Essays on Water Quality Policies of the Baltic Sea and Technological Innovation

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Abstract

This thesis contains four papers on the water quality of the Baltic Sea and technological innovation. The first paper examines the effect of environmental regulation aimed at reducing eutrophication on innovation in nitrogen and phosphorus management technology in the wastewater treatment sector and agricultural sector. Using patent statistics from Sweden over 1960 to 2015 as a measure of innovation, it is shown that increased environmental stringency has a positive effect on technological innovation in the wastewater treatment sector, but not in the agricultural sector.

The second paper examines the ex-post cost-effectiveness of nitrogen load reductions to the Baltic Sea due to environmental regulation. Using a counterfactual approach, we estimate the total nitrogen reductions from 1996 to 2010 to be roughly 145,000 tons. Result from a cost-effectiveness model suggests this reduction could have been achieved at 12% of the realized cost. If the same budget had been used efficiently, nitrogen reductions could have been twice as large.

The third paper uses data from a choice experiment over five Baltic Sea countries to analyze the effect of the distance to the coast and nitrogen retention on farmers' compensation demand for agri-environmental schemes. The results suggest that the two spatial variables affect farmers' compensation demand and, the effect depends on the spatial variation in production conditions within the countries. The results also show that providing higher compensation to farmers closer to the recipient is not always motivated, and by that, providing differentiated payments, the budgetary cost can be reduced.

The final paper examines the development of environmental technological innovations in the private and public sectors, in six major countries from 1990 to 2014. The result from our decomposition framework shows a shift toward environmental technologies in general and energy-related technologies in particular. We attribute the shift in the private sector to changes in research priority, and increased scale of research activity. The growth in the public sector is attributed to increased efficiency of the research process.

Keywords: Technological innovation, eco-innovation, water quality, Baltic Sea, environmental policy, cost-effectiveness, ex-post analysis, eutrophication.

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Essäer om Politik för Minskad Övergödning av Östersjön och Teknologisk Innovation

Sammanfattning

Denna avhandling innehåller fyra artiklar rörande politik för minskad övergödning av Östersjön och teknologisk innovation. Den första artikeln undersöker effekterna av miljöregleringar för kväve och fosfor i vattenreningssektorn och jordbrukssektorn i Sverige från 1960 till 2015. Vi använder data över patent som ett mått på innovation och undersöker hur införandet av nya miljöregleringar påverkar teknologisk utveckling i kväve och fosfor relaterade tekniker. Resultatet visar att de närmaste åren efter en åtstramning av miljöpolitiken har varit förknippade med ökad innovation i vattenrening. Vi hittar ingen motsvarande effekt i jordbrukssektorn.

Den andra artikeln undersöker kostnadseffektiviteten i genomförda minskningar av kväveutsläppen från nio länder runt Östersjön till följd av miljöpolitiken. En kontrafaktisk ansats används för att skatta utsläppsminskningen mellan 1996 och 2010. Resultaten visar att den uppnådda minskningen på 145,000 ton kunde åstadkommits för cirka 12% av den realiserade kostnaden. Den totala budgeten för politiken skulle ha räckt till en mer än dubbelt så stor utsläppsminskning.

Den tredje artikeln använder sig av ett s.k. *choice experiment* för att undersöka hur avståndet till kusten och kväveretentionen påverkar jordbrukares kompensationskrav för att ansluta sig till program för frivilliga miljöåtgärder. Resultaten visar att de två spatiala variablerna har effekt på kompensationskraven, och effekten skiljer sig mellan olika länder. I vissa fall finns det inte skäl att ge högre ersättning till jordbrukare som befinner sig närmare recipienten, och genom att införa differentierade ersättningsnivåer kan programmens budgeteffektivitet ökas.

Den sista artikeln jämför utvecklingen i privat och offentlig sektor av miljöteknologiska patent mellan 1990 och 2014 i sex länder. En dekomponering av drivkrafterna visar att det har varit ett generellt skift mot miljöteknologiska patent, och ett specifikt skift mot energirelaterade patent. Resultaten för privat sektorn visar att detta beror på ändrad prioritering inom forskningen och ökad omfattning på denna. Tillväxten i offentlig sektor beror till stor del på ökad effektivitet.

Nyckelord: Teknologisk innovation, vattenkvalitet, Östersjön, miljöpolitik, kostnadseffektivitet, övergödning.

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Dedication

To Sara.

Contents

List of publications

This thesis is based on the work in the following papers, referred to by Roman numerals in the text:

I Häggmark T.*, Elofsson, K. (2019). The Impact of Water Quality Policies on Innovation in Nitrogen and Phosphorus Technology in Sweden. *(Revise and Resubmit to Applied Economics)*.

II Häggmark T.*, Elofsson, K. (2019). The Ex-Post Cost-Effectiveness of Nitrogen Load Reductions From Nine Countries to the Baltic Sea Between 1996 and 2010. *Water Resources Research*, 55 (6), pp. 5119-5134.

III Häggmark, T. (2019). Spatial Heterogeneity in Farmers' Willingness to Pay for Agri-Environmental Contracts. (*Manuscript*)

IV Häggmark, T.*, Elofsson, K. (2019). International Comparison of the Drivers of Private and Public Eco-Innovations (*Manuscript*)

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The contribution of Tobias Häggmark to the papers included in this thesis was as follows:

I Planned the paper with the co-author. Carried out data collection and estimation of the econometric models. Wrote the paper jointly with the co-author.

II Planned the paper with the co-author. Carried out data collection and estimation of the econometric models. Wrote the paper jointly with the co-author.

III Planned the paper. Carried out estimation of the econometric models and wrote the paper.

IV Planned the paper with the co-author. Carried out data collection and estimation of the models. Wrote the paper with comments from co-author.

1 Introduction

This thesis focuses on environmental policy related to the management of the Baltic Sea and the impact of environmental regulation on environmental innovation. The Baltic Sea is heavily polluted and environmental regulations along with improvements in abatement technologies are central to remedy the issue. Paper I examines if more stringent environmental policy in Sweden has affected technological innovation relevant for nitrogen and phosphorus emissions from wastewater treatment and agriculture sectors. The two sectors play a large part in the deteriorating condition of the Baltic Sea and are subject to several environmental regulations. The second paper estimate counterfactual nitrogen emissions to the Baltic Sea with the aim to examine the ex-post cost-efficiency of implemented water quality policies during the period 1996-2010. Paper III uses a choice experiment to study the spatial aspect of farmers' willingness to accept contracts under agricultural-environmental schemes (AES) that change their farming practices and reduce nitrogen emissions. The fourth and final paper examines the growth of environmental technologies in recent history in six major nations using patent statistics. The focus is to compare the development, and important determinants thereof, in the public and private sectors. We perform the analysis at an aggregated country level and for different fields of technology.

