Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

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Master's thesis · 30 hec · Advanced level
Environmental Economics and Management – Master's Programme
Degree thesis No 883 · ISSN 1401-4084
Uppsala 2014

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Credits: 30 hec
Level: A2E
Course title: Degree Project in Economics
Course code: EX0537
Programme/Education: Environmental Economics and Management, Master's Programme
Faculty: Faculty of Natural Resources and Agricultural Sciences

Place of publication: Uppsala
Year of publication: 2014
Name of Series: Degree project/SLU, Department of Economics
No: 883
ISSN 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: cultural eutrophication; innovativeness; nitrogen; stringent policies; phosphorus; patents; Porter hypothesis

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Abstract

A first step in the so-called Porter hypothesis relates to the link between stringent environmental policy and increased innovativeness. This thesis tests this step by investigates the relationship between stringent policy on phosphorus and nitrogen emissions in Sweden and the number of innovations that aim to reduce these emissions. Regulations and laws, introduced during the period 1960 – 2010, are used in order to measure the stringency of the policy. Patent data is used to reflect the number of innovations during the period in question. Three models, based on different sub periods, capture an eventual relationship from an econometric analysis. The result from the econometric analysis suggests that a relationship exist in the case of phosphorus, but not in the case of nitrogen. The model that takes into account the periods in which the targets from the regulations and laws were reached captures the expected development best.

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1. Introduction

Two essential nutrients for growth of plants are phosphorus and nitrogen. The process where the plants take up these nutrients is called eutrophication (Smith *et al.,* 1999). Considering aquatic plants, natural levels of phosphorus and nitrogen that reach water bodies, e.g. seas and inland lakes, are limited and therefore restrict the growth of aquatic plants. However, human activities can increase the level of phosphorus and nitrogen, which may result in a very fast growth of for example algae. The increase in the growth of algae (or of other aquatic plants) that is caused by human activities is called "cultural eutrophication". One example of a human activity that speed up the eutrophication is untreated wastewater. The high growth of algae, together with its short life span, results in high concentrations of dead organic material on the bottoms in water bodies. The decomposition of the increased level of dead organic material need a lot of dissolved oxygen, which results in reduced level that is available for live aquatic animals and plants. Without a sufficiently high level of dissolved oxygen many aquatic animals and plants cannot survive, which in turn may result in changes of the eco system in the water body. These changes can affect both the aesthetic and the recreational value of the water body negatively (Leng, 2009).

"Cultural eutrophication" is a global problem (Smith, 2003). In Sweden, which this thesis covers, the most affected areas are in the Baltic Sea and in the inland lakes in the south. Two of the largest sources of human activity that affect the level of phosphorus and nitrogen in water bodies in Sweden are the agriculture and municipal wastewater treatment plants. In order to stop the "cultural eutrophication" in surrounding seas and lakes the government in Sweden is using and has used policy regulations, for example requirements on minimum abatement technology and minimum levels on the degree of purification of nitrogen (Alavi *et al.* 2011).

A fundamental question regarding to environmental policy is whether, and to what extent, stringent environmental policy can contribute to both a better environment and a better business development. It is possible to distinguish two broad views on how business development effects of a stringent environmental policy.

The first and most common view says that stringent environmental policy creates an extra cost to a firm. This extra cost lead to impaired productivity, which in turn make the firm less competitive compared to a firm in a country with no or less stringent environmental policy. In other words, according to this view, a stringent environmental policy leads to an impaired business development.

Porter and Linde (1995) questioned above view and argue that the reason to why stringent environmental policy leads to an extra cost, impaired productivity and competiveness is that this view is based on markets with *perfect* information. In a market with *perfect* information a firm always makes the most optimal choices, in for example the choice of production technology. Therefore, no efficiency improvements are possible and a stringent environmental policy thus leads to an increased cost for a firm. Porter and Linde (1995) instead assume markets with *imperfect* information, where a firm does not always makes the most optimal choices, and efficiency improvements are therefore possible. A stringent and well-designed environmental policy will create incentives for a firm to reduce the extra costs, which arise from the stringent environmental policy, by using new technology that decrease the pollution and thus the extra costs. In the same time the new technology make the production more efficient, which creates revenue that eventually offset, or even exceed, the cost from the new technology. According to this second view, called the Porter hypothesis, stringent environmental policy may create a win-win situation with both a better environment and a better business development.

The first step in the Porter hypothesis relates to the link between stringent environmental policy and increased innovativeness. Jaffe and Palmer (1997) divide the hypothesis into three different versions, where one of them, a weak version, states that stringent environmental policy enhance innovativeness. The other two versions, a strong and a narrow, are about the effects from a stringent environmental policy on a firm's productivity and competitiveness and which types of environmental policy instruments that increase the innovativeness.

This thesis intends to test the weak version of the Porter hypothesis by investigate the relationship between a stringent environmental policy and innovativeness in the field of nitrogen and phosphorous emissions in Sweden. As mentioned above, two large sources of nitrogen and phosphorus emissions in Sweden are the agriculture and the wastewater from municipal wastewater treatment plants. Due to insufficient data[1] for the agriculture sector this thesis focuses on the link between policy regulations and innovations aimed to reduce nitrogen and phosphorous emissions from municipal wastewater treatment plants, not from the agriculture. The period covered in this thesis is 1960-2010. Three different models, both in the field of nitrogen and in the field of phosphorus, are used in order to estimate an eventual relationship between stringent policies and increased number of innovations.

In order to reflect the number of innovations, the dependent variable, I use patent data from the Swedish patent and registration office's (PRV) own database. Measuring the stringency of the policy, the independent variable, is problematic. There are no available continuous time series data that reflect the stringency of the policy aimed to reduce nitrogen and phosphorus emissions from municipal wastewater in Sweden. Instead, I use regulations and laws introduced during the period 1960 – 2010 in order to capture the stringency.

The purpose of this thesis is to answer the following question: *is there a positive relationship between stringent policies on phosphorus and nitrogen emissions from municipal wastewater and innovations that aim to reduce these emissions?*

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1 There were very few approved patents aimed to reduce phosphorus and/or nitrogen emissions from the agriculture during the period in question, 1960 – 2010.
2 See Goldeberg (1972) for more information about estimating using unobserved variables.
3 See for example Downing and White (1986) and Milliman and Prince (1989)

The rest of this thesis is organized as follows. Section 2 presents a brief review on previous studies that have investigated the relationship between a stringent environmental policy and increased innovativeness. In section 3 I provide relevant economic theory about environmental policy instruments and their affect on innovations. Data and the econometrics models are presented in section 4. Section 5 presents the results from the regressions and section 6 concludes and discusses weaknesses of the analysis.

2. Previous literature on the Porter hypothesis

It is possible, following Laoine *et al.* (2007), to divide previous literature on the Porter hypothesis into two groups of studies. The first group of studies examines the relationship between a stringent environmental policy and increased innovativeness (the weak version of the Porter hypothesis). The second group of studies examines how a stringent environmental policy affects a firm's productivity and thus its competitiveness (the strong version of the Porter hypothesis). There are not so many studies done about to the narrow version of the hypothesis. However, some of them are mentioned in next section about how different policies affect innovations differently. Since the purpose of this thesis is to test for an eventual positive relationship between a stringent policy and innovations (in the field of phosphorus and nitrogen) the most relevant previous literature is in the first group of studies. In this section I briefly review most of these studies and outline some similarities and differences between this thesis and previous studies.

Lanjouw and Mody (1996) did one of the first studies that investigate the relationship between environmental policy and innovations. In order to reflect the number of innovations patent data from U.S., Germany and Japan were used. They focus only on environmental patents. By using keywords in the search for patens in databases, they were able to distinguish environmental patents from others. In order to measure the strictness of the environmental policies Lanjouw and Mody use pollution abatement control expenditures (PACE), where the underlying assumption is that a more stringent environmental policy should increase these expenditures. The study covers the period 1970 – 1990. By comparing trends in the data, they show that a more strict domestic environmental policy increases the number of environmental patents. The data also suggest that a country's environmental patent activity responded to environmental policies in a foreign country.

