

Should the Norwegian commercial transport sector be subsidized?

Katarzyna Segiet



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Skal norsk tungtransport subsidieres?

Katarzyna Segiet

Norsk tungtransport står for ca. 10 prosent av CO₂-utslippene i Norge. Denne oppgaven prøver å finne ut den optimale miljøpolitikken for denne sektoren. Ved bruk av teoretisk modell analyserer jeg en kombinasjon av skatt og subsidier for investering i kapital og utslipp reduksjon, noe som ville effektivisere overgang til miljøvennlige teknologier. Analysen av resultatene følger av en numerisk simulering av modellen. Hovedresultatet av oppgaven er at skatten skal være den viktigste miljøpolitikken, og at innføring av subsidier kun er ønskelig under visse forutsetninger.

Should the Norwegian commercial transport sector be subsidized?

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Abstract

Norway has ratified the Paris Agreement, according to which the country has committed to reducing greenhouse gas emissions by 40 percent by 2030, compared to emission levels in 1990. The Norwegian commercial transport sector is responsible for about 10 percent of CO_2 emissions in Norway. This thesis analyzes the optimal environmental policy for this sector. More specifically, it argues under which circumstances it would be optimal to introduce subsidies on investment in capital and abatement, which would spur a transition to environmentally-friendly technologies. The theoretical model features a two-stage game. The analysis of results follows from a numerical simulation of the model. The main result of the thesis is that the tax should be the main environmental policy and that introducing subsidies is only desirable under certain circumstances.

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The simulation of the model was performed using the Microsoft Excel Solver Add-In. The Excel workbook file is available upon request.

All errors and mistakes are solely my own.

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1 Introduction

As part of the Paris Agreement, Norway, together with EU member countries, has committed to cutting its greenhouse gas emissions by 40 percent by 2030, compared to 1990 levels. In 2015, 33 percent of greenhouse gas emissions in Norway were caused by the transport sector. Land-based transportation accounted for almost 78 percent of all transport sector emissions, from which 45 percent was caused by light-duty and heavy-duty vehicles (Miljødirektoratet, 2017). The government predicts that the biggest potential contributor to the decline of emissions by 2030 could be a reduction of emissions in road transport (Meld. St. 41, 2017, pp. 18). To achieve such a reduction, the introduction of a CO_2 fund for the freight sector has been proposed. It was stated that the fund should cover as many sectors as possible within the shipment industry: trucks, buses, vans, agricultural machinery, ferries, short sea shipping and aircraft association¹ (NHO, 2016a). Revenues from the fund would be used to finance the development of green technology and incentivize replacing fossil fuels with climate-friendly (renewable propulsion) technologies.

A similar policy of refunding emissions payments has been successful in decreasing the emissions of NO_x in Norway and Sweden. Hagem et al. (2017) compare the mechanisms used in Sweden, in which the refunds depend on the output produced by the emitting firms, and in Norway, where the refunds depend on the expenditure on abatement. The NO_x fund in Norway was established in 2008 by an agreement between the Ministry of the Environment and 15 cooperative business organizations in response to the NO_x tax, which proved not to have a sufficient effect on emissions of NO_x . The NO_x fund has so far helped to reduce Norway's NO_x emissions by 30 000 tons and has contributed greatly to fulfilling Norway's international obligations. In addition, the NO_x Agreement resulted in an annual reduction in greenhouse gas emissions of 0.5 million tons (NHO, 2016a).

The 2017 national budget stated that the Norwegian government would assess any concrete proposal from the industry regarding a private CO_2 fund modeled on the existing NO_x fund, and that financial and administrative consequences of such a fund would need further investigation

¹Since 2012, all emissions from aviation have been included in the EU emissions trading system (The European Commission, 2015)

(Meld. St. 1, 2016). Subsequently, the NHO² commissioned the TØI³ to evaluate the costs and potential emission reductions of the CO_2 fund. In the analysis by Pinchasik and Hovi (2017) the workings of the CO_2 fund resemble those of the NO_x fund. The Business Sector's NO_x fund is an association. Companies that become members of the NO_x fund are exempted from paying the NO_x tax and instead pay a smaller fee to the fund. In the report by Pinchasik and Hovi a similar scenario is analyzed, in which companies that become members of the CO_2 fund would be exempted from paying the current CO_2 duty and instead would pay a smaller amount to the fund. Members of the fund would then be able to apply for funding for environmental initiatives. This includes subsidizing members' additional costs of investing in renewable propulsion technologies for vehicles, transport equipment and for partial coverage of investment in infrastructure (e.g. charging and filling stations). For instance, companies would receive a subsidy to buy vehicles that run on hydrogen, electricity or biofuels.

The revised national budget from May 2017 presented some shortcomings of the CO_2 fund. It was argued that an environmental agreement like the CO_2 fund would give fewer incentives to reduce the emissions than the environmental tax and would not be cost-effective. It was also stated that the parliament had not suggested a concrete plan for introducing a CO_2 fund, but that there existed several alternative concepts for designing a CO_2 fund. One alternative would be to have a mechanism similar to the NO_x fund, and another alternative would be based on directly transferring a portion of the tax revenue to the fund (Meld. St. 2, 2017).

In my analysis, unlike in the proposal of Pinchasik and Hovi, instead of having a CO_2 fund, which constitutes a separate association, I analyze a policy in form of subsidy on capital and abatement, which would apply to all the potential beneficiaries within the light-duty and heavy-duty vehicles sectors in Norway. If we find that a subsidy is not desirable, it would also be the case for the CO_2 fund, since a CO_2 fund is essentially a subsidy to abatement with the additional constraint that the sum of subsidies must be equal to the sum of tax revenues.

In the thesis, I address the following research questions:

What is the optimal environmental policy in the commercial transport sector in Norway?

How does the result of the optimal environmental policy change when firms act strategically

²The Næringslivets Hovedorganisasjon (The Confederation of Norwegian Enterprise)

³Transportøkonomisk institutt (Institute of Transport Economics in Norway)

and can influence government's policy, in case the government cannot commit to a certain level of tax in the future?

Does the optimal policy differ between the light-duty vehicles and heavy-duty vehicles sector?

Should the government subsidize both short-term and long-term investments (both abatement and capital investments)?

