the ex ante perspective. Inducement prizes do not include those that reward remarkable research such as the Nobel Prize. In these cases the development of the idea is already implemented. This type of prizes reward past breakthroughs. The purpose of innovation contests is to induce new knowledge.

In the literature this distinction between ex ante and ex post rewards can easily be confused, since both contexts use the term “prize”. An organized overview of the previous literature on prizes is necessary to avoid confusion. Some papers consider getting the patent rights equivalent to receiving a prize (Scotchmer 2004). Others follow Wright (1983) where the prize, a lump sum transfer, rewards successful projects ex post as a first best alternative to patents (Hopenhayn, Llobet and Mitchell 2006; Newell and Wilson 2005; Chari, Golosov and Tsyvinski 2012). When a prize is rewarded in these scenarios the discovery is set in public domain after the competition. The purpose of this type of prizes are to avoid monopoly rents created by patents, and to push the diffusion of the discovery.

In the article by Shavell and van Ypersele (2001) the innovator may choose either patent or reward, and they show that this policy is superior to the patent system alone. Kremer (1998) models a patent buyout scheme that uses auctions to estimate the patent value to determine the buyout price. Kremer suggests that prizes could be used to buy out patents instead of waiting until contest specifications is fulfilled. A similar model of prizes occurs in Weyl and Tirole (2012). They design a mechanism where an up-front prize is rewarded in combination with patents such to reduce welfare loss from monopoly rents. The common feature of all these articles is that prizes are considered an alternative to patents, and their main concern is to reduce the deadweight loss from intellectual property rights.

In this thesis an alternative view is introduced. Prizes are not interpreted as patent buyouts, but rather as a inducement mechanism accompanying patent rights when the system is not performing well. Brennan, Macauley and Whitefoot (2012) lists essential reasons for why the patent buyout literature does not succeed in explaining the type of ex ante prizes considered in this thesis. First, winning a prize in this context is not necessarily equal to losing possible patent rights. The contest can be designed in several ways, and do not necessarily block the opportunity of getting a patent. Patent buyout may potentially discourage innovators to enter the competition when winning is equivalent to loosing rights to their invention. Second, prizes should only be used in cases where the victory conditions can be clearly specified and the performances can be judged without ambiguity.

Another argument against the focus on the buyout literature is related to the necessary size of a buyout reward. If the prize is set equal to the total social value of the invention some prizes would become astronomical and the buyout mechanism would never be sustainable for the governmental budget. This was one of Polanyi's concerns in the article *Patent Reform*:"(...) considering firstly whether it would not be intolerably unfair to the taxpayers" (Polanyi 1944).

The size of the prize, as modeled in this thesis, is set at the level that would induce enough incentives. Ex ante inducement prizes act as an extra pull to increase R&D additional to the private patent value, and are therefore feasible to implement.

Implementing a patent buyout prize on the other hand, would offer several challenges. If prizes were supposed to replace the patent system completely, it would imply heavy administrative challenges of estimating the correct value for every invention (Newell and Wilson 2005). The revenue to these enormous buyout rewards would have been collected with distortionary taxes, and the social gain from increased incentives may be exceeded by the deadweight loss from tax raising.

I will take the existing patent system as given. Since the prize transfer is relatively small I choose to neglect the issue of tax funding. A prize contest in my context does not necessarily require a patent transfer. The winning innovator may keep the patent rights. Removing market distortions from the existing patent system is not a priority. Prizes are accompanying instruments, promoting innovation in under-invested research fields where special circumstances lower the incentives. The patent system is addressed to solve the problem of appropriability, but the system of prizes does not rely on this approach. The contest is implemented with the aim to create incentives and spurring new R&D in a social valuable direction.

3.1 Historical prizes

Throughout history some valuable inventions have been developed as a result of prize competitions. Today the prize mechanism is most common in architectural competitions, except some new announcements in 2014. One could argue that the prize mechanism has its renaissance in Europe these days. The European Commission announced its first innovation challenge in 2011 where a German biopharmaceutical company won the €2 million prize for their innovative vaccine technology in 2014. After this success several new prizes were announced in 2014 under the name Horizon Prizes. The prizes vary in extent from €500,000 to €3 million depending on the solution requested. These prizes are not patent buy-outs but a single transfer to the winner, with the binding assurance of producing the invention. The common feature of all Horizon prizes is solutions with great social value either in terms of health, communication or global data traffic. All fields are in need of a radical breakthrough to manage continuous population growth.

The Innovation UK and the innovation charity organization Nesta announced the Longitude prize 2014, a challenge that offers a £10 million prize to those that solve the problem of global antibiotic resistance. The name of this contest refers to the original Longitude Prize that was announced in 1714 and is known today as the most famous example of a successful innovation contest.

March 25, 1714 The British government announced a prize contest as a response to a petition from the Royal Navy and Captains of Her Majesty's Ships to improve navigation by finding a solution of measuring longitudes. The prize competition consisted of several prizes. The grand prize of £20,000 was offered to the method accurate within 0.5 degree, a prize of £15,000 to a method accurate within 40 minutes and a £10,000 reward for measures of longitudes within 1 degree (Horrobin 1986). At that time these amounts were truly astronomical reflecting the extent of the challenge and the believed minor probability of succeeding. The announcement boosted the field of navigational research and exited wide public interest. John Harrison, a self-educated clockmaker, developed after many attempts the first reliable and accurate hand-held chronometer. The experts of the Royal Society tried to deny him the prize until King George III intervened and secured Harrison, at the age of 80, the legitimately won award in 1773. This remarkable story of maybe the first well known innovation prize provides a fine introduction to many aspects of the prize mechanism that will later be discussed in more detail.

The French government has had several innovation contests through history. Two of the competitions in the late 18th century ended with successful innovations. In 1775 the French Academy of Science announced a prize of 2,400 Livres for the development of artificial alkali from inexpensive materials. The chemist Nicholas Leblanc successfully produced soda from salt, but due to turbulent times in France the revolutionary government refused to grant him the reward. The tragic story of the unrewarded innovator ends with Leblanc committing suicide in 1806, but his discovery provided the foundation of the French industrial chemical industry and the process bears his name today (Davis and Davis 2004; Newell and Wilson 2005; Davis 2002). The story of Nicholas Leblanc reflects the importance of a credible prize and the danger of an unaccountable government.

The second prize was announced in 1795, twenty years later. The French Directory offered a 12,000 Franc reward for a method of preserving food under petition from Napoleon. Nicolas Appert, a confectioner in Paris with no formal education, experimented with vacuum sealed glass bottles that contained precooked food. After 15 years of experimenting he received the prize and opened a canning factory (Davis and Davis 2004; Newell and Wilson 2005; Davis 2002). Both the story of John Harrison and of Nicolas Appert illustrate the self-educated innovator that dares to think out of ordinary conventions, and therefore manages so solve a problem of high social value. They both started their experimentation and research after the prize was announced and were undoubtedly induced by the high reward. Would these inventions been discovered without a prize? Clearly the contests contributed to an early technological breakthrough and opened for unschooled engineers to enter the field.

Many more examples of innovation prizes could have been discussed in detail. Through the 19th century the Fourneyton turbine and the rocket locomotive were invented as a result of prize competitions. The article "Inducement Prizes and Innovation" by Brunt, Lerner and Nicholas (2011) contributes to the literature with an empirical overview that examine whether prizes have affected the technological development. They use a dataset that reaches over 100 years on awards by the annual technology contest organized by Royal Agricultural Society of England (RASE) between 1839 and 1939. Their results reflect that prizes may be a significant inducement for innovation: "The contests organized by the RASE attracted large number of inventor and the competitions as public events encouraged the diffusion of useful knowledge across innovators" (Brunt et. al. 2011, page 6). An interesting result from the analysis was that prestigious medals had higher inducement power than money: "We detected statistically significant effects of monetary and medal awards and we show that medal awards had the largest effect on patenting activity" (page 5). This may imply that the size of the prize is less important, and that reputation and promotion has a significant importance.

Another article that uses historical events to analyze the effect of prizes is "How Effective are Prizes as Incentives to Innovation? Evidence From Three 20th Century Contests" by Davis and Davis (2004). The authors use three historical examples to take a case-based retrospective view on the effect of prizes. They suggest that if a prize system, in addition to the existing methods, manages to influence the direction of research this instrument should be used in cases with potentially high social welfare: "(. . .) if welfare arguments for a specific prize contest are sufficiently strong, this 'change of direction' argument must remain an important justification for prize contest design" (page 25). The authors call for more analysis of assessing the effects of an incentive prize system for social welfare.

4 Environmental R&D

In the field of environmental economics the negative externalities from pollution complicates the analysis of incentives. Investments in environmental research is somehow "double" under-provided because of two types of externalities. Both the knowledge spillover that exists in all research fields, and the social damage from pollution makes the level of environmental innovations suboptimal.

Environmental policies, such as emission taxes and the cap and trade system, create the demand for environmental innovations. The polluting firm experiences higher cost when the tax is implemented and this creates incentives to reduce the cost by cutting emissions. Either the firm can invest in environmental R&D, or it can buy new technology from a specialized innovator. Examples of environmental research can either be green input substitutes, end-of-pipe cleaning technology or new production methods that emit less emissions.

The question is whether incentives created by environmental policies are satisfactory. Jaffe, Newell and Stavin (2005) argue that it is unlikely that environmental policy alone creates sufficient incentives for environmental R&D. They front the view that optimal policies should also include instruments designed explicitly to foster innovation and stimulate new technology to internalize the environmental externality (Jaffe et. al. 2005).

General economic theory gives no reason for why the positive externalities of green R&D should be greater than in the field of ordinary marked goods R&D. But there are reasons to believe that the incentives to invest in green R&D are lower than to market good research. The necessary decline in emissions creates the market and the demand for green technologies. By green innovation I mean an end-of-pipe abatement technology, a cleaning invention that erases emissions and decreases abatement costs with no impact on the production function. This type of R&D is process-innovation that affects the manufacturing, a contrast to product-innovation that improves quality of the product.

If the emission price generated by a carbon tax or quotas is too low the demand for green substitutes will also be under the optimal level. When demand is low, fewer incentives to invest in green R&D are generated. Innovators do not expect high returns in a field with low demand since the patent value in the green technology sector will be too low.

If environmental R&D has been under-provided for decades it may be that the knowledge base in the field is small, (see e.g. Acemoglu et. al. 2012; Aghion et. al. 2014). The pace of innovations is determined by the existing pool of knowledge and the level of investment in the field (Stiglitz 2013). Research fields with a small base of knowledge often have a larger developing potential, but the probability of a successful outcome is smaller. The probability of success is often thought of being conditional on the aggregate research activity in the field. Because of the involuntary flow of knowledge the probability of success increases as more innovators enter.

The arguments in favor for additional inducement in the green sector are based on the impression of an under-investment in environmental R&D due to insufficient environmental policy. The question is whether innovation prizes are a suited instrument to reach the optimal level of R&D. Brennan et. al. (2012) list several "idosyncratic" advantages, among these are publicity, flexibility, contestant management, pre-commitment, and non-patentability. In the following sections I will discuss to what extent these and other advantages apply to environmental R&D.

4.1 Risk and uncertainty

Any innovator, either for market goods or environmental technology, will front the many uncertainties that characterize the innovative sector. The innovator will never know in advance whether the invention will be a commercial success or what value a patent will bring. Potential patent value depends on future demand which is unknown to the innovator. For environmental R&D future demand will be determined by future environmental policy.

The many uncertainties in the developing process affect incentives to innovate. The innovator must balance the potential return to the probability of failing. If the innovator is risk averse, the uncertainty will discourage investments. Research fields characterized by particular high uncertainty will then attract less investments, resulting in especially little R&D.

The question is whether the risk of investing in environmental R&D is greater than the risk associated with development of ordinary market goods. If so, incentives in the green sector is substantially lower than other sectors. Special for environmental research is the uncertainty about future energy sources, and which that appear most beneficial to concentrate on.

By participating in a prize contest the expected revenue increases, which increases the incentives to innovate. This re-allocation of risk is a feature that distinguishes prizes from patents. The risk shifts from the innovator to the prize funder, changing expected revenue to the innovator. If risk and uncertainty is particularly high for green R&D an inducement prize could solve this problem.

4.2 Publicity

The announcement of a prize contest will attract attention and the winner will receive honor and glory. The advantage of positive publicity and free advertisement is significant for firms that launch new technologies to the competitive market. The innovator will always be uncertain about future demand since the market for the new product does not yet exist. How quickly will the invention diffuse, how fast will competing firms copy the technology and when is the product outdated? Most likely environmentally friendly products are in greater need of this extra publicity to push adaption, especially if the existing policies do not create sufficient demand for green R&D.

4.3 Flexibility

The flexibility of prize design is especially an advantage in cases where solution to a problem is not known. A prize contest can be formulated in several ways and adjusted to the object of interest.

With prizes the funder is able to manage and arrange competition aiming at a specific goal. The crucial premise for prizes to be applied is whether the funder knows the objective. If the objective is unknown ex ante, winning criteria cannot be specified. In many cases neither the funder nor the private market has enough information to know what research to induce. In the case of renewable energy, nobody knows with certainty which energy source will appear most valuable in the future. However, the funder can avoid specifying the energy source, and rather demand a renewable energy that gives them a desired energy level and cost ($\$/kWh$).

Characteristic for prizes is the opportunity to widen up or narrow down criteria adjusted to the research field. This ability to customize makes prizes a flexible mechanism. Newell and Wilson (2005) discuss design in detail where the narrowness is an important issue for environmental R&D. “The overarching goal is clear: to slow or stop the rise of net GHG emissions in order to mitigate the risk of global climate change” (page 26), but this target would be too broad making the declaration of a single winner difficult. Instead the prize should be restricted to specific technologies or particular energy sources with focus on one research area at the time Newell and Wilson (2005).

4.4 Contestant Management

A prize contest can be designed such that only qualified contestants can participate. Then the possibility of duplication of effort can be prevented. If two innovators come up with identical ideas, the effort of one of the innovators was wasteful and should have been optimally allocated to other research fields. Davis (2004) writes that even though diverse innovators have different technologies and methods, duplication may occur: “Thus they cannot accurately read signal from each other with regards to investment choices, leading to inefficient investment and duplication of effort, with the consequent welfare losses” (page 5). Duplication of innovation is equivalent to unnecessary duplication of cost. The announcement of a prize contest can increase innovation within a specific field, and the possibility of duplication may increase due to few innovators with same knowledge base.

To prevent duplication the prize designer can limit entrance. Newell and Wilson (2005) comment that limiting marginal participants that are unlikely to win might also eliminate potential winners: “It might also screen out small firms without the initial capital to compete with larger firms. (...) such small firms have historically been closely associated with more revolutionary technological developments” (page 36). Davis (2002) comment that the requested solution may appear completely different from what the prize funder expected. The advantage of such competitions is to allow both “garage” thinkers, high school classes and high-tech engineers to enter and trade ideas. “(. . .) prizes attract the attention of less hidebound thinkers who are willing to challenge technological orthodoxies” (Newell and Wilson 2005, page 28). Newell and Wilson further claim the opportunity to encourage any type of researcher to extend their knowledge is a special advantage of inducement prizes: “Inducement prizes could trigger an advance in GHG-reducing technologies that research-subsidizing levers might not have” (page 28). In the field of environmental research the need for new thoughts and ideas at the cutting edge is significant. Prizes could be a suitable instrument to induce radical innovations in environmental R&D.

Another prize design to prevent duplication is based on knowledge exchange between the contestants. Forcing the participants to display their developments in an early stage of the contest may lead further research in complementary directions (Davis 2004). This knowledge exchange evolves benefits by pushing the competition and increasing the quality of the inventions.