As mentioned in the introduction, Jaffe and Palmer (1997) divide the Porter hypothesis into three different versions (weak, narrow, strong). Jaffe and Palmer also try to *"summarize the broad statistical relationship that exist among pollution control expenditures and measures of innovative activity and performance across industries and time"* (1997, p. 611). The study focuses on U.S. manufacturing in the period 1977 – 1989. In order to measure the innovative activity they use two measures. The first measure is total expenditures that the industry put on R&D. The second measure is the number of patent applications. The model with patent as a proxy for innovation (which is most relevant for present thesis) is stated as follows.

$$\begin{aligned} Log(Patents)_{i,t} = {} & \gamma_1 \log(Value\ added)_{i,t} \\ & + \gamma_2 \log(Foreign\ patents)_{i,t} \\ & + \gamma_3 \log\,(PACE)_{i,t-1} + \alpha_i^P + \mu_t^P \end{aligned}$$

Where *i* represents industry at time *t*. *Patents* are the number of successful patent applications in the U.S. by domestic investors. *Foreign patents* represent the number of successful patent applications in U.S. by foreign investors and are included to show if U.S. industries that are complying with domestic environmental policy are more innovative than foreign firms. *PACE* is, as mentioned above, the pollution abatement controls expenditures. *Value added* refers to industry value added and is included in the regression to avoid a spurious correlation between *Patents* and *PACE* that depends on the size of the industry. The result from the regression shows a non-significant relationship between an increase in *PACE* and an increase in *Patents.* However, the result from the regression with R&D as a proxy for innovativeness shows a significant relationship between an increase in R&D and an increase in patent activity.

Brunnermeier and Cohen (2003) did a similar study where they investigate how changes in PACE and government monitoring activities affect the innovativeness in 146 U.S. manufacturing industries. Unlike Jaffe and Palmer (1997), who use all patents, they only use environmental patens in order to reflect the innovativeness. They also include more control variables to, in a better way, test for an eventual relationship. The following model uses to estimate an eventual relationship.

$$(PATENTS_{i,t}) = \alpha_i + \gamma_t + \beta_1(PACE_{i,t}) + \beta_2(VISISTS_{i,t}) + \beta_3(VALSHIP_{i,t}) + \beta_4(CONC_{i,t}) + \beta_4(CAPINT_{i,t}) + \beta_5(EXPINT_{i,t}) + \varepsilon_{i,t}$$

PATENTS is the number of approved patents for industry i in time *t*. *VISITS* represent the number of air and water pollution related inspections. *VALSHIP* is industry shipments. *EXPINT, CAPINT* and *CONC* represent export intensity, capital intensity and industry concentration respectively. Brunnermeier and Cohen find a significant and small effect from an increase in PACE on the number of patents, but no significant effect from an increase in the number of inspections.

Popp (2004) examines both the innovation and diffusion of air pollution control equipment. Popp uses patent data from U.S., Japan and Germany in order to investigate how stringent domestic environmental policy affects domestic innovativeness, both by investors from the own country and from foreign countries. The study focuses on environmental policy instruments that aim to reduce sulphur dioxide (SO_2) and nitrogen (NOx) emissions. The data suggest that more stringent environmental policy on pollution from SO_2 and NO_x in one country enhances domestic patenting by domestic investors, but not by foreign investors.

Vries and Withagen (2005) use three different models in order to measure the strictness of the environmental policies. Their purpose was to test if a more stringent environmental policy enhances innovativeness in the field of SO_x emissions. Vries and Withagen use patent data from 14 countries. The technologies behind these patents are aimed to reduce emission of SO_x. Keywords uses to distinguish patents aim to reduce SO_x emissions from other patents. The period that is covered by Vries and Withagen (2005) is 1970 – 2000. In the first model, the strictness of the environmental policy is captured by international agreements, where the underlying assumption is that these agreements become stricter over time. They divide the period in question into four sub periods that covered the period between two international agreements, where each sub period complied with different stringent policy. In the second model, they use an index of environmental sensitivity performance (IESP) to determine if a country has a strict or tolerant environmental policy. A country is classified as strict if $50.1 > \text{IESP} \leq 100$, and tolerant otherwise. In the third model the strictness of the environmental policy is a latent variable, i.e. it is not directly observable.[2] Vries and Withagen do not find a positive significant result in the first two models. However, the result from the third model obtains a positive significant relationship between a stringent environmental policy and innovativeness in particular.

There are some similarities between previous studies and this thesis. Following Lanjouw and Mody (1996) and Vries and Withagen (2005) I am using keywords in order to find patents of technology aimed to reduce nitrogen and phosphorus from municipal wastewater treatment plants (see section 4.1). As mentioned above, one of the models used by Vries and Withagen (2005) measures the strictness of the policy by using international agreement, where the period in question is divided into four sub periods that each complied with different stringent policy. Using sub periods in order to capture the strictness of the policies is the same technique that is used in this thesis. Although instead of using international agreements this thesis uses domestic regulations and laws on phosphorus and nitrogen emissions in municipal wastewater.

There are also some basic differences between previous studies and present thesis. Firstly, some previous studies are using R&D in order to reflect innovations, instead of using patent data. Secondly, previous studies focus on how stringent environmental policy affects innovations aimed to *private owned* firms, i.e. where the demand for new technology arises from *private owned* firms. This thesis instead focuses on how stringent policies affects innovations aimed to *municipally owned* wastewater treatment plants, i.e. where the demand for new technology arises from *municipally owned* wastewater treatment plants. There is an important difference in why these two forms of ownership want to reduce, by using new technology, the extra cost from complying with a stringent environmental policy. A private owned firm wants to reduce the cost in order to maximize its profit and therefore demand new technology. A municipally owned wastewater treatment plant wants to reduce the cost in order to use its budget, the tax money, in an efficient way and therefore demand new technology. One can argue that the incentive for new technology is higher for a private owned firm in order to maximize its profit compared to a municipality that aim to use the tax money in the most efficient way as possible. However, since Sweden has only used and is using command and control instruments, which forces the municipally to use for example a specific abatement technology, this difference should not be a problem; a private own firm and a municipality should both want to follow the regulations and laws and therefore have equal incentives for using new technology. Further, a large private owned firm often pursues its own research on new technology (or use technology created by other firms), while a municipality usually *only* buy new technology from private firms. This difference should not affect the application of the hypothesis that a stringent environmental policy increases innovativeness.

[2] See Goldeberg (1972) for more information about estimating using unobserved variables.

3. Environmental policy instruments and their effects on innovativeness

Since Sweden mostly has used minimum technological requirements in order to stop the emissions of phosphorus and nitrogen in municipal wastewater treatment plants (see section 4.2), it can be of value to see what the theory and previous studies says about how such types of instruments should affect innovativeness. The various types of policies can be divided into two groups of instruments. The first group contains so-called *command and control instruments* and the second group contains *economic incentive instruments* (Stavin, 1997). In this section a summary is stated about policy instruments in general and how these affect innovativeness in particular.

Using command and control instruments is the most common way to control over polluters. In order to control pollutions from a firm, these instruments can be applied to all levels in a firm's production process. The most common types of command and control instruments used are non-transferable emission licences and minimum technology requirements. Non-transferable licenses refer to individual licenses, constructed by the responsible authority, that include total allowable quantity. These licenses are not transferable between firms. Minimum technology requirements refer to requirements on the production process or the capital equipment used in a firm (Perman *et al., 2011, p.189).* Both these types of command and control instruments can be analysed in how fast they reduce the pollution; if they are cost efficient (reach the target at least cost) and how they affect innovativeness. Perman *et al. (2011)* argue that command and control instruments in general result in a fast reduction of the pollution, but in an inefficient way. However, this is not very relevant since this thesis only focuses on how strict policies affect the innovativeness. Jaffe and Stavins (1994), among others[3], argue that command and control instruments generate weak incentives for innovations in the *long run*. The reason is that when the target from a command and control instrument is reached there are no longer any strong incentives for a firm to invest in more new technology. However, they have still the potential to create innovativeness in the short run, since they require firms to change their production process to be more environmental friendly (Jaffe et al., 2002).