I set up a theoretical model with subsidies on capital and abatement and contrast it with the NO_x fund model. In an analysis of refunded emission payments in Sweden and NO_x fund in Sterner and Isaksson and Hagem et al., the refunding emission payments are assumed to be permanent, thus, there is only one stage. In the model proposed in this thesis, we assume that the subsidies are temporary, and hence two stages are analyzed, with the subsidy in place only in the first stage. I distinguish between a subsidy on abatement (short-term investments) and a subsidy on capital (long-term investments). In the first stage, the government sets the levels of taxes and subsidies and the companies choose their output and the level of investment in abatement and capital. In the second stage, the government sets the level of tax and companies choose their output. The objective of the government is to choose the level of tax and subsidies to maximize the social welfare, while the objective of the companies is to choose the level of output, investment on abatement and capital to maximize profits.

I analyze six scenarios. In the first scenario, the government can pre-commit to a particular tax level in the second period. In the second and third scenarios, the government in the first stage cannot pre-commit to its tax level in the second stage. When the government cannot pre-commit, we will have that firms either do not choose the level of investment in capital strategically, in which case the results will be the same as in the commitment case, assuming that firms have correct expectations about the tax level in the second stage, or, alternatively, firms act strategically by choosing a level of investment in capital such that the tax level in the second period is lower than in the case without strategic investment. Subsequently, the tax level in the second period affects the level of investment in abatement technologies in the second stage.

Moreover, I analyze three scenarios, which represent second-best solutions. First, a scenario in which the government can pre-commit to a certain level of period 2 tax and additionally, there is a regional policy that requires the demand for freight to be above a certain threshold \bar{x}_t . Second, a scenario in which the government introduces a subsidy on abatement. Lastly, a

scenario with a subsidy on capital.

I discuss the importance of the CO_2 tax and discuss the circumstances under which it is plausible to introduce a subsidy on capital and abatement, even though it is not cost-effective compared to a Pigouvian tax.

The thesis is structured as follows. In chapter 2, I present the current Norwegian climate policy and the policy related to the commercial transport sector in Norway. Chapter 3 provides a brief analysis of the markets for heavy-duty vehicles and light-duty vehicles and presents a variety of abatement opportunities, which includes more efficient use of current fleet, substitutes for road transport and shifts in technology. Chapter 4 proceeds to explain the proposal of the CO_2 fund and its downsides, motivating the choice of a model presented in the later chapter. Chapter 5 presents a literature review, which forms a base for the model of environmental policy presented in chapter 6. Chapter 7 concludes.

2 Norwegian Climate Policy

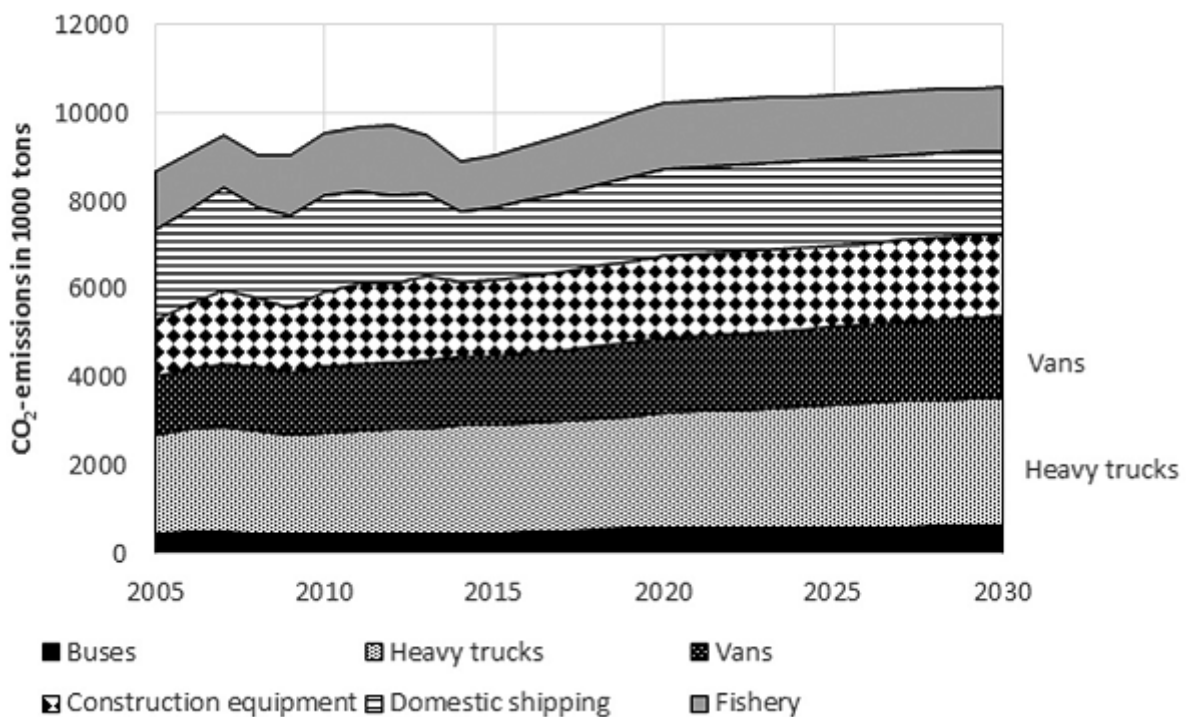
The Paris Agreement was adopted at the 21st session of the Climate Change Convention in Paris in December 2015 and subsequently entered into force on November 4th, 2016. The goal of the agreement is to ensure that the global temperature rise in the 21st century does not exceed 2 degrees Celsius, compared to the temperature in the pre-industrial period, and to pursue efforts to limit the increase to 1.5 degrees Celsius. To date, the Paris Agreement has been signed by 195 countries and ratified by 160 countries.

The 2030 Climate and Energy Framework adopted by EU leaders in October 2014 has three main goals: to achieve at least a 40 percent cut in greenhouse gas emissions from 1990 levels, at least a 27 percent share of renewable energy and at least a 27 percent improvement in energy efficiency. To achieve the reduction of greenhouse gas emissions in a cost-effective way, the European Commission has claimed that sectors covered by the EU Emissions Trading System (EU ETS) would need to cut emissions by 43 percent and sectors which do not fall under EU ETS would need to cut emissions by 30 percent, compared to 2005 levels. In the EU, about 45 percent of greenhouse gas emissions in 2016 were covered by the EU ETS. This includes carbon dioxide emissions produced by the power and heat generation sector, commercial aviation as well as energy-intensive industries including oil refineries, steel works and the production of different materials such as iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals. On July 20th, 2016, the European Commission presented an Effort Sharing Regulation - a proposal which sets emissions targets for member countries applicable to the sectors not covered by the EU ETS. Even though the joint target is 30 percent, the country-specific targets vary between 0 and 40 percent and are calculated based on countries' GDP per capita. Sectors that fall under the Effort Sharing Regulation accounted for almost 60 percent of the total EU emissions in 2014 and include transport sector as well as buildings, agriculture and waste management (The European Commission, 2016a).

