Bachelor's in Economics

Facilitating induced green innovation in Finland: An evaluation of the effectiveness of carbon pricing and subsidies.

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Abstract

This thesis addresses climate change by discussing how policy interventions can foster green innovation in Finland. Moreover, this literature review will discuss the effectiveness of carbon pricing and subsidies to incentivize innovation. The findings suggest that the key in environmental policy is the dual externality structure of the market, with a negative externality from carbon emissions and a positive externality from innovation. Furthermore, the optimal policy portfolio to incentivize green innovation includes both carbon pricing and R&D subsidies, because the two externalities need to be addressed separately. More specifically, with R&D subsidies are dominant in the short-term and carbon pricing in the long-term. First, I will delve into the policies and their effectiveness on a global scale, after which the focus will be narrowed down to Finland.

Keywords Green Innovation, Environmental Policy, Carbon Pricing, R&D Subsidies, Climate Change, Innovation Policy

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1 Introduction

Climate change is an issue that poses a threat to both current and future generations, thus finding a solution to stop it is crucial. Furthermore, carbon emissions have been identified as the main contributor to climate change and limiting them is vital. Accordingly, international agreements such as the Kyoto Protocol in 1997 and Paris Agreement in 2015 have established global collaboration to mitigate climate change. Currently, Finland's primary environmental goal is to reach carbon neutrality by 2035 (Clarke, 2023). Additionally, green innovation and a transition to clean technology have been recognized to be key players in limiting carbon emissions and achieving carbon neutrality (e.g., Acemoglu et al., 2018; Einiö et al., 2022; Goulder & Schneider, 1999; Martínez-Zarzoso et al., 2019; Ollikka, 2023).

This literature review evaluates the effectiveness of two policies–carbon pricing and subsidies–in inducing green innovation, with the case study of Finland. Effectiveness refers to the ability of carbon pricing and subsidies to induce green innovation in Finland, measured by their capacity to address externalities and drive technological advancement. Thus, the research question that guides this investigation is: *"Which policy instrument—carbon pricing or subsidies—is most effective in inducing green innovation in Finland?"*

In order to examine the effect of policy on green innovation, this thesis incorporates two aspects. First, I will delve into the general economic implications for the policies under review, based on global literature. Second, I will focus on Finland specifically to evaluate the policies within the context of its economy.

1.1 Rationale for study

This review is economically significant as the answer to the research question offers guidance for governments globally to address climate change. Additionally, evaluating the effectiveness of innovation incentivizing policies is essential, as current technology is not yet sufficient for economies to operate under carbon neutrality, making the development of new clean technologies critical in achieving this goal.

When considering climate change, externalities—costs or benefits to society—are central to economic policy. These externalities lead to market failure, where goods or services are either over- or underproduced. Carbon emissions create a negative externality that harms the environment without imposing full costs on polluters, leading to overproduction (Ollikka, 2023). Green innovation, however, generates a positive externality that benefits society more than the inventor, leading to underproduction (Ollikka, 2023). To correct these imbalances, carbon pricing mechanisms set a price on emissions, discouraging overproduction (Ollikka, 2023). Meanwhile, R&D subsidies provide monetary aid for innovation, this encourages the production of new knowledge (Ollikka, 2023).

In line with these principles, Finland's policy framework includes carbon pricing through a carbon tax and participation in the EU Emissions Trading System (EU ETS), along with R&D subsidies aimed to promote green innovation. While there are other methods to drive innovation, this thesis focuses on these two instruments because they directly address the key externalities of emissions and knowledge spillovers and are the primary tools employed in Finland's climate policy.

The notion that strict environmental regulation is believed to indirectly induce green innovation is the Porter Hypothesis, first introduced in Porter (1991). This thesis will explore the Porter Hypothesis, using Finland as a case study.

1.2 Research approach

The thesis will synthesize existing research, both theoretical and empirical, to answer the research question. The literature selected for this review spans multiple fields, including economics, environmental policy, and innovation studies. Additionally, the research is multi-dimensional as it considers both the short and long-term impacts of carbon pricing and R&D subsidies in incentivizing green innovation.

Specifically, I will examine:

1. Analyses on carbon pricing and R&D subsidies that focus on their impact on innovation and carbon reduction.
2. Empirical studies that provide insight into the effectiveness of the policy instruments separately.

3. Empirical studies that explore the interconnectedness of the policies.
4. Reports that highlight Finland's approach to carbon pricing and subsidies and their current and projected outcomes

Although sufficient literature exists on induced green innovation, a few limitations remain. First, since all policy instruments work simultaneously it is difficult to differentiate their effects in empirical evaluation. Second, the empirical literature reviewed often focus of different countries. Therefore, this thesis assumes that the results found elsewhere equally apply in the Finland, which may introduce geographical biases. Furthermore, this thesis seeks to address this gap by offering an evaluation of the policies in Finland. Third, there exists a time lag between policy implementation and tangible innovations, which poses a challenge for evaluation. Fourth, the use of patent data in some empirical studies may reflect merely short-term output as opposed to long-term technological progress. Innovation a long time materialize, especially considering relatively new policies such as the EU ETS. This makes it difficult to assess the long-term impacts of policy interventions.

Despite this, the literature review provides valuable insights into the impact of carbon pricing and R&D subsidies on green innovation. While, incentivizing green innovation is important on a global scale, Finland has been a pioneer in climate policy since its introduction of the world's first carbon tax in 1990, thus offers a valuable perspective in a case study. Moreover, while this study looks at a local issue it also provides ideas on how economic growth and environmental protection can be balanced globally. The findings of the literature review suggest that the optimal approach to incentivize green innovation effectively is a dual-policy approach where carbon price and R&D subsidies work in synergy. Furthermore, with R&D subsidies in the short-term and carbon pricing in the long-term.