In Section 2, I put the papers in a more general context and describe the theoretical foundations of environmental economics that the papers are standing on, along with mentioning of a couple of key contributions to the relevant literature. In Section 3, I describe the Baltic Sea, the associated water quality issues, and important regulatory changes, with a focus on the agricultural and wastewater treatment sectors. In Section 4, short summaries of the papers included in the thesis are given.

2 Theoretical Framework

Classical economics studies the allocation of scarce resources. Environmental economics is a subfield that investigates the effects of human decisions on the environment, and the impact of the environment on human activity and wellbeing, using economic theory. Using economic theory, environmental economics explains how we can use environmental goods and services more efficiently and sustainably (Carton, 2018). In this section, I introduce a couple of topics within environmental economics that are central to the understanding of the papers included in the thesis. First, we can note three concepts that are key to understanding environmental economics are: (i) market failure, (ii) externality and, (iii) social cost.

Environmental problems are seen as a consequence of market failures where the market does not consider the total cost of production of goods or services (Baumol and Oates, 1988; Carton, 2018). One type of market failure is negative externalities, which inflicts a cost on a third party in a transaction and is viewed as an unintended negative effect of economic activity. Similarly, positive externalities may occur. Hence, the concept of externalities is a significant topic in environmental economics. The social cost of economic activity thus considers both the private cost benefits and the costs and benefits associated with negative and positive externalities.

An example displaying these fundamentals is as follows: a manufacturing plant located on a river releases polluted wastewater into the river. The pollution negatively affects people using the river downstream for recreational purposes and firms that are dependent on good water quality for their business. There is no cost for the manufacturing plant to release its wastewater; hence, the cost of polluting is zero (O'Shea, 2002). Since no market mechanism exists to limit this pollution, there is a market failure because the production plant does not take into account the negative externality it causes. One key component for the occurrence of negative externalities is property rights. If property rights are not clearly defined, environmental problems often follow (O'Shea, 2002). In this example, the people and firms downstream may not have any right to claim that there should be a reduction in pollution, and it may be challenging to organize all victims in order to pay the upstream firm for reducing pollution.

Environmental policy can help to solve market failures and externality problems. Therefore, I will review some environmental policy-relevant economic concepts that closely relate to the papers included in this thesis: cost-effectiveness, maximization of the environmental outcome under budget, and technological innovation. These concepts are described in further detail in the sections that follow.

2.1 Cost-Efficiency and Environmental Policy

While the goal for environmental policy is often presented as being the protection of the environment, the decisions faced by policymakers are more complex. Policymakers have to decide what projects and measures should be implemented. With environmental policy, which is commonly associated with considerable costs to society, even if a least-cost solution is attained, cost-effectiveness becomes a warranted policy criterion. Simply put, cost-effectiveness implies that the target of the policy is met at the lowest cost possible for society as a whole. Cost-efficiency is however, not the only criterion for policy evaluation, other concepts such as; ease of implementation, enforcement and monitoring capabilities, distributional effects and, political feasibility also play an important role for policymakers as well as citizens (Hahn and Stavins, 1992).

When discussing cost-effectiveness, the costs considered are the resources a society uses for reaching the target. This cost can be divided into direct and indirect costs. The former concerns the costs directly associated with the policy, for example, operational and investment costs. The latter pertains to costs incurred to other sectors of the economy, for example, the increase in prices the consumers or producers face, or reduced production and loss of producer surplus. Theoretically, the cost-effectiveness of environmental policy requires the marginal abatement cost for all measures to be equal (Baumol and Oates, 1988). Therefore, the measure with the lowest abatement cost in relation to the impact on the target will be chosen first. When the marginal costs are not equal, it is possible to reduce the total cost by reallocating resources from a more costly measure to a measure with lower cost, while keeping the overall level of abatement constant.

Paper II analyzes the ex-post cost-efficiency of the Baltic Sea countries' nitrogen load reductions. It investigates if the achieved reductions were made cost-effectively and what a cost-effective solution would be. We use the principles of cost-efficiency—that the marginal abatement costs need to be equal—to find the cost-effective solution for the countries. The countries with lower abatement costs will thus have to do a larger share of the total abatement, which warrants a discussion on potential solutions needed to accommodate a cost-effective outcome.

2.1.1 Policy Measures

The policymakers have at their disposal different policy measures to accommodate pollution abatement. Given the complexity of creating good environmental policy, there is no *one-size-fits-all* measure that works (Harrington and Morgenstern, 2007). Available instruments include; emission taxes, tradeable permits, performance or technology standards, subsidies for emission reduction, or research (Goulder and Parry, 2008). In some instances, taxing a pollutant is better, while in others, an overall ban can be necessary. The correct choice is difficult, and therefore, economists tend to focus on economic efficiency or cost-effectiveness (Goulder and Parry, 2008). The basic *Pigouvian* principle states that pollution taxes should be set equal to the marginal external cost, and it is usually suggested to be a superior measure (Goulder and Parry, 2008). However, in the presence of, for example, asymmetric information or institutional constraints, this principle is not always applicable.

The policy measures can be categorized as either market-based or command-and-control measures depending on their design. The former provides relatively more flexibility in how firms abate compared to the latter (Hahn and Stavins, 1992), and thus have a differentiated impact on the regulated agent's behavior. Command-and-control policies allow regulators through legislation or regulation to directly affect the market and production process. One advantage of using command-and-control is that in some instances, they can make sure policy goals are reached quickly, however, long-term improvements might be reduced (Harrington and Morgenstern, 2007).

Market-based instruments, for example, tradable permits or taxes, are designed to signal changes in behavior through market mechanisms. The economic incentives created by market-based instruments make them more cost-effective in reaching a given level of abatement and creates continued incentives to reduce pollution (Harrington and Morgenstern, 2007). If there is significant heterogeneity in abatement costs across firms, market-based instruments perform better as it does not punish low polluting firms (Stavins, 2004). However, in situations where regulation is so stringent that all abatement measures must be adopted, market-based instruments do not have an advantage over command-and-control (Harrington and Morgenstern, 2007). The gains in efficiency from a market-based instrument are also partly because the polluter has better information regarding their cost of abatement.

2.1.2 Maximization of Environmental Outcome Under a Budget Restriction

Governments do not have unlimited funds for environmental policy implementation. Maximization of environmental outcomes is, therefore, important for governmental agencies operating under a budget restriction. This is an important consideration when designing, for example, AES or other payments for ecosystem services (PES) because the cost and environmental effect of an implemented AES or PES may differ across measures and locations, and over time. The opportunity cost for farmers to change their practices will be different for different farmers depending on the farm productivity and land quality, while differences in the environmental outcome of a measure depend on geographic and ecological conditions. Research has shown some results that the adoption of AES can vary spatially. Targeting specific areas can be useful to increase adoption rates (Grammatikopoulou et al., 2016). However, results regarding the effect of the environmental status of the resource on adoption are mixed, and the economic incentives appear to be the major driver for adoption of AES by farmers (Broch et al., 2013; Grammatikopoulou et al., 2016).