Norway ratified the Paris Agreement on June 20th, 2016. According to the Paris Agreement, Norway has committed to reduce the emissions of greenhouse gases by 40 percent by 2030, compared to emissions levels in 1990. This target is in line with the emission reduction

target of the European Union. According to the Effort Sharing Regulation published in July 2017, Norway's reduction target for the sectors outside the EU ETS amounts to 40 percent from the level in 2005, which is the highest target among all the member states (The European Commission, 2016b). As mentioned previously, the EU quota system covered about 45 percent of the total greenhouse emissions of its members in 2016. About 50 percent of emissions in Norway were covered in 2012 (Meld. St. 41, 2017). The transport sector, which is not covered by the EU ETS, was responsible for over 30 percent of the greenhouse gas emissions in Norway in 2015 and constituted almost 60 percent of emissions among the industries not covered by the EU quota system. Heavy transport - trucks and buses over 3.5 tons - accounts for about 30 percent of land-based transport emissions of about 10 million tons of CO_2 . Light-duty vehicles (cars for freight under 3.5 tons) account for about 15 percent of land-based transport emissions (Miljødirektoratet, 2017). Given the existing policies, the emissions from the freight transport sector are expected to increase through 2030, as shown in Figure 1.

Figure 1: Emissions in CO_2 equivalents from the industry's domestic transport: Pinchasik and Hovi (2017) (pp.190)



The emissions from the sectors that do not fall under the quota system have decreased from 28.1 million tons of CO_2 equivalents in 2013 to 27.4 million tons in 2016. The Norwegian government predicts that the biggest potential contributor to the decline of emissions by 2030 would be a reduction of emissions in road transport (Meld. St. 41, 2017, pp. 18). Emissions

from non-EU ETS sectors are predicted to decrease from 15.6 million tons of CO_2 in 2015 to 13.5 million tons by 2030. The decline is mainly due to reduced emissions from road traffic, which are expected to fall from 10.3 million tons to 8.4 million tons in the same period. In its National Transport Plan, the Norwegian government established a goal for 2025 to have all new personal cars and light-duty vehicles be emission-free and to have city buses be either emission-free or powered by biogas. Another goal was that, by 2030, all new heavier light-duty vehicles and 75 percent of long-haul vehicles will be emission-free vehicles. For the heavy-duty vehicles, the established goal was to reduce emissions by 25 percent by 2025 relative to the level in 2020 and to reduce emissions by 50 percent by 2030 relative to the level in 2020. However, analysis shows that these ambitious goals will not be achieved without employing certain incentives (Meld. St. 33, 2017, pp. 217).

The current policies on private cars include the registration tax¹, the annual motor vehicle tax², and the re-registration fee³ (see table 2 in the appendix). The amount of registration tax depends on the weight of the vehicle and the CO_2 emissions (with the rate depending on g/km). The annual motor vehicle tax varies by type of car: It is lowest for the electric vehicles, higher for the petrol and diesel cars with a factory-fitted particle filter and highest for petrol and diesel cars without a factory-fitted particle filter. In addition, users pay road tax on fuel⁴ and CO_2 tax⁵, both of which depend on the fuel type. These charges serve as an incentive to reduce the consumption of fuel by either driving less or switching to technologies which produce fewer emissions.

Furthermore, for vehicles over 7500 kg, there is an annual weight-based motor vehicle tax⁶. The weight-based motor vehicle tax consists of two parts. The first part varies by the vehicle's weight and number of axels, while the second part depends on the euro-class type, which varies according to environmental characteristics.

In addition to taxes, there are a number of toll roads, especially on the major road networks and in the neighborhoods of larger cities. Tolls are higher for the heavier vehicles. In some cities, there is an additional rush-hour levy (Pinchasik and Hovi, 2017, pp. 190).

¹engangsavgift

²årsavgift

³omregistreringsavgift

⁴veibruksavgift på drivstoff

⁵ CO_2 -avgift

⁶vektårsavgift

Current policy has resulted in a vast increase in the number of private electric cars. In February 2017, number of electric cars exceeded 100 000. Between 2016 and 2017, the number of registered electric vehicles increased by over 40 percent (Statistics Norway, 2017). The reason for such success is due to tax benefits, increased number of charging stations and the development of new car models with longer range. Electric car owners have been exempted from the registration tax (engangsavgiften) and the VAT, pay the lowest annual motor vehicle tax (there are three different rates for different types of vehicles), get higher compensation for using a car to drive to work, are exempted from paying tolls and can park their electric cars for free (Figenbaum and Kolbenstvedt, 2013). It seems that this, together with behavioral factors, has had a big impact on growing of the market for electric passenger cars in Norway. On top of that, the current tax rates for using diesel and petrol cars are relatively high.

However, when it comes to the sector of light- and heavy-duty vehicles, the transition to environmentally-friendly technologies has not been as substantial. Only 1.8 percent of new vans were electric in 2016. One of the reasons is that the number of available models is small. The available models have a short range and are more expensive than comparable diesel models. Additionally, when light-duty vehicles are used in business, the VAT is deductible from the income statement. Hence, the fact that electric vehicles are VAT-exempt is not an incentive for a company considering whether to buy an electric van, as all types of vehicles are tax deductible, regardless.

Light-duty vehicles are divided into two categories: Category 1 vans and Category 2 vans. Category 1 vans belong to the same tax category as passenger cars. Category 2 vans (with green license plates) are subject to a registration tax equal to 20 percent of the charge on private cars and Category 1 vans.