1.3 Structure of the thesis

The literature review is organized in the following way. Section 2 explains the theoretical framework behind the analysis. Moreover, delves into the economic theory of externalities and market failure related to green innovation. Section 3 outlines why green innovation is significant in carbon abatement. Section 4 reviews each policy instrument in terms of their significance in incentivizing green innovation. Section 5 draws a focus on Finland and considers how the concepts from Section 4 apply. Section 6 will discuss the findings. Section 7 concludes.

2 Theoretical framework

This section outlines the relevant economic theory related to green innovation to create a foundation for the discussion of these concepts. I will focus on the dual nature of externalities—positive and negative—in the environmental market and the role of government interventions in addressing them. An externality is a cost or benefit from an economic activity on a third party. Additionally, market failure, where the free market is not trading at the optimal equilibrium level, occurs due to externalities. In economic theory, market failures due to externalities are corrected with market interventionist policies to restore equilibrium.

In the context of the environmental market, the positive externality is the knowledge spillover from green innovation, and the market failure arises from the lack of the positive externality. Contrastingly, the negative externality is pollution from carbon emissions and the market failure arises from the excess of the negative externality. Furthermore, the lack of knowledge spillover is traditionally corrected with R&D subsidies and the excess of pollution is corrected with carbon pricing.

2.1 Positive externality: knowledge spillover

A direct externality from green innovation is the knowledge spillover, which is a positive externality from R&D. Essentially the knowledge spillovers from new inventions create more social benefit to the public than private benefit to the inventor. Therefore, there exists limited incentives for private firms to produce at the socially optimal level and these incentives need to be offered externally (Popp, 2010). Because of this, R&D is often underproduced by the market relative to the social equilibrium, leading to market failure (Popp, 2010). This is because knowledge is a public good (Popp, 2010). Furthermore, it is non-excludable (once produced, it is hard to prevent others from using it for free) and non-rivalrous (one person's use does not reduce its availability to others). This makes it difficult to charge users since the cost of sharing it is typically zero, which gives rise to the free-rider problem, where individuals or firms use resources without payment. This underproduction knowledge is traditionally corrected with a subsidy (Popp, 2010).

2.2 Negative externality: emissions

In the context of this review, the knowledge spillover seems to be more relevant as the underproduction of R&D exists because of it. Nonetheless, the negative externality of carbon emissions is highly relevant as it is a component of the market where green innovations are introduced and needs to be addressed. Therefore, an indirect externality to consider is the negative externality of carbon emissions. Contrastingly to the positive externality, the invisible hand mechanism leads markets to overproduce the negative externality relative to the socially optimal amount, creating another market failure (Popp et al., 2010). The overproduction occurs as there is a gap between the high social cost borne by society and the lowe private cost to the firm. Moreover, unregulated markets overproduce emissions as they do not factor in the external costs imposed on society, which leads to inefficient allocation of resources. This overproduction of emissions is traditionally corrected with carbon pricing (Popp, 2010).

2.3 R&D subsidies

R&D subsidies are used to correct for the positive externality of knowledge spillover from innovation. Subsidies are financial incentives provided by the government to encourage investment in areas that produce social benefits, such as R&D. To correct the market failure and reach an efficient market, the marginal private cost of R&D to producers must be equal to the marginal social cost of supplying R&D (Goulder

& Schneider, 1999). In the context of the subsidy, the monetary value of the subsidy must equal the marginal social benefit (MSB) from the positive externality, i.e. knowledge spillover (Goulder & Schneider, 1999). MSB is difficult to measure accurately, and expensive to provide in the long-term (Paukku, 2021). The mechanism of the subsidy is that the government pays a portion of the marginal cost of R&D. Since the marginal cost is lower after the subsidy, the firm will invest more in R&D, thereby addressing the positive externality (i.e., the difference between the private and social optimum). By removing the positive externality, R&D subsidies foster technological advancement by providing firms incentive to innovate.

2.4 Carbon pricing

Carbon pricing is used globally to correct for the negative externality from carbon emissions. The carbon pricing policies assessed in this paper are carbon taxation and EU ETS. The carbon tax sets a price on emissions, and the firms determine how much they are willing to emit given this price. The emissions trading system, EU ETS, sets a cap on the emissions and allocates allowances to countries and firms according to the cap. Firms who need more allowances can buy them later from a market where they are auctioned by firms that have them in excess. Essentially, setting a price on carbon internalizes the externality. In other words, it forces the polluter to pay for the social cost the externality. This is referred to as the polluter-pay principle, which is the most common environmental policy (Paukku, 2021).

In this thesis, the carbon tax and the EU ETS are collectively referred to as "carbon pricing," since both function through setting a price on carbon. The carbon price is an opposite mechanism to subsidies as it increases the marginal cost of emissions. Thereby it increases the production costs of the firm which will incentivize them to reduce their emissions and correct the negative externality (i.e., the difference between private and social cost of emissions) and maximizes social welfare. Economic theory also suggests that the carbon taxes and emissions trading systems are equivalent (Clarke, 2023). This equivalence arises because the carbon price is traditionally set to align with the marginal social cost of emissions (MSC). More specifically, the two are equivalent when the carbon price is precisely equal to the MSC (Clarke, 2023). It should be noted that measuring the true level of MSC is difficult, but easier in contrast to MSB. In addition to reducing emissions, carbon pricing incentivizes polluting firms to switch to clean technology and by extension invest in clean technology R&D (e.g., Porter, 1991; Ottelin et al., 2018; Popp, 2010; Goulder & Schneider, 1999; Veugelers, 2012). This is the aspect of carbon pricing under review in this thesis.