Historically, payments were fixed and given on a per unit of land basis (Bulte et al., 2008). This approach usually maximizes the area enrolled, and attracts the least profitable land. However, it is not evident that the environmental outcome and the profitability of land are correlated. If there is a negative correlation between environmental outcome and profitability, then the described situation will maximize environmental quality (Bulte et al., 2008). However, if changes at more profitable land yield a higher environmental effect, then a payment per unit of land will not maximize the environmental effect. Hence, differentiated payments conditional on the ratio of environmental outcome to costs can be motivated and will increase the budgetary efficiency.

The effect of maximizing the environmental outcome is evident in Paper II. We show how much greater the nitrogen reductions could have been when using the funds spent on the achieved reductions as a budget restriction. In that setting—with a cost-efficient solution—the environmental outcome could have been twice as large.

Differences in production conditions, profitability, and environmental impact are important for maximizing environmental outcomes. In Paper III, the role of these factors in farmers' preferences for entering AES contracts are investigated, and it is discussed how these preferences can be due to both farmers' profitability concerns and their concerns for the environment. Given the above described linkages to governmental policy, one can note that the more the government knows regarding the variation in environmental effects of policy measures, and about the farmers' preferences for participation, the more they will be able to achieve environmental improvements under a given budget restriction.

2.2 Environmental Innovation

Technological innovation is essential for economic growth and a central part of environmental policy. Environmental innovation depends on the same factors as innovation in general, but additional factors related to institutional and political factors can act as specific determinants (Horbach, 2008). For example, environmental regulations create pressure and incentives for economic agents to improve their environmental performance. Further, technological innovation is often necessary to reach a desired level of environmental sustainability. While environmental policy has to consider the environmental problem, it also has to regard the knowledge market failures. The central concept related to environmental R&D and knowledge market failures is the public good nature of knowledge (Geroski, 1995; Popp, 2019). Once an innovation is made, it has to be made public in order to yield any profit, this creates opportunities for others to make additional innovations or copies. This produces knowledge spillovers that benefit society but not the innovator (Popp, 2019). Hence, the combination of negative environmental externalities and knowledge market failures has a negative impact on the level of R&D and the incentives for technological innovation (Popp et al., 2010). The negative externalities create too much pollution, while the knowledge market failure creates too little incentives for R&D (Popp et al., 2010).

Innovation is not only driven by regulation. The search for future profits also motivates R&D, and R&D decisions respond to changes in relative prices (Binswanger and Ruttan, 1978; Hicks, 1932). The theoretical framework for technological innovation highlights the importance of technology-push and market-pull factors for the process of generating new technology (Horbach et al., 2012). Technology-push factors, such as the firms' stock of physical capital and knowledge capital, are supply side factors affecting firms' ability to develop new technologies and are especially important for newer technologies and products (Horbach, 2008). Market-pull factors are central for the diffusion of new technologies and are usually viewed as demand side factors where consumers' demand for certain products is driving innovation into newer products. However, the empirical literature suggests that the effect of demand side factors for environmental products is weak (Horbach et al., 2012).

In Paper I, supply side factors are considered when analyzing the effect of environmental regulation on innovation. Similarly, we incorporate supply side factors, approximated, in Paper IV by R&D spending. The results indicate a notable effect on the development of environmental technology, and we observe supply side factors to increase their contribution to the development of new technologies. As discussed in Paper IV, this potentially follows from technologies becoming progressively more advanced.

Significant attention has been given to the innovation incentives different policy measures induce. Theoretical models have provided results of how various environmental policy measures impact technological innovation, which has later been tested in empirical work (Popp, 2019; Popp et al., 2010). Policy design is thus essential for the effects on environmental technology. Theoretical contributions suggest that market-based policies should, in general, be preferred to command-and-control as the former rewards continued improvement of environmental quality (Fischer et al., 2003; Magat, 1978; Milliman and Prince, 1989).[1] However, current research indicates that the issue can be more complex. Findings by Fischer et al. (2017) and Lehmann and Söderholm (2018) on renewable energy suggest that other types of market failures such as capital market failures and path dependencies have implications for the development of new technology. Besides, the importance of different market failures on the development of technology is heterogeneous (Lehmann and Söderholm, 2018). The type of market failure will influence the choice of policy, for example, in the presence of network externalities, technology standards can be necessary to signal to firms the direction of change (Vollebergh and Van Der Werf, 2014). Additionally, as shown by Klemetsen et al. (2018), command-and-control policies can be useful in inducing innovation when the cost of non-compliance is sufficiently high. The incentives created by different policies are central to Paper I. In that, we discuss—based on our empirical estimations—how the different policy measures related to environmental regulation in Sweden impact technological innovation. Our findings support the predictions suggested in the theoretical literature. In addition, results indicate that policy coherence is important for the outcome as the incentives created by stringent environmental regulation may be weakened if other policies reduce the need for firms to innovate.

Significant empirical contributions in this field have examined environmental regulations' effect on innovation. Johnstone et al. (2010) provide evidence that environmental policy impacts technological innovation, and that technologies respond differently to different policy measures. Lanoie et al.

1. A short definition of command-and-control policies and market-based policies is given in Section 2.1.1.

(2011) show that the level of policy stringency can be relatively more important than the type of policy in inducing innovation. A recent paper by Fabrizi et al. (2018) suggests that market-based policies will induce more innovation than non-market based polices. Similarly, Reichardt and Rogge, (2016) and Kim et al. (2017) find that price-based policies perform better in inducing innovation in the long-term, as they create incentives for continued cost-reductions by firms. Given this discussion, the outcome appears to be a function of both policy design and which context the measures are implemented in, i.e., it can depend on the specific environmental issue at hand.

3 The Baltic Sea

The environmental problems of the Baltic Sea, where eutrophication is one of the more complex issues, are a consequence of human economic activities. Excess loads of nutrients, i.e., phosphorus and nitrogen, reaching the Baltic Sea, cause eutrophication. The major sources of these pollutions are the agricultural sector and the wastewater sector. In this thesis, three papers are concerned with various aspects related to nutrient pollution. Thus, I will here give some background on the development of the eutrophication issue and what has been done to remedy the problem with a focus on the two major polluting sectors.