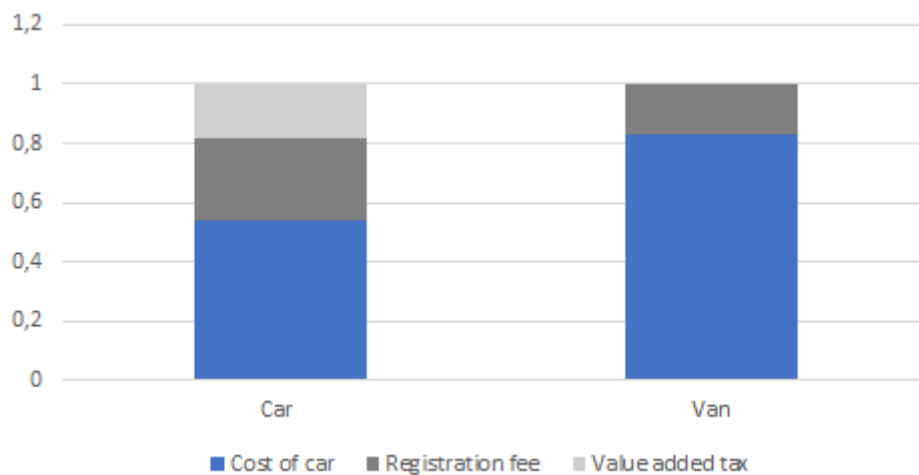
The VAT is not deductible for passenger cars because private use is assumed. However, if a personal vehicle is used for business purposes, it may be entitled to a tax deduction. If the distance driven for business purposes exceeds 6000 km per year, all expenses from running the vehicle for business purposes can be charged to the business' accounts. If the distance for business purposes is less than 6000 km per year, then a charge of 3.50 NOK per km is charged on the company's account (Altinn, 2017b).

On the other hand, the private use of Category 2 vans and trucks is taxed. For instance, the tax applies to private driving between home and workplace. Thus, the VAT to be paid

by the van owner needs to be estimated based on the expected use of the vehicle for private purposes (Altinn, 2017a). One issue that arises is not reporting private use of work vehicles to avoid paying the VAT.

All in all, when buying a new car, the cost structure for private cars and vans is different. For private vehicles, the VAT and registration fee constitute a larger share of the costs, as illustrated below. This could be an incentive for car owners to have cars which are registered as vans. However, because the number of electric models of light-duty vehicles is small and they are more expensive, and because the VAT is deducted regardless of the type of vehicle, buyers of vans do not have enough incentives to invest in electric vans.

Figure 2: Comparison of cost structure



One could argue that subsidizing electric vans could be a way to incentivize buyers to choose buying electric vans instead of fossil fuel vans. However, it seems that a non-deductible higher tax on gasoline and diesel vans, which would change the cost structure of vans in such a way as to resemble the cost structure of private cars, would be a more efficient solution. Having higher non-deductible tax would make it more plausible to invest in electric vans, for which the tax would be comparably lower.

The only policy that currently incentivizes investment in electric vans is an increase of vehicle scrap deposit⁷. Vehicle scrap deposit is the reduction one can get on a vehicle's annual motor vehicle tax after scrapping an old vehicle. The vehicle scrap deposit has been increased by 13000 NOK relative to the normal amount for those who buy a van with emission-free technology (Meld. St. 33, 2017, pp. 225).

⁷vrakpant

When it comes to heavy-duty vehicles, the transition to alternative technologies is even more challenging. Hydrogen and electric heavy-duty vehicles are still not widely available on the market, the technology is expensive and the infrastructure is lacking. Additionally, only a small fraction of trucks use biofuels as alternative to gasoline and diesel.

In the following chapter, the heavy- and light-duty vehicle sectors are described, as well as abatement opportunities.

3 Market analysis

The present section provides a brief analysis of the sector of heavy- and light-duty vehicles. The goal is to understand the criteria used to characterize such vehicles, as well as to have a sense of the size of these two sectors. Understanding the structure and concentration of the market is important to be able to discuss the dynamics between the companies and the government. We also want to compare the relative amount of emissions. At the end of the chapter, abatement opportunities are discussed on three fronts: First, abatement due to reduced driving; second, the available substitutes to road freight; and finally, technological shift.

Norwegian regulations make a distinction between 3 different types of cars for freight:

1. Car group N1 (van): Cars for freight with a maximum authorized weight not exceeding 3500 kg (light commercial vehicle/light goods vehicle). These are further divided into two categories which are taxed at different levels. A Category 1 van is a car that falls under the N1 category and does not meet the requirements of a Category 2 van. A Category 2 van (with a green license plate) is a van with either a one-seat row, a cargo compartment or a flatbed in the back. It has a protective wall between the driver's and passenger's seats, in addition to fulfilling other requirements (Vegvesen, 2015).
2. Car group N2 (lorry): Cars for freight transport with a maximum authorized weight exceeding 3500 kg but not exceeding 12000 kg (heavy goods vehicle/large goods vehicle).
3. Car group N3 (lorry): Cars for cargo with a maximum authorized weight exceeding 12000 kg.

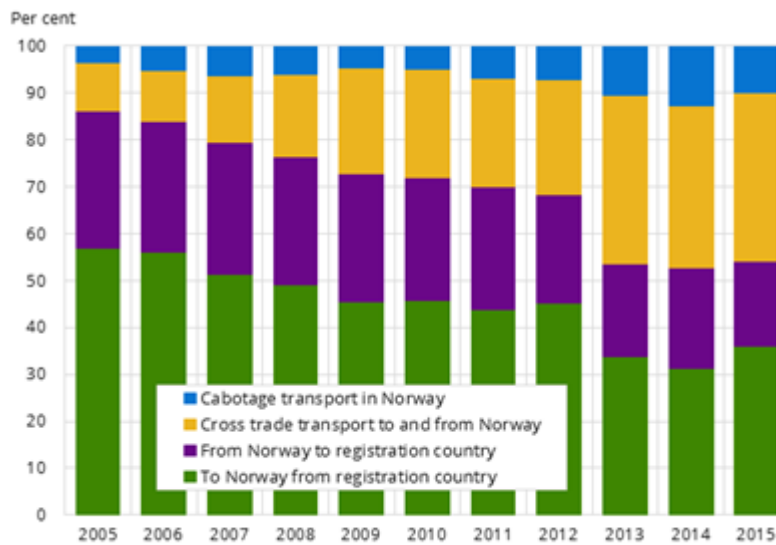
We want to perform an analysis of the heavy-duty vehicles sector and the light-duty vehicles sector, where the former is comprised of trucks from car groups N2 and N3 and the latter is comprised of vans from car group N1.