In contrast to command and control instruments, which forces firms to change their behaviour, economic incentive instruments creates economic incentives for firms to voluntary change their production process to be more environmental friendly and thus reduce the extra cost from complying with the instruments. This can be done in many ways by changing the relative prices between pollution abatement and to pollute. Perman *et al. (2011)* mentioned three examples of instruments that are able to do this. These are emission tax, subsidy and tradable emission permit. Just like the command and control instruments these instruments can be analysed in how fast they reduce the pollution; if they are cost efficient and how they affect innovativeness. When it comes to their affect on innovativeness Milliman and Prince

[3] See for example Downing and White (1986) and Milliman and Prince (1989)

(1989) and Jung et al. (1996), for example, came to the conclusion that economic incentive instruments have higher effect on innovations than command and control instruments. The reason for that can be explained by comparing a minimum abatement level requirement (a command and control instrument) and an emission tax (an economic incentive instrument). Assume the responsible authority requires an abatement level at Z_1 in figure 5 and that a firm has the choice of two technologies with different marginal cost of abatement, MC_1 and MC_2. Technology 1 can assumed to be the old technology and technology 2 to be the new technology. If the firm chooses technology 1 it has to pay the abatement cost B + C, while if it chooses technology 2 it has to pay the abatement cost C. Hence, by choosing technology 2 it saves the abatement cost B in figure 5. If the investment cost of technology 2 is smaller than the saving B, the firm has an economic incentive for choosing technology 2. Consider instead the emissions is regulated with a tax, t. As long as the marginal abatement cost is lower than the tax, the firm will chooses to abate. If the firm chooses technology 1 the abatement cost is B + C and the tax bill is D + E + I. If the firm instead chooses technology 2 the abatement cost will be C + E and the tax bill will be I. The abatement level in this case is Z_2. Thus, the firm saves B + D by choosing technology 2 (compared with B in the case of a minimum abatement level requirement), which means that the economic incentives for new technology (technology 2) is higher in the case of a tax than in the case of a minimum abatement level requirement (Brännlund and Kriström, 2010, p. 218). Since Sweden mostly has used and is using command and control instruments in terms of technological requirements and minimum degree of purification on nitrogen in order to stop the emissions one can expect that the effect on innovations should be quite weak.

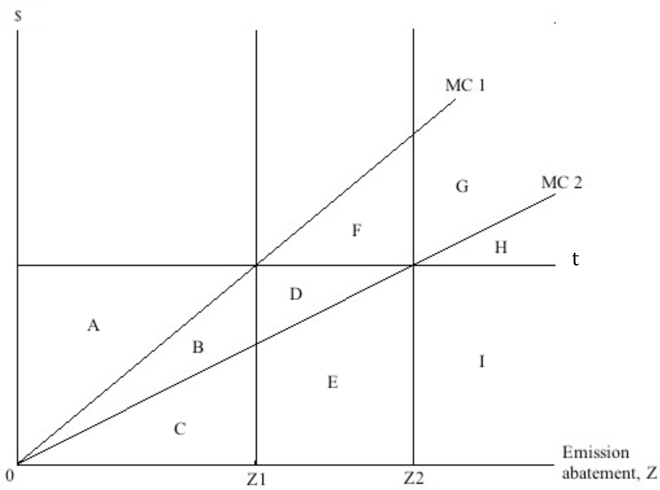

Figure 1. A comparison between the incentives for new technology in the case of a minimum abatement level requirement and a tax. Source: Brännlund and Kriström (2010)

4. Data and econometric models

In this section I describe the data used in the analysis. First, I present the dependent variable: patents aimed to reduce nitrogen and/or phosphorus emissions from municipal wastewater treatment plants. After that the independent variable, stringent policies, together with some other control variables are presented. I finally outline the econometric models used in the analysis.

4.1 Dependent variable: patents

Patent as a proxy for innovation has been used in several similar previous studies.[4] Griliches mention three advantages in using patents as a proxy for technological change: *" they are available; they are by definition related to inventiveness, and they are based on what appears to be an objective and only slowly changing standard"* (1990, p. 1). Since present study focuses on reflecting the innovativeness during the period 1960 – 2010 all these advantages are attractive in order to do this.

Griliches (1990, p. 7) also states disadvantages in using patent for economic analysis. One of them that is relevant for this thesis is classification. Classification deals with the problem that patents are not classified into for example industries or product groups. Patents are instead usually classified according to its technical area. Since present thesis focuses on patents for technology aimed to reduce phosphorus and nitrogen in municipally owned wastewater treatment plants, classification is a problem in the sense that it is not possible to search for patents aimed entirely to wastewater treatment plants. How to handle this problem describes below.

The patent data used in this thesis comes from the Swedish patent and registration office´s (PRV) own database, "Svensk Patentdatabas". The database includes documents of Swedish patents from 1885 until today. Each patent is divided into a certain class depending on which technical area the invention concerns. Swedish patents are divided into classes according to the international patent classification system IPC. The classification makes it possible to search, using keywords, after patents in a specific technical area. This is useful in present thesis in order to find patents aimed to reduce nitrogen and phosphorous. Another feature that makes it easier to divide patents into a specific technical area is the possibility to search for patents by using Boolean operators. The Boolean operators AND, OR and NOT can be used to limit or expand the search for the technical areas as requested. [5]

As mentioned above this thesis focuses on patents aimed to reduce nitrogen and phosphorus emission from municipally owned wastewater treatment plants. The class C02 in the

[4] See for example Brunnermeier and Cohen (2003) and Vries and Withagen (2005).
[5] For more information visit www.svenskpatentdatabas.se

international class system IPC contains patents related to treatment of water, mud and sewage. Unfortunately there is no subgroup containing patents aimed to reduce nitrogen and phosphorous emissions. Because of that I use keywords together with the Boolean operator OR in order to find patents in class C02 which documents contains at least one of the keywords. The Swedish keywords FOSFOR (phosphorous), FOSFATER (phosphates), KVÄVE (nitrogen), NITRATER (nitrates) together with the Boolean operator OR lead to the following search: FOSFOR OR FOSFATER OR KVÄVE OR NITRATER. This search gave a group of 426 patents, which documents contain at least one of above keywords. Since there were only a few patents found before 1960 and since regulations against nitrogen and phosphorous emissions in municipal wastewater treatment plants first introduced in the end of the 1960s the period covered in this thesis is from 1960 until 2010. In order to find patents aimed to reduce phosphorous and nitrogen in municipally owned wastewater treatment plants, and to separate patents aimed to reduce phosphorous from those aimed to reduce nitrogen, all 426 patent's documents were carefully read. This resulted in a group of 67 patents aimed to reduce phosphorous in municipally owned wastewater treatment plants and a group of 37 patents aimed to reduce nitrogen. A few patents were aimed to reduce both nitrogen and phosphorus emissions, these were counted as one patent aimed to reduce phosphorous emissions and one patent aimed to reduce nitrogen emissions.

The trends in the number of patents are illustrated in below figures. Figure 1 shows a clear increase in the number of patents aimed to reduce phosphorous emissions between the end of the 1960s and the end of the 1970s. The trends for patents aimed to reduce nitrogen emissions (figure 2) are not as clear. However, it is possible to see an increase in the number of patent between the early 1980s and the early 1990s and also between the mid-1990s and the early 2000s, but this increase consists of only 1-2 patents. The small number of patents approved each year aimed to reduce nitrogen is problematic for the analysis, especially in the sense that it is hard to distinguish any clear trends.