3 Significance of green innovation

In order for emissions from energy production to decrease, the old technology must be replaced by new clean alternatives. It has been established in empirical literature that polluting and non-polluting technology are good substitutes (Papageorgiou et al., 2017). Regardless, Bretschger (2024) highlights how even with a high elasticity of substitution, substantial advancements in clean technologies are essential for achieving decarbonization. This section will show why green innovation is significant and why investing in it is essential for solving the climate crisis.

3.1 Two-period partial equilibrium model

Let's examine the two-period partial equilibrium model developed by Goulder and Schneider (1999) to investigate the interplay of green innovation and carbon abatement (reduction of emissions). The core focus of the model is to explore how technological development can lower the cost of carbon abatement and increase the benefits of carbon price. Through utilizing a two-period model Goulder and Schneider (1999) show the relationship between innovation and carbon abatement over time in a simplified manner. In period 1 technological change is exogenous and the firm decides if they will engage in R&D activities. In period 2 technological change is no longer exogenous but determined by the firm's decision in period 1. **Figure 1** represents the marginal costs (MC) for two firms in period 2, one which has not engaged in R&D activities in period 1 (**MC**) and one which has (**MC'**).

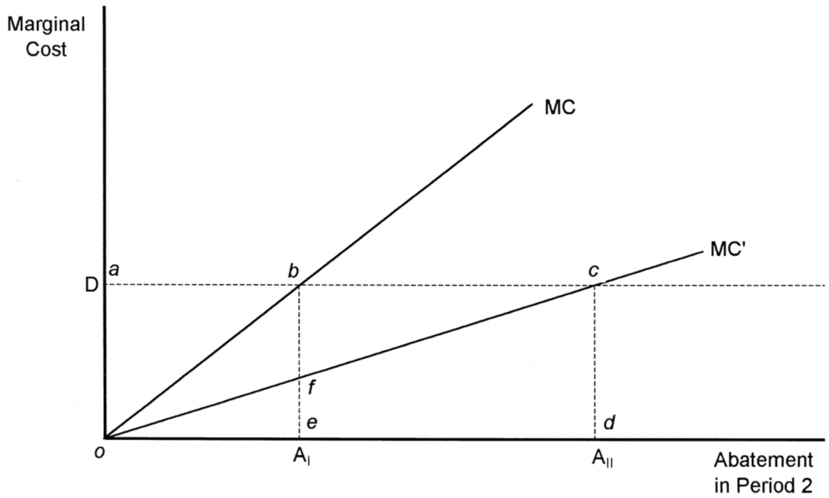

Figure 1 - Green innovation and marginal cost of carbon abatement, Source: Goulder and Schneider (1999)

The above figure illustrates how R&D can lead to cost-savings in abatement for firms and governments. R&D expenditures in period 1 lead to technological advancements in period 2. This new clean technology that is incorporated will reduce the cost of abatement in period 2, thus pivoting the MC curve downward.

Given the abatement level $\mathbf{A_I}$, the cost of achieving this level is lower in the presence of innovation. The area of the triangle **obe** represents the gross cost of abatement level $\mathbf{A_I}$ in the absence of innovation, while the triangle **ofe** indicates the gross cost in the presence of innovation. Thus, the area between the marginal cost curves **MC** and **MC'** illustrate the cost-savings from R&D (i.e. triangle **obf**).

Additionally, consider that the carbon price is set to level **D**, which is the extent of the negative externality or MSC. As a response to the carbon price (D), the innovating firm will choose abatement level $\mathbf{A_{II}}$. Here, the gross abatement cost is given by the triangle **ocd**. In the absence of innovation, gross cost would again be **obe**. Despite larger gross costs, the gross benefits in the presence of innovation (rectangle **oacd**) are larger compared to those in the absence (rectangle **oabe**). This leads to higher net benefits as long as the carbon price rate is set at the correct level, i.e. MSC (Goulder & Schneider, 1999). Goulder and Schneider (1999) note; however, that the analysis above does not provide grounds to subsidize R&D. The justification requires another market failure in addition to emissions, however as discussed in **Section 2.1** the market failure due to the knowledge spillover provides this justification.

Furthermore, other literature also supports the findings from Goulder and Schneider (1999). For instance, Popp (2010) reinforces how the combination of carbon pricing and R&D accomplishes carbon abatement at a substantially lower cost. Additionally, it has been established that innovation and economic growth are positively correlated (e.g., Acemoglu et al., 2018). These findings reinforces the notion that green innovation is of great value, for not only emission reductions but also the cost-savings of governments. In general, the aforementioned arguments provide a solid ground for the benefit and significance of innovation in terms of hindering climate change.

4 Evidence on innovation inducing policy

Market failures, driven by externalities, prevent markets from achieving Pareto-efficiency. According to neoclassical economic theory, competitive markets generally yield the most efficient outcomes when individuals act in their self-interest (Mazzucato et al., 2019). However, in the presence of market failure this is not the case and government intervention is necessary to restore efficiency. Since there exists two distinct externalities and by extension two market failures, addressing these with separate policies is necessary.

Additionally, the Porter Hypothesis suggests that beyond merely addressing market failures caused by externalities, abatement policies can actively stimulate green innovation (Porter, 1991). This thesis focuses on a particular aspect of the Porter Hypothesis—the Weak Porter Hypothesis—which examines the relationship between abatement costs on R&D (Martínez-Zarzoso et al., 2019). In line with the Porter Hypothesis, this paper considers carbon pricing as an innovation incentivizing policy. This section reviews literature on two interventionist policies–subsidies and carbon pricing–by evaluating their effectiveness in addressing market failures and incentivizing green innovation.

In addition, Popp et al. (2010) delves into the interconnectedness of the externalities and innovation incentivizing policy. According to Popp et al. (2010), these two externalities present “two hurdles for policy makers to address” when incentivizing green innovation. Thus, they highlight how policymakers need to decide between two approaches: to correct the positive or the negative externality but emphasize how in the long run both require attention. The policies and their effect on the market will be explored below.