The characteristics of the Baltic Sea make it susceptible to high levels of pollution. Around 85 million people live in its 420,000 km^2 large catchment area across 14 countries, in which nine have a coastline to the sea (HELCOM, 2018a). The fact that the Baltic Sea is relatively shallow given its size, i.e., one third is shallower than 30 meters and being a semi-enclosed sea, adds to the problem as it becomes more sensitive to excess pollution loads (HELCOM, 2018a). The environmental consequences of eutrophication are well known and have a negative impact on, for example, recreational activity, biodiversity, fishing, and tourism (Tynkkynen et al., 2014). In monetary value, economic losses for not reducing eutrophication, such that a good ecological status is reached, has been estimated to range between 3.8 and 4.4 billion euros annually for the Baltic Sea region (HELCOM, 2018a). The diverse set of economic activities, pollution, the unique hydrological characteristics of the Baltic Sea, and the international setting makes the process of managing eutrophication through regulation a delicate one.

The contribution of the agricultural and wastewater sectors to the problem of eutrophication is large. The agricultural sector is responsible for 70-90% of the diffuse nitrogen emissions and 60-80% of the diffuse phosphorus emissions to the Baltic Sea and around half of the total waterborne inputs. The releasing of wastewater to the sea also contributes to the waterborne inputs: wastewater sector emissions correspond to approximately 12% of the nitrogen and 20% of the phosphorus load (HELCOM, 2015).

3.1 Point and Nonpoint Source Pollution

Pollution from the wastewater and agricultural sectors can be categorized as point and nonpoint source pollution, respectively. The pollution by the agricultural sector is predominately viewed as diffuse, i.e., the link between an individual source and its impact on the recipient is hard to establish and monitor. Nonpoint pollution is also frequently described as a stochastic process, and there can be a nonlinear relationship between pollution and the effect on the environment (Shortle and Braden, 2013). Pollution from the wastewater treatment sector fits the description of point source pollution as it primarily comes from identifiable sources, with an identifiable impact on the recipient.

From a policy perspective, these distinctions are important as they have significant implications for policy design. When pollution can be monitored at reasonable costs, policy instruments should target the level of pollution (Shortle and Braden, 2013). However, to regulate nonpoint source pollution, policymakers have to consider what variables are measurable. Nonpoint source pollution regulation, thus, focuses on inputs and practices related to the polluting activity. However, the heterogeneity in environmental outcome when regulating nonpoint sources introduce inefficiencies when using uniform measures, increasing the cost of pollution control (Shortle and Braden, 2013).

The distinction between point and nonpoint source is observed in Paper I, where we conduct a review of implemented policies for the wastewater treatment and agricultural sectors related to nutrient pollution in Sweden. This can have an effect on technological innovation. In Paper II and Paper III, the above aspects are also important. The methodological approach in Paper II is partly motivated by the fact that the link between implemented environmental policies and the consequential effect on agricultural loads is not known. However, adding to this problem, data on the level of implementation at the nonpoint source is also lacking in most cases. Therefore, we apply a counterfactual approach to determine changes in costal loads, subsequently using a programming model to calculate the ex-post cost-efficiency. The concept of AES, relevant for Paper III, is one tool policymakers use to influence input choices and production practices when they cannot easily monitor the pollution sources. This makes studying the impact of measures adopted by AES difficult. A paper by Grenestam and Nordin (2018), however, analyze different measures adopted under AES using water quality data in Sweden, and their respective impact on nutrient runoff. However, as is discussed in Paper III, examining the outcome of policy measures becomes more difficult, as environmental effects are heterogeneous across space. Paper III thus provides information on possibilities on how to differentiate policy with the purpose of reducing the cost of pollution control.

3.2 Governance of the Baltic Sea

The Baltic Sea is a common resource, and, thus international cooperation is necessary to improve the environmental status. Currently, two governing bodies are important for the cooperation and overall regulation of pollution for the Baltic Sea, namely, the Helsinki Commission (HELCOM) and the European Union (EU).

The Helsinki Convention of the Protection of the Marine Environment of the Baltic Sea Area was established the HELCOM in 1974. The aim of HELCOM was to administer the convention and support cooperation amongst the coastal countries. From 1980, the countries were required to control various pollution inputs and report their pollution levels in a consistent manner (Vandeveer, 2010). A new convention was implemented 1992 stating that countries need to employ the polluter pays principle (PPP), best available technology (BAT) and best environmental practice (BEP) standards (Vandeveer, 2010). In 2007, the Baltic Sea Action Plan (BSAP) was introduced, stating that the Baltic Sea should return to *good ecological status* as of 2021 (HELCOM, 2007). New in BSAP was the basin and country-wise nutrient load reductions to be implemented through various national programs (Tynkkynen et al., 2014). Targets in the BSAP stipulated the reduction of loads of total phosphorus by 40% and total nitrogen by 20% (Elofsson, 2010a).

The EU has also implemented regulations aimed at improving water quality relevant for the Baltic Sea, and as of 2004, the EU encompasses all the coastal countries of the Baltic Sea but Russia (Tynkkynen et al., 2014). Important EU regulations that target water quality of the Baltic Sea and the reduction of nutrient inputs are: the Urban Wastewater Treatment Directive (UWWTD) and the Nitrates Directive (ND) from 1991, and the Water Framework Directive (WFD) from 2001. The goal of the latter was to achieve *good status* of European ground and surface waters as of 2015 (Schumacher, 2011). The member states were then tasked with implementing national regulations and protection plans to meet the goals of the directives. An additional tool that has been used by the EU to target emissions from agricultural sources is the Common Agricultural Policy (CAP). Under the CAP, farmers who engage in water protection activities can be compensated through various AES, chosen by the individual country (Tynkkynen et al., 2014).

Nutrient loads have been observed to decrease (HELCOM, 2015). However, 97% of the Baltic Sea is still considered as suffering from eutrophication and being below *good ecological status* (HELCOM, 2018b). Certain basins have seen improvements, while others have deteriorated. Previous research has shown that the adopted total target loads were not cost-efficient (Elofsson, 2010a, 2010b). A mentioned reason is that the targets were designed with a focus on ecological objectives and did not explicitly consider that allocation of reductions across countries cost-efficient. Paper II adds to the research regarding the cost-efficiency of the load reductions for the Baltic Sea while providing ex-post estimations, taking into account that the final targets have not been met. The approach is novel, given that the earlier literature has been focused on the ex-ante cost-efficiency under target compliance.

4 Summary of Appended Papers

In the following sections, I will present a summary of each of the four papers in this thesis. The aim is to present findings, methodology, and policy implications.