The data on road freight transport is measured either by the tonnage carried, which is the gross weight of the transported goods (measured in thousands of tons), transport performance (measured in million ton-km) and traffic (number of kilometers driven per year).

3.1 Heavy-duty vehicles

In this section we analyze heavy-duty vehicles sector, which include vehicles from car groups N2 and N3, as explained in the previous section. The number of trucks registered in Norway in 2016 was 75 238 (with the highest number of trucks registered in Oslo, Akershus and Hordaland). 95 percent of the registered vehicles had diesel engines, whereas only two trucks had electric engines. In the past 10 years, the number of trucks registered in Norway has been steadily decreasing (from 84 350 in 2008). This may be due to the increasing number of cabotage (foreign truck transporting goods within Norway) and cross-trade operators from abroad, where cross-trade means the transportation of goods between Norway and other countries without passing through the country where the shipping company is located (See Figure 3 below). This can be explained by foreign companies' relatively lower operating costs.

Figure 3: Road goods transport by foreign lorries to, from and within Norway. Tonnage carried by type of transport: Statistics Norway (2015)



In 2015, Norwegian trucks' transport performance was equal to 23 144 million ton-km. 20 470 million ton-km (over 88 percent) of that amount was transport within Norwegian borders.

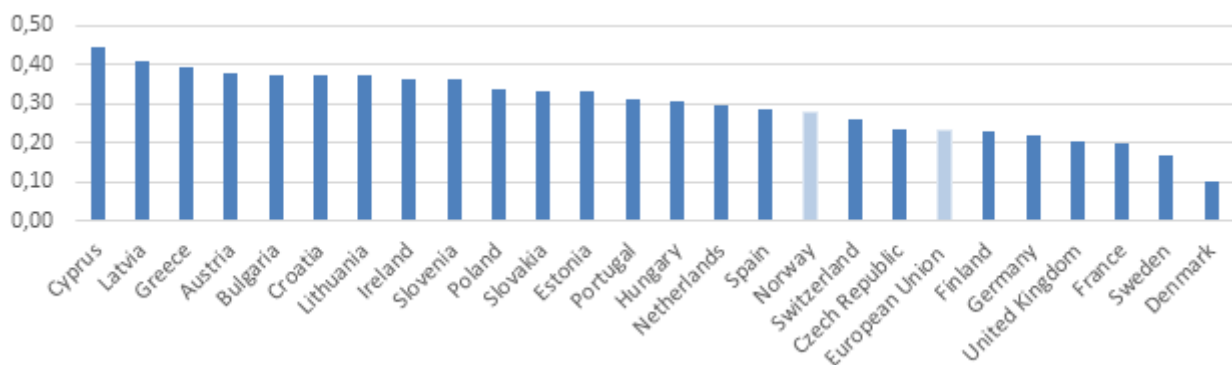
In 2015, the domestic goods transport, including cabotage, was equal to 20 879 million ton-km by road transport (28.9 percent of the total million ton-km). 98 percent of that was by Norwegian trucks.

The performance of Norwegian trucks has been increasing over the years. However, the

percentage of Norwegian trucks that drive internationally has been decreasing. It is likely because transport across Norwegian borders is performed by foreign companies, which have lower operating costs relatively to Norwegian companies.

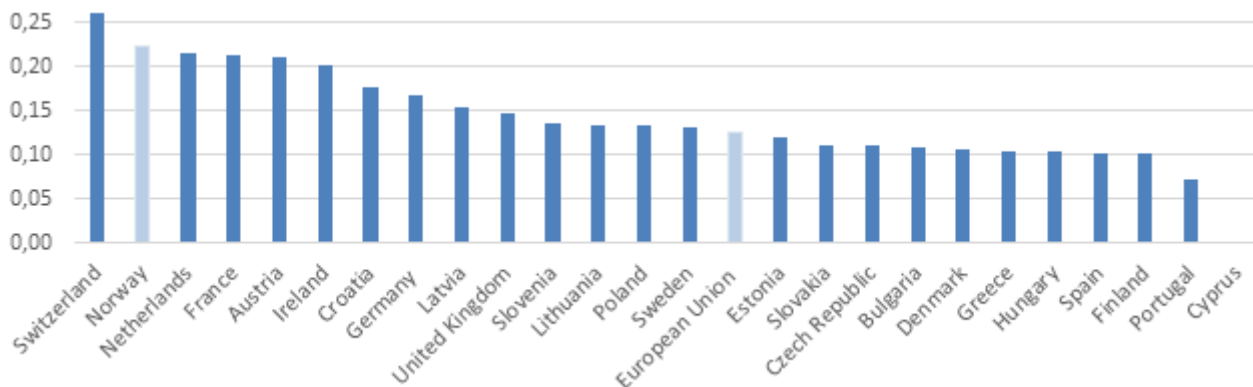
The rate of empty kilometers in national transport has ranged between 25 and 28 percent between 2011 and 2016. In international transport, it ranged between 16 and 23 percent. In 2016, the rate of empty kilometers in Norway was close to the average across EU countries.

Figure 4: Rate of empty kilometres in national transport in 2016: Eurostat (2017)



However, in international transport, the rate of empty kilometers in Norway was second highest.

Figure 5: Rate of empty kilometres in international transport in 2016: Eurostat (2017)



The number of empty kilometers in international transport could be reduced by more efficient logistics. If the information on unloading destinations and loading places were more readily available, vehicles' routes could be arranged in such a way that the distance between the place where trucks unload and where they load, thus the number of empty-kilometers, would be minimized. It is possible to achieve a reduction of emissions through better exploitation of vehicles by minimizing the number of return journeys without load, through better planning of

routes and by using larger trucks. In order to incentivize companies to undertake these actions, a tax on emissions needs to be in place.

3.2 Light-duty vehicles

A total of 461 498 vans were registered in Norway at the end of 2016. The number of vans has been steadily increasing since 2008, when there were 379 343 vans registered. In 2016, almost 93 percent of the vans had diesel engines. The number of electric vans has been increasing over the years. In 2016, there were 2 568 registered electric vans, which is only about 0.5 percent of all vans. The number of electric vans has been increasing even though the number of available models of electric vans is small and that they have a relatively short range and are more expensive when compared to diesel vans (Meld. St. 33, 2017, pp. 225).