Susan Scotchmer (2004) argues that the duplication of cost is not considered a problem when ideas are scarce: “(...) scarcity means that only one inventor can fill the market niche defined by his or her idea” (page 45). Scarce ideas are an issue for environmental R&D. The research field is young and insufficient demand over time has not provoked the necessary radical invention.

4.5 Non-patentability

Another fundamental advantage of inducement prizes is the possibility to reward non-patentable research: "(...) the most striking if not crucial idiosyncratic difference between prizes and patents is that prizes can be and are employed for all sorts of achievements" (Brennan et. al. 2012). Ideas and undeveloped concepts are not patentable. Neither are complex machinery, combining several patented technologies. The contest can be designed not to request finished products, but rather induce new thoughts and different approaches to an unsolved problem. For example the solution to carbon capture and storage would be an intricate technology, not patentable alone. Without the possibility to patent a new invention the incentives decrease, and a development is unlikely to happen. In the field of green R&D an undeveloped invention is not only a loss of profit to the innovator, but a loss of social welfare to the global society.

Brennan et. al (2012) writes that several circumstances prevent the patent system from providing the optimal R&D investment: "For areas that could be characterized as "big science", areas with significant spillovers (e.g. access to space) or un-internalized externalities (e.g., climate change abatement), the value that the innovator is able to appropriate from their intellectual property may not be enough to overcome R&D costs even if the social welfare gain is large enough to justify the investment" (page 18). In these cases a prize in combination to the patent system may encourage firms to invest more in environmental innovation.

4.6 Pre-commitment

Previous arguments from section 5.1 to 5.5 may equally apply for other research areas than environmental R&D, although they can be interpreted to argue in favor for green innovation. However, the issue in this section do apply for environmental R&D in particular and is the fundamental framework of the model in this thesis.

Market for environmental R&D depends crucially on future policies since environmental policy creates the demand for green technology. A pollution tax would affect the innovator's respond and determine how the innovator sets the license fee[2] on the invention. Size of the license fee is crucial for the spread of the innovation, a

[2]The license fee is the price variable, set by the innovator, that determines how much firms must pay to adopt the new invention.

high fee signify expensive technology followed by less adaption. Policies are known to be unstable as politicians come and go in a democratic process. It is therefore complicated to commit to a future tax level, or an ongoing subsidizing of input. The innovator therefore faces uncertainty about future demand, affecting the investment decision in R&D.

This is referred to as the commitment problem, and has been further analyzed by Laffont and Tirole (1996) and Greaker and Hoel (2011). The source of the commitment problem is the problem of expropriation. This implies that the government is tempted to use their regulating power and expropriate rents from the invention. The government can put a downward pressure on the license fee by force of being major purchaser, the arbiter of intellectual property rights or assessor. The inventor has no guarantee the license fee is not pushed below the level that covers her research costs. Greaker and Hoel (2011) writes "As long as the government cannot commit to environmental policy several years into the future, the government may thus end up partly or fully expropriating the rents for pollution abatement innovations" (page 3). The commitment problem contributes to the uncertain surroundings of future demand.

One can point out several similarities between the market for vaccines and the market of environmental R&D. Both are public goods, benefiting globally. The development and diffusion of a good has social value that exceeds the private value of the innovator. The curse following global public goods is caused by the free-rider problem. No single country has enough incentives to encourage research since it is more beneficial to free-ride on the research of others.

This is similar to the market for environmental R&D and applies especially for climate change. Abatement is a public good and pollution has external effects where affected agents live in different nations. This gives a transboundary environmental problem, where the environmental policy of a single government depends on the actions of all other countries. The market of environmental R&D is often international and depends therefore on all governments policies. If the policies are weak, the value of environmental research decreases and lowers the incentives to invest.

Kremer (2001) divides the different inducement programs in two subgroups, "push" and "pull". Programs that push innovation fund research inputs and pull-programs buy the developed invention. Kremer suggests a system that verifies commitment, named Advanced Market Commitment (AMC), where the government commits to purchase a given quantity that meets prespecified criteria. AMC is defined as a pull program. In the special case of vaccines this would both provide incentives and ensure that the finished product reaches out to those that need them.

An inducement prize is very similar to AMC, albeit the distributional aspect. Winner of the prize will keep both the intellectual property rights and the control of the commercialization. In the case of AMC the innovator keeps the patent, but a number of doses must be sold at a guaranteed price. Kremer's results are based on future uncertainty in demand resulting from governmental policies, similar to the commitment problem with environmental R&D described in this thesis.

The main advantage of prize contests is the possibility to avoid the commitment problem. The funder promises the prize in the announcement ex ante where the prize transfer act as a payment commitment. Risk is reduced with the probability of winning the prize. Since the field of environmental R&D is especially vulnerable for unstable politics a prize can decrease uncertainty, and hence increase incentives.

Often, in the case of environmental R&D, the funder is the only interested party willing to purchase the winning invention. Either because the demanded technology is specially designed for governmental use, or a private funder wants to contribute to the spread of knowledge. The inventor seeks the prize to increase expected revenue and cover research expenditures. An optimal prize should provide a guarantee for future purchases such that the firm can recoup these costs (Brennan et. al. 2012).

The optimal R&D investment level, from the regulators point of view, would maximize welfare. The core of the problem is that private investments are not a decision parameter of the regulator. Investments can therefore only be affected implicitly through taxes and inducement mechanisms. Requate (2005) finds that committing to a prespecified tax schedule will dominate all other policy regimes, eliminating the commitment problem:

> (...) early commitment before R&D activity is socially beneficial since then environmental policy has a stronger impact on R&D effort. However, the commitment should include a flexible menu of tax rates (permit quantities) contingent on R&D success (page 194).

In this analysis I will show that a prespecified menu of taxes is not the only instrument that can solve the commitment problem.

5 Model framework

This analysis investigates how an innovation prize could solve the commitment problem when the patent system does not restore the optimal level of incentives. The prize work as a minimum payment commitment. The conditions are announced ex ante, such that the innovator has full information of what transfer to expect when entering the competition. This inducement prize is considered to accompany the patent system, giving the innovator an extra return in case of successful development.

The model will be based on the working paper by Greaker and Hoel (2011), where incentives for environmental R&D are compared to incentives for market good R&D in a framework of a commitment problem. Their aim is to conduct a systematical comparison of incentives in a general economic model of innovation. In the literature on environmental R&D many models are based on special cases with little or no relation to a reliable general case (Greaker and Hoel 2011).

Greaker and Hoel (2011) find that timing is crucial for how incentives are determined due to the commitment problem. In this thesis the innovator acts after the governmental taxation decision. The core of the problem is inconsistent actions of the government in case of successful development. For a successful innovation the environmental policy is set before the license fee. The government may be tempted to set a low tax and expropriate rents from the innovation. As a result the innovator must undercut the emission tax, and the license fee is driven downwards to uphold the profitability of adopting the new technology.

When the license fee is low the innovator will not benefit from her research. In the extreme case of the expropriation argument, illustrated in Laffont and Tirole (1996), no R&D is performed despite the existence of a patent system. Because the government set the tax as low as possible level, such that the innovator is forced to set the license fee to zero.

Greaker and Hoel (2011) question whether the commitment problem creates systematically lower incentives to environmental R&D. They analyze the appropriability problem by comparing private incentives, hence the patent value to the innovator. In the working paper they presume the regulator willl induce the same level of private incentives in both R&D cases. However, they show in an unpublished paper (Greaker and Hoel 2014) that a comparison would also depend on the gain in net surplus generated by the innovation. In this thesis I include the effect on net welfare when modeling the appropriability problem, arguing that this gives a more proper model of incentives.

The contribution to the literature by this thesis, is the modeling of inducement prizes. I will take the set up in Greaker and Hoel (2011) as a baseline for the specific model and analyze how prizes are suited to restore the optimal level of incentives. The prize is assumed to be a lump sum transfer only rewarded in case of success. The prize is determined as the difference between private incentives and net welfare effects of innovation, giving a positive prize if the private incentives is too low.

My findings for a general commitment problem when incorporating net welfare effects follow the result in Greaker and Hoel (2011). No special ranking of incentives to market good R&D and environmental R&D is possible. I will therefore further expand the model by including a political disturbance in the environmental case, implying an *extended* commitment problem. My analysis aim to compare the incentives for ordinary market good R&D to environmental R&D with political disturbance.

6 The political economy of environmental R&D

To model the under-investment in environmental R&D this thesis includes an aspect of political economy. I assume that pressure groups of organized producer interests try to restrain the environmental policy. This only applies in the case of environmental R&D, not in the laissez-faire case. I will further assume that the single innovator and other consumers do not manage to create groups that represent the interests that could push back.

The government sets a tax on pollution to achieve the target of economically efficient level of emissions. Efficient level of pollution will maximize social net welfare. In absence of an emission tax the producing firms have no incentive to abate pollution. An emission tax creates incentives to reduce pollution in form of tax avoidance and investments in environmental R&D. Taxation reduces the profits of the producing firms, it is profitable to abate as long as marginal abatement cost is less than the tax rate per unit of pollution.

Private incentives of the producing firms may conflict the optimality criteria of welfare economics. Moreover, members of the producing industry have special interests in not following the goal of the welfare maximizing government. As a result interest groups are established and these groups find it rational trying to influence the political decision, instead of passively adopting the decisions of the political system.

In the model, the polluting industry contains of many small firms, together constituting a large competitive sector. Every single firm takes the market price and governmental decisions as given. This condition of perfect competition breaks if firms manage to organize and participate in the political process. Sandmo (2000) discusses how interest groups are established in a model of environmental economics:

> (...) it is natural to assume that the owners of 'dirty' industries are likely to be against attempts by the government to impose special taxes or regulations on them, and they will therefore be motivated to spend resources on attempts to make the government deviate form a policy of pure welfare maximization (Sandmo 2000, page 146).

I assume the pressure groups manage to influence the tax decision since the government suffers from "weakness of will", but there are other potential explanations. The parties in the government could crave for re-election, and groups are willing to pay for campaign-contributions. The benevolent government must balance between protection of firms and welfare maximization when setting the emission tax.

Olson (1971) establishes a theory of collective actions, and explains how the interests of an organized and concentrated minority may trump the interests of a majority due to the free-rider problem. Olson argues that the existence of "selective incentives" in a group is the crucial factor that motivates and succeeds collective actions. A large group of people with common interests is not enough to achieve collective actions. The participants miss the concentrated incentives that bind them together. Without selective incentives participants in a group are likely to free ride on the effort of others, and the group becomes less able to succeed. Olson put forward the argument that costs of organizing group actions increase in group size and that gain from successful actions is less per participant in large groups.

The theory by Olson applies to the model in this thesis if we assume the majority of society have a diffuse environmental awareness and there is a tightly organized producing sector. The large group of environmentalists lacks the concentrated incentive to push lobbyism back by demanding a stricter environmental policy. Small firms have the selective incentives to reduce taxes, and are therefor able to influence the government in the decisive moment.

To extend the commitment problem I will both consider a planner not able to precommit to a tax such that inducement on R&D is not fully reflected. Secondly, the commitment problem is extended with a political aspect where the government[3] is relented by interest groups. The welfare maximizing government does not manage to set the optimal policy due to some political disturbance. The planner knows the optimal level of incentives she wishes to induce, but by the time the tax is to be set the interest groups influence the decision and the planner is not strong enough to resist. The benevolent planner suffers from “weakness of will”, such that an extra weight is set on the producers’ profit in the objective.

The result of including an aspect of political economy and lobbyism is a situation where incentives to environmental R&D is low due to a weak environmental policy, hence a low tax on emission followed by a low license fee. Neither the optimal abatement level nor the optimal R&D level is achieved. I will investigate how an inducement prize could restore the optimal level of incentives in these type of situations.

The model includes an application from Bommer and Schultze (1999), where the government sets the environmental policy as a political trade-off among different interest groups. The political support function from Bommer and Schulze will in this analysis be interpreted as a weighted average, where the profit of the downstream sector is weighted with a significant share in the object function. Bommer and Schultze contribute to the canon of positive political economy, by discussing why and how politicians objective is formed. However, this analysis contributes with a normative perspective where we start out with a welfare function and see how political disturbance makes the realized welfare deviate from a first best outcome.

The analysis is organized as followed: First the general set up and the timing of each R&D case will be explained and illustrated. Then a numerical example is introduced specifying the functional forms in each R&D case. At last I will clarify how a prize could solve an extended commitment problem.

[3]A welfare maximizing government and a benevolent social planner will be interpreted as equivalent in this analysis and used as synonyms.

7 The model

Consider a model with a single innovator and a continuum of several downstream firms. The model is divided into two different R&D scenarios. One sector produces a normal market good with no regulations, the laissez-fair scenario. The other sector has “dirty” industry regulated with an emission tax by a benevolent planner. As in Greaker and Hoel (2011), I let the (i) market good R&D output (x) denote the aggregate production of a market good. For (ii) environmental R&D the output (x) refer to *total abatement* for both the old and the new technology (Greaker and Hoel 2011).

For both cases of R&D the old technology is supplied by the downstream sector, while the innovator supplies new technology in exchange for a payment, the license fee. The formal model has a similar setup as in Laffont and Tirole (1996) with a single innovator. I follow their assumption that more R&D increases the probability of successful innovation (z). In my model the outcome of the inventive process (α) is determined by nature[4]. Hence, the innovator can influence the probability with her investment level but not the output of the innovation process.

The assumption of a single innovator corresponds to the monopoly power the innovator achieves through the patent system. A patent discloses the knowledge base underlying the innovation that could have been used by rivals to develop substituting technologies (Gerlagh et al 2009). Since patents rule out potential competition, an assumption of only one innovator seems reasonable.

The simplification of a single innovator in the research process before achieved patent can be questioned. This assumption rules out the effects from patent races, where two or more innovators compete to first obtain the patent rights. To justify this simplification we assume that the outcome of a patent race would have been equal for both cases of R&D. Only the comparison of the two R&D cases are interesting for this analysis, and therefore it is redundant to include a stage with several innovators ax ante.

The sequences of environmental R&D is illustrated in figure 1, where a pollutive downstream sector demand abatement technology. The sequence begin with the announcement of the prize (P) ex ante, followed by the investment decision of the

[4] This is the same as in Laffont and Tirole (1996), but their α is fixed and in this thesis I vary α to generalize the model of the innovation process.

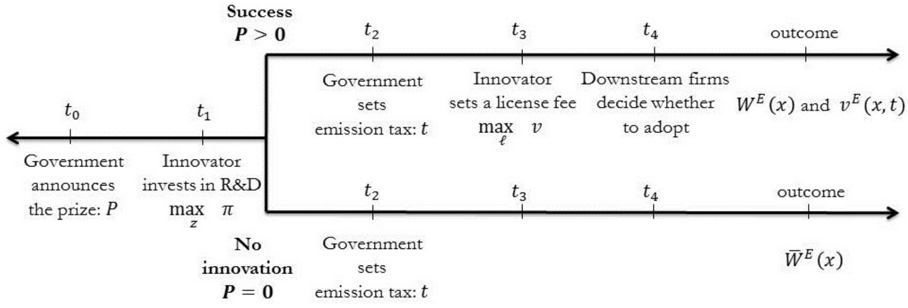

Figure 1: The progress of environmental R&D with a benevolent planner

innovator. The innovator maximize the probability of successful innovation (z) subjected to her expected profit (π). Her decision variable is the investment level (I). The innovation process is assumed to be uncertain, and the sequence is therefore divided into two potential outcomes. One path of successful development followed by winning the positive prize ($P > 0$), and one path where the innovation process fails and no prize is rewarded ($P = 0$).

The benevolent planner maximizes social welfare and sets an emission tax to reach the pollution target. The target should be the economically efficient level of pollution where aggregated marginal cost of abatement equals the aggregated marginal benefit from abatement. The output variable (x) denotes total abatement. The planner takes into account whether the innovation process was a success and the tax will therefore differ in the two paths, (t and $\bar{t}$).