Paper I and IV focuses on environmental technological innovation. Technological innovation is imperative for reaching environmental targets, and it is important to examine if environmental regulations foster or inhibit the development of environmental technology. To measure innovation, I use patent counts. The use of patents as an innovation measure related to innovative output has been established in the literature (Popp, 2019). Patents provide several advantages to be used in research as they have detailed records of each innovation, providing information on the type of technology, the identity of the innovator, and origin. While patents are highly connected to the innovative process, some drawbacks should be acknowledged. The patents have to be relevant for the topic studied. In Paper I, specific words was used when searching the database within each technology classification. The set of keywords were developed in connection with a patent engineer. In Paper IV, I rely on the IPC Green Inventory to construct appropriate patent counts. Another aspect concerns the skewness of the value distribution of patents. I try to overcome this in Paper IV using triadic patents that are considered as high value patents. Two additional topics that are relevant when using patents are (i) that the existence of a patent does not necessarily mean the technology is adopted, and (ii) intellectual property rights. The latter will affect innovators' propensity to file for patents. In Paper I, I control for intellectual property rights to capture the changes in the protection innovations receive.

In Paper II, the cost-efficiency model used is relying on a set of assumptions about the data. This is a consequence of the lack of data on abatement measures and their allocation within each country. It assumes that abatement efforts are cost-efficient within each country. In addition, the model uses capacity constraints to describe economic and physical restrictions when implementing abatement measures. These constraints are based on expert judgement because the necessary data is not available. A sensitivity analysis is conducted to examine the importance of the capacity constraints on the results, and the changes are small. Paper III uses a choice experiment conducted as a survey. Survey fatigue amongst farmers is an issue that was established during the survey process; hence, the response rate was relatively low. In addition, different survey methods were used; however, according to previous research, this should not affect the result, as survey mode effects are hard to establish (Menegaki et al., 2016). The use of other modes of surveying was necessary as internet access amongst farmers where limited in a few countries.

The quality of the data is always important when conducting empirical research, and more detailed information regarding potential caveats of the papers and the data are discussed in more detail in the individual papers.

4.1 Paper I: The Impact of Water Quality Policies on Innovation in Nitrogen and Phosphorus Technology in Sweden

This paper focuses on the effect of increased environmental stringency of agricultural and wastewater treatment policies aimed at improving the water quality of the Baltic Sea and technologies reducing nutrient emissions in Sweden. To this end, we use a patent dataset over 1960-2015 as a measure of innovation. We chose to focus on the two economic sectors, which are detrimental to the environmental problems of the Baltic Sea and because of interesting sector characteristics. This paper contributes to the eco-innovation literature with the analysis of a particular environmental problem. The few earlier studies related to innovation and water quality have been concerned with water pollution in general (Horbach et al., 2012; Johnstone et al., 2012). Johnstone et al. (2012), studying water related innovation but including innovations related to oil spills, treatment of chemicals in water, and cleaning and removal of polluted surface waters, as well as nitrogen and phosphorus technology. With a broad definition of water pollution, it is hard to define the relevant regulations to consider. We know that policies are highly dependent on the relevant environmental target and the economic sector (Horbach et al., 2012; Kammerer, 2009), hence, focusing on the two major polluting sectors, and on nitrogen and phosphorous technology, will facilitate relevant policy conclusions.

By surveying the relevant literature, we identify Swedish environmental policies aimed at reducing nitrogen and phosphorus emissions and adopted during the period. We find examples of environmentally motivated taxes, investment subsidies, and performance and design standards. Thus, both market-based policies and command-and-control type policies are used.

Our econometric framework builds on both reduced form estimations and control functions based on Wooldridge (2015). To model environmental regulation, we use a dummy variable approach to identify the effect of the implementation of new regulation. These dummy variables are thus the variables of interest for the effect of environmental regulation on technological innovation. Additionally, we control for the more general determinants of innovation, given that not only environmental stringency affects the development of new technology (Johnstone et al., 2012). The dependent variable is a count variable of the number of patent applications and the number of granted patents. Specifically, we estimate a count data model assuming a negative binomial distribution because of the non-negativity of the dependent variable.

The patent data is from the Swedish Patent and Registration Office (PRV) and corresponds to patent activity at both PRV and EPO[2]. We use the International Patent Classification System (IPC), and a set of keywords for patent specific searches to construct annual patent counts for phosphorus and nitrogen reducing technology for the two sectors. The final patent count corresponds to granted patents and patent applications for Swedish innovators because innovators mainly respond to regulation in their country of residence (Popp, 2006).

The results suggest a positive effect of increased environmental regulation on patent activity for a subset of the policies in the wastewater treatment sector. We do not identify a similar result in the agricultural sector. Specifically, three of the six included regulations for the wastewater sector have a positive effect on patent activity. The results suggest that in the years following new regulation, patent activity increased between 40 and 70% in the wastewater treatment sector. In absolute terms, this corresponds to 1.5 and 2.4 additional units of patents per year for the four years following the introduction of the significant regulations. We also observed a long-run effect after the first introduction of wastewater treatment policies in the 1960s. Additionally, we examine if innovators are anticipating the effects of policy, i.e., if patenting occurs before the actual introduction of the regulation. This could be, for example, due to new regulation following from public debate. We do not observe such an effect.

Possible reasons that we do not identify an effect in the agricultural sector are policy instrument design, monitoring and compliance and, sector objectives. The policy measures used for the agricultural sector are typically technology standards or technology specific subsidies, providing limited incentives for the development of new technologies. For the wastewater treatment sector, there are predominantly performance standards. Compliance and monitoring are important for the outcomes of policy. The level of compliance most likely differs between the sectors. Wastewater treatment facilities are few and usually under public control, while the agricultural sector is private with multiple entities. Being under public control should facilitate monitoring and enforcement.
Future research on water quality policies—especially in the agricultural sector—should focus on enforcement and policy design considering the coherence of

2. We extract EP-validated patents at PRV i.e., patents filed first at the EPO by Swedish innovators but validated for protection in Sweden.

policy incentives. Hence, a review of the policies related to the agricultural sector is motivated, especially since it is subject to policies that regulate its pollution but also that supports its production. This can create conflicting incentives. Further, because we observe increased patent activity in the wastewater sector, an extension of this research could be to evaluate if increased technological innovation has increased actual nutrient abatement capacity. A follow-up, examining if the new technologies have helped in offsetting the changes in costs and economic performance usually associated with environmental regulation, are useful topics for future research that can help policymakers.

4.2 Paper II: The Ex-Post Cost-Effectiveness of Nitrogen Load Reductions From Nine Countries to the Baltic Sea between 1996 and 2010

The Baltic Sea is one of the most polluted bodies of water in the world (Diaz and Rosenberg, 2008), a result of excessive pollution of nutrients from anthropogenic sources. This paper examines the ex-post cost-effectiveness of nitrogen load reductions to the Baltic Sea between 1996 and 2010. During the period, load reduction targets have been presented, and the policy efforts introduced under the governance of HELCOM pose a high cost to society.

With this in mind, the paper answers three specific questions: (i) what is the cost of the nitrogen reductions achieved through water quality policies between 1996 and 2010, per country and total? (ii) How large are the savings that would be made if the reductions had been implemented in a least-cost manner? and (iii) What is the maximum amount of reduction in nitrogen loads, which could be reached given the funds used for achieved reductions?