In Norway, 30 percent of vans in 2016 were registered in Oslo and Akershus. About 30 percent of kilometers were driven in 14 urban areas. If the number of charging stations were higher and incentives to buy electric vans were in place by adjusting the current policy, there would be a greater potential to increase the number of electric vans. The average age of vans when they were discarded was equal to 15.3 years in 2016, while the average age of vans which were registered in the same year was equal to 8.6 years and has been steadily increasing from 6.9 years since 2008. In the following years, a large part of the fleet will be replaced. Thus, correcting the current policy, which would give the incentives to invest in electric vehicles not only for private use but also light-duty vehicles, has great potential.

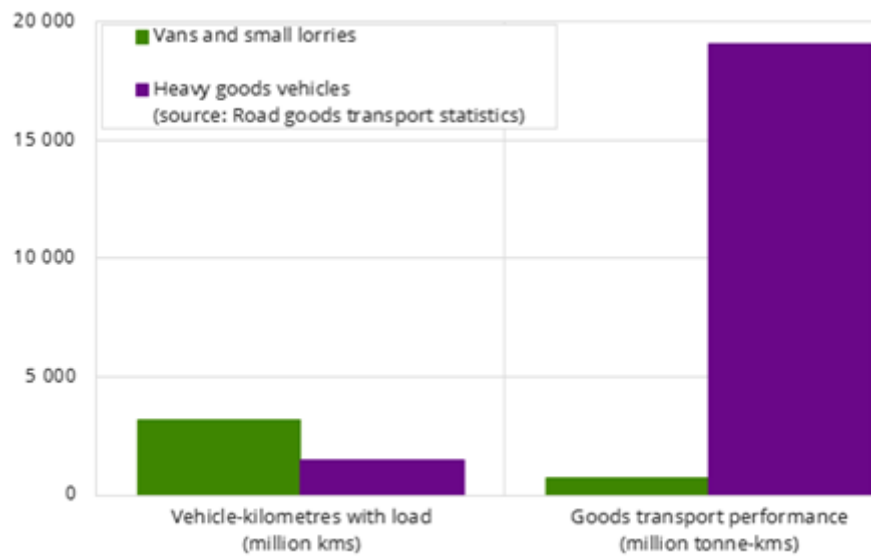
In 2008, 48 percent of the mileage of vans was driven for service purposes, 30 percent for private purposes, multi-stop journeys accounted for 13 percent and single- stop journeys for 6 percent. In 2015, the mileage of vans driven for service purposes increased to 59 percent, 24 percent of mileage was due to private purposes. Multi-stop journeys accounted for 11 percent, whereas single-stop journeys for 6 percent.

The traffic of light-duty vehicles in 2016 was equal to 7 307 million kilometers. 43 percent of that was with cargo. Traffic of light-duty vehicles constituted 16.2 percent of all road traffic. In 2015, vans carried 16.1 million tons. The performance was equal to 739.7 million ton-km.

In the graph below, we can see a comparison between, on the one hand, the mileage of

loaded vans and small trucks and heavy goods vehicles, and on the other hand, these vehicles' relative performance (that is, goods transported in million ton-km). We see that the mileage of vans and small trucks is almost twice the mileage of heavy goods vehicles. However, the number of large trucks is almost ten times smaller than the number of vans and small trucks. Yet still, the tonnage carried by vans and small trucks constitutes only about 6 percent of all the tonnage transported by Norwegian road goods vehicles.

Figure 6: Transport by vans and small lorries and heavy-duty vehicles. 2014/2015: Statistics Norway (2015)



3.3 Market structure

To optimize the effect of the subsidy, it is important to consider the different characteristics of the light-duty vehicles sector and the heavy-duty sector. The question is whether the subsidy should apply to both sectors. Later we will discuss the impact of market concentration on the dynamics between companies and the government when there is an issue of commitment.

According to Statistics Norway, there are about 9200 firms within the road transport sector, and 15 percent of them are responsible for 70 percent of employment. Even though the number of firms is large, there are several companies which have big share of the market, such as Asko, Tine, Posten, Schenker, PostNord, Bring, DHL and Kühne and Nagel. Some of the companies are owned by foreign firms. On the other hand, there are many private truck owners who often

own only one vehicle and drive by themselves. In 2014, an average number of employees was equal to 11. This shows a big variety in the light- and heavy-duty vehicles markets.

An important question is whether foreign companies that drive on Norwegian roads would also be entitled to a subsidy on abatement.

3.4 Abatement opportunities

There are several interventions which can be undertaken in order to achieve a reduction in CO_2 emissions from the heavy-duty vehicles. One alternative would be to ensure that the trucks on road drive in an efficient way by using efficient logistics, maximizing the load and driving large trucks (the larger the truck, the lower the emissions of CO_2 per kg of load). A second alternative would be to use different means of transportation that has lower emission per weight carried, such as trains or maritime. Lastly, a reduction of greenhouse gas emissions can be achieved by a shift in technology, using vehicles powered by biofuels, hydrogen or electricity.

3.4.1 Reduced driving, more efficient logistics

As mentioned before, the rate of empty kilometers at the national level in transport by heavy-duty vehicles has ranged between 25 and 28 percent in the period from 2011 to 2016. It is possible to achieve a reduction of emissions through better exploitation of vehicles, by minimizing the number of return journeys without load, by better planning of routes and by using larger trucks.

To achieve a lower climate impact from the long haulage of goods on the road, it would be advantageous to use fewer vehicles with a higher transport capacity, as opposed to more vehicles with a lower transport capacity. For instance, replacing three smaller trailers for long haulage with two higher-capacity vehicles, by using a modular carriage train of length of up to 25.25 meters on road networks capable of accommodating such vehicles, could result in a 25-30 percent reduction in emissions (Hagman et al., 2017). Using large vehicles would be especially beneficial over long distances. Another strategy is for the trucks to drive in so-called “platoons”, which is when trucks get grouped and drive closely at the same pace over long distance. This

can reduce the CO_2 emissions by up to 16 percent from the trailing vehicle and up to 8 percent from the lead vehicle because the air-drag friction is reduced significantly (SARTRE, 2012).

Moreover, it has been shown that idle driving wastes energy and creates unnecessary emissions of greenhouse gas emissions, especially when the engine is cold. Idle driving causes emissions of particulate matter and unburnt fuel residues thus locally affecting the quality of the air (Hagman et al., 2017). Current regulations prohibit unnecessary idle driving (Trafikkregler, 2014).