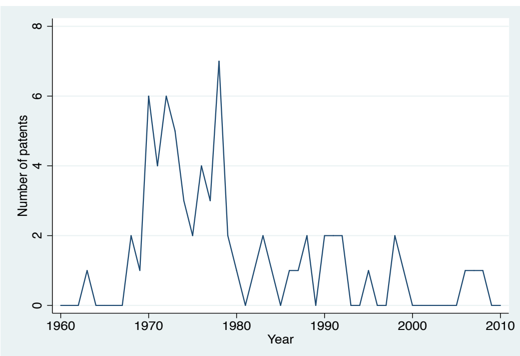

Figure 1 – trends in patents aimed to reduce phosphorous emissions from Swedish wastewater treatment plants

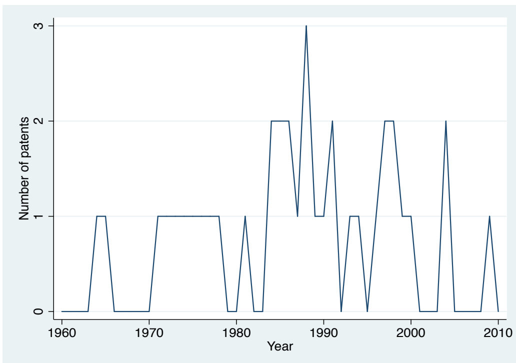

Figure 2 - trends in patents aimed to reduce nitrogen emissions from Swedish wastewater treatment plants

4.2 Independent variable: stringent policies

There are no available continuous time series data that measure the stringency of the policy aimed to reduce nitrogen and phosphorous emission from municipal wastewater treatment plants during the period 1960 – 2010. Instead, in order to capture the stringency I use laws and regulations introduced during the period. The laws and regulations regulate both nitrogen and phosphorous emissions from the municipal wastewater treatment plants, although different minimum degree of purification on nitrogen and phosphorous can be stated inside the law or regulation. The following laws and regulations are the most important regarding to emission of nitrogen and phosphorous from municipal wastewater treatment plants during the period 1960 – 2010.

1956: Law about supervision on watercourses, lakes and other water districts (Lag om tillsyn över vattendrag, sjöar och andra vattenområden) (SFS 1956:582). This law does not say anything about purification of phosphorus and nitrogen especially and does not require any specific abatement technology. However, 1 § and 2 § states that the Swedish Environmental Protection Agency shall supervise wastewater and has the right to give advices and assignments to the owner of the wastewater treatment plants in order to prevent water pollution.

1969: Environmental Protection Act (Miljöskyddslag) (SFS 1969:387). 7 § states that urban wastewater that has not undergone further purification than primary treatment shall not be discharged into streams, lakes or other water bodies if it is not obvious that it can be done without inconvenience. The Environmental Protection Act was abrogated 1999-01-01 and was replaced by "Miljöbalken" (Environmental Code) (1998:808).

Approximate values for the degree of purification of phosphorous and nitrogen in the primary treatment, which was required in the regulation above, are 10 – 20 % and 5 – 15 % respectively.[6]

1994: Regulation on treatment of urban wastewater (Föreskrift om rening av avloppsvatten från tätbebyggelse) (SNFS 1994:7). 3 § says that urban wastewater shall before it goes out in the nature undergo at least secondary biological, or equivalent, treatment. There are also some stricter regulations, stated in 5 § and 6 §, on urban wastewater with more than 10.000 pe[7] that releases into the sea along the coast from the Norwegian frontier, around the south coast, up to Södertälje. This wastewater shall undergo purification that reduces nitrogen with at least 70 percent. The regulation is still in force.

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[6] See table 1.1 in Norwegian Water paper nr 168 (2009) - Veiledning for dimensjonering av avlöpsrenseanlegg.

[7] Pe (population equivalent) is a measure of the amount of oxygen required to break down the organic material a person produce in a day (http://www.swedishepa.se).

Approximate values on the degree of purification of phosphorous and nitrogen in the secondary biological treatment, which was required in the regulation from 1994 above, are 25 % and 17 % respectively.[8]

1998: Environmental code (Miljöbalken) (SFS 1998:808). Chapter 2 states different regulations about environmentally hazardous activities in general, which also apply to municipal wastewater treatment plants. For example, the responsible authority for an environmentally hazardous activity has to be well known about the risks and apply the safety equipment and precaution in order to avoid damage on the environment. In chapter 9 there is also a paragraph about treatment of wastewater especially. 7 § states that wastewater shall drain and purifies such that human health and the environment do not damage. The Environmental code replaced the Environmental protection act from 1969, but it did not include any new and more stringent requirements. The Environmental code is still in force.

2007: HELCOM's Baltic Sea Action Plan (BSAP). HELCOM is an organization consisting of the countries around the Baltic Sea. In 2007 the organization adopted a rescue plan, the Baltic Sea Action Plan (BSAP), in order to achieve a good ecological status in the Baltic Sea by year 2021. The plan is divided into four main parts, where one of them concerns eutrophication. Every country assigned a specific minimum emissions target of phosphorous and nitrogen, which should be met in 2021. Sweden shall reduce their emissions of phosphorous and nitrogen by 290 ton/year and 21.000 ton/year respectively until 2021[9].

Note that the policies above have become stricter over time. With "stricter" here I mean that the policies require for example technology that purify phosphorus and nitrogen more than previous. It is therefore possible to classify the period 1960 – 2010 into four different sub periods, where each sub period is regulated with different stringent policy. The four sub periods are 1960 – 1968, 1969 – 1993, 1994 – 2006 and 2007 – 2010. Since the Environmental code 1998 replaced the Environmental protection act from 1969 and did not include any new and more stringent regulations it is omitted from the classification. The sub periods together with above policies that are relevant for the period 1960 – 2010 are illustrated in the timeline below.

[8] Swedish Environmental Protection agency's paper nr 5815 "Näringsbelastning på Östersjön och Västerhavet 2006".
[9] See www.helcom.se for more information.

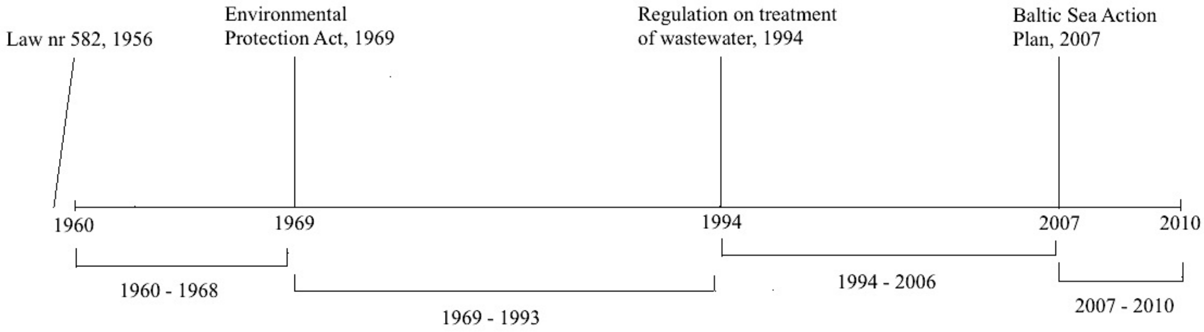

Figure 3 - Timeline including the most important laws and regulations on nitrogen and phosphorous emission from Swedish municipal wastewater treatment plants during the period 1960 – 2010.