Environmental policy will determine incentives to R&D, but due to the commitment problem and the appropriability problem the level of incentives would not be optimal without a prize. In case of success the innovator sets the license fee (ℓ) on her innovation by maximizing the patent value (v). The downstream firms decide whether to purchase the new invention due to their private marginal abatement cost. The realized outcome in case of success is the welfare surplus ($W^E(x)$), and the patent value ($v^E(x,t)$) as a function of abatement and the tax level. However, in the case of no innovation[5] the planner max welfare subjected to the tax ($\bar{t}$). Only the welfare surplus is realized ($\bar{W}^E$) since no patent is issued.

In the case of market good R&D there is no other governmental intervention than the announcement of the prize competition at the beginning of the game. For

[5]Notice the notation with an upper bar will denote the no innovation outcome scenarios for all R&D cases in the analysis

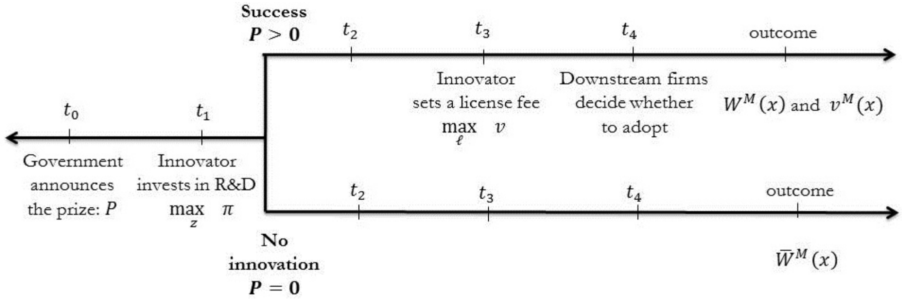

Figure 2: The progress of market good R&D, the laissez-faire scenario

the sector of market goods the new technology is a type of manufacture improvement that decreases production costs. The downstream sector produces a quantum denoted (x). The sector is defined as an industry with no need for governmental interference and is therefore interpreted as the laissez-faire scenario. Since the stages of taxation is omitted, there is no commitment problem in this case.

Following the illustration in figure 2 we see how this case differs from the environmental R&D case. The prize (P) is announced ex ante followed by the innovator's investment decision (z). In case of no innovation the sequence ends with the realized social surplus $(\bar{W}^M(x))$. On the other hand, in case of success the innovator sets the license fee (ℓ) followed by the downstream sector adoption decision. The realized outcome is the welfare surplus $(W^M(x))$ and the patent value $(v^M(x))$. Note that the patent value is not a function of the tax in the laissez-faire case. R&D for market goods is underprovided due to the appropriability problem such that the welfare outcome is not optimal without a prize.

7.1 Decision of the innovator

Market good R&D and environmental R&D has the same point of departure where the innovator maximizes expected return, $\pi(z)$, by investing in R&D. The innovator decides her investment level (I) and will then also determine the probability of success (z). The decision is based on the innovator's incentives created by expected payoff. In both cases of R&D the expected return is what the patent allows the innovator to charge for the innovation and the prize transfer. The patent value is determined by commercial success and the demand for the new technology. In this model the quality output of an innovation is taken as given, and we are only interested in the choice variable of the innovator: the probability of success determined by investments.

Total payment to the innovator (v) is given by a revenue function that depends on the license fee (ℓ) and aggregated output or abatement units (x). The revenue is also determined by the exogenous output of the innovation process (α):

$$v = v(x, \ell; \alpha) \tag{1}$$

For the revenue function I follow Greaker and Hoel in assuming that a zero price or zero output would give zero revenue, $v(x, 0) = v(0, \ell) = 0$. It is also reasonable to assume that use of the new technology is increasing in output, $\frac{dv}{dx} > 0$. I assume that for small values of ℓ the revenue increases, but for high fees the revenue decrease since less firms can afford the new technology. The patent return will also increase the better innovation given by the exogenous process, $\frac{dv}{d\alpha} < 0$.

The probability of success is denoted z, which can be interpreted as a function of the investment level, $z(I)$. The probability increases as the innovator increases her investments, such that $z'(I) > 0$ and $\lim_{I\to\infty} z(I) = 1$, but at a diminishing rate as the probability approaches one, $z''(I) < 0$. The maximization problem of the innovator in case of success becomes:

$$\max_{z} \quad \pi(z(I)) = z(I)\big(v(x, \ell; \alpha) + P\big) - I \tag{2}$$

where $v(x, \ell; \alpha)$ denotes the patent value and $P > 0$ is the inducement prize set by the government. The cost of investing is denoted I. In case of failure the revenue becomes negative due to sunk investment costs, $\bar{\pi}(z) = -I$. The license fee and the patent value is then automatically set to zero and the prize is not rewarded ($P = 0$).

The probability is multiplied with the patent value and the prize, such that increased investments increase returns. The first order condition gives the private optimal level of incentives, z:

$$v(x, \ell; \alpha) + P = (z')^{-1} \tag{3}$$

where the private gain from R&D equals the marginal investment cost, giving the optimal level of investments I^*. Note that private gain is not equal to total social gain from the invention. The solution is given by $z'(v, P, I)^{-1}$, where the probability is a function of the patent value, the prize and the investment level. The probability is increasing in all terms, $\frac{dz}{dv} > 0$, $\frac{dz}{dP} > 0$ and $\frac{dz}{dI} > 0$.

7.2 The downstream sector

The cost function of the downstream sector differs in the two potential outcomes of the R&D process. In case of success the license fee influences the spread of the new technology implying that the cost function C depends on ℓ, such that $C = C(x, \ell)$. Since a higher fee imply either unchanged or less use of the new technology, I follow Greaker and Hoel (2001) and assume $C_\ell \geq 0$. Following standard assumptions the cost function is convex and increasing in output such that $C_x(x, \ell) > 0$ and $C_{xx}(x, \ell) > 0$.

However, in the case of no innovation the innovator is not present in the rest of the sequence. The cost function modifies to $\bar{C}(x)$, where $\bar{C}'(x) > 0$ and $\bar{C}''(x) > 0$.

When a new technology is successfully invented the total cost of the downstream sector consists of payment to the innovator and production/abatement costs. In aggregated terms the total payment to the innovator is the revenue function, $v = v(x, \ell; \alpha)$. Usage of the new technology increases the return to the innovator such that $v_x(x, \ell; \alpha) > 0$. Installation or adaption cost is not considered in this model.

Total private cost in the downstream in case of success becomes:

$$C(x, \ell) + v^i(x, \ell; \alpha) \qquad i = M, E, E(\Omega) \tag{4}$$

where M denotes the market good R&D, E denotes environmental R&D with a benevolent planner and $E(\Omega)$ denotes environmental R&D with lobbyism.

Note that in case of success the private cost $(C+v)$ is not equivalent to the social cost (C). The payment to the innovator makes this distinction, creating a market failure with a following welfare loss.

7.3 Specifying functional forms

To derive the outcomes of the different R&D cases we need an example with specific functional forms. The functions used in this example follow standard microeconomic theory. The simplest way to illustrate the example is with linear marginal curves.

I will follow the specific functions used in the example of Greaker and Hoel

(2011). The functions are derived from a sector where each firm produces one unit at different cost. The functions emerges when lining up all firms such that the cost function is increasing in numbers of firms.

The new technology will not be beneficial for all producing firms. We let $\hat{x}$ denote the threshold level for innovation adaption where x denotes the marginal firm. For firms below the threshold, $x < \hat{x}$, the revenue to the innovator is $v = 0$, positive revenue is only obtained for the marginal firm on the threshold and those above, $x \geq \hat{x}$. The revenue function (1) can then be given a specific form, following from Greaker and Hoel (2011):

$$v(x, \ell; \alpha) = \ell[x - \hat{x}] \tag{5}$$

where the license fee is multiplied with total adaption of the new technology. For high fees the revenue increases, but at a dimishing rate since less firms are above the threshold, $(x \geq \hat{x})$.

The innovator can develop a new technology denoted α, where the quality $\alpha \in (0, 1)$ is exogenous. The innovation has higher quality and is more radical whenever $\alpha \to 0$. For environmental R&D this would signify an increased cleaning potential, and for market good R&D the cost of producing one unit decreases, $\alpha x \to 0$. If the R&D process fails, then no improvement is achieved $\alpha = 1$ and automatically the license fee becomes $\ell = 0$.

The aggregated social cost function in the case of success is derived from the area beneath the cost curve:

$$C(x, \ell) = \int_0^{\hat{x}} s ds + \int_{\hat{x}}^{x} \alpha s ds = \frac{(1-\alpha)\hat{x}^2}{2} + \frac{\alpha x^2}{2} \tag{6}$$

The marginal social cost of output becomes $C_x(x, \ell) = \alpha x$. The value of $\hat{x}$ is derived in equation (8), giving a specific expression of the cost function in case of success.

If the innovation process fails there exist no threshold, such that $\hat{x} = x$. Then by inserting this into (6) we can derive the social cost function in case of no innovation:

$$\bar{C}(x) = \frac{x^2}{2} \tag{7}$$

where the marginal cost is linear, given by $\bar{C}'(x) = x$. Note that marginal cost for firms below the threshold in case of success equals the marginal cost in the no

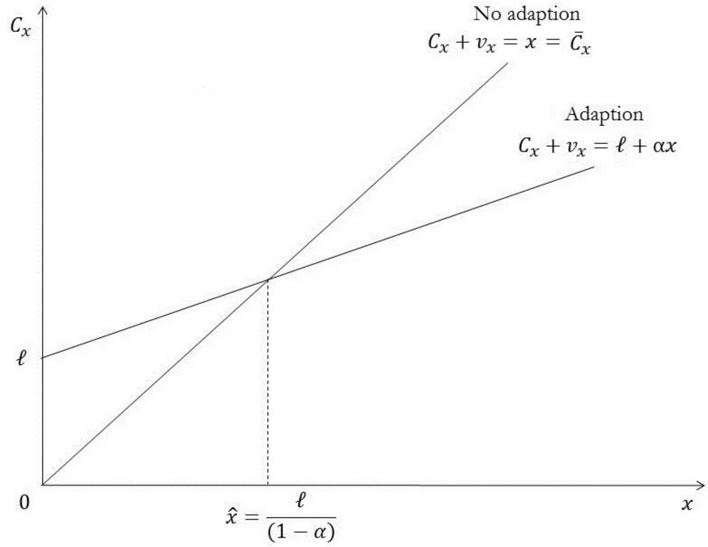

Figure 3: The threshold level of innovation adaption

innovation state, $C_x(x, 0) + v_x(x, 0) = \bar{C}'(x)$. For those firms choosing not to adopt the new technology nothing changes relative to the no innovation outcome.

Firms above the threshold will purchase the new invention, and those below hold on to their old technology. Those producing firms that keep the old technology have private marginal cost $C_x(x, 0) + v_x(x, 0) = x$, and those firms that purchase the new technology have the private marginal cost $C_x(x, \ell) + v_x(x, \ell) = \ell + \alpha x$. The equilibrium is illustrated in figure 3, where we see how the new cost curve has reduced slope and a higher intercept after adaption. From the intersection we can derive the threshold level of technology adaption:

$$\hat{x} = \frac{\ell}{(1-\alpha)} \tag{8}$$

By inserting (8) into (6) we can derive the expression of the social cost function in case of success:

$$C(x, \ell) = \frac{\ell^2}{2(1-\alpha)} + \frac{\alpha x^2}{2} \tag{9}$$

When inserting (8) into (5) we get the expression for the revenue function:

$$v(x, \ell; \alpha) = \ell \Big[x - \frac{\ell}{(1-\alpha)} \Big] \tag{10}$$

which is concave in ℓ and increasing in x such that the conditions suggested for (1) in the general model holds. The revenue to the innovator will differ in the three cases of R&D depending on the specific level of x and ℓ in each case.

Note the difference between the social cost function (6) and the private cost function given by (4). From (10) the private cost function can be given a specific expression:

$$C(x,\ell) + v(x,\ell;\alpha) = \frac{\alpha x^2}{2} + \ell\Big[x - \frac{\ell}{2(1-\alpha)}\Big] \tag{11}$$

Social benefits from (i) produced output or (ii) pollution abatement is given by:

$$B(x) = Bx - \frac{\beta x^2}{2} \tag{12}$$

such that the linear part dominates the quadratic and the standard properties holds, $B'(x) > 0$ and $B'' \leq 0$. Where β denotes the slope of the benefit curve. For the results in this analysis to hold I have added the restriction $\beta \geq 0$. If $\beta = 0$ the marginal benefit curve is a constant flat line equal to B. The lower β the more society benefits from (i) producing the market good or (ii) reducing pollution, the steeper is the social benefit curve. B could have been normalized to one without loss of generality.

If no invention is developed the welfare outcome is given by the difference between social benefit of production and the social cost:

$$\bar{W}^i(x) = B(x) - \bar{C}(x) \qquad i = M, E, E(\Omega) \tag{13}$$

For a explicit expression we insert equation (12) and (7) into (13) and derive the welfare outcome when the innovative process fails:

$$\bar{W}^i(x) = Bx - \frac{x^2}{2}(1+\beta) \qquad i = M, E, E(\Omega) \tag{14}$$

In the case of successful development the realized welfare is derived with the improved social cost function including the cost of adopting the new technology and the improvement of the production. The potential outcome is denoted:

$$W^i(x,\ell) = B(x) - C(x,\ell) \qquad i = M, E, E(\Omega) \tag{15}$$

Notice that the benefits is independent of the innovative process, i.e. $B(x)$ is unchanged for the two potential outcomes (13) and (15).

For a specific expression of realized welfare we insert (12) and (9) into (15). The welfare outcome for successful innovation becomes a function of x and ℓ:

$$W^i(x,\ell) = Bx - \frac{x^2}{2}(\beta+\alpha) - \frac{\ell^2}{2(1-\alpha)} \qquad i = M, E, E(\Omega) \tag{16}$$

The further analysis will compare the different types of R&D to analyze in what means they differ. For environmental R&D the analysis is divided into two subsections, one case with a benevolent government (E) and one scenario with extended commitment problem due to lobbyism ($E(\Omega)$). All cases consist of several sequences, such that they should be solved by backward induction. The "games" are strategic, where the "players" take into account the future actions of the other "players" when deciding their best response.

7.4 Net welfare

With the two potential outcomes, W^i and $\bar{W}^i$, in each of the three R&D cases we can derive the realized gain as the net welfare surplus:

$$\Delta W^i = W^i(x^i,\ell^i) - \bar{W}^i, \quad i = M, E, E(\Omega) \tag{17}$$

From this we define ΔW as the increase in net welfare. With a fee on the technology the invention will be adapted less than optimal since cost increases, $C(x,\ell) > C(x,0)$. Full gain from an innovation is only obtained if the license fee is set to zero.

The definition of net welfare is this thesis' contribution to the investigation of incentives and a distinction from the model in Greaker and Hoel (2011)

7.5 Maximum net welfare

Figure 4 illustrates the welfare losses appearing from innovator's monopoly power. Realized output is x and output level in case of no innovation is denoted by $\bar{x}$. The two triangular losses are marked with bold lines. Realized net welfare is the area between the losses, marked with grey.