Impact evaluation of environmental policy requires detailed information regarding the type of measures implemented. This information is, however, not available, and thus a bottom-up approach to calculating ex-post cost-effectiveness is not possible. In this paper, we estimate counterfactual nitrogen loads to the Baltic Sea and thus circumvent this problem, using the difference between the counterfactual loads and actual loads to calculate the achieved net load reductions. This paper thus contributes to the literature by providing a methodological framework to establish counterfactual load reductions, but also by providing an ex-post cost-effectiveness analysis. Only evaluating policy using observed loads will yield biased results, as changes will depend on confounding factors. For example, pollution can decrease given a reduction in economic activity, and not only because of increased environmental stringency. We estimate total nitrogen (TN) loads during the period 1992-1996 for 105 catchments in the nine Baltic Sea countries[3] using nitrogen load regressions developed by Hägg et al. (2010). We refer to this period as the baseline period. The TN loads are a function of catchment-specific runoff, atmospheric deposition of nitrogen, and total primary emissions (PE). PE is emissions from humans and agricultural livestock. This model has been proven in the literature to be successful in modeling large-scale nitrogen loads over a heterogeneous area (Hägg et al., 2010; Smith et al., 2005), like the Baltic Sea. Country-specific dummy variables are introduced to capture country effects.

To calculate the relevant monetary values to answer the questions posed above, we use a cost-minimization model developed by Elofsson (2010a). The model covers nine abatement measures for the agricultural and wastewater treatment sectors. The measures should represent what is available to a policymaker. Further, the effect of the measures is differentiated depending on where they are implemented to capture the effect of spatial variation in cost and the effects of emissions.

From the estimated coefficients from the TN load regressions, we calculate the counterfactual TN loads using average data for the period 2008-2010. These loads are compared to the TN loads reported in HELCOMs Pollution Load Compilation (PLC) 5.5 dataset. The result shows that the counterfactual TN loads are approximately 23% higher than the observed loads. This corresponds to a load reduction from the bassline period of approximately 145,000 tons.

We use this estimated achieved load reduction to examine if the reductions could have been done at a lower cost using the cost-minimization model. First, we calculate the total cost associated with the 145,000 ton reduction, setting country-specific reduction targets. The achieved reduction corresponds to a cost of 2,093 million euro divided across the nine countries included in the model. Denmark and Russia carry the largest costs while Finland and Lithuania have the lowest costs in this setting. To examine if the reduction could have been achieved at a lower cost than 2,093 million euro, we use the cost-minimization to find the least-cost solution using the achieved reduction as total load restriction. The difference in total cost is approximately 1,843 million euro, and in the least-cost solution, Lithuania and Poland face the largest costs. This implies that according to our model the achieved reductions of 145,000 tons TN could have been achieved at 12% of the realized cost. Lastly, we calculate what the maximum reduction could have been given a reduction budget of 2,093

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3. Included countries are: Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, and Sweden.

million euro. Our cost-minimization model yields a total reduction of approximately 330,000 tons TN, i.e., more than twice the achieved reductions.

In summary, the ex-post analysis indicates that the TN reductions by the Baltic Sea countries have not been carried out in a cost-effective manner. The most significant reason for this result is that the allocation of reductions is inefficient. To reach a cost-effective solution, reallocation of reduction loads is necessary. However, to reach a cost-effective solution, side-payments between countries would most likely be necessary, as there would be political resistance from countries taking on a relatively higher cost burden. Nevertheless, the substantial cost savings associated with a least-cost solution should incentivize the countries to accept a side-payment solution. Side-payments is also an instrument that could increase compliance of reduction agreements (Ahlvik and Pavlova, 2013). An alternative solution could be an international emission-trading scheme for nitrogen.

4.3 Paper III: Spatial Heterogeneity in Farmers' Willingness to Pay for Agri-Environmental Contracts

The purpose of this paper is to estimate the effect of two spatial variables, distance to the coast and nitrogen retention, on farmers' willingness to accept (WTA) for enrolling in agricultural-environmental schemes (AES). AES have a central part in changing farm practices to become more environmentally friendly, and with the high levels of spending, approximately 22 billion euros in EU27 from 2007 to 2013 (Zimmermann and Britz, 2016), it is wise to consider ways increase efficiency. One suggested way to increase the budgetary efficiency of AES programs is to provide differentiated payments to the farmers enrolled. Farmers' WTA and willingness to enroll in AES depends on the opportunity cost the farmers face when changing farm practices but also the preferences towards AES. Having a uniform payment scheme to all farmers in a program is inefficient as the WTA will be heterogeneous amongst farmers and by providing payments that are closer to WTA, the rents to farmers can be reduced.

The relationship between the spatial factors and the farmers' WTA is, to a certain degree, similar to the relationship between spatial factors and WTP for protecting an environmental good. It has been established that spatial factors influence the WTP for environmental goods (Bateman et al., 2006; Concu, 2009). For example, proximity to a forest has an effect on the WTP for protecting it. In this paper, it is assumed that farmers extract private utility from environmental public goods, which affects their compensation demand.

However, the spatial impact on farmers' compensation demand will also depend on how production conditions at the farm vary in relation to the spatial variables.

The paper uses data from a choice experiment conducted in five Baltic Sea countries; Denmark, Estonia, Finland, Poland, and Sweden, proposing contracts aimed at reducing their emission of nitrogen.

I estimate a mixed logit model (MXL) in a panel setting. Contract attributes and compensation vary in each choice situation and are determinants in the MXL. Interacting the choice to enter into the proposed contracts with the spatial variable of interest introduces the spatial effect on WTA. Additionally, I control for relevant farm and decision maker characteristics. The choice experiment asks farmers to choose between three types of contracts: set aside, catch crops and, application techniques of fertilizers and manure. The farmers were presented with the following contract attributes: contract length, area enrolled, farm advisory services, flexibility of termination, and monetary compensation, in each choice situation.

The results obtained from the MXL estimates suggest that the distance to the coast and nitrogen retention have an impact on the farmers' compensation demand. However, the result varies depending on the country and is sometimes contract specific. The significant estimates for Denmark, Poland, and Sweden suggest that, as the distance to coast increases, the compensation demand decreases. For Estonia, the significant estimates suggest that compensation demand increases as the distance from the coast increases. For Finland, the result for the significant contracts is mixed. The estimates interacting the choice with nitrogen retention suggests that farmers in areas with higher nitrogen retention have a lower compensation demand than the average in Denmark and Poland. For Sweden, the result is the opposite.

Land quality and production conditions is a factor that is important for the spatial variation in compensation demand for changed farm practices. This can provide, to some degree, information as to why results differ between the countries. For example, in Denmark, compensation demand and land quality decreases in the distance from the coast; it implies that the effect of production conditions is dominating that of the proximity to the environmental good.