The reasoning behind the classification is the following. During the period 1960 – 1968 the emissions of nitrogen and phosphorous from municipal wastewater treatment plants were regulated by the law from 1956 (nr 582) about supervision on watercourses, lakes and other water district. This law did not include any specific requirements on abatement technology or on minimum degree of purification of phosphorus and nitrogen. The period 1969 – 1993 was regulated with the Environmental protection act introduced in 1969, which required at least primary treatment of wastewater. This implies that the sub period 1969 – 1993 had a more stringent policy compared to the sub period 1960 – 1968. Further, the sub period 1994 – 2006 was regulated with both the Environmental protection act from 1969 (replaced by the Environmental code in 1998) and the regulation from 1994, where the latter required at least secondary biological or equivalent treatment and in some areas a minimum purification on nitrogen by at least 70 per cent. Thus, the sub period 1994 – 2006 can be seen as more stringent regulated than the previous sub periods 1960-1968 and 1969 – 1993. Finally, the last sub period 2007 – 2010 complied with both the regulation from 1994; the environmental code from 1998 and is also affected by the Baltic Sea Action Plan (BSAP) from 2007. However, the requirements from the Baltic Sea Action Plan were not included in the Swedish legislation in that period, although it may have created expectations about a more stringent policy in the nearest year, which in turn may have created incentives for new technology (this effect should be weaker, though). Because of that, the sub period 2007 – 2010 can be seen as the most stringent regulated compared to the previous sub periods 1960 – 1968, 1969 – 1993 and 1994 – 2006. Since the first sub period 1960 – 1968 was not regulated with any specific requirement on phosphorus and nitrogen it is called the base level.

One can argue, following the weak version of the Porter hypothesis, that the patent activity should increase over time when the policy becomes more stringent. But since Sweden mostly used/using command and control instrument (most in terms of technological requirements) it is not reasonable to think that each new requirement on better purification technology should create higher incentives for innovations than previous requirement on purification technology. For example, the requirement of secondary biological treatment in 1994 would not necessarily has forced a municipality to demand more innovations, given that it already have primary treatment, than the requirement of primary treatment, given that it has no previous purification, in 1969 did.

4.3 Other control variables

Stringent policy may not be the only factor that affected the number of patents during the period 1960 – 2010. In this section I state some other available variables, which also may affected the patent activity during the period in question. Note that some of the variables only refer to patens aimed to reduce phosphorus and some only refers to patents aimed to reduce nitrogen.

Subsidy system, 1968 – 1981 (phosphorus*)*

Between 1968 and 1981 there was a possibility, published in "Kungörelse" (announcement) (1968:308), to receive a subsidy for a new or an expansion of a municipal wastewater treatment plant. The level of the subsidy depended on how much the new or expanded wastewater treatment plant purified BOD and phosphorous. BOD is a measure on how much dissolved oxygen that an organism in a water body needs to break down organic material.[10] If the new (or expanded) wastewater treatment plant had a degree of purification on for example 90 percent for both BOD and phosphorous, the costs were funded with 50 percent.[11] The subsidy system, which is a economic incentive instrument, is expected to increases the number of patents since it creates an economic incentive for a municipality to invest in new purification technology in order to receive the subsidy. As mentioned before, an economic incentive instrument is expected to have higher effects on innovations than a command and control instrument (see for example Millian and Prince (1989) and Jung et al. (1996)).

Real Gross Domestic Product per capita (GDP/capita) (phosphorus and nitrogen)

It is reasonable to think that higher incomes for a municipality should result in higher demand for innovations. Furman *et al.* (2002) argue that an increase in the national income affects the number of patents in a country positively. For that reason, together with the fact that for example Vries and Withagen (2005) have included GDP in a similar regression, one can argue that including GDP is reasonably. However, since GDP is increasing over time (see figure 4) and the available patent data is not increasing over time (see figure 1 and 2), it is not likely that GDP would have had any affect on the number of patents during the period 1960 – 2010. Including GDP in a regression with the data available in this thesis makes the result confusing. Table 1, column 3 (appendix I) shows the result from model 1 when including GDP as a control variable[12]. The result shows a negative significant relationship between GDP and patents aimed to reduce phosphorus, which is not very realistic. Also, the coefficient for the constant (the base level) is 4.87, which means that the number of patents in the base level (which complied with no regulations), in average, would have been 130 patents. This not makes any sense (see figure 1). In order to avoid misleading results, GDP is omitted from the econometric models in next sections

[10] For a more detailed explanation, see Penn et al. (2002)
[11] See SNFS (1994:7) for more details.
[12] The problem with including GDP is the same for all models in section 4.4, not entirely for model 1.

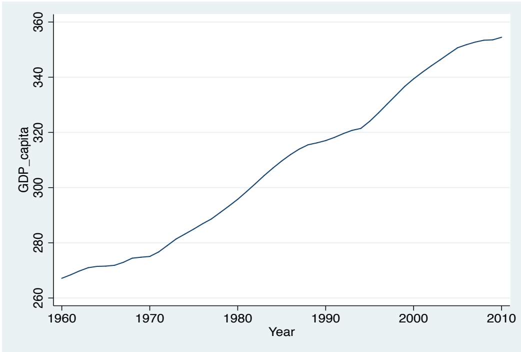

Figure 4 – Trends in real GDP per capita in Sweden (in thousand kronor).

Target reached: purification technology (phosphorus and nitrogen)

As mentioned in section 3, Jaffe and Stavins (1994) argue that the incentive for further purification should decrease when the target from a command and control instrument is reached, which in turn should affect the number of innovations negatively. Since the Environmental Protection Act 1969 required at least primary treatment in municipal wastewater treatment plants, one can argue that when all the wastewater is purified with primary treatment the incentive for further purification should decrease. Which in turn should affect the patent activity negatively. The same reasoning can be done with the requirement of secondary biological treatment from the regulation in 1994.

By using the diagram below (figure 5) it is possible to see roughly when 100 percent of the urban wastewater (y-axis) was purified with these two technologies. When it comes to primary treatment, 100 percent of the urban wastewater was purified with primary treatment in around 1980. For secondary biological treatment, 100 percent of the urban wastewater is purified with that technology in around 1985. Thus, the patents activity should have decreased after these years, before it went up in again when a new regulation was introduced.

Target reached: degree of purification (nitrogen)

For the same reason as for the purification technology above it is reasonable to control for when the target of the degree of purification on nitrogen is reached. The regulation from 1994 required 70 percent purification of nitrogen in wastewater from urban with more than 10.000 pe that releases into the sea along the coast from the Norwegian boarder around the south coast up to Södertälje. One can therefore expect the number of patent aimed to reduce nitrogen emission to decrease after the year when all the wastewater in question was purified from nitrogen with 70 percent. Unfortunately, there are no available data on the degree of purification of nitrogen for this wastewater. However, it is possible by using the diagram below (figure 5) to see roughly when the wastewater from this area was purified from nitrogen with 70 percent. An approximate value of the degree of purification in the tertiary treatment with nitrogen removal is 70 percent[13]. As can be seen in figure 5 the share of the urban wastewater (y-axis) that was purified with tertiary treatment with nitrogen removal increased rapidly in around 1996 (which is indeed just two year after the requirement) and then levelled out in year 2000. When the curve levelled out it is reasonable to assume that all the regulated area's wastewater was purified with tertiary treatment. This means that the target was reached and the incentives for further purification should have decreased after year 2000, which in turn should have affected the number of patent aimed to reduce nitrogen negatively.