The loss to the left is created by those firms not adapting the new technology since their marginal cost is lower than the threshold ($x < \hat{x}$). It is more beneficial for these firms to keep their old technology. The second loss to the right comes from

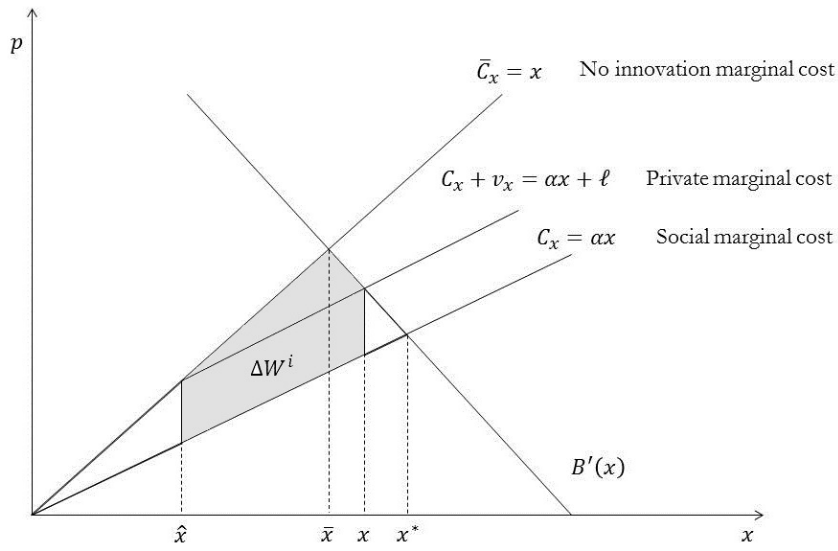

Figure 4: The deadweight losses in the market of R&D

the fact that a positive license fee do not restore the optimal quantum of output. The private cost of adaption is not equal to the social cost of adaption, $(x < x^*)$.

The loss would diminish if more (i) output or (ii) abatement was achieved, but that would only follow from a lower license fee. With a license fee equal to zero the marginal private cost curve would coincide with the marginal social cost curve. However, with a zero license fee the innovator achieves no revenue from her research, $v(x, 0) = 0$ and hence the private incentives decrease. This is the crucial trade off in the appropriability problem.

Figure 4 can be interpreted for all cases of R&D. For the environmental case the figure measures units of abatement on the horizontal axis and price of pollution abatement on the vertical axis. When abatement is zero, the maximum level of emissions is realized. Interpretation is the same for market good R&D with the only difference that produced quantum is measured on the horizontal axis and no governmental interference is applied to reduce the losses. We see from the graph that more abatement/output is achieved the better technology, since the marginal cost curve becomes less steep as $\alpha \to 0$.

To be able to compare the three cases of R&D we need a common benchmark. Defining the *maximal* net welfare surplus that is obtained when $\ell = 0$ we have a equal measure for all three cases. We denote the maximum net welfare as:

$$\Delta W^* = W^* - \bar{W} \quad where \quad \ell = 0 \tag{18}$$

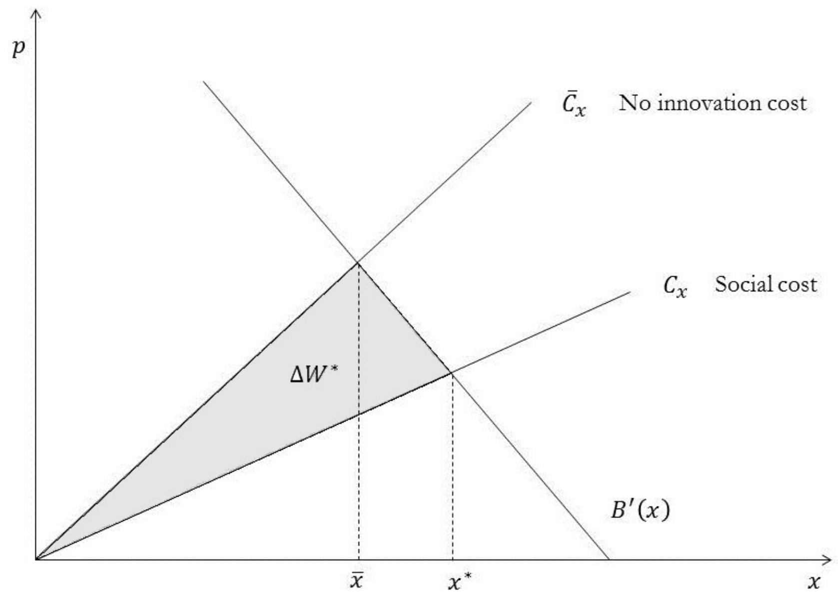

Figure 5: Maximum net welfare

In figure 5 the triangular area marked grey represents the maximum net welfare. The mission of the benevolent planner is to minimize any deadweight loss in the three cases of R&D such that the realized net welfare, ΔW^i come as close to maximal ΔW^* as feasible. The optimal output level in case of successful development and a zero license fee is denoted by x^*.

Deriving an expression for the maximal net surplus in case of success we use the social benefit function (12) and the social cost function (4) where $\ell = 0$ and insert these two into (15):

$$W^* = Bx^* - \frac{(\beta + \alpha)}{2}(x^*)^2 \tag{19}$$

The equilibrium condition is the intersection of marginal benefit and marginal cost $C_x(x, o)$ curves, $B - \beta x = \alpha x$. Solving for x gives the socially optimal level of output:

$$x^* = \frac{B}{(\alpha + \beta)} \tag{20}$$

Inserting (20) into (19) gives the realized max surplus in case of success:

$$W^* = \frac{B^2}{2(\alpha + \beta)} \tag{21}$$

In case of no innovation the equilibrium is given by $B'(x) = \bar{C}'(x)$, i.e. $B - \beta x = x$, giving the no innovation outcome;

$$\bar{x}^M = \frac{B}{(1+\beta)} \tag{22}$$

By inserting (22) into (14) we can derive the realized surplus in case of no innovation:

$$\bar{W} = \frac{B^2}{2(1+\beta)} \tag{23}$$

Since ΔW^* is a common benchmark for all R&D cases, it must follow that $\bar{W}$ also equalize across cases, giving the following proposition:

Proposition 1 *The welfare level in the no innovation state is equal for environmental R&D with a benevolent planner and market good R&D,* $\bar{W} = \bar{W}^E = \bar{W}^M$.

From these two potential outcomes (21) and (23) we can derive maximal net welfare:

$$\Delta W^* = \frac{B^2}{2}\frac{(1-\alpha)}{(\alpha+\beta)(1+\beta)} \tag{24}$$

The maximum net welfare will never be realized because the patent rights allows the innovator to charge a positive fee. It is the monopoly power introduced by the patent system that destroys the chance of restoring the maximum net welfare.

One approach to force realization of the optimal quantum is to set a tax equal to the intersection of marginal cost and marginal benefit. Since the innovator sets the license fee after governmental policy, the innovator seizes the opportunity to set a high license fee, resulting in a deadweight loss. If the government set the tax lower such that the license fee decreases, less incentives to invest in R&D is created.

7.6 The commitment problem

Consider a state of no innovation that we have denoted $\bar{W}$, without the cost of the innovation sector such that $\bar{W} = B(x) - C(x)$. The optimal emission tax set by the government from the desired maximization problem:

$$\max_z \quad \{z(I)W(x,\ell) + (1-z(I))\bar{W} - I\} \tag{25}$$

The first order condition of this maximization problem with respect to the optimal investment, where the notation is simplified by $\Delta W = W - \bar{W}$, would give:

$$\Delta W - (z')^{-1} = 0 \tag{26}$$

From the first order condition of expected revenue to the innovator, equation (3), we know that $v(x, \ell) + P = (z')^{-1}$, giving the condition:

$$\Delta W = (z')^{-1} = v(x, \ell) + P \tag{27}$$

The governmental commitment problem is an issue if the social value of the innovation exceeds the private patent value to the innovator, such that $\Delta W > v(x, \ell)$. My research question is to investigate whether the difference $\Delta W^E - v^E(x, \ell)$ is larger than $\Delta W^M - v^M(x, \ell)$. The appropriability problem makes the innovator unable to collect all private gain from her invention, and therefore the first order condition (26) does not hold. If the government could set a prize such that $P = \Delta W - v(x, \ell)$. Then $P > 0$ and the commitment problem would be solved and the government achieves the optimal investment level. This gives the following proposition:

Proposition 2 *An innovation prize, defined as $P^i = \Delta W^i - v^i$, would yield the optimal investment level I^* and solve the commitment problem.*

This proposition defines the inducement prizes that is this thesis's contribution to the literature on innovation. As far as I know no article has yet modeled these type of prizes in a general model of incentives.

8 Market good R&D

R&D of ordinary market goods represent a laissez-faire case, free of governmental intervention.

8.1 Successful innovation

In case of success the market cross changes with the new cost curve, $C(x, \ell)$. The market price will equalize marginal social benefit with aggregated marginal private cost of production such that $B'(x) = p = C_x + v_x$. Applying (12) and (4), this gives the relation $B - \beta x = \alpha x + \ell$, from which we can solve for produced quantum as a function of the license fee:

$$x^M(\ell) = \frac{B - \ell}{(\alpha + \beta)} \tag{28}$$

The innovator will set the license fee directly after the success since there is no intervention of the government. The innovator does only benefit from those firms above the threshold ($\hat{x}$), those that adopt the new technology. From the threshold level (8) and the output quantum (28) the expression of the patent value (10) becomes:

$$v^M(\ell) = \ell \left[\frac{B(1 - \alpha) - \ell(1 + \beta)}{(\alpha + \beta)(1 - \alpha)} \right] \tag{29}$$

The patent value holds the properties from the general case (1). The innovator maximizes the return of the patent (29) and the first order condition gives an expression for the license fee:

$$\ell^M = \frac{B(1 - \alpha)}{2(1 + \beta)} \tag{30}$$

When inserting (30) into (28) we have achieved an expression for x^M:

$$x^M = \frac{B(1 + \alpha + 2\beta)}{2(\alpha + \beta)(1 + \beta)} \tag{31}$$

Produced quantum increases the better innovation $\frac{dx}{d\alpha} < 0$, and decreases the less social benefit the product gives $\frac{dx}{d\beta} < 0$.

By inserting (30) and (31) into (29), we have an expression of v^M:

$$v^M = \frac{B^2(1 - \alpha)}{4(\alpha + \beta)(1 + \beta)} \tag{32}$$

When inserting (30) and (28) into (16) we find an expression for realized welfare in case of successful innovation:

$$W^M = \frac{B^2}{8} \frac{(3 + \alpha + 4\beta)}{(\alpha + \beta)(1 + \beta)} \tag{33}$$

8.2 Net surplus

If no invention is developed the welfare outcome is given by (14). Realized welfare in the no innovation state is given by (23) from proposition 1. With the potential outcome of the two scenarios, we can derive the increase in net surplus, $\Delta W^M =$

$W^M - \bar{W}^M$ for the case of market good R&D:

$$\Delta W^M = \frac{B^2}{8}\frac{3(1-\alpha)}{(\alpha+\beta)(1+\beta)} \tag{34}$$

Comparing (20) to (22) and (31) gives the ranking of output illustrated in figure 4.

Proposition 3 *Output in the no innovation state is lower than output for successful innovation, but none reach the social optimal level of output, $\bar{x} < x^M < x^*$, and by transitivity it follows that $\bar{x} < x^*$.*

Proof.
Consider $\bar{x} > x^M$, then by rearranging it follows that $0 > (1-\alpha)(1+2\alpha)$. From the restriction $\alpha \in (0,1)$ we know that $0 > (1-\alpha)$ never holds, contradicting the statement and implying that $\bar{x} < x^M$.
Consider $x^M > x^*$ then by rearranging it follows that $(1+\alpha) > 2$. From the restriction $\alpha \in (0,1)$ we know that this never holds, and therefore by contradiction it implies that $x^M < x^*$.
By transitivity it follows that $\bar{x} < x^*$. This holds as long as $\frac{1}{(1+\beta)} < \frac{1}{(\alpha+\beta)}$ that imply $\alpha < 1$, supported by the restriction $\alpha \in (0,1)$. ■

We see from this proposition that the patent system prevents realized output in both scenarios ($\bar{x}$) and (x^M) to reach the social optimum level. The social optima would only be realized if the successful innovation was spread free of charge.

Comparing the net welfare for market good R&D (34) with the maximum net surplus (24) we see that the realized welfare falls short for the maximum value. This follows from the monopoly power the innovator achieves from the patent rights. Since the license fee is set to larger than zero some downstream firms choose not to adopt the new technology and a deadweight loss is created. For less radical inventions ($\alpha \to 1$), the difference in net welfare, $\Delta W^M - \Delta W^E < 0$ diminishes.

Proposition 4 *The realized welfare in the case of market good R&D is less than maximal net welfare, $\Delta W^M < \Delta W^*$ due to intellectual property rights.*

9 Environmental R&D with a benevolent planner

The case of environmental R&D involves more uncertainty for the innovator. At the time the innovator decides her investment the future tax level is unknown, the uncertainty is followed by what fee she can charge. The planner sets the tax strategical, considering the license fee the innovator sets as best response.

In this section we interpret the output (x) as units of abatement. The equilibrium output level is given by the objective of the benevolent planner, maximizing welfare with respect to the emission tax. The no-innovation case and the successful innovation case is analyzed respectively.

9.1 No innovation

When the outcome of the R&D process fails it implies that $\alpha = 1$. The market adjusts such that private cost equals the tax on the margin, implying that the abatement level becomes equal the emission tax::

$$\bar{t}^E = \bar{C}'(x) = \bar{x}^E \tag{35}$$

In the case of no-innovation the government maximizes (13) subjected to (35). The no-innovation tax level $\bar{t}^E$ is derived from the first order condition. The policy is set such that marginal benefits from abatement equals marginal social cost of abatement:

$$\left(B'(x) - \bar{C}'(x)\right)\frac{dx}{dt} = 0 \tag{36}$$

Rearranging with respect to the tax we can derive an expression for the tax level:

$$\bar{t}^E = \frac{B}{(1+\beta)} = \bar{x}^E \tag{37}$$

From (37) we see that the abatement level in the no innovation case is equal to the quantum in the no innovation case for market good R&D, $\bar{x}^E = \bar{x}^M$. By inserting (37) into the welfare function (14) we get realized welfare (23), as already stated when discussing the benchmark. Then we have proven that proposition 1 holds for the environmental R&D case.

9.2 Successful innovation

Taxation makes the production sector less profitable, creating demand for environmental R&D. This encourages the innovator to invest in R&D and to supply green technology to meet the request. In the downstream sector the private abatement cost (4) is adjusted such that it equals the tax on the margin:

$$t^E = C_x(x, \ell) + v_x(x, \ell; \alpha) \tag{38}$$

The patent allows the innovator to set a positive price on the invention. For a positive license fee, $\ell > 0$ it is costly to adapt the invention. The higher license fee less abatement is be achieved.

With respect to the tax the innovator set the license fee by maximizing returns:

$$\max_{\ell} \quad v(x(t, \ell), \ell(t); \alpha) \tag{39}$$

The response function of the innovator is then denoted $\ell(t)$, where the innovator can charge a higher fee the stricter policy, $\frac{d\ell}{dt} > 0$.

From these equations the realized level of abatement $x = x(t, \ell)$ can be derived. Downstream firms consider whether it is profitable to buy the new technology due to their individual abatement cost, the tax and the license fee. By purchasing the new technology the producing firms can decrease emissions and avoid the tax, this would only be profitable if $\ell \leq t^E$.

When deriving specific expressions the abatement level will be determined from the equilibrium adjustment condition (38). The downstream sector adjust their marginal private abatement cost to be equal the emission tax, this gives $t = \alpha x + \ell$. From this equilibrium condition we can derive the the abatement level:

$$x^E(t, \ell) = \frac{t - \ell}{\alpha} \tag{40}$$

The innovator incorporates the abatement level (40) into her expected revenue such that the patent value (10) becomes:

$$v^E(t, \ell; \alpha) = \ell \left[\frac{(1 - \alpha)t - \ell}{\alpha(1 - \alpha)} \right] \tag{41}$$

By maximizing the patent value we derive the innovator's best response function:

$$\ell^E(t^E) = \frac{(1-\alpha)t^E}{2} \tag{42}$$

The license fee becomes a function of the tax. We can further determine the abatement level as a function of the tax by inserting (42) into (40):

$$x^E(t^E) = \frac{(1+\alpha)t^E}{2\alpha} \tag{43}$$

The social planner has full information about the R&D outcome and knows whether the development was successful. The tax setting would implicitly yield the abatement level through governmental maximization.