4.1 Empirical evidence of carbon pricing on innovation

Carbon abatement policies and innovation are intertwined in several ways. The consensus among economists is that carbon pricing may be used to incentivize green innovation (e.g., Porter, 1991; Ottelin et al., 2018; Popp, 2010). Essentially, when the price of polluting increases, profit-maximizing firms are inclined to engage in R&D for lower production costs (Popp, 2010). Additionally, carbon pricing accelerates the adoption of clean technology (Bretschger, 2024). This is important, as the diffusion of new technology is often an issue (Owen, 2006). Bretschger (2024) also argues how carbon pricing is vital, as it targets both emissions and innovation.

Furthermore, Matterne et al. (2024) examines the effect of the carbon tax in the Canadian province British Columbia (the only province to implement the carbon tax in 2008) using Canadian provincial level data from 1997 to 2015. They conduct a Difference-in-Difference (DiD) analysis, using British Columbia as the treatment group and the other provinces as the control group. They find that the carbon tax in British Columbia increased R&D expenditure by $485 million compared to the average, $1.313 million, of other provinces. Nevertheless, all patent applications decreased by 10% in British Columbia compared to other provinces. They explain this with how their model did not differentiate green patents from other patents.

On the other hand, Grüber et al. (2002) creates a model which embeds an innovation production function into an economic model of climate change to examine the effect of many variables, most notably policy, on innovation. They find that while doubling the carbon price would increase R&D by 80%, carbon price is not the most effective way to incentivize innovation. They note how, effective climate policy is not merely increased regulatory stringency and includes subsidizing R&D in clean technology. Grüber et al. (2002) reinforces the notion that there is a limited pay off in incentivizing innovation through creating a necessity for it with stringent regulation. While both Matterne et al. (2024) and Grüber et al. (2002) recognize that carbon pricing is positively correlated with green innovation, they both also conclude that carbon pricing alone is insufficient.

Additionally, other scholars, such as Paukku (2021), argue that the political feasibility of setting sufficiently high carbon prices remains a challenge, which limits its real-world applicability and should be accompanied with subsidies.

4.2 Empirical evidence of R&D subsidies on innovation

R&D subsidies directly target the positive externality, and solely aim to increase green innovation. Empirical research has investigated the success of subsidies in increasing innovation.

Veugelers (2012) uses firm-level data from a Flemish CIS-VI survey to estimate the impact of government policies—such as regulations, taxes, and subsidies—on the likelihood of firms adopting or developing green innovations. Veugelers (2012) finds that the effectiveness of subsidies when used alone is minimal and suggests a combination of subsidies and carbon taxes to effectively induce innovation.

In addition, Popp (2006) utilizes a database spanning from 1970 to 1999 of patents in the United States, targeting patents in 11 energy-related technology categories. The study finds that energy patents originating from government R&D investments were cited more frequently compared to other energy patents. This finding reinforces the argument that public investments in R&D can generate knowledge spillovers, which are crucial for advancing clean technology. Overall, the findings suggest that government subsidies and expenditures in R&D have enhanced the knowledge stock and supported private sector innovation through effective technology transfer and by focusing on basic research.

Additionally, Bloom et al. (2019) suggests that subsidies should be combined with strong protection of intellectual property rights (strong patent laws) to address the knowledge spillover externality and increase innovation. However Takalo and Toivanen (2018) underline, how strong patent laws reduce consumer surplus and the spillovers as opposed to increasing them. According to economic theory, tradeoffs regarding patent laws make the shape of the relationship between social welfare and patent law strength an inverse-U (Belleflamme & Peitz, 2015). Furthermore, there is limited empirical evidence that strong patent laws boost innovation (Takalo & Toivanen, 2018). Moreover, both Veugelers (2012) and Popp (2006) find that R&D subsidies are vital in fostering green innovation, yet a combination with carbon pricing would yield more effective results.

4.3 Interplay between carbon pricing and subsidies

Subsequent this examination of the policies it should be highlighted that the policies exist for different purposes and target different failures. Therefore, an efficient market along with an efficient incentivization of green innovation requires the combination of both policies (e.g., Paukku, 2021; Acemoglu et al., 2016; Popp et al., 2010). In this section I will explore 2 empirical studies, Martínez-Zarzoso et al. (2019) and Acemoglu et al. (2016) both of which delve into the interconnectedness of the policies and their joint application.

4.3.1 Panel-quantile regression model in OECD countries

Martínez-Zarzoso et al. (2019) tests the Porter hypothesis using data from 14 OECD countries to analyze the impact of environmental policy stringency (EPS) on innovation. Policy stringency is measured with the OECD Environmental Policy Stringency Index, which includes a plethora of policies including both carbon pricing and subsidies. They divide the countries into quantiles based on how innovative they are and the model shows whether EPS has different effects depending on quantile. Table 1 presented below shows the regression coefficients from Martínez-Zarzoso et al. (2019) on how EPS impacts R&D expenditure and patent applications.

Table 1 – The regression coefficients of EPS on R&D expenditure and patent applications

EPS on R&D expenditure					
Quantile	10th	25th	50th	75th	90th
1-year-lag	0.11	0.053	0.014	-0.03	-0.02
5-year-lag	0.17	0.15	0.12	0.06	0.07
EPS on patent applications					
Quantile	10th	25th	50th	75th	90th
1-year-lag	0.01	0.016	0.09	0.09	0.11
5-year-lag	0.03	0.04	0.05	0.06	0.05

For R&D expenditure they find that in the short term (1-year-lag) coefficient for EPS is **0.11** for the 10th quantile and **0.053** for the 25th quantile, indicating a statistically significant positive impact on R&D expenditures in countries that spend relatively less on R&D to start with (the lower quantiles). This supports the Porter Hypothesis in the short run; however, only for countries with less-established R&D infrastructure. Coefficients for the higher quantiles suggest that policy stringency does not further incentivize R&D investment for nations already leading in innovation in the short run.