Moreover, the digitization and further development of logistics systems would increase efficiency and reduce costs. This could be achieved by using tracking services, route optimization and better capacity utilization. Yet, this is another argument for keeping a CO_2 tax and not relying solely on subsidies, as higher tax would give a larger incentive to such abatement options.

3.4.2 From road to rail

The socioeconomic gains from transferring road freight to rail or maritime is not only a reduction in emissions of CO_2 , but also less pollution, fewer accidents and less congestion (Meld. St. 33, 2017, pp. 190).

It is impossible to transfer all of the road freight to either rail or maritime. Heavy-duty vehicles dominate freight for short-distance trips. Very often road transport is the most flexible option, thanks to the existence of a good road network. Additional factors are related to structural changes in logistics, such as warehouse centralization, economics of scale and just-in-time deliveries. However, there is a potential to transfer a fraction of the freight from roads to rail. The government wants to transfer 30 percent of goods transported over distances longer than 300 km by road to either train or ferry, which would be equivalent to 5-7 million tons of the total 270 million tons of annual transport. However, there are some reasons why the potential for transferring the transport of goods from roads to rail and maritime is limited and not necessary economically profitable.

First, competition between rail and maritime transport is small, because both sectors focus on different types of goods. This lack of competition between the two sectors increases the price,

making them a less attractive alternative. Moreover, the fact that there is little competition within rail transport drives up the prices, hence making it a less attractive substitute (Meld. St. 33, 2017, pp. 189).

Secondly, about 90 percent of road transport consists of the local transport of goods and short-distance transport of materials to construction sites.

Finally, the decision to use road transport is made by individual market players, small companies or large global logistics companies. To incentivize all of the different parties to switch from road to rail or sea, several different policies would need to be put in place.

The 30 percent transfer proposed by the government is expected to result in a reduction of roughly 0.2 million tons of CO_2 per year (Meld. St. 33, 2017, pp. 189). The government would need to use some financial incentives to achieve the transfer, for instance simplifying the fee structure in maritime transport. On top of that, it would need to invest in rail tracks and stations, to increase rail transport capacity.

As mentioned earlier, heavy-duty vehicles dominate freight over short distances. However, when it comes to long distances (over 3000 km), only about 30 percent of haulages are carried out by trucks. It would be plausible to further decrease this number, so that whenever railway stations are not close enough to the supplier of goods and to the receiver of goods, trucks could be used solely as an intermediary, thus transporting goods from the supplier to the rail station and then from the rail station to the receiver of the good, in which case most of the transport would be performed by rail.

Another alternative is transferring from the road freight to maritime transport, which could be enhanced by developing more effective cargo terminals and harbors (Meld. St. 33, 2017, pp. 187).

3.4.3 Technology shifts

There are several technologies that could be introduced to decrease or eliminate the emissions of CO_2 . These technologies have different costs and different impacts on environment. First, we discuss the costs of each technological alternative. Next, we look at the emissions associated

with each type of technology. Finally, we present different forecasts and scenarios related to the choice of technology in the light-duty and heavy-duty vehicles markets in the future.

- Costs

There are three types of costs related to introduction of new technology. First, the cost of investment in developing the technology, second, the infrastructure cost related to providing charging and refueling stations, and third, the cost of running the vehicles. These vary for different types of technologies.

However, it is important to bear in mind the difficulty in evaluating the technical and economic maturity of new technology and new types of fuels. Different actors and interest groups have different access to information and different incentives. Politicians may be influenced by these actors and interest groups and get the impression that a certain technology is more accessible and mature than it actually is (Hagman et al., 2017, pp. III).

Table 1 plots the relative costs for biofuels, hydrogen and electric vehicles. Investment cost and cost of infrastructure are denoted as ΔK . These costs will represent the cost of capital in the model presented in chapter 6. Running cost has a label y , where y represents abatement due to switching to alternative technologies.

Type of vehicle	Investment cost (ΔK)	Infrastructure (ΔK)	Running cost (y)
Biofuels	Low	Low	Higher than fossil
Hydrogen	Very High	Very high	Same as fossil
Electric	High	High	Lower than fossil

Table 1: Relative costs of different technologies

For biofuels, the costs of infrastructure are low, as biofuels are sold at petrol stations. Investment costs related to changing technology of the vehicles are also relatively low, since biofuel can be mixed with fossil fuels and be used in existing internal combustion engines, storage systems and distribution systems. We assume that the sustainable biofuels are available on the market.

For electric vehicles, the costs of infrastructure are related to building charging stations. The demand for charging stations increases with the number of electric vehicles. Enova

subsidizes investments of charging stations. In 2016, it made a commitment to pay 50.5 million NOK in subsidies, which contributed to the construction of 230 fast chargers between the largest cities (NHO, 2016b, pp. 235). The investment costs are relatively high, as the production of batteries is expensive. Vehicles that use slow charging need a battery with a big capacity, which further increases costs (Hagman and Amundsen, 2017, pp. 22). Running costs are relatively low, since electric vehicles have high efficiency and Norwegian electrical energy is cheap. The costs of using an electric vehicle are lower than for vehicles powered by fossil fuels or biofuels.

Introducing hydrogen technology is very costly for several reasons. First, because the fuel cells are not yet produced on a large scale. Second, because of uncertainty related to the potential for diffusion of the technology. Third, because access to hydrogen, filling stations and infrastructure is limited and the production of hydrogen and infrastructure is expensive. Additionally, the cost of running a hydrogen vehicle per km is similar to the cost of vehicle which uses petrol (Hagman and Amundsen, 2017, pp. 28). The cost of using hydrogen vehicles would be lower if fuel cell efficiency was to increase.

- Emissions

In the Norwegian National Transport Plan 2018-2029, the type of technology is either defined as zero-emission technology¹ or low-emission technology². Zero-emission technologies in transport are using electricity or hydrogen as a source of energy in batteries or fuel cells, which do not produce greenhouse gas emissions. Both battery electric technology and hydrogen technology are classified as electric propulsion technology. Low-emission technology in transport uses hybrid solutions, for instance a combination of a combustion engine and an electric engine.

In the heavy-duty vehicles market, the most mature technology that could replace diesel is biodiesel. In 2015 there were over 5000 heavy-duty vehicles powered by biodiesel. This number has increased since the road tax on biodiesel was eliminated in 2015 (NHO, 2016b, pp. 37).