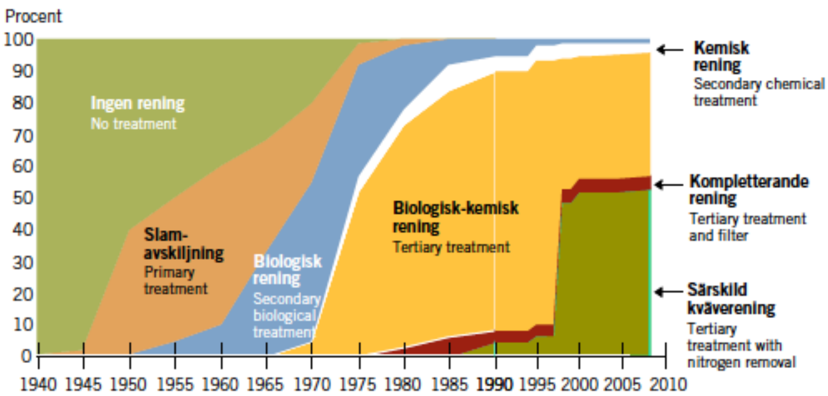

Figure 5 – The development of abatement technologies in municipal treatment plants, percent of the urban wastewater. Source: SEPA (2008)

Taking the two latter control variables (target reached) into account, one can argue that (given that a relationship between stringent policies and innovativeness exist) the patent activity in the period from when the target of a regulation is reached until a new regulation is introduced, should *not* be higher than the patent activity in a period with no regulations. More specifically: the incentives for new technology should not be higher in a period in which the targets are reached, compared to the incentives for new technology in a period that complied with no regulations. However, the patent activity should be higher in the period from when a new requirement is introduced until the target from this requirement is reached, given that a positive relationship between strict regulations and innovations exist.

In the case of phosphorus, the periods below refers to the periods in which the targets from the regulations and laws were reached. These periods should not have higher patent activity compared to the base level in 1960 – 1968 that complied with no regulations.

- 1981 – 1993: the target of primary treatment of all wastewater (from the Environmental Protection Act in 1969) was reached in 1980, and the new regulation was introduced in 1994. Thus, the period refers to a period in which the targets were reached.

[13] See Swedish Environmental Protection agency's paper nr 5815 "Näringsbelastning på Östersjön och Västerhavet 2006".

- 1994 – 2006: since all the wastewater was purified with secondary biological treatment already in 1985, the regulation about secondary biological treatment in 1994 (nine years later) did not require any new technology. The BSAP was introduced in 2007. Thus, the period 1994 – 2006 also refers to a period in which the targets were reached.

The other periods, 1969 – 1980 and 2007 – 2010 (periods from when a new regulation was introduced until the target from it was reached), should have higher patent activity than the base level between 1960 and 1968, if a relationship exists.

In the case of policies aimed to reduce nitrogen, the following periods represent periods in which the targets from these policies were reached.

- 1981 – 1993: the target of primary treatment (from the Environmental Protection Act in 1969) was reached in 1980 and the new regulation was introduced in 1994 (same as for phosphorus).
- 2001 – 2006: the target of a 70 % degree of purification was reached in 2000 and the new regulation was introduced in 2007. Thus, in the period 2001 – 2006 the target was reached.

The other periods, 1969 – 1980, 1994 – 2000 and 2007 – 2010, should have higher patent activity compared with the base level between 1960 and 1969.

The timeline below includes the sub periods, the regulations and laws and the periods in which the targets were reached. The line with rectangular dots represents the period in which the targets were reached from the regulations on phosphorus emissions. The line with circular dots refers to the period when the targets were reached in the case of nitrogen. Note that the subsidy system aimed to phosphorous purification was introduced in 1968, which was almost the same year as the more stringent (compared to the law from 1956) Environmental Protection Act was introduced in 1969. The target from the Environmental Protection Act in 1969 about primary treatment was reached in 1980, almost the same year as the subsidy system for phosphorous purification ended in 1981. Note also that all wastewater was purified with secondary biological treatment already in 1985, which was indeed 9 year earlier than the regulation of just secondary biological treatment of wastewater in 1994.

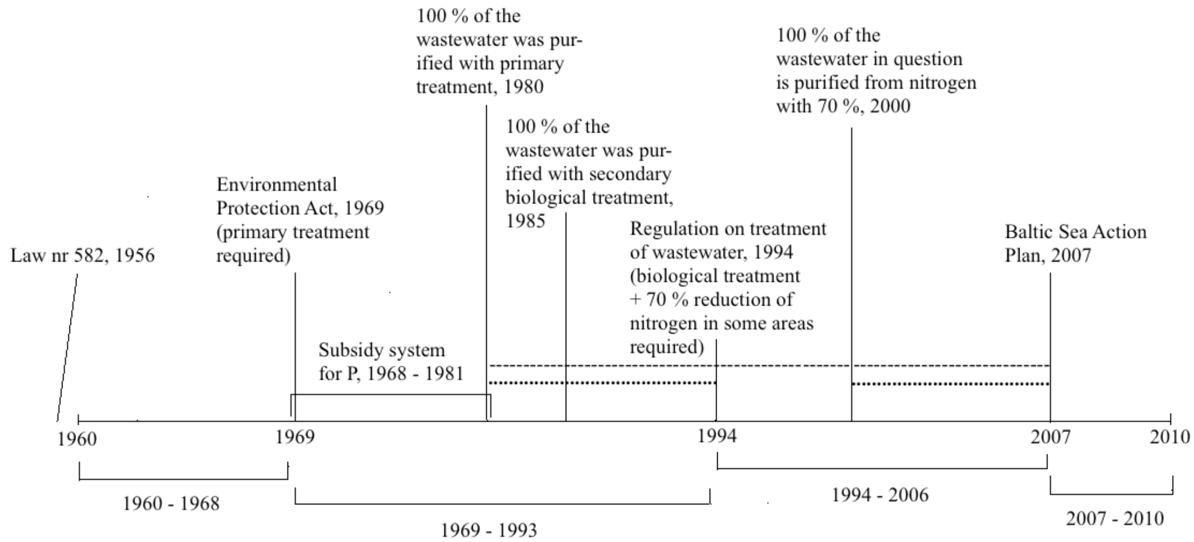

Figure 6 – Timeline including the sub periods, the period with the subsidy system, the regulations and laws and the periods when the targets from these were reached.

4.4 Econometric models

In this section the econometric models used to capture an eventual relationship are presented. Three different models are used, which all are applied to both the case of phosphorus and of the case of nitrogen. Model 1 uses two periods (before and after regulations) in order to test for an eventual relationship. The second model uses the (original) periods between two regulations in order to find an eventual relationship. Finally, model 3 takes into account the periods in which the targets were reached. Since the dependent variable, patents, both in case of phosphorus and nitrogen only contains integers and has occasionally the value zero (see figure 1 and 2), it is reasonable to assume that it has a Poisson probability distribution.

4.4.1 Model 1

This model is specified based on two periods: the base level 1960 - 1968 (complied with no regulations or laws) and the period between 1969 and 2010 (complied with regulations and laws). Since the period 1969 – 2010 represents the regulated period it should has higher patent activity than the base level if a relationship exists.

Phosphorus

The model in the case of phosphorus is stated as follows.

$$\log(Patents_t) = \beta_1 Subsidies6881 + \beta_2 Regulations + \varepsilon_t \tag{1}$$

$Patents$ is the number of approved patents in time t. $Subsidies6881$ refers to the period with the subsidy system in 1968 – 1981 and equals 1 for that period and 0 otherwise. $Regulations$ captures the effects from the two sub periods and equal value 1 for the period

1960 – 1968 and the value 2 for the period 1969 – 2010. ε_t is an error term and captures other things that affect the number of patents at time t.

Nitrogen

Model 1 in the case of nitrogen is specified as for the case of phosphorus, although without the subsidy system for phosphorus purification included in the model.

$$\log(Patents_t) = \beta_1 Regulations + \varepsilon_t \tag{2}$$

$Patents_t$ is the number of approved patents aimed to reduce nitrogen in time t. $Regulations$ captures the effects from the two periods, and has the same reasoning as in the case of phosphorus above. ε_t is an error term and captures other things that affect the number of patents at time t.

4.4.2 Model 2

This model is specified based on the (original) sub periods between the regulations. The following periods are included in the model, both in the case for phosphorus and nitrogen, in order to find an eventual relationship.

- 1960 – 1968 (the base level)
- 1969 – 1993
- 1994 – 2006
- 2007 – 2010

Since the sub periods 1969 – 1993, 1994 – 2006 and 2007 – 2010 are regulated with more stringent policies than the base level 1960 – 1968 the intuition is that each sub period should have higher patent activity compared to the base level.