Similarly, in the long term (5-year-lag) the coefficient for EPS is positive and statistically significant impact across all quantiles in the long term. Moreover, this underscores that while EPS initially boosts R&D more in countries with less R&D spending, the long-term benefits spread more evenly across countries with all levels of R&D spending.

The results show a notable positive effect of EPS on patent applications, particularly at higher quantiles (50th, 75th and 90th). This suggests that EPS has a more immediate impact on patent activity for countries with already established innovation ecosystems. Countries at higher quantiles may have the infrastructure to quickly translate policy pressures into tangible innovations–patents. For the lower quantiles (10th and 25th), the coefficients are **0.01** and **0.016**, respectively, and are not statistically significant.

Meanwhile, in the long term (5-year-lag) the coefficients for EPS indicate a positive impact across all quantiles, with the effect being stronger in the middle and upper quantiles. This pattern suggests that EPS initially drives innovation more effectively in sectors that are already inclined toward patenting and technological development.

Overall, these findings suggest that carbon pricing and subsidies can act as a catalyst for innovation when functioning simultaneously. In the short run environmental policy acts as an incentive for the quantity of R&D expenditure in less established countries, while the coefficients for patents suggest that for more established countries the quality of the R&D is impacted. In the long run, all countries are positively affected in both.

4.3.2 Microeconomic model to study the path of optimal policy

While Martínez-Zarzoso et al. (2019) provide empirical support for policy incentivized innovation, Acemoglu et al. (2016) outline the 'optimal policy path' to promote clean technology. This is done based on their microeconomic model developed with data from the energy sector of the United States that compares "dirty" and "clean" technology in production and innovation. The result optimal policy path found through their model is illustrated below in **Figure 4**.

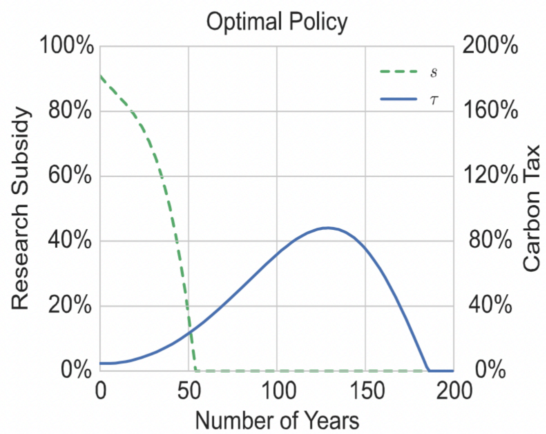

Figure 4 - The optimal policy paths for research subsidies (s) and carbon taxation (τ), Source: Acemoglu et al. (2016)

Overtime there is a clear transition in policy focus, starting with high R&D subsidies and low carbon taxes, then gradually shifting to high carbon taxes as R&D

subsidies are phased out. Acemoglu et al. (2016) plead to intuition in their explanation, as with a high subsidy firms will be incentivized to conduct clean technology research. When clean technology research becomes sufficiently profitable the subsidy will be decreased. Furthermore, the carbon tax is initially set low, because with a high carbon tax the price signal for consumers would decrease consumption (Acemoglu et al., 2016). Furthermore, the hump shape of the carbon tax is explained to be due to two mechanisms; (i) for the social planner, future economic inefficiencies are perceived as less significant because of discounting; (ii) as clean technologies develop, the decrease in consumption because of the price signal from the carbon tax decreases. Finally, over time as production and consumption have transitioned to clean technology the carbon tax is no longer needed. This aligns with the discussion of Martínez-Zarzoso et al. (2019) where the effects of carbon pricing are more prominent in the long run for firm level R&D investment.

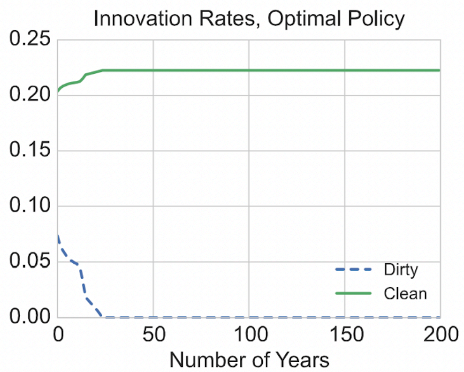

Figure 5 - Effect on the innovation rates of “dirty” and “clean” technology from optimal policy, Source: Acemoglu et al. (2016)

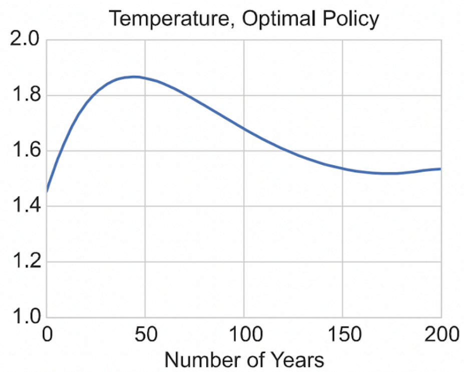

Figure 6 - Effect on temperature from optimal policy, Source: Acemoglu et al. (2016)

Moreover, **Figure 5** depicts the path of the innovation rates of ‘dirty’ and ‘clean’ technology under optimal policy. As shown, the innovation in dirty technology declines and simultaneously that of clean technology increases. Similarly, **Figure 5** is consistent with the regression coefficients in Martínez-Zarzoso et al. (2019) for patent applications, as they find effect of EPS to be more prominent in the short run.