Several policy conclusions can be drawn from the result. For example, for some countries, the standard economic recommendation to provide higher payments to agents closer to the recipient, due to the higher environmental impact, need not always be appropriate. In both Finland and Estonia, compensation demand is increasing in distance; hence, suggesting lower compensation to farmers closer to the sea might be suitable if high adoption rates are targeted. By considering how compensation demand varies across space, the budgetary efficiency of AES can be increased, and additional farmers could be brought into a program. Additionally, if compensation demand is lower in areas with high nitrogen retention, it is appealing to a policymaker to provide lower compensation to farmers in those areas. Changing farm practices in high retention areas will have a relatively lower effect on the Baltic Sea.

The choice of relevant spatial variables will depend on the environmental problem examined. One natural extension of this paper is to perform a similar analysis but focus on local waterbodies. The conditions of local waterbodies can potentially influence the compensation demand if policies are on water quality.

4.4 Paper IV: International Comparison of the Drivers of Private and Public Eco-Innovations

The development of new environmentally sustainable technologies is an integral part for the creation of a sustainable society (Popp, 2019). The majority of new technology is developed in the private sector. However, the public sector also conducts research and development (R&D). Although the size of its R&D has decreased over time, the public sector can still play an important role. The private sector is reluctant to commit to R&D in areas where benefits are widespread but long-term or uncertain (Conceiçao et al., 2004). Private sector R&D is mainly a search for establishing future profits, hence, public sector R&D can provide innovation where large societal gains are possible.

The aim of this paper is to examine and compare the contributions to environmental innovation done by the public and private sectors, respectively. Using data on triadic patent applications as a measure of technological innovation, we investigate the determinants of environmentally sustainable technologies over 1990-2014 in six major patenting nations. Combined, the six countries, China, France, Germany, Great Britain, Japan, and the US, are responsible for approximately 84% of the total patent volume.

We use a Logarithmic Mean Divisia Index (LMDI) framework (Ang, 2015), to compare the determinants between the public and private sectors. The LMDI is estimated first at a country aggregate level, and then for a subset of technological sectors. We decompose the growth in triadic patents into four factors: *priority*, *environmental share*, *efficiency*, and *scale*. The four factors all have a natural interpretation. *Priority* describes how priority in research has shifted at the technology specific level. *Environmental share,* defined as the ratio of environmental patents over the total number of patents, indicates if environmental patents are growing faster than other patents. The third factor, *efficiency,* describes the efficiency of the R&D process and, defined as the ratio between total numbers of patents over R&D spending. The fourth and final variable, *scale*, is the funds spent on R&D and captures the scale effect of R&D

spending on output. The specific technological sectors we analyze are energy conservation, alternative energy production, forestry and agriculture and, waste management.

We use data from the PATSTAT database and classify patents as environmentally sustainable using the IPC green inventory. Additionally, we determine if the patents belong to a private sector or a public sector entity. This is done using ECOOM-Eurostat-EPO PATSTAT Person Augmented Table Database (du Plessis et al., 2009; Magerman et al., 2006). This allows us to distinguish environmental patents between the private and public sectors. If patents belong to both classifications, a fractional count is done based on the appropriate share each applicant belongs to.

The LMDI results at the country aggregate level show that from 1990 to 2014, environmental patents in both the public and private sectors increased except in France. The change in private environmental patents over the period ranged between -8% in France and 202% in Japan. From the decomposition factors, we observe a general shift in research towards environmental technologies as *environmental share* is positive. This effect is the most evident in GB and Japan, where the factor contributed with 69% and 134% respectively to the increase in patents. This implies that environmental patents grow faster than the total number of patents. In the public sector, all countries have increased the number of environmental patents. The smallest change is in the US, with 14% while Japan has experienced an increase of 615%. The change in the public sector is driven by increased efficiency and scale of R&D activities. The most significant difference between the sectors is that *efficiency* is negative across all countries in the private sector and positive for the majority of the countries in the public sector. Hence, reductions in relative R&D efficiency in the private sector has contributed negatively to the growth of environmental patents. Additionally, as expected, the increase in the scale of R&D activities has had a positive impact in both sectors, as *scale* is positive.

When analyzing specific technological fields, we observed that the private and public sectors are, to some degree changing, in a similar direction. More focus is given to energy related research, i.e., alternative energy production and energy conservation. Energy conservation patents have increased substantially; the average increase is 240% and 828% in the private and public sectors, respectively. The dominant factor driving the change is *priority*, in both sectors, indicating the researchers' emphasis on energy conservation technologies. A difference between the sectors is found for technology related to agricultural and forestry, which has historically been associated with research in the public sector (Clancy et al., 2016). The result indicates that this relationship still holds, as patent counts are increasing in the public sector, while it is decreasing in the private sector. Contrary to other technologies, the increase is mostly driven by an increase in the scale of R&D and not priority changes.

The most striking difference between the public sector and the private sector is that the relative efficiency of R&D has decreased in the private sector, whereas it increased in the public sector. With the importance of environmentally sustainable technologies for society, a good research policy is necessary, and decreases in research efficiency is an issue future policy should address. Creating incentives using both environmental policy and research policy to foster new technologies is therefore important. Policymakers need to consider the incentives policy create, and in which direction adopted policies push technological development. Cooperation between the sectors is also a good way to ensure the long-term development of new technologies (Fujii and Managi, 2016).

While this paper provides an overview of the development of environmental innovation and highlights differences between the public and private sectors, future research on a more detailed level, focusing on the determinants in the public sector can be fruitful. Micro-level datasets, providing the necessary 'right-hand side' variables, have successfully been used to study innovation in, for example, manufacturing industries (Horbach, 2008; Triguero et al., 2013); efforts to acquire similar information concerning the public sector could provide good research opportunities.

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Popular science summary

The Baltic Sea is one of the most polluted bodies of water in the world. Economic activity causes heavy loads of nutrients to reach the sea. The main contributors to these loads are the agricultural and wastewater sectors. With too much emission, the sea has become strongly eutrophic, with negative environmental consequences. Efforts to remedy the problem and improve the water quality of the Baltic Sea have been taken at both the international and national levels. In recent decades, the countries surrounding the Baltic Sea have adopted reduction targets, which over time, have become more rigorous.

This thesis focuses on the effects of increased attention on environmental concerns and environmental regulation on technological innovation and issues related to the cost-effectiveness of nutrient reductions to the Baltic Sea. New technologies are important for improving the water quality of the Baltic Sea. Policymakers should, therefore, design environmental regulations such that they foster innovation. Policies should also be implemented with cost-effectiveness in mind. For the Baltic Sea, ambitious and expensive targets to reduce nutrient pollution have been set by the surrounding countries. The countries and governments, however, are operating with a limited amount of resources and have to make tradeoffs on where to use these resources. Therefore, reductions should preferably be done at the lowest possible cost.