The benevolent planner sets the emission tax by maximizing social welfare (15) subjected to (43). The first order condition of (15) gives the optimal emission tax equation:

$$\big(B'(x) - C_x\big)\frac{dx}{dt} - C_\ell \frac{d\ell}{dt} = 0 \tag{44}$$

We see from equation (44) how the tax level differs in the diverse outcomes of the R&D process, $\bar{t}^E \neq t^E$. Since the planner encompasses the development of a new innovation when setting the environmental policy, the tax becomes a strategic parameter that depends on the outcome of the innovative process.

The last term in (44) is negative, since a higher tax will increase the license fee, following the best response of the innovator. The last term ensures that the first best condition is not satisfied, where marginal benefits form abatement should equal marginal abatement cost. Instead, since the benefits of pollution reduction is increasing at a diminishing rate, the first term must be positive such that marginal benefits exceed the marginal cost in order of the first order condition to hold, $B'(x) > C_x$. The last term reflects in what manner the planner considers how the tax affects the license fee. If the tax is high the license fee will follow and the new technology becomes expensive. A deadweight loss is created through mark-up pricing by the monopolistic innovator.

Proposition 5 *The optimal tax balances two existing deadweight losses: Too little abatement is carried out and the tax prevents the license fee from becoming too high.*

This illustrates the commitment problem. Policies are not consistent with the innovation process as policies change relative to the outcome. The first order condition (44) clarifies the two market failures the tax is intended to correct for. The first term is pollution abatement correction, and the last term is deadweight loss from monopoly pricing.

When maximizing (16) subjected to (43) and (42) we can derive an expression for the tax level:

$$t^E = \frac{B2\alpha(1+\alpha)}{\beta(1+\alpha)^2 + \alpha(1+3\alpha)} \tag{45}$$

To derive the realized social welfare level in the state of successful innovation we insert (45) into the objective (16):

$$W^E = \frac{B^2}{2}\frac{(1+\alpha)^2}{\beta(1+\alpha)^2 + \alpha(1+3\alpha)} \tag{46}$$

When we have derived the tax level we can insert (45) into (43) and find an explicit expression for the abatement level:

$$x^E = \frac{B(1+\alpha)^2}{\beta(1+\alpha)^2 + \alpha(1+3\alpha)} \tag{47}$$

From expression (47) we see that more abatement is accomplished in presence of a new technology, compared to (22).

Proposition 6 *More abatement is achieved when an innovation has been successfully developed,* $\bar{x} < x^E$

Proof. Consider $\bar{x} > x^E$ then by rearranging (37) and (47) it follows that $0 > (1+2\alpha)(1-\alpha)$. From the restriction $\alpha \in (0,1)$ we know that $0 \geq (1-\alpha)$ never holds. This implies by contradiction that $\bar{x} < x^E$. ■

From proposition 9.2 we see that R&D rise the abatement level, but it does not reach the social optimal level (x^*) because too few firms adopt the new invention.

Proposition 7 *The abatement level in case of successful innovation is not social optimal due to a positive license fee,* $x^E < x^*$

Proof. Consider $x^E > x^*$ then by rearranging (20) and (47) it follows that $0 > \alpha^2(1-\alpha)$. From the restriction $\alpha \in (0,1)$ we know that $0 \geq (1-\alpha)$ never holds. This implies by contradiction that $x^E < x^*$. ■

Successful innovation and the increase in abatement is accompanied by a deadweight loss created by patent rights. Comparing the abatement levels alone does not give any indication about welfare effects. Therefore we need a comparison of the two potential welfare outcomes.

The patent value in the case with a benevolent planner is derived by inserting (45) into (82):

$$v^E = \frac{B^2(1-\alpha)\alpha(1+\alpha)^2}{(\beta(1+\alpha)^2 + \alpha(1+3\alpha))^2} \tag{48}$$

When inserting (45) into (42) we can derive the an expression for the license fee:

$$\ell^E = \frac{B\alpha(1+\alpha)(1-\alpha)}{\beta(1+\alpha)^2 + \alpha(1+3\alpha)} \tag{49}$$

Comparison with (30) depends on the combinations of β and α, and no specific ranking of the two license fees is possible. For a higher license fee the intercept of the new cost function is higher (Figure 4), followed by an increased deadweight loss. Giving an outcome further away from the maximal net surplus, ΔW^*.

9.3 Net surplus

From (46) and (23) we can derive the net surplus, $\Delta W^E = W^E - \bar{W}^E$:

$$\Delta W^E = \frac{B^2}{2} \frac{1+\alpha-2\alpha^2}{(\beta(1+\alpha)^2 + \alpha(1+3\alpha))(1+\beta)} \tag{50}$$

We see from this expression that realized net welfare do not reach potential maximum net surplus ΔW^*, the limiting cases gives:

$$\lim_{\alpha \to 0} \Delta W^E = \Delta W^* = \frac{B^2}{2\beta(1+\beta)} \tag{51}$$

$$\lim_{\alpha \to 1} \Delta W^E = \Delta W^* = 0 \tag{52}$$

These limits illustrate that net welfare in the case of environmental R&D never reaches the maximal net welfare level, since $\alpha \neq 0$ and $\alpha \neq 1$.

Proposition 8 *The realized welfare in the case of environmental R&D with a benevolent planner will always be less than maximal net welfare, $\Delta W^E < \Delta W^*$, due to intellectual property rights and insufficient policies.*

This follows from the two market failures present in this case: the environmental externality and the patent monopoly power. The benevolent planner has only one instrument to correct for these to failures, the emission tax, and is therefore falling short in his mission to max welfare.

10 Environmental R&D with lobbyism

In this section the benevolent social planner suffers from “weakness of will” such that planners objective is not equivalent to the realized welfare functions (15) and (13). The objective is influenced by interest groups from the downstream sector trying to protect their private profit. When introducing private interests we need to extend the model such that the downstream sector produce both a profitable product, denoted q, and abatement denoted x.

By including the aspect of lobbyism the tax decrease and incentives to invest in environmental R&D becomes significantly lower. The social planner misses the target. But, on the other hand, a low tax is followed by a lower license fee contributing to the diffusion of the innovation. The interesting aspect is which effect dominates the other, the net welfare or the patent revenue to the innovator. This determines the effect on incentives.

The planner's objective is modeled as a weighted average, where ρ denotes the lobby parameter, $\rho \in (0, 1)$. For low values of ρ the interest groups have more impact on the governmental decision and the planner puts less weight on social benefits. The lobby parameter expresses the trade-off with the pressure groups.

I assume that the cost of producing the product q is independent of abatement cost. The private profit function in case of innovation is denoted:

$$\Omega(q, x, \ell) = \Omega(q) - C(x, \ell) \tag{53}$$

However, if no innovation is developed the private profit function becomes:

$$\bar{\Omega}(q, x) = \Omega(q) - \bar{C}(x) \tag{54}$$

Where the revenue for the profitable product is given by $\Omega(q) = pq - c(q)$ and is unchanged in the two potential outcomes, independent of x and ℓ. Note that the cost of abatement is independent of production cost, $C(q)$. This follows from the assumption that the new technology only affects costs and not production methods. The emission tax is set on the level of abatement and not on produced outcome. Therefore only the last term, the cost of abatement are affected by the taxation and relevant for the analysis.

10.1 No innovation

In the case of no innovation the governmental objective becomes:

$$\max_t \quad \bar{G}^{\Omega}(x(t), q) = \rho B(x(t)) + (1-\rho)\Omega(q) - \bar{C}(x(t)) \tag{55}$$

We see that the planner puts full weight on abatement cost, and weight the benefit of abatement with the lobby parameter such that benefits are less prioritized in presence of lobbyism.

The first order condition, with some rearranging is given by:

$$\big(B'(x) - \bar{C}_x\big)\frac{dx}{dt} - \frac{(1-\rho)}{\rho}\bar{C}_x\frac{dx}{dt} = 0 \tag{56}$$

This condition can easily be compared to (36) in the case with a benevolent planner. We see that the additional negative term decreases the tax level relative to the case with a benevolent planner.

The private adjustment condition for the downstream sector becomes:

$$\bar{t}^{\Omega} = \bar{C}'(x) = \bar{x}^{\Omega} \tag{57}$$

We insert (57) into $\bar{C}(x)$ to derive an expression for the profit function of the downstream sector (54) as a function of the tax:

$$\bar{\Omega}(q,t) = \Omega(q) - \frac{1}{2}(t^{\Omega})^2 \tag{58}$$

The planner maximize (55) subjected to (57), (58), (7) and (12). The first order condition gives the tax level in the no innovation state:

$$\bar{t}^{\Omega} = \frac{B}{1/\rho + \beta} \tag{59}$$

We see from this expression that the presence of the lobby parameter gives a negative shift in the tax level. The significance depends on the magnitude of the parameter, the smaller value the lower becomes the tax. When the pressure groups are weak, $\rho \rightarrow 1$, the tax approaches the tax level in the no innovation state for environmental R&D with a benevolent planner:

$$\lim_{\rho \rightarrow 1} \bar{t}^{\Omega} = \bar{t}^{E} = \frac{B}{(1+\beta)} \tag{60}$$

Already from the general derivation of the first order conditions, (36) and (56) we were able to compare the expressions for the tax levels and notice the striking difference. An extra negative term is added to the first order condition from the influenced objective.

Proposition 9 *In the case of no innovation the tax is lower in state of lobbyism than the tax in the state of a benevolent planner,* $\bar{t}^{\Omega} < \bar{t}^{E}$.

Proof. Consider $\bar{t}^{\Omega} > \bar{t}^{E}$ then by rearranging (59) and (37) it follows that $0 > (1-\rho)$. From the restriction $\rho \in (0,1)$ we know that $0 \geq (1-\rho)$ never holds. This implies by contradiction that $\bar{t}^{\Omega} < \bar{t}^{E}$. ■

Note that the tax level, derived from the influenced objective, is inserted into the original welfare function to find an expression for realized welfare. By inserting (59) into the original welfare function (14) we find the realized level of welfare in the state of no innovation:

$$\bar{W}^{E(\Omega)} = \frac{\rho B^2}{2(1+\rho\beta)^2}(2-\rho+\rho\beta) \tag{61}$$

From (61) we see that welfare is determined by the significance of the lobby parameter. Welfare decreases the stronger the influence by lobby groups. In the extreme case with max lobbyism no welfare of abatement is realized since all weight in the objective is on the private profit of the downstream firms:

$$\lim_{\rho \rightarrow 0} \bar{W}^{E(\Omega)} = 0 \tag{62}$$

This follows from a realized abatement level equal to zero, $x = 0$. Notice that even though welfare of abatement becomes zero, there will be some realized welfare from the output q.

Proposition 10 *The lobby parameter decreases the welfare in the no innovation state due to the significance of influence,* $\lim_{\rho\to 0} \bar{W}^{E(\Omega)} = 0$.

On the other hand, If the lobby parameter approaches one and the significance is weaker, welfare becomes equivalent to the no innovation welfare of both market good R&D and environmental R&D with a benevolent planner:

$$\lim_{\rho\to 1} \bar{W}^{E(\Omega)} = \bar{W}^{M} = \bar{W}^{E} \tag{63}$$

With approximately no lobbyism, the net welfare in the no innovation state will coincide with the result in proposition 1.

10.2 Successful innovation

In the case of successful development the distorted objective for taxation becomes:

$$\max_{t} \quad G^{\Omega}(x(t), q) = \rho B(x(t)) + (1-\rho)\Omega(q) - C(x(t), \ell(t)) \tag{64}$$

The lobbyism applies extra costs in the objective and the result is a weaker policy. The first order condition is given by:

$$\big(B'(x) - C_x\big)\frac{dx}{dt} - C_\ell \frac{d\ell}{dt} - \frac{(1-\rho)}{\rho}\Big(C_x \frac{dx}{dt} + C_\ell \frac{d\ell}{dt}\Big) = 0 \tag{65}$$

An extra negative term is added to the equation, compared to (44). This implies that the tax level (t^{Ω}) derived from (65) would be lower compared to the tax in case of environmental R&D with a benevolent planner, (t^{E}). The significance of the negative shift will depend on the value of the lobby parameter ρ.

To determine specific expressions we use backward induction and start out with the producing firms following their taxation adjustment equation:

$$t^{\Omega} = C_x(x, \ell) + v_x(x, \ell) \tag{66}$$

From (66) we derive the abatement level as a function of the tax and the license fee:

$$x(t, \ell) = \frac{t-\ell}{\alpha} \tag{67}$$

Given the realized abatement level (67) we can derive the best response function of the innovator, $\ell(t^\Omega)$ as a function of the lobby tax:

$$\ell^\Omega(t^\Omega) = \frac{(1-\alpha)t^\Omega}{2} \tag{68}$$

Then by inserting (68) into (67) the abatement level becomes a function of the tax alone:

$$x^\Omega(t^\Omega) = \frac{(1+\alpha)t^\Omega}{2\alpha} \tag{69}$$

When inserting (69) the profit function of the downstream firms (53) becomes:

$$\Omega = \Omega(q) - \frac{1+3\alpha}{8\alpha}t^2 \tag{70}$$

The government maximize (64) subjected to (68), (69), (70), (6) and (12). Deriving the first order condition we have an expression for the lobby tax in the successful innovation state.

$$t^\Omega = \frac{2\alpha\rho B(1+\alpha)}{\rho\beta(1+\alpha)^2 + \alpha(1+3\alpha)} \tag{71}$$

The limiting cases gives us:

$$\lim_{\rho\to 1} t^\Omega = t^E \tag{72}$$

$$\lim_{\rho\to 0} t^\Omega = 0 \tag{73}$$

When lobbyism is weak, $\rho \to 1$, the tax approaches the tax level in the case of a benevolent planner. On the other hand, the stronger interest groups the lower is the tax, until the tax fades out completely.

Proposition 11 *In the case of successful innovation the tax is lower when lobbyism is present than the tax in the state of a benevolent planner,* $t^\Omega < t^E$.

Proof. Consider $t^\Omega > t^E$ then by rearranging (71) and (45) it follows that $0 > \alpha(1+3\alpha)(1-\rho)$. From the restriction $\rho \in (0,1)$ we know that $0 \geq (1-\rho)$ never holds. This implies by contradiction that $t^\Omega < t^E$. ■

When inserting the lobby tax (71) into the patent function (82) we can derive an expression for the patent value in the case of lobbyism:

$$v^\Omega = \frac{B^2\rho^2(1-\alpha)\alpha(1+\alpha)^2}{(\rho\beta(1+\alpha)^2 + \alpha(1+3\alpha))^2} \tag{74}$$

Inserting the lobby tax into the original welfare function (16) we have an expression for realized welfare:

$$W^{E(\Omega)} = \frac{\rho B^2}{2}\left(\frac{2\alpha + 6\alpha^2 - \rho\alpha + \rho\beta - 3\rho\alpha^2 + \rho\beta\alpha^2 + 2\rho\beta\alpha}{(\rho\beta(1+\alpha)^2 + \alpha(1+3\alpha))^2}(1+\alpha)^2 - \frac{(2-\rho+\rho\beta)}{(1+\rho\beta)^2}\right) \tag{75}$$

The limiting cases gives us the same results as above:

$$\lim_{\rho\to 1} W^{E(\Omega)} = W^E \tag{76}$$

$$\lim_{\rho\to 0} W^{E(\Omega)} = 0 \tag{77}$$

The stronger lobbyism, the more weight is put on the private profit in the objective and less welfare is realized.