On a globally significant note, **Figure 6** shows the path of temperature under optimal policy. Acemoglu et al. (2016) find that their combination of policies will limit the temperature rise to below 2 degrees; additionally, after 40 years, the temperature will begin to decrease.

The microeconomic model developed by Acemoglu et al. (2016) provides valuable insight into the dynamic interaction between R&D subsidies and carbon pricing in incentivizing clean technology. Specifically, it provides a theoretical foundation for evaluating the relative effectiveness of carbon pricing and R&D subsidies in Finland's efforts to induce green innovation. Finland, which has already adopted both mechanisms, can benefit from understanding how these policies should evolve over time to maximize innovation and minimize carbon emissions.

5 Green innovation incentives in Finland

This section draws a focus on Finland and delves into the implementation and effectiveness of carbon pricing and subsidies there. As discussed earlier, Finland's main environmental policies are carbon pricing and R&D subsidies.

5.1 Overview of carbon pricing and R&D subsidies in Finland

Finland prices carbon through the EU ETS and carbon taxes. Carbon pricing has a long history in Finland, as it was the first country to adopt the carbon tax in 1990 (Clarke, 2023). In Finland's energy sector "liquid fossil and bio-derived fuels, electricity, and some other fuels such as peat, natural gas and coal" are under carbon taxation, while "peat and pine oil are not" (Clarke, 2023). That being said, peat and pine oil are under an independent energy tax (Clarke, 2023). The EU ETS was established in 2005. For Finland power stations, other combustion plants, airlines and district heating are subject to it (Clarke, 2023). Additionally, Finland offers aid for indirect costs caused by the EU ETS to firms, and it is mandated that at least half of the aid must be used in green R&D (Clarke, 2023).

Furthermore, Finland's government grants R&D subsidies for green innovation. The subsidies are primarily managed by Business Finland, which operates under the Ministry of Economic Affairs and Employment (OECD, 2022).

Currently, Finland’s R&D subsidies for green innovation can be categorized into “investment subsidies, production subsidies and other subsidies” (Paukku, 2021). While other OECD countries have adopted tax credit schemes in order to incentivize green innovation further, in the current Finnish energy taxation policy renewable energy production is merely left out of energy taxation, i.e. carbon taxation (Paukku, 2021). Furthermore, Finland is currently in the minority as they rely solely on R&D subsidies as direct incentive for innovation (Takalo & Toivanen, 2018).

Overall, according to Finland’s Ministry of Economic Affairs and Employment transition to clean energy production is considered a method of promoting Finland’s economy as well as increase welfare (Huttunen, 2017). It is, therefore, crucial to find the optimal approach in Finland to incentivize green innovation cost-effectively. Cost-effectiveness refers to achieving a desired objective with low costs while maintaining a balance between costs and benefits.

5.2 Green innovation in Finland currently

Strategic R&D investments are essential for Finland to meet its environmental targets efficiently. Currently, Finland ranks among the top OECD countries in environmental patents (**Figure 2**), yet further improvements are needed to achieve the carbon neutrality target by 2030 (Ministry of the Environment, 2024).

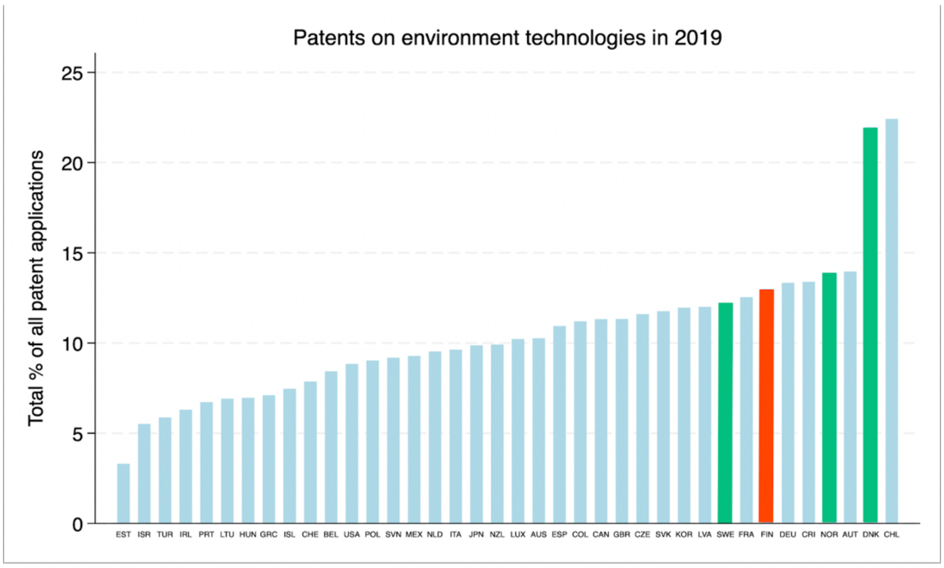

Figure 2 - Environmental patents in OECD countries in 2019, Source OECD (2022)

The OECD (2022) reports that Finland is “broadly on track” to meet its target of carbon neutrality but highlights opportunities for cost reductions. The Ministry of Economic Affairs and Employment notes that Finland’s current carbon pricing does not sufficiently incentivize green innovation, necessitating R&D subsidies, which are projected to generate long-term cost-savings for Finland's economy (Huttunen, 2017). Furthermore, Finland intends to increase R&D spending to 4% of GDP by 2030 (OECD, 2022).

5.3 Evaluation of Finnish innovation inducing policy

Carbon pricing has a long history in Finland and has been effective, yet improvements can be made. A survey of Finnish firms indicates that environmental regulation has influenced their R&D activities (Ali-Yrkkö et al., 2021). On the other hand, Ottelin et al. (2018) analyze the consumption-based carbon footprints in Finland. They suggest that taxation should be shifted to goods and services with high carbon emission intensity, which can be done without increasing the overall taxation (Ottelin et al., 2018). These high emission goods and services are composed mainly of public services and government investments (Ottelin et al., 2018).