Phosphorus

The model is specified as follows.

$$\log(Patents_t) = \beta_1 Subsidies6881 + \beta_2 Regulations + \varepsilon_t \tag{3}$$

$Patents_t$ and $Subsidies6881$ have the same definition as in model 1 and have the same reasoning. $Regulations$ captures the eventual effects from each sub period, with the value 1 for the period 1960 – 1968, 2 for the period 1969 – 1993, 3 for the period 1994 - 2006 and 4 for the period 2007 – 2010. ε_t is an error term and captures other things that affect the number of patents at time t.

Nitrogen

The model is specified as follows in the case of nitrogen.

$$\log(Patents_t) = \beta_1 Regulations + \varepsilon_t \quad (4)$$

$Patents_t$ is the number of approved patents aimed to reduce nitrogen emissions in time *t*. $Regulations$ captures the effects from each sub period and have the same reasoning as in the case of phosphorus. ε_t is an error term and captures other things that affect the number of patents at time t. Note that the model does not include any other control variables than the sub periods.

4.4.3 Model 3

This model is specified based on the periods in which the targets were reached. Recall, the intuition is that the periods in which the targets were reached should *not* have higher patent activity than the period with no regulations (the base level). The other periods, in which the targets were not reached, should have higher patent activity compared to the period with no regulation. Given that this development hold, and given that you control for other things that could affect the patent activity, one could argue that a relationship exists.

Phosphorus

As stated in section 4.3, the targets from the regulations on phosphorus emissions were reached in the periods 1981 – 1993 and 1994 – 2006. Given that a relationship exists, these periods are expected to *not* have higher patent activity than the base level 1960 – 1968. The period 1969 – 1980 is expected to have higher patent activity than the base level, because of the more stringent regulations. The last period 2007 – 2010 should have higher patent activity compared to the base level, because of the expectations (from the BSAP in 2007) about stricter regulations in nearest future. The relevant periods are summarized below.

- 1960 – 1968 (the base level)
- 1969 – 1980
- 1981 – 1993 (target reached)
- 1994 – 2006 (target reached)
- 2007 – 2010

In order to test for this expected development the following model is used.

$$\log(Patents_t) = \beta_1 Subsidies6881 + \beta_2 Regulations + \varepsilon_t \quad (5)$$

$Patents_t$ and $Subsidies6881$ has the same meaning as in previous models. $Regulations$ captures the effects from the periods stated above, and has the value 1 for the first period 1960 – 1968, 2 for the period 1969 – 1980, 3 for the period 1981 – 1993, 4 for the period 1994 –

2006 and 5 for the last period 2007 – 2010. ε_t is an error term and captures other things that affect the number of patents at time t.

Nitrogen

The periods in which the targets were reached in the case of nitrogen are: 1981 – 1993 and 2001 – 2006. Again, these periods should *not* have higher patent activity compared to the base level. The periods 1969 – 1980 and 1994 – 2000 should have higher patent activity than the base level, because of stricter regulations introduced in the beginning of each period. The last period 2007 – 2010 should have higher patent activity compared to the base level due to the expectations on stricter regulations in the upcoming years. The periods included in the model are summarized below.

- 1960 – 1968 (the base level)
- 1969 – 1980
- 1981 – 1993 (target reached)
- 1994 – 2000
- 2001 – 2006 (target reached)
- 2007 – 2010

The model is specified as follows.

$$\log(Patents_t) = \beta_1 Regulations + \varepsilon_t \qquad (6)$$

$Regulations$ captures the expected effects from the above mentioned periods and has the value 1 for the period 1960 – 1980, the value 2 for the period 1969 -1980, the value 3 for the period 1981 - 1993 and so on. ε_t is an error term and captures other things that affect the number of patents at time t.

5. Results

In this section the results from above models are presented. The tables with the results from the regressions are presented in appendix I and II. Note that the dependent variable, patents, is in log format in all models and that the sub periods in column 1 are compared with the base level represented by the constant in the tables. A value close to 1 for the parameter (1/df) deviance confirms that the model fit the data well and that a Poisson distribution of the dependent variable is reasonable. The results are presented in the same order as the models were stated above.

5.1 Model 1

Phosphorus

The result from model 1 in the case of phosphorus is stated in table 1, column 2 (appendix I). The period 1969 – 2010 that complied with regulations has a small significant (at the 10 % level) higher patent activity than the period with no regulations between 1960 and 1968. The period with the subsidy system has a significant (at the 1 % level) higher patent activity, compared to the base level.

Nitrogen

The result from model 1 in the case of nitrogen is displayed in table 2, column 2 (appendix II). The sub-period 1969 – 2010, which complied with regulations on nitrogen emissions, has a small significant (at the 10 % level) higher patent activity than the base level between 1960 and 1968. Unlike model 1 in the case of phosphorus, this model does not includes any other control variables than the sub-period with regulations, which makes this result more uncertain.

5.2 Model 2

Phosphorus

The result from model 2 in the case of phosphorus is stated in table 1, column 4 (appendix I). As can be seen in column 4, the sub-period 1969 – 1993 has a significant (at the 5 % level) higher patent activity than the base level. The period with the subsidy system, 1968 – 1981, has a significant (at the 1 % level) higher patent activity, compared to the base level. However, the periods 1994 – 2006 and 2007 – 2010 have not a significant higher patent activity than the base level, despite stricter regulations than the base level.

Nitrogen

The result from the regression shows in table 2, column 3 (appendix II). The result shows that the periods 1969 – 1993 and 1994 – 2006 have a significant (at the 5 % and 10% level respectively) higher patent activity, compared with the base level in 1960 – 1968. However, the last period 2007 – 2010 has not a significant higher patent activity than the base level, despite expectations (from the BSAP in 2007) about stricter regulations in the nearest future.

5.3 Model 3

Phosphorus

The result from the regression is stated in table 1, column 5 (appendix 1). The period 1969 – 1980 has a significant (at the 5 % level) higher patent activity than the base level between 1960 and 1968. The result for period with the subsidy system, 1968 – 1981, does not show a significant higher patent activity, compared to the base level. However, there is a problem with these two results. Since the sub-period 1969 – 1980 almost exactly overlap the period with the subsidy system in 1968 – 1981, the result from these two periods are misleading. It is not possible (within the model) to distinguish whether the most effect on the patent activity came from the more stringent regulation in 1969 or the subsidy system introduced in 1968. The period 1981 – 1993 has a small but significant higher patent activity than the base level, which was not expected (target was reached in this period). However, the increase is very small and only significant at the 10 % level. The result for the period 1994 – 2006 does not show a significant higher patent activity than the base level, which is in line what was expected (the targets were reached in this period). Finally, the last period 2007 - 2010 has not a significant higher patent activity than the base level. This period was expected to have higher patent activity due to the expectations (from BSAP in 2007) about stricter regulations in the upcoming years.

Nitrogen

The result, stated in table 2, column 4 (appendix II), was not what was expected. The period 1969 – 1980 has not a significant higher patent activity than the base level, despite stricter regulations and despite the fact that the target was not reached. The result from the period 1981 – 1993 was also not what was expected. The period has a significant (at the 10 % level) higher patent activity compared to the base level, despite that the targets were reached. The period 1994 – 2000 has a significant higher patent activity, which is in line with what was expected due to stricter regulations and the fact that the target from the regulation in 1994 was not reached. The result for period 2001 – 2006 does not show a significant higher patent activity than the base level, which is also in line with what was expected (target from the regulation in 1994 was reached). Finally, the last period, 2007 – 2010, has not a significant higher patent activity than the base level, despite expectations (from BSAP in 2007) about stricter regulations in the upcoming years.