Proposition 12 *The lobby parameter decreases the welfare in the successful innovation state,* $\lim_{\rho\to 0} W^{E(\Omega)} = 0$, *due to the significance of influence.*

10.3 Net surplus

The net surplus in presence of lobbyism is derived from (61) and (75):

$$\Delta W^{E(\Omega)} = \frac{\rho B^2}{2}\left(\frac{\rho\beta(1+\alpha)^2 + (2-\rho)\alpha(1+3\alpha)}{(\rho\beta(1+\alpha)^2 + \alpha(1+3\alpha))^2}(1+\alpha)^2 - \frac{(2-\rho+\rho\beta)}{(1+\rho\beta)^2}\right) \tag{78}$$

Lobbyism affects the only governmental instrument to remedy the environmental market failure, such that less abatement is achieved and too little innovation is generated. However, a low tax makes the innovator able to charge a lower license fee for the innovation such that more firms afford to purchase the new invention.

After deriving explicit expressions for the realized net welfare and the private return in each R&D scenario we can start to systematically compare incentives. Following proposition 2, the prize is determined as the difference in net welfare and patent value, following from the regulators optimizing of incentives.

I will first compare net surplus in the different cases, followed by a comparison of the patent values in each case. Thereafter I derive and analyze the prizes based on the result from the two following sections.

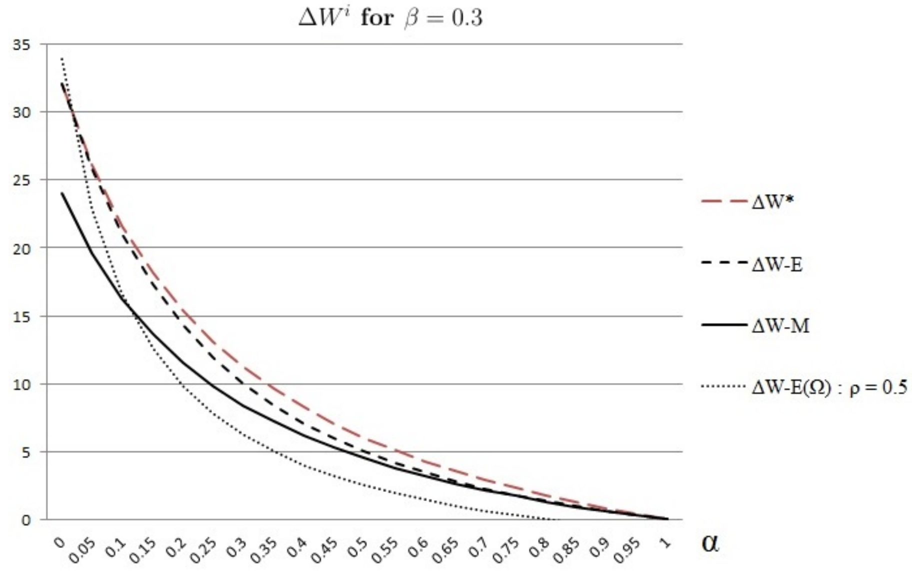

Figure 6: Comparison of net surplus (ΔW^i) given $\beta = 0.3$

11 Comparison of net surplus

Illustrated in figure 6 is the net welfare of the three different cases (34), (50) and (78) and the maximum net surplus (24). The graph is drawn for a given value of β set to 0.3. We see that net welfare depends on the significance of the innovation quality, α. The better innovation thus greater net welfare is realized in all cases.

From figure 6 we see that maximum net surplus lies significantly above all other realizations. Recall proposition 4 and proposition 8 where the two relationships: $\Delta W^M < \Delta W^*$ and $\Delta W^E < \Delta W^*$ was stated. The net welfare of any R&D case will never reach the maximum level due to intellectual property rights.

From the limiting cases of ΔW^E, equation (51) and (52), the net welfare is approaching the maximum, as illustrated in figure 6, but the max is never reached. Maximal net surplus is only achievable if the new invention is spread for free.

Net welfare in the case of environmental R&D (50) is larger than net welfare for ordinary market goods (34), and this holds for any value of $\beta \geq 0$. The difference, $\Delta W^E - \Delta W^M \geq 0$, is more significant for high quality innovations, yielding more social welfare in the environmental case due to the pollution externality.

Proposition 13 *Net welfare in the case of environmental R&D with a benevolent planner is greater than net welfare in case of market good R&D,* $\Delta W^M < \Delta W^E$ *as long as* $\beta > 0$*, given that all other parameters are equal.*

Proof. If $\Delta W^M < \Delta W^E$ then by rearranging (50) and (34) it follows that $\beta > \frac{-\alpha}{(1+3\alpha)}$. Consider $\beta < \frac{-\alpha}{(1+3\alpha)}$ then $\beta < 0$, contradicting the restriction $\beta \geq 0$. Consider $\beta = \frac{-\alpha}{(1+3\alpha)}$ then $\beta < 0$, again contradicting the restriction $\beta \geq 0$. Then it follows that $\Delta W^M < \Delta W^E$. ■

The reason behind proposition 13 is the policy intervention by the government. The planner determines the demand for R&D indirectly when setting the environmental policy such that more innovation is stimulated and net welfare increase. The emission tax will increase realized net welfare in the environmental case, even if the innovation has the same social value in both cases.

Net welfare in the case of lobbyism shifts downwards and further away from maximal net welfare the stronger lobbyism influences the welfare function, $\rho \to 0$, as illustrated in figure 6.

It follows from proposition 10 and proposition 12 that the net welfare in case of lobbyism approaches the net welfare for environmental R&D with a benevolent planner when lobbyism diminishes:

$$\lim_{\rho \to 1} \quad \Delta W^{E(\Omega)} = \Delta W^E \tag{79}$$

The poorer innovation, less net welfare is realized and it reaches the level of zero sooner than the other cases, see figure 6:

$$\lim_{\alpha \to 1} \quad \Delta W^{E(\Omega)} = 0 \tag{80}$$

The functions of net welfare depends on the parameter values. An comparison of ΔW^M and $\Delta W^{E(\Omega)}$ will therefore depend on the combination of α and β for a given value of ρ. To illustrate a comparison three examples are plotted, each with a different lobbyparameter. Figure 7, figure 8 and figure 9 illustrates weak lobbyism, strong lobbyism and intermediate lobbyism respectively.

The figures are 3D plots where net welfare is measured on the vertical axis, and values of β (to the left) and α (to the right) on the two horizontal axes. The net welfare for market good R&D (ΔW^M) is illustrated with a black "carpet", and the white "carpet" illustrates net welfare with lobbyism ($\Delta W^{E(\Omega)}$). For each combination of α and β we can compare net welfare to see which effect dominates.

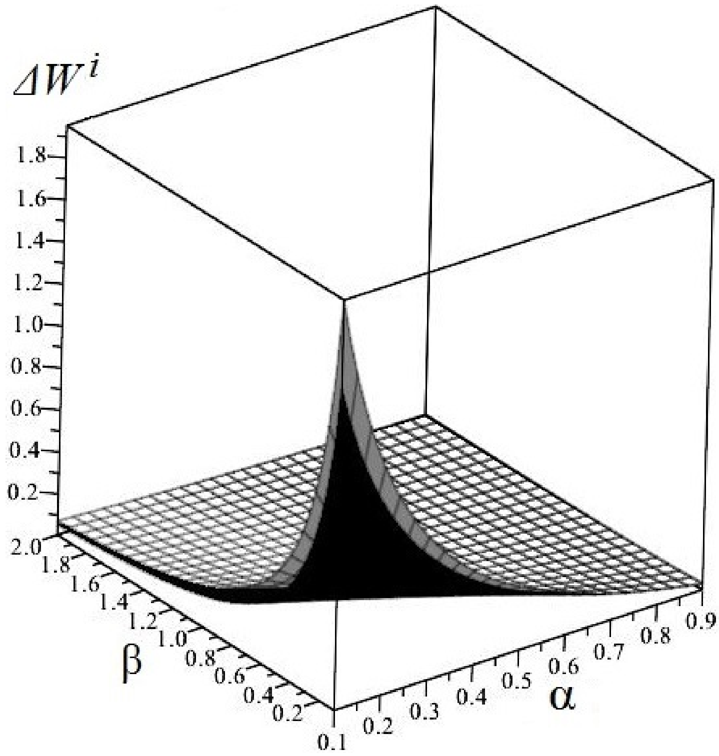

Figure 7: 3D plot of ΔW^M (black) and $\Delta W^{E(\Omega)}$ (white) given $\rho = 0.9$

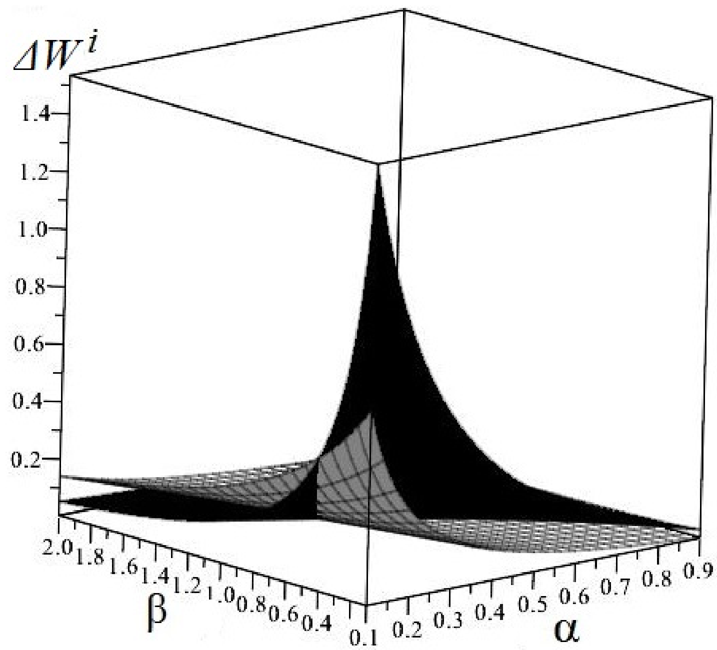

Figure 8: 3D plot of ΔW^M (black) and $\Delta W^{E(\Omega)}$ (white) given $\rho = 0.1$

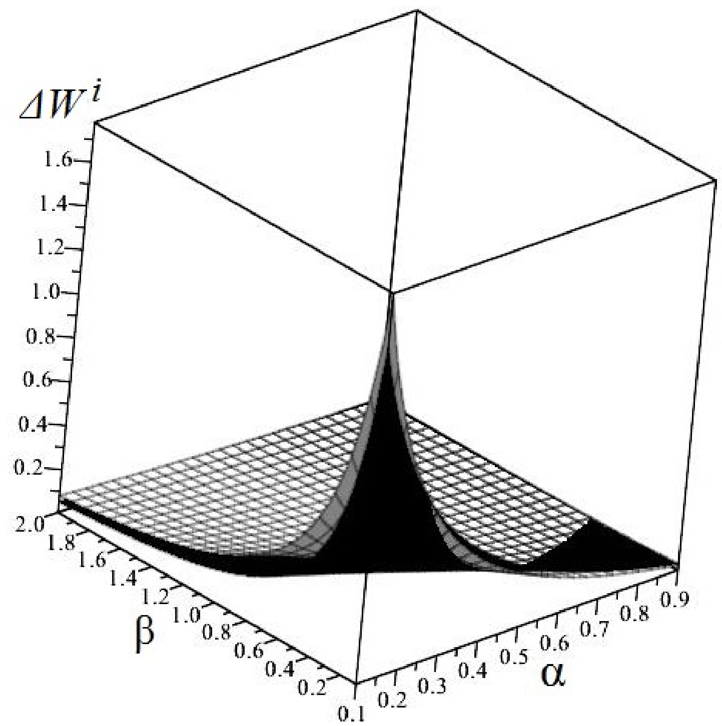

Figure 9: 3D plot of ΔW^M (black) and $\Delta W^{E(\Omega)}$ (white) given $\rho = 0.5$

When the two planes (white and black) cross each other it implies that the net welfare functions are equal for that specific combination of α, β and ρ. In figure 7 we see that for weak impact of interest group the comparison reminds of proposition 13 where the net welfare for environmental R&D completely dominates the net welfare of ordinary market good R&D. There is no intersection of the two planes.

Looking at figure 8 and figure 9 we notice that when the influence by lobby groups is stronger the planes cross, and hence none effect strictly dominates the other. This yields for any value of ρ larger than 0.9.

The 3D plots has a common feature, net welfare effects increases for low values of α and low values of β. In this case the marginal benefit curve is steep giving a great social gain when developing a good quality invention.

From these graphs, in figure 7, 8 and 9, I have illustrated that a general ranking of the two net welfare functions, net welfare in case of lobbyism ($\Delta W^{E(\Omega)}$) compared to the laissez-faire case (ΔW^M), is not possible:

Proposition 14 *Comparing ΔW^M to $\Delta W^{E(\Omega)}$ gives no specific ranking that holds for all values of $\rho \in (0, 1)$.*

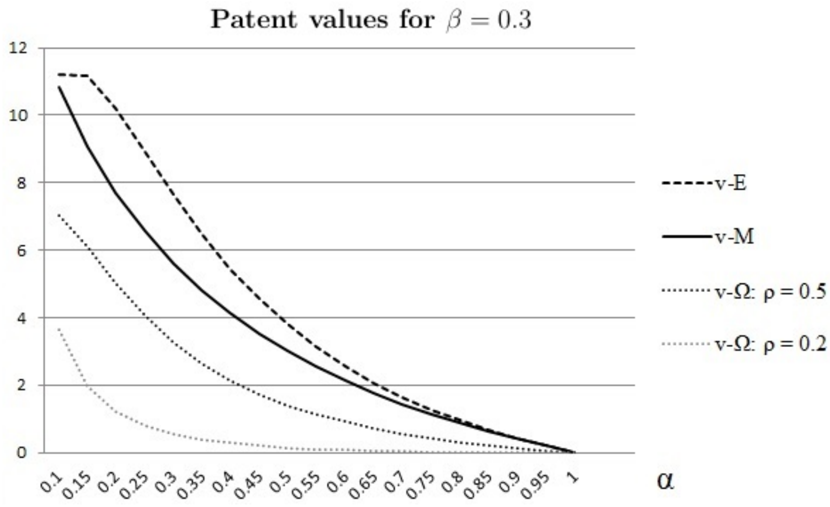

Figure 10: The patent values of the three different R&D cases

12 Comparison of patent values

Figure 10 illustrates the different patent values for a given value of β. In the case of lobbyism two distinct values of ρ is indicated in the figure. The graph illustrates that highest revenue to the innovator is achieved in the case with environmental R&D, given $\beta = 0.3$. This only states whats illustrated in the figure and it turns out not to hold as a general result.

The lower quality on the innovation ($\alpha \to 1$), less revenue is achieved. This holds for all three R&D cases:

$$\lim_{\alpha \to 1} v^i = 0 \qquad i = M, E, E(\Omega) \tag{81}$$

In the case of market good R&D, the laissez-faire scenario, the demand for the new technology is created from the downstream firms' desire to reduce production costs. The patent value is given by equation (32). We see that the patent value increases the better quality ($\alpha \to 0$) the innovation has, $\frac{dv}{d\alpha} < 0$, and the patent increases in social benefits, i.e $\frac{dv}{d\beta} < 0$.