Results from the thesis show that environmental regulations aimed at reducing nutrients from the wastewater treatment sector, in Sweden, have increased technological innovation in the sector. A similar effect is not found in the agricultural sector. The difference can be explained by the design of adopted policies. The policies for the wastewater treatment sector allowed for more flexibility in the choice of means for complying with the new regulations, creating stronger incentives for the development of new technology. The opposite was the case for the agricultural sector, where regulations target specific technologies.

The thesis also compares the development of technology in the private and public sectors in six major countries. Using patents as a measure for innovation, the results suggest that, over the period 1990 to 2014, there has been a shift towards environmentally sustainable technologies in both sectors. Specifically, research priority has shifted towards energy related technologies. In addition to changes in research priorities, the scale of research and development efforts have increased over time. A notable observation is that the research efficiency in the private sector has decreased while in the public sector, it has increased.

The cost-effectiveness of the nitrogen reductions made by the Baltic Sea countries from 1996 to 2010 was analyzed in the thesis. The results show that reductions made were unnecessarily expensive. The reductions made were eight times as expensive as the least-cost solution. Put differently, the achieved reduction in nitrogen could have been twice as large without increasing the costs. To reach a more cost-effective reduction, a redistribution of the reduction efforts between the countries would be necessary. Low-cost countries, like Poland, would be required to do more. However, this can be difficult to achieve without compensation to countries asked to increase their effort.

A popular instrument to reduce nitrogen pollution from agriculture is agricultural-environmental support schemes (AES). In these programs, farmers decide voluntarily whether they should enroll in programs to change their farming practices. With the preferences of farmers and the environmental effectiveness of changes in farm practices varying within a country, one could increase the budgetary efficiency by having differentiated payments. Using a choice experiment in five Baltic Sea countries, the thesis shows how providing differentiated payments, based on the distance to the coast or nitrogen retention, can be used to achieve this. The result suggests that for some countries, the compensation demand increases as the distance from coast increases. In this situation, a lower compensation could be given to farmers closer to the coast, where the environmental outcome is higher.

Populärvetenskaplig sammanfattning

Östersjön är ett av världens mest förorenade hav. En bidragande orsak är den höga ekonomiska aktiviteten i området, som leder till stora utsläpp av näringsämnen. Jordbrukssektorn och reningsverkssektorn är de två största källorna till kväve och fosforutsläppen. För att minska utsläppen har en mängd olika åtgärder genomförts på internationell och nationell nivå. Under de senaste decennierna har östersjöländerna tillsammans antagit olika reduceringsmål för kväve och fosfor, vilka över tid har blivit allt stramare.

Denna avhandling fokuserar på effekterna av miljöpolitik på teknologisk innovation, samt kostnadseffektivitet gällande kvävereduceringar till Östersjön. Utveckling av hållbar teknologi är ett viktigt verktyg för att nå en förbättrad vattenkvalitet. När nya miljöpolitiska åtgärder genomförs är det därför önskvärt att de bidrar till ökad utveckling av ny teknologi istället för att vara begränsande för densamma. Åtgärderna ska helst också ha kostnadseffektivitet i åtanke. De reduceringsmål för näringsämnen som Östersjöns kustländer beslutat om är ambitiösa men dyra. Staterna har dock begränsade resurser och måste göra olika avvägningar när de beslutar om hur de ska spendera dessa. I och med detta är det önskvärt att de åtgärder som utförs görs till en så låg kostnad som möjligt.

Resultat från denna avhandling visar att miljöregleringar för minskningen av näringsämnen från vattenreningssektorn har haft en positiv effekt på innovationer inom sektorn. En motsvarande effekt kunde inte identifieras i jordbrukssektorn. En förklaring till detta är de regleringar som införts i vattenreningssektorn har varit mer flexibla vad gäller hur man skulle uppnå de nödvändiga minskningarna. Detta leder i sin tur till att det finns starkare incitament för vidareutveckling av ny teknologi. Det motsatta är fallet för jordbrukssektorn.

Avhandlingen studerar även miljöinnovation på en mer aggregerad nivå i sex olika länder, med syfte att jämföra utvecklingen inom offentlig och privat sektor. Patent används som ett mått på innovation inom de båda sektorerna över perioden 1990 till 2014. Resultatet visar att utvecklingen av energirelaterade innovationer har fått ett ökat fokus inom både privat och offentlig sektor. I den privata sektorn har ökningen främst drivits av en större skala på forskningen samt ökad prioritet för just dessa teknologier. Dock, så har forskningseffektiviteten minskat i den privata sektorn, vilket har haft en negativ påverkan på tillväxten i patent. I offentlig sektorn är förhållandet det motsatta: förbättring i forskningseffektiviteten har haft en positiv påverkan på tillväxten i patent.

Kostnadseffektiviteten för kväveminskningarna för nio östersjöländer för perioden 1996 till 2010 analyseras i avhandlingen. Resultaten visar att de uppnådda reduktionerna inte var kostnadseffektiva. Kostnaden var för dessa var åtta gånger så hög jämfört med om den samlade utsläppsminskningen skulle ha uppnåtts till minsta möjliga kostnad. Om man vänder på det skulle minskningarna kunna ha dubblerats utan att den faktiska kostnaden skulle öka. För att uppnå en kostnadseffektivlösning så skulle fördelningen av minskningen mellan länderna behöva ändras. Lågkostnadsländer som Polen skulle behöva stå för en större del av reduktionerna. Politiskt skulle detta förmodligen kräva att andra länder som får minskade krav skulle behöva kompensera de länder som behöver göra mer.

En vanlig åtgärd för att minska jordbrukens miljöpåverkan är miljöstödsprogram där jordbrukare frivilligt, fast med kompensation, går med på att ändra sina jordbruksmetoder. Jordbrukares vilja att gå med i dessa program beror på deras privata preferenser, som varierar. Utöver detta så varierar miljöeffekten beroende på var dessa åtgärder införs. Genom att ta hänsyn till variationen i kompensationskraven från jordbrukare är det möjligt att erbjuda anpassade ersättningsnivåer och på så sätt öka budgeteffektiviteten i programmet. I avhandlingen visas det genom ett valexperiment hur avståndet till kusten samt kväveretentionen kan påverka jordbrukares kompensationskrav. Resultaten visar att i vissa länder ökar kompensationskravet när avståndet till kusten ökar. När så är fallet, kan lägre kompensation ges till jordbrukare vid kusten, där miljöeffekterna också kan väntas vara högre. Att kunna erbjuda olika ersättningsnivåer kommer minska kostnaden i programmet, och på så vis öka antalet jordbrukare som kan ansluta sig till programmet vid en given budget.

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Tobias Häggmark
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