However, the choice of type of biofuel to be used is very important. Biofuels are classified into three different categories, by generation. The sustainability of each generation

¹nullutslippsteknologi

²lavutslippsteknologi

depends on where and how the fuel was produced. First-generation biofuels generally describe fuels that use edible feedstock, which includes bioethanol produced from sugar or starch via fermentation, biodiesel produced from esterification of vegetable oils, fats and waste streams and biomethane produced from upgrading biogas or landfill gas. Second-generation biofuels are defined as fuels produced from an array of different feedstock, including alcohols and synthetic biofuels produced from lignocellulosic biomass or waste streams and hydrogenated vegetable oils or used vegetable oils as well as municipal solid wastes. Advanced biofuels or third-generation biofuels are biofuels produced from non-lignocellulosic biomass such as aquatic biomass, direct sugar and alcohol conversion to paraffinic biofuels, as well as those which are produced through microbial conversion and other microorganisms (Hagman et al., 2017, pp. 7-8).

Today's bioethanol is produced mainly from corn and cane and biodiesel from vegetable oils and oil waste, which means that production of those competes with food production. (NHO, 2016b, pp. 24). There is a potential to produce advanced biofuels from forest waste in Norway. That would, however, require large investments and technology which is not yet mature. The price of advanced biofuel will be higher than that of fossil fuels and thus, the production could result in losses in the absence of appropriate policy (Hagman et al., 2017, pp. II).

Enova has introduced a subsidy program which enables companies to apply for a subsidy to produce advanced biofuels. However, whether this policy is desirable is questionable. Subsidies for the production of biofuels make biofuels relatively cheaper, which could in turn lead to their excessive use, as the private cost of transport is reduced compared to the scenario without subsidies and the level of carbon tax, which reflects the social cost (Eggert and Greaker, 2014, pp. 4435). EU directive 2009/28/EC on the promotion of the use of energy from renewable sources, sets a requirement, which states that at least 10 percent of fuels used by transport sector by 2020 should come from renewable biofuels or other renewable types of fuels. There are specific criteria for classifying whether a certain type of biofuel can be classified as renewable. The criteria consist of two parts. The first part is related to the reduction of greenhouse gas emissions. According to the directive, for biofuel to be classified as sustainable, it needs to reduce total greenhouse gas emissions by at least 35 percent compared to the emissions from gasoline and diesel. From January

2018 the requirement will increase to 50 percent. The second requirement is related to production location. Biofuel cannot be grown in areas with high biodiversity (The EU, 2010). According to the requirement of the directive all biofuels sold in Norway must fulfill the criteria set in the document. To maximize the potential emissions reduction when using biodiesel in standard diesel engines, the highest attainable share of biofuel should be used.

In this thesis, we assume that sustainable biofuels are widely available on the Norwegian market.

Electric vehicles are classified as zero-emission technology.

Hydrogen is a climate-neutral energy carrier, given that the energy source used in production comes from renewable energy sources, such as hydro power, solar power and wind power. For instance, methane in the form of natural gas is not considered to be a renewable energy source for hydrogen production. In Norway, hydrogen can be produced by electrolysis of water or by using natural gas. Electrolysis of water for the production of hydrogen has an energy loss of about 30 percent. Alternatively, producing hydrogen from steam reforming of methane involves a loss of about 30 percent of the energy.

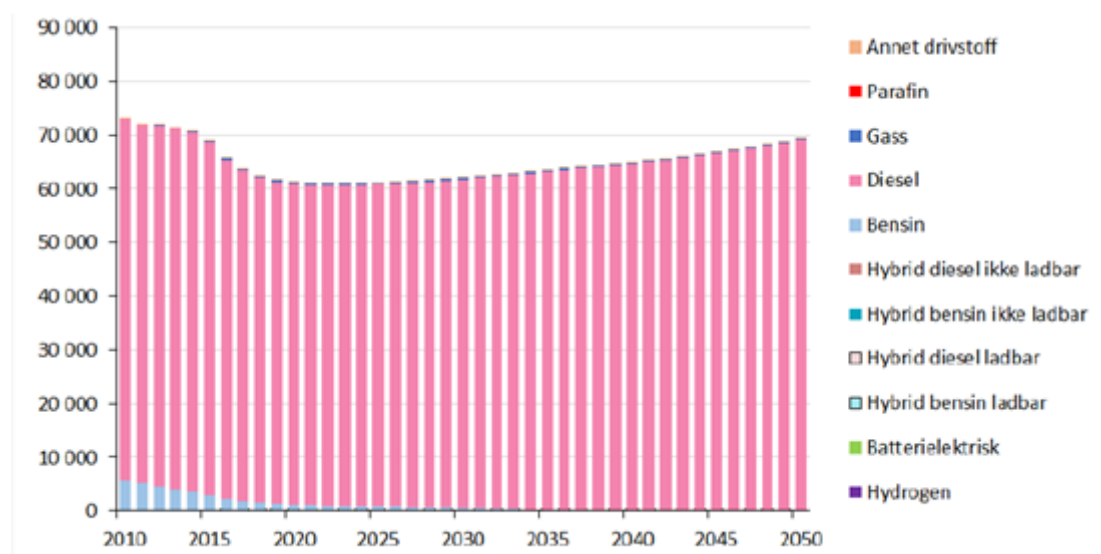
Before hydrogen is used as fuel, it must either be compressed and stored in pressure tanks or stored in liquid form. Afterwards, in the vehicle, hydrogen must pass through a fuel cell to be converted into electrical energy and water. At best, the engine that uses hydrogen produced from hydro power, fuel cell and electric motor is half as energy-efficient as electric propulsion with power from hydro power (Hagman et al., 2017). The advantage of hydrogen compared to electric engines is that with a hydrogen engine one can get a larger range.

- Forecast

When it comes to the choice of technology, it is important to differentiate between light-duty and heavy-duty vehicles. A report by Fridstrøm and Østli (2016) “Vehicle fleet forecasts based on stock-flow modeling” presets two scenarios of development of light-duty and heavy-duty vehicles’ fleets in Norway by 2050. The first scenario is a prediction based on the trend in the stock development between 2010 and 2015. The second scenario presents an ultralow emission path.

For the heavy-duty vehicles, according to