For environmental R&D the patent is derived from $v(x(t), \ell(t); \alpha)$. Inserting (43) and (42), or equivalent (69) and (68), gives a patent value determined by the tax:

$$v^i(t^i) = \frac{(1-\alpha)}{4\alpha}(t^i)^2 \qquad i = E, E(\Omega) \tag{82}$$

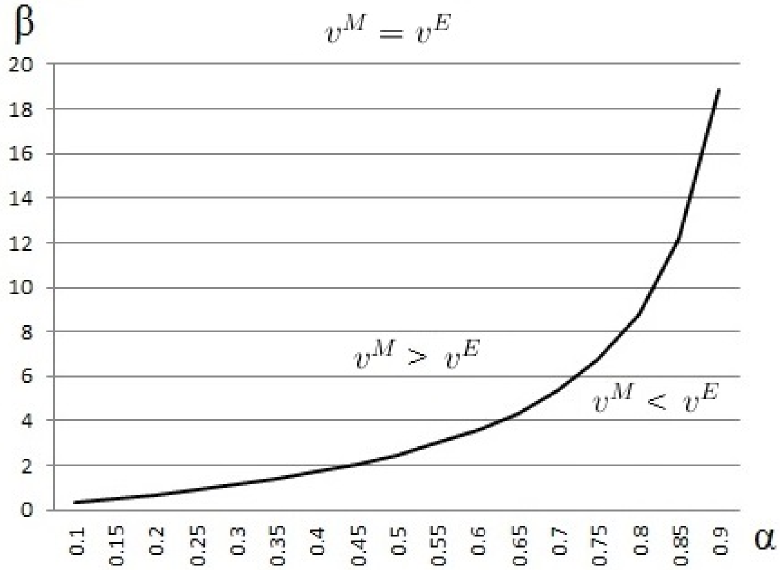

Figure 11: The combinations of β and α that equalize v^E to v^M

where the patent increases in the tax level, $\frac{dv}{dt} > 0$. With a higher tax on emissions more firms are pushed over the threshold $\hat{x}$. Adapting the new technology becomes profitable for more firms when abatement is costly, increasing the returns to the innovator.

The patent value in the case of a benevolent planner is given by equation (48). When comparing the patent of environmental R&D to the patent value of the laissez-faire case we see from figure 11 what combinations of α and β that equalize the patent values. There exist combinations where the private incentives to innovate is equal in both scenarios. All combinations of α and β above the line yields $v^M > v^E$. Hence, in our example a radical invention ($\alpha \to 0$) implies a larger range of β for which this holds. This gives the result from Graker and Hoel (2011):

Proposition 15 *No general ranking of the patent values v^E and v^M is possible.*

An expression for the patent value in the case of lobbyism is given by equation (74). Lobbyism affects the revenue to the innovator indirectly through the environmental policy, making it less profitable to invent. Weaker policy decreases incentives:

$$-\frac{dv^{\Omega}}{d\rho} < 0 \tag{83}$$

Proposition 16 *The private incentives to invest in R&D decreases the more lobby groups influences the objective of the planner, ($\rho \to 0$).*

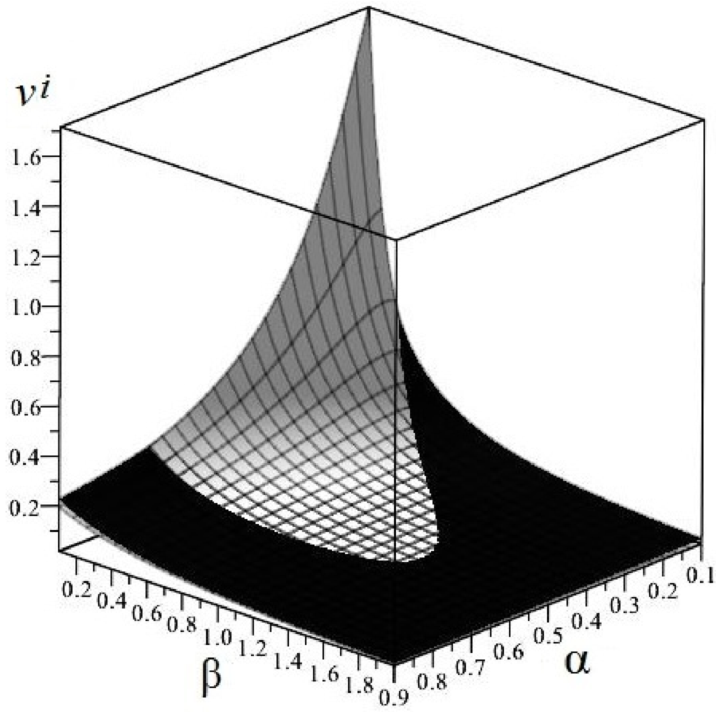

Figure 12: 3D plot of v^M (black) and v^Ω (white) given $\rho = 0.9$

When interest groups put a downward pressure on the tax, the demand for environmental R&D decreases. On the other hand, a low tax yields a low license fee such that more firms can afford to purchase the new invention. The negative effect from demand is stronger than the increased spread. Lobbyism gives a substantial negative shift in the patent value, and the effect is stronger for high quality inventions ($\alpha \to 0$), compared to the case with a benevolent planner.

Proposition 17 *In the presence of lobbyism the patent value decreases,* $v^\Omega < v^E$ *due to less private incentives.*

Proof. Consider $v^\Omega > v^E$, then by rearranging (48) and (74) it follows that $0 > \alpha(1+3\alpha)(1-\rho)$. From the restriction $\rho \in (0,1)$ we know that $0 \geq (1-\rho)$ never holds. This implies that $v^\Omega < v^E$ and the proposition holds. ■

Comparing the patent value in presence of lobbyism to the patent value in the laissez-faire does not give a general ranking, holding for all values of ρ. The comparison of v^M and v^Ω is illustrated in two 3D plots, figure 13 and figure 12. The patent value is measured on the vertical axis, and this is graphed for two different values of ρ, strong and weak.

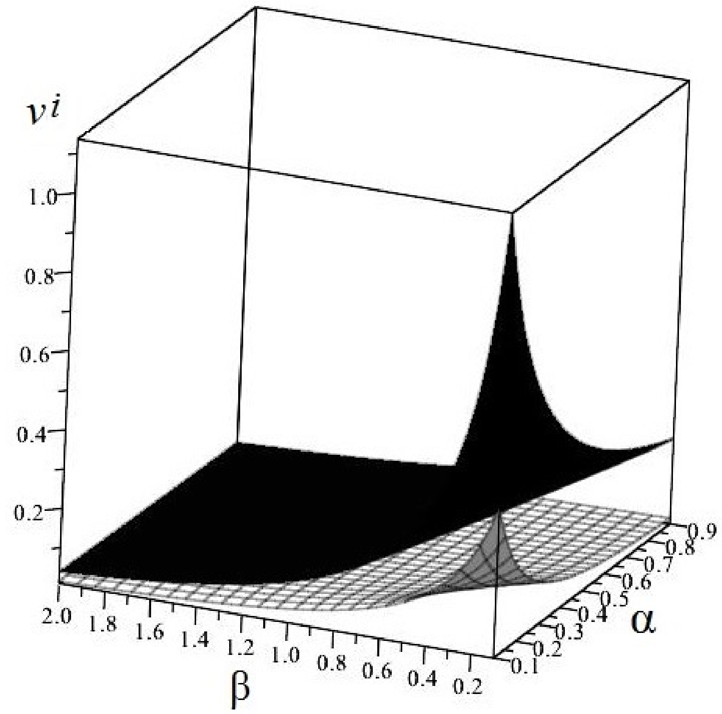

Figure 13: 3D plot of v^M (black) and v^Ω (white) given $\rho = 0.3$

We see from figure 12 that in the case of weak lobbyism the two patent values coincides for low values of β, giving an ambiguous ranking. When lobbyism is weak the patent value v^Ω approaches v^E such that this result follow the result in proposition 15, where a comparison gave no possible ranking.

Figure 13 illustrate the comparison for a intermediate lobby parameter, and the same picture is given for all other values of the lobby parameter. The figure illustrate that for all values of $\rho \neq 0.9$ the patent value in the lobby case lies underneath the patent for market good R&D. This imply that significant lobbyism $\rho > 0.9$ decreases the private incentives to invest in green R&D.

Proposition 18 *There exist no possible ranking of* v^Ω *and* v^M *that holds for all values of* $\rho \in (0,1)$. *For significant influence of lobbygroups,* $\rho > 0.9$, *private incentives decrease,* $v^\Omega < v^M$, *due to weaker environmental policy.*

In contrast to the analysis in Greaker and Hoel (2011) this thesis includes the effects on net welfare when analyzing incentives. The interesting research question is whether the decrease in net welfare exceeds the decrease in private revenue. Therefore I analyze prizes to compare the differences of $(\Delta W^i - v^i)$ for $i = M, E, E(\Omega)$.

13 Prizes

In this section I analyze prizes based on the findings in the two previous sections. I derive prizes for each R&D scenario, market good R&D (P^M), environmental R&D with a benevolent planner (P^E) and environmental R&D in presence of lobbyism (P^Ω). First I compare incentives in an ordinary commitment problem, as in Greaker and Hoel (2011). Thereafter I analyze an extended commitment problem to see how this result comply with my hypothesis that incentives to environmental R&D is lower than the incentives to ordinary market good R&D.

The definition of innovation prizes was given by proposition 2:

$$P^i = \Delta W^i - v^i \qquad i = M, E, \Omega \tag{84}$$

A positive prize signify necessary inducement. If the prize is zero it means that social and private gain of successful innovation equalize, $\Delta W^i = v^i$, and no inducement is needed. By comparing the prizes for the different R&D cases, we are actually comparing incentives. A ranking of prizes yields a possible ranking of incentives.

13.1 Comparing P^M and P^E

In this section I compare the incentives in an ordinary commitment problem, similar to Greaker and Hoel (2011). This issue was first discussed in Laffont and Tirole (1996) where they indicated that no R&D would be implemented due to the commitment problem. In this analysis I show how an innovation prize can restore the optimal level of incentives depending on the parameter values of α and β.

The prize for market good R&D is derived from (34) and (32):

$$P^M = \frac{B^2}{2} \frac{(1-\alpha)}{4(\alpha+\beta)(1+\beta)} \tag{85}$$

We see from expression (85) that P^M increases the better quality of the invention, ($\alpha \to 0$). For low values of α the appropriability problem is greater since the invention is more valuable, giving a high positive prize to restore incentives. The less social value of the invention, the less inducement is needed:

$$\lim_{\alpha \to 1} P^M = 0 \tag{86}$$

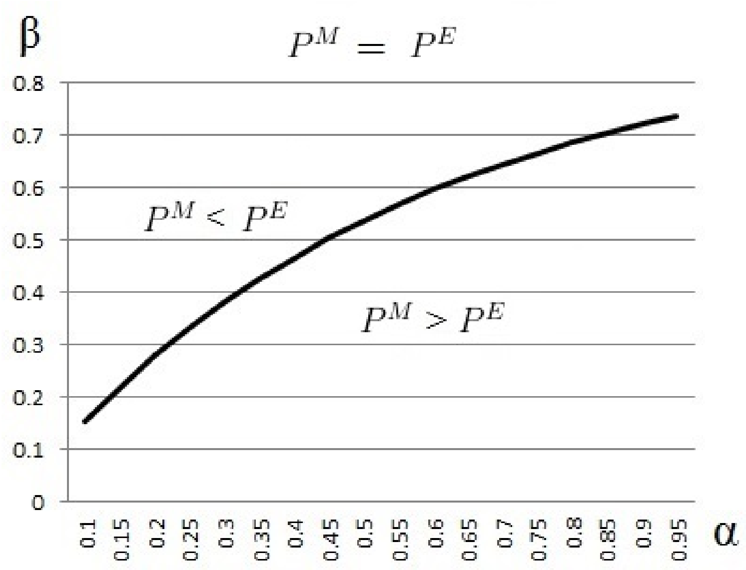

Figure 14: Combinations of α and β that equalize P^M and P^E

It follows from (85) that the prize increases in social benefit, $B(x)$. High values of β gives less social benefits and then smaller inducement prize is needed.

For the case of environmental R&D with a benevolent planner the prize is derived from (50) and (48):

$$P^E = \frac{B^2}{2}\left(\frac{\beta(1+\alpha)^2 + \alpha(5\alpha - 1)}{(\beta(1+\alpha)^2 + \alpha(1+3\alpha))^2}(1+\alpha)^2 - \frac{1}{(1+\beta)}\right) \tag{87}$$

By this expression we see that P^E is not monotonically increasing in neither innovation quality nor slope of the benefit curve. The cross derivative also depends on other parameters, complicating the analysis of the function.

The comparison of innovation prizes for marked good R&D (P^M) and environmental R&D with a benevolent planner (P^E) seem to confirm the results in Greaker and Hoel (2011). This rejects my hypothesis that incentives to environmental R&D is lower than incentives to market good R&D. The comparison gives an arbitrary result, relying on the combination of the parameter values.

When comparing P^M to P^E we see that the level of the benefit function B has no impact on the difference. The comparison in illustrated in both figure 14 and figure 15. In figure 14 the line indicates which combinations of α and β that equalize the prizes, $P^M = P^E$. Interpreting figure 14 we see how the combinations of β and α above the curve yields a higher prize to environmental R&D, indicating

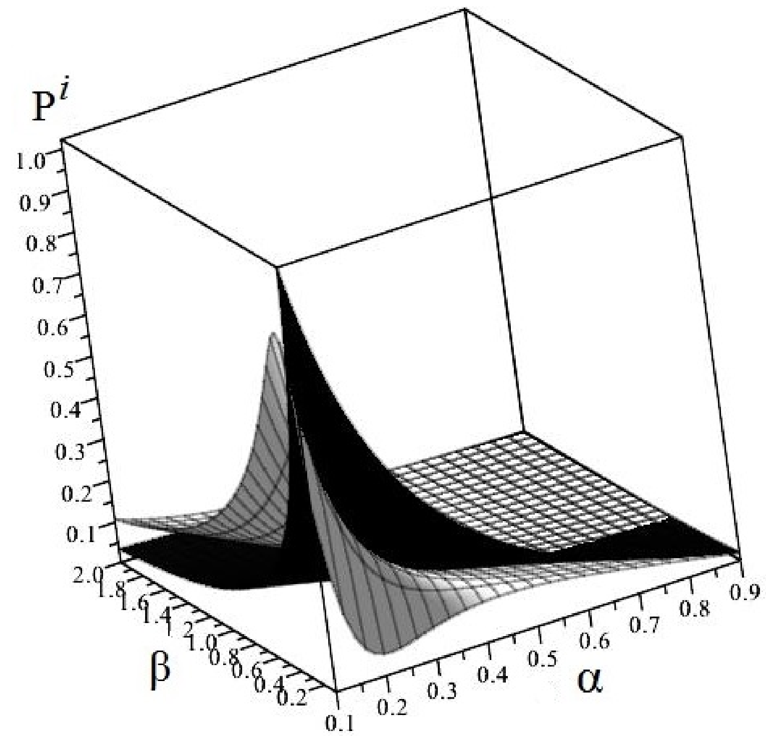

Figure 15: 3D plot of P^M (black) and P^E (white)

understimulated incentives, $P^M < P^E$. Below the curve we have the combinations that yields $P^M > P^E$. A high quality invention, i.e. a low α, implies a broader range of β for which $P^M < P^E$.

Figure 15 is a 3D plot of the same comparison. This figure illustrates how the prizes change for a broader range of α and β. The prize for environmental R&D has a shape like a "wave", illustrating why the derivatives is not monotonic. For high values of β the environmental prize dominates, and for low values of β the market good prize dominates. The extent of the dominance depends on α. The intersection of the two planes is the line in figure 14.

We know from proposition 13 that net welfare is higher for environmental R&D, $\Delta W^E > \Delta W^M$. However, comparison of the different patent values, v^E and v^M, was arbitrary, review proposition 15. These two results determine the comparison of P^M and P^E.