6. Discussions and conclusions

The purpose of this thesis was to answer the following question: *is there a positive relationship between stringent policies on phosphorus and nitrogen emissions from municipal wastewater and innovations that aim to reduce these emissions?*

In this section I answer this question based on the result from each model. First the conclusion regarding to the relationship between stringent policies and the number of innovations aimed to reduce nitrogen emissions is presented. After that, the conclusion about the relationship in the case of phosphorus is presented. This thesis has some weaknesses, which are also discussed in this section.

The result from model 1 in the case of nitrogen shows a small but significant (at the 10 % level) increase in the patent activity for the regulated period 1969 – 2010, compared to the base level in 1960 – 1968. However, since there are no available control variables included in the model, it is difficult to draw any conclusion about an eventual relationship. Based on this model it is possible to say that the regulated period has a bit higher patent activity than the non-regulated period, but it is not possible to conclude whether this increase depended on the regulations or not.

The second model was specified based on the periods between the regulations which were introduced during the period 1960 – 2010. The result shows that the periods 1969 – 1993 and 1994 – 2006 have a higher patent activity compared to the base level in 1960 – 1968. The increased patent activity in these two periods could be a result from more stringent regulations, but it is still a problem that the model does not include any other control variables. The model can neither explain why the patent activity decreased in the last period 2007 – 2010.

The third model takes into account the periods in which the targets from the regulations were reached. The result was not exactly what was expected if a relationship would exist. For example, the period 1969 – 1980 has not a significant higher patent activity compared to the base level, despite more stringent regulations and despite the fact that the target was not reached. Also, the period 1981 – 1993 has a significant higher patent activity, despite that the target about primary treatment from the Environmental Protection Act in 1969 was reached in that period. Because of this it is not possible to conclude that the stricter regulations had any positive affect on the number of innovations.

The overall conclusion in the case of nitrogen is that, based on the result from these three models, it is not possible to conclude that a relationship between stringent policies and increased innovation exists. On the other hand, it is not possible to rule out a relationship. In order to do a more advanced analysis, better data is necessary. As can be seen in figure 2 there is few patents approved each year during the period 1960 – 2010, which makes it difficult to distinguish any clear trends. This, together with the lack of any other available continuous control variables, makes the regressions a bit weak. Examples of other continuous control variables that would have been reasonable to include in the models (if they were available) are: degree of purification, pollution abatement cost (PACE), and environmental protection costs.

The result from model 1 in the case of phosphorus shows that the period with the subsidy system 1968 – 1981 has a significant (at the 1 % level) higher patent activity, compared with the base level. The regulated period has also a significant (at the 10 % level) higher patent activity. In other words, the regulated period has a higher patent activity when controlling for the subsidy system, although only on the 10 % level. However, the model is simple and test for a quite long regulated period, which makes it difficult to draw, with certainty, any conclusion about an eventual relationship based on entirely this model.

Model 2 tests for an eventual relationship by using the periods between the regulations and laws that were introduced during the period 1960 – 2010. The result shows that the period 1969 – 1993 has a significant (at the 5 % level) higher patent activity than the base level. The period with the subsidy system has also a significant (at the 1 % level) higher patent activity. The results from the other sub periods, 1994 – 2006 and 2007 – 2010, shows a non-significant higher patent activity, compared to the base level. The increase in the sub period 1969 – 1993 could be a result from the regulations, but the model cannot explain why the periods 1994 – 2006 and 2007 – 2010 did not have a higher patent activity. Hence, it is not possible to draw the conclusion that a relationship exists, based on this model.

The third model tests for an eventual relationship by taking the periods in which the targets from the regulations (and laws) were reached into account. The result was quite good in line with what was expected if a relationship would exist. However, there are three things that are notable from the result. Firstly, the last period 2007 – 2010 has not a significant higher patent activity than the base level in 1960 – 1968. The lack of effect in this period is the same for all models, which may suggest that only expectations about stricter regulations in the nearest years is not enough in order to create innovativeness. Secondly, the result shows that the patent activity in the period 1981 – 1993 is higher than in the base level, despite that the target of primary treatment from the Environmental Protection Act was reached in 1980. However, the number of patents is only a bit higher and only significant at the 10 % level. Thirdly, the result shows that the period 1969 – 1980 has a higher patent activity than the base level, but the period with the subsidy system 1968 – 1981 has not. Since these periods almost exactly overlap each other the results are misleading. It is not possible, within the model, to conclude whether the increased patent activity depended on the regulation in 1969 or the subsidy system introduced in 1968. One thing that speaks for the regulation is that the effects from the other periods are in line what one could expect if a relationship between stringent regulations and increased innovations exists. What speaks for the subsidy system is that previous studies have shown that economic incentive instruments have higher positive affect on innovations than command and control instruments. It is also more reasonable to think that the reason for why all wastewater was purified with secondary biological treatment already in 1985 was due to the subsidy system[14]. There is no particular reason to believe that the requirement of primary treatment in 1969 would have created incentives for further treatment than just primary treatment. However, it is not possible to rule out an effect from a more stringent policy. Instead, it is more reasonable to think that both the subsidy system and the stricter regulation affected the patent activity positively.

The overall conclusion in the case of phosphorus is that the subsidy system has a positive effect on innovations and that, if taking the periods in which the targets were reached into account, more stringent regulations also affect the number of innovations positively. However, as in the case of nitrogen, more available continuous control variables would have made it possible to do a more advanced regression analysis, which in turn could have made the result even more credible.

[14] Since the subsidy system probably is the reason for the lack of effect in the period 1994 – 2006, one can argue that there is a problem with multicollinearity. However, since these independent variables are factor variables (not continuous) this is not a problem.

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Appendix I – Regression results (phosphorus)

Table 1. Regression results (phosphorus).

	Model (1)	Model (1) (GDP)	Model (2)	Model (3)
VARIABLE	*log(patents)*	*log(patents)*	*log(patents)*	*log(patents)*
Subsidies6881	1.603***	0.070**	1.175***	0.389
	(0.262)	(0.498)	(0.306)	(0.753)
Regulations (1)				
1969 – 2010	1.099*	2.055***		
	(0.595)	(0.778)		
Regulations (2)				
1969 – 1993			1.390**	
			(0.611)	
1994 – 2006			0.365	
			(0.735)	
2007 – 2010			0.628	
			(0.917)	
Regulations (3)				
1969 – 1980				2.061**
				(0.872)
1981 – 1993				1.188*
				(0.637)
1994 – 2006				0.195
				(0.739)
2007 – 2010				0.457
				(0.920)
GDP (per capita)		-0.022**		
		(0.011)		
Constant (1960 – 1968)	-1.463**	4.871	-1.321**	-1.150**
	(0.586)	(3.114)	(0.584)	(0.589)
Observations	51	51	51	51
(1/df) Deviance	1.108	1.083	1.103	1.087

Note: Standard errors in parentheses. *** Significant at 1 % level. ** Significant at 5 % level. * Significant at 10 % level. The dependent variable, patents, is in log format.

Appendix II – Regression results (nitrogen)

Table 2. Regression results (nitrogen).

VARIABLE	Model (1) *log(patents)*	Model (2) *log(patents)*	Model (3) *log(patents)*
Regulations (1)			
1969 – 2010	1.349*		
	(0.726)		
Regulations (2)			
1969 – 1993		1.463**	
		(0.736)	
1994 – 2006		1.337*	
		(0.769)	
2007 – 2010		0.120	
		(1.225)	
Regulations (3)			
1969 – 1980			1.099
			(0.790)
1981 – 1993			1.712*
			(0.750)
1994 – 2000			1.755**
			(0.782)
2001 – 2006			0.405
			(1.000)
2007 – 2010			0.118
			(1.224)
Constant (1960 – 1968)	-1.504**	-1.504**	-1.504**
	(0.707)	(0.707)	(0.707)
Observations	51	51	51
(1/df) Deviance	0.936	0.919	0.828

Note: Standard errors in parentheses. *** Significant at 1 % level. ** Significant at 5 % level. * Significant at 10 % level. The dependent variable, patents, is in log format.