Evaluations of Finnish R&D support by Business Finland have shown mixed results. For example, Fornaro et al. (2020) found that support increased firm R&D spending by 30% per euro of sales, boosting both R&D intensity and job creation. However, Koski and Parajanen (2015) observed no significant improvements in labor productivity from direct R&D support neither in the short nor in the long run. Additionally, the OECD (2022) country report on Finland criticizes how Finland’s current R&D subsidy policy is currently “thinly spread across regions, measures and agencies, often lacking sufficient scale to reach a critical mass”. OECD (2022) advices Finland to move toward a more “strategic innovation policy”, similar in other OECD countries, which targets specific market failures. Furthermore, both Paukku (2021) and Ollikka (2023) stress the importance of focusing R&D support on emerging technologies that are not yet economically viable. For example, onshore wind power in Finland is now established in the market and no longer requires subsidy support, giving an opportunity for other technology to receive them (Ollikka, 2023). On the other hand, research by Einiö et al. (2022) using a firm-level innovation model developed by Acemoglu et al. (2018) and data from Finland shows that targeting R&D support at firms with high innovation capacity increases productivity. This enhances the competitiveness of the productive firms as they begin to attract resources like skilled workers, and driving out less innovative firms from the market. Thus, while subsidies boost innovation, their cost-effectiveness remains crucial for maximizing welfare.

5.4 Impact on consumer surplus, welfare, and cost-efficiency

When evaluating climate policy incentivizing innovation, increasing social welfare and consumer surplus is key. In their qualitative analysis of Finland's innovation policy, Takalo and Toivanen (2018) emphasize how it is vital for a open economy, like Finland, to monitor how much consumer surplus and spillovers leak to other countries, where the Finnish tax payer does not benefit. Additionally, Takalo and Toivanen (2018) conduct a quantitative welfare analysis using Tekes R&D subsidy data from 2000 to 2008. Takalo and Toivanen (2018) find that while R&D subsidies increase investment and spillovers by at least 25%, they also slightly reduce overall welfare. This paradox is explained by the administrative and application costs associated with subsidies, which outweigh the benefits. Overall, Takalo and Toivanen (2018) raise the concern of cost to public funds along with firms, as due to them the effect of welfare is minimal. Overall, they emphasize the need for rigorous evaluation of the R&D subsidy policy.

Additionally, in her paper on Finnish carbon pricing Clarke (2023) identifies the "waterbed effect", whereby overlapping policies target the same emissions. In Finland, in the instance of electricity, natural gas, peat and coal the carbon tax and EU ETS overlap (Clarke, 2023). The carbon tax will incentivize Finnish firms to reduce their emissions, and meanwhile the demand for emission permits decreases and thus so does their price (Clarke, 2023). Globally, this reduces incentives for other countries without the carbon tax to reduce their emissions as they may purchase allowances at a cheaper price (Clarke, 2023). EU has addressed the 'waterbed effect' from overlap by removing the excess allowances, but this in turn may increase cost of abatement (Clarke, 2023). Overall, Finland's subsidy and carbon pricing policies have expanded R&D investments and the spillovers to a great extent (Takalo & Toivanen, 2018; OECD, 2022).

6 Discussion

The research question this literature review aimed to answer was *"Which policy instrument—carbon pricing or subsidies—is most effective in inducing green innovation in Finland?"*. The findings from this review highlight two key takeways: the requirement for 1. a dual-policy approach and 2. cost-effectiveness. This section will provide an additional discussion on them before concluding.

6.1 Required dual policy approach

Since there are two externalities in the market, the research found that because of this, two policies are required to fix the market failure. More specifically, knowledge spillover and carbon emissions need to be targeted separately to reach market efficiency. Since R&D subsidies are designed to directly incentivize innovation and maximize the knowledge spillover according to economic theory they should be more effective compared to carbon pricing. Nevertheless, the economy is complex and R&D subsidies were found to be rather ineffective in isolation and need carbon pricing to reach their full potential. Thus, one of the most significant findings to discuss further is the interaction or carbon pricing and subsidies.

Section 4.3 outlines how carbon pricing and subsidies interact currently in incentivizing innovation and the optimal path for their utilization. It should be noted that subsidies not only increase R&D spending, but also direct innovation towards environmentally sustainable technologies, which is critical for achieving Finland's climate goals. As shown in the optimal policy path by Acemoglu et al. (2016), by starting with a high R&D subsidy level, the government can initially direct the innovation toward green technology. When the required level of green technology level is reached, carbon pricing is introduced as the main method to drive out fossil fuel production.

In addition, the research by Martínez-Zarzoso et al. (2019) supports this notion of how policies interact to incentivize green innovation (R&D expenditure and patents). For instance, in the short run environmental policy has a greater positive effect on R&D expenditure for countries with low R&D and on patent applications for countries with high R&D. This is because countries with high R&D already have sufficient infrastructure to turn R&D into patents. Furthermore, this is in line Acemoglu et al. (2016), as R&D subsidies are required in the short run for low innovative sectors to enable innovation toward green technology. Additionally, in the long run there exists a positive effect in both R&D expenditure and patent applications across the board, the strong carbon price suggested by Acemoglu et al. (2016) is justified as carbon price offers a continuous incentive to innovate.

Similarly, Finland's experience with carbon pricing and R&D subsidies highlights the necessity of a dual policy approach. As the first country to adopt a carbon tax, Finland has demonstrated a strong commitment to reducing emissions through market-based mechanisms. However, research reviewed in **Section** Error! Reference source not found. show that carbon pricing alone has not been sufficient to drive the level of green innovation necessary for achieving the country's targets and the subsidy policy should be reformed. Furthermore, the criticism on Finnish subsidy policy stems from its lack of focus and aligns with the findings of Martínez-Zarzoso et al. (2019). As discussed earlier, environmental policy affects the R&D expenditure level of low innovation countries relatively more compared to high innovation countries. This can be applied to sector or technology specific R&D support, and how in Finland it should be directed to sectors where R&D expenditure is not yet high enough. Similarly, as delved into in **Section** Error! Reference source not found. Ottelin et al. (2018) notes the carbon tax in Finland should be directed toward sectors with high emissions, aligning with Acemoglu et al. (2016). This will allow the Finnish carbon tax to take over in the long run, once clean technology infrastructure has been established as suggested by the optimal path in Acemoglu et al. (2016). Furthermore, as discussed in **Section 2.3** R&D subsidies are an expensive long-term strategy particularly for Finland, supporting the optimal path by Acemoglu et al. (2016) further.

Overall, the interplay between addressing two distinct externalities—emissions (a negative externality) and knowledge spillover (a positive externality)—requires a dual policy approach. As discussed earlier, Popp et al. (2010) emphasizes that addressing only one market failure is not enough; both the negative and positive externalities must be managed through separate, yet complementary, policy instruments.

6.2 Cost-effectiveness in abatement policy

This review found that one of the most significant challenges Finland faces is the need to reduce the costs associated with green innovation. The model by Goulder and Schneider (1999) explored in **Section 3.1** illustrates how R&D activities can significantly lower the marginal costs of carbon abatement over time, and Finland's policy mix reflects this principle. By subsidizing R&D, Finland reduces the upfront costs of developing clean technology, which in turn lowers future carbon abatement expenses. Nevertheless, as noted in the evaluations of Finnish R&D policies in **Section** Error! Reference source not found., subsidies should be redirected technologies that are not yet established in the market. This could drive cost reductions further. As discussed earlier, this gives the opportunity for innovation in areas with less R&D activity.

Additionally, Finland could improve the coordination between its carbon pricing. The "waterbed effect" described in also **Section** Error! Reference source not found. highlights the issue of overlapping carbon tax and EU ETS. A more refined strategy could involve adjusting the carbon tax to focus on sectors not covered by the EU ETS since the two are theoretically equivalent. This would generate cost reductions in the administration of carbon pricing for the government.

6.3 Limitations

In the introduction, three limitations to the research were identified. In this section I will discuss how each limitation was addressed and how each may have impacted the results.

First, the simultaneous implementation of carbon price and subsidies could distort the empirical analysis. This is addressed in the research methods of the empirical studies in **Sections 4.1 and 4.2** through using a DiD model where carbon price is the treatment and by using survey results as data, that analyze firms' motivation for innovation. Additionally, the relevance of the separate impact is debatable, as Finland and many other countries are implementing both and the empirical conclusion is that a combination is optimal.

Second, from the assumption that the results found elsewhere apply equally in the Finnish economy introduces bias. To minimize the bias from the assumption, the research aimed to select studies on countries with a similar economy to that of Finland. The list is composed of democratic OECD countries, that are high-income, industrialized, and innovation driven, namely Netherlands, Canada, the United States, Australia, Belgium, Czech Republic, France, Germany, Hungary, Italy, Japan, Korea, Norway, Portugal, and the United Kingdom.

Third, the time lag between policy implementation and tangible innovation activity poses a challenge for evaluation. This limitation was addressed by incorporating empirical studies that considered both short- and long-term effects, had lagged variables, and two-period models to account for the delayed impact of policies.

Fourth, use of patent data to measure the effectiveness of policy, may not accurately capture the true impact of innovation, as they merely focus on the short-term output compared to long-term technological advancement. Furthermore, patents can be influenced by the strength of intellectual property laws rather than actual innovation. Nevertheless, the measurement of technological advancement is difficult, and patents do reflect innovation activity to an extent. Additionally, while for instance Martínez-Zarzoso et al. (2019) uses patent data to characterize innovation, they also incorporate R&D expenditure to

7 Conclusion

Green innovation is a crucial driver in addressing climate change through fostering technological advancements that are essential for reducing carbon emissions.

Therefore, prioritizing incentives for green innovation should be a central objective of environmental policy. In this thesis, I have evaluated both carbon pricing and R&D subsidies, considering their roles on a global scale and specifically in Finland.

Firstly, an optimal innovation policy for Finland requires a dual approach. While based on economic theory, R&D subsidies directly incentivize innovation, subsequent to examining empirical literature I found that in practice they are in insufficient by themselves. Therefore, carbon pricing is required as a complement to create a strong economic incentive for firms to shift to greener alternatives. If carbon pricing is too low or nonexistent social responsibility is left as the main motivator. Since carbon pricing and subsidies work in opposite mechanisms, literature consistently supports a balanced policy mix, combining carbon pricing with R&D subsidies to maximize innovation.

Secondly, Finland faces significant challenges in managing the costs of incentivizing innovation and ensuring the diffusion of new technologies. An essential component is ensuring that subsidies target emerging technologies that are not yet economically viable. Furthermore, literature again suggests that a balanced mix of carbon pricing and subsidies can help tackle the financial burden. In addition, policies that promote technology diffusion are crucial for widespread adoption.

In conclusion, as Finland strives to meet its carbon neutrality target by 2035, a balanced policy portfolio of carbon pricing and well-targeted subsidies will be key to incentivizing green innovation. Additionally, the findings of this thesis extend beyond Finland and offer valuable lessons for other countries seeking to incentivize green innovation through policy measures. As nations set climate targets in line with the Paris Agreement, an understanding of the interplay between carbon pricing and R&D subsidies can guide more effective policymaking on a global scale. Future policy evaluations should optimize this balance to achieve environmental targets while maximizing social welfare and economic sustainability.

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