Proposition 19 *No general ranking of P^M and P^E is possible*

This result show that the conclusion in Greaker and Hoel (2011) holds when including the net welfare effect, although they only look at private return to the innovator. The effect on incentives is still ambiguous and depends on the combinations of the parameter values, α and β. This result implies that innovation prizes may solve the appropriability problem but we cannot state that the market failure is larger for environmental R&D than market good R&D. Thus, the innovation prize for environmental R&D should not necessarily be larger than for market good R&D. Although such cases may exist, depending on the combinations of innovation quality and social benefits of output. Hence, we cannot make a general rule stating that innovation prizes are better suited for environmental R&D in this example.

13.2 Comparing P^M and P^Ω

To examine whether my hypothesis holds for other environmental R&D scenarios, I compare incentives in case of lobbyism (P^Ω) to incentives in the case of marked good R&D (P^M). I will show that we cannot reject the hypothesis for intermediate values of political disturbance.

The contribution of this analysis is the incorporation of political disturbance. The question is whether an innovation prize can solve an extended commitment problem. Calculating the prize for environmental R&D with lobbyism from (78) and (74) gives:

$$P^\Omega = \frac{\rho B^2}{2}\left(\frac{\rho\beta(1+\alpha)^2 + 2\alpha(1+3\alpha) - \rho\alpha(\alpha+3)}{(\rho\beta(1+\alpha)^2 + \alpha(1+3\alpha))^2}(1+\alpha)^2 - \frac{(2-\rho+\rho\beta)}{(1+\rho\beta)^2}\right) \tag{88}$$

where the lobby prize is a function of three variables, α, β and ρ, (B is redundant). The lobby prize (88) is not monotonically decreasing or increasing in $\rho \in (0,1)$, complicating the analysis.

To investigate the extended commitment problem we need a comparison of the lobby prize (P^Ω) to the prize for marked good R&D (P^M). The previous sections with comparison of the net welfare functions and the patent values have indicated that a specific ranking is unobtainable. It appears that if we avoid the extreme values of the lobbyparameter, and restrict the analysis to intermediate lobbyism we obtain a result where P^Ω dominates P^M.

We start out by analyzing the two extreme cases, where $\rho \to 1$ and $\rho \to 0$. Note that we have assumed the limits is never reached, $\rho \in (0,1)$.

Illustrated in figure 16 is the combinations of β and α that equalize the prizes, $P^M = P^\Omega$ for very strong lobbyism, $\rho = 0.1$. Interpreting the figure we see that for low α a broader range of β imply $P^M < P^\Omega$.

The same issue is illustrated In the 3D plot in figure 17. The size of the prizes are measured on the vertical axis, and values of β and α on the two horizontal axes. The prize for market good R&D is illustrated with a black "carpet" that lies underneath the white "carpet" illustrating the lobby prize. In the lower corner to the right, where β is low and α is high, we see that P^M exceeds P^Ω (the black "carpet" covers the white). This denotes a scenario where abatement has great social value but the innovation is poor and lobbyism is particular strong. In this scenario the is no need for inducement. Note that both prizes approaches zero for poor quality inventions. These two figures illustrates that for very strong lobbyism, $\rho = 0.1$, a specific ranking of P^M and P^Ω is not possible.

Analyzing the opposite extreme value of the lobby parameter, we see how the two prizes behave as lobbyism diminish. If there is approximately no influence from lobbyism ($\rho \to 1$) the lobby prize coincides with the prize in the environmental case with a benevolent planner, and hence no specific ranking is possible.

$$\lim_{\rho \to 1} P^\Omega = P^E \tag{89}$$

This is illustrated in a 3D plot, figure 18. We observe a similar intersection between P^M and P^Ω as in figure 18. For a certain combination the two plains coincide. For low value of β the market good prize P^M dominates, but for high values of β the lobby prize P^Ω dominates, as in figure 14. This makes a specific ranking of incentives impossible for $\rho = 0.9$.

When choosing a lobby parameter between the two extreme values, we get plots similar to figure 19. We see that the lobby prize always exceed the market good R&D prize for any combination of β and α. The white plane completely covers the black plane. The same picture yields for all intermediate values of the lobby parameter, $\rho \in [0.2, 0.8]$.

The difference of the prizes, $P^\Omega - P^M > 0$ is more significant for radical innovations ($\alpha \to 0$). Notice how the gap between the two planes increases in the front corner. The two planes decreases towards zero for high values of α. Low quality innovations gives little social gain and is not in need of extra inducement, independent of R&D case. The high values of P^Ω when α and β are low, signal the need for

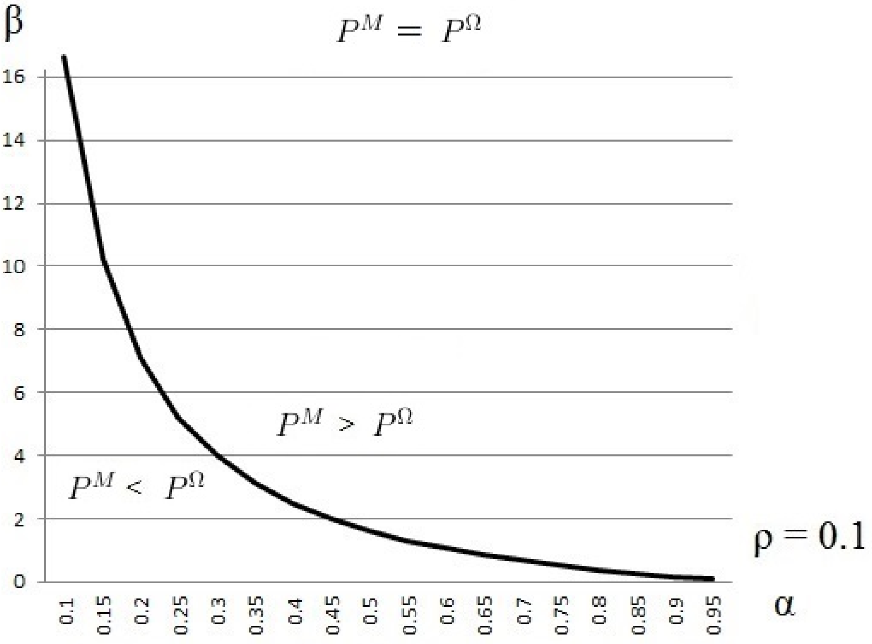

Figure 16: Illustrating the ambigous result $P^M = P^\Omega$ when $\rho = 0.1$

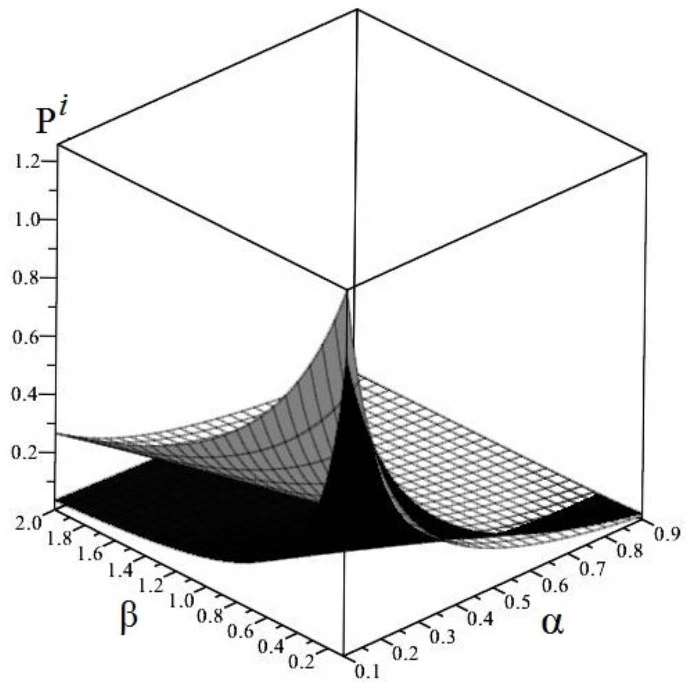

Figure 17: 3D plot of P^M (black) and P^Ω (white) given $\rho = 0.1$

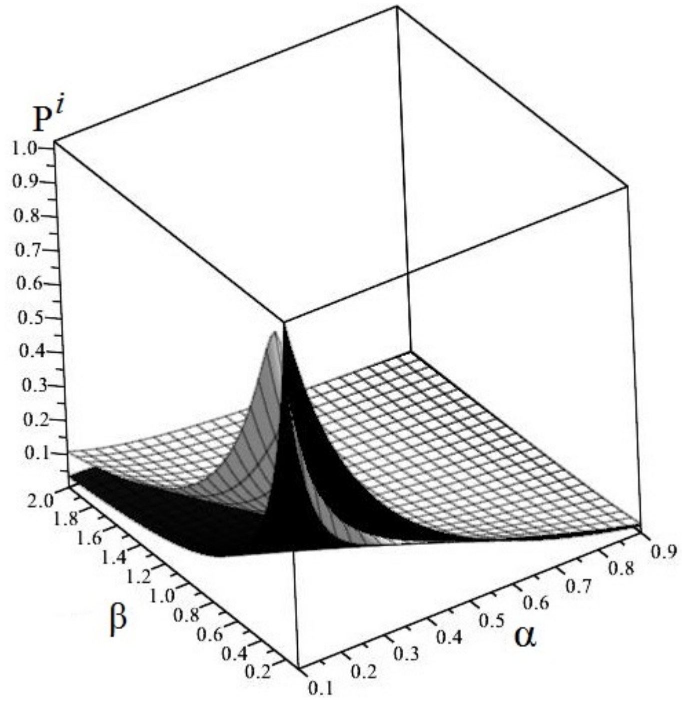

Figure 18: 3D plot of P^M (black) and P^Ω (white) given $\rho = 0.9$

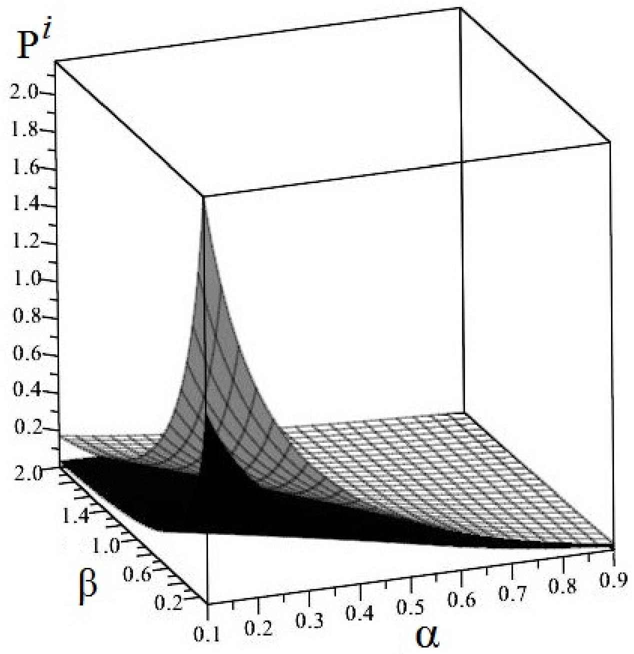

Figure 19: 3D plot of P^M (black) and P^Ω (white) given $\rho = 0.3$

inducement mechanisms.

Proposition 20 *The lobby prize exceeds the prize for market good R&D, $P^{\Omega} > P^{M}$ for intermediate values of the lobby parameter, $\rho \in [0.2, 0.8]$.*

Implying that the incentives for environmental R&D in presence of moderate lobbyism is significantly lower compared to market good R&D. This is the main result of the thesis, making us keep the hypothesis. But no general rule for the use of innovation prizes has been established.

The research question of this thesis was whether the difference, $\Delta W^{E(\Omega)} - v^{\Omega}$ was exceeding the difference of $\Delta W^{M} - v^{M}$, and hence whether a prize could solve the extended commitment problem. By this analysis I have showed that this yields for intermediate values of the lobby parameter, but the ranking breaks as ρ approaches one of the two extreme values.

This imply that the appropriability problem is larger for environmental R&D in case of lobbyism than for ordinary market good R&D. Hence, a larger market failure yield a larger inducement mechanism. I have showed how innovation prizes can remedy this market failure and restore the optimal level of incentives.

14 Discussion

The analysis has been based on the issue of governmental commitment problem distorting the incentives to invest in R&D. Given a successful outcome the planner may be tempted to expropriate rents from the innovation, and by adjusting the tax the planner can limit the innovator's ability to extract monopoly profit.

Timing has therefore been a crucial assumption. In this model I have only considered the case where environmental policy is set after the R&D process is carried out, but before the innovator sets her license fee. The innovator must undercut the tax when setting the license fee to uphold the profitability. To obtain widespread diffusion of the innovative knowledge the license fee should be as low as possible. Social optimal outcome is only obtained if the fee is set to zero. This is only feasible by simultaneously lowering the private payoff to the innovator, and hence the incentives to invest in R&D. This is the crucial trade-off between knowledge creation and knowledge use. Had the timing been different, i.e. the planner acted after the innovator, the commitment problem is eliminated.

I have assumed the small firms in the downstream sector has the selective incentive to create pressure groups that manages to reduce the tax. The result is determined by the assumption that the environmentalists lack the power to unite and push the lobbyism back. If the two opposite groups had the same level of influence on the objective, the realized welfare would not differ from the case with a benevolent planner.

The assumption of only one pollutive sector can be criticized for being too simplifying. For the environmental problem of climate change there are many diverse pollutive sectors emitting the same type of pollution. If the new technology developed by the single innovator only adapt for one sector, the planner may not be able to expropriate rents form the innovation and the commitment problem is no longer an issue.

If the research took place either in the dowstream sector or was public funded such that the new knowledge was spread free of charge, the issue of this model disappears. The problem is derived from the innovator's ability to control access to her invention through the patent rights, and the social planners desire to counteract this control. My aim was to investigate this interesting scenario. If I had chosen to look at prizes as patent buyouts, the tension between the innovator and the welfare maximizer would have been lost.

Innovation prizes, as described in this thesis, is an inducement mechanism that can be implemented without changing the well funded patent system. This thesis did not argue for prizes as an alternative to intellectual property rights, but rather as a complement when the welfare loss is distinct.

15 Conclusion

In this thesis I have presented a model based on the working paper by Greaker and Hoel (2011), where incentives to R&D is systematically compared to investigate whether they attain a specific ranking. I have included welfare effects in the modeling of incentives and introduced an aspect of political economy. The main contribution is the analysis of innovation prizes as the inducement mechanism to restore the social optimal level of incentives. No literature, as far as I know, model this type of ex ante innovation prizes in a general framework of incentives to environmental R&D.

In their working paper Greaker and Hoel (2011) base the model of incentives on the comparison of private return to the innovator. Their aim is to conduct the comparison in a general economic model of innovations. No specific ranking of ordinary market good R&D compared to environmental R&D is possible.

My point of departure has been the difference between market good R&D in a laissez-faire economy compared to environmental R&D in context of a commitment problem. The crucial aspect of green technology is that demand for environmental R&D is determined by planner's choice of environmental policy. The research question of Greaker and Hoel was whether the commitment problem distorted the incentives to green R&D. My research question has been whether innovation prizes are a suitable inducement mechanism if incentives to environmental R&D was lower than to market good R&D.

This thesis argues for using inducement prizes as a payment pre-commitment mechanism to restore potential distortions. But the result from a comparison of incentives with a standard commitment problem gave no specific ranking.

By including an aspect of political disturbance this thesis have showed that the incentives to environmental R&D is lower than incentives to ordinary market good R&D. This analysis found a significant difference if the benevolent planner is influenced by interest groups and not able to set the optimal tax. The planner suffers from "weakness of will", modeled by a weighted average, where the objective becomes linear in the lobby parameter in the decisive moment. For intermediate values of lobbyism there exist a specific ranking of incentives. This systematic difference in incentives to R&D can be used as an argument for increased support to environmental R&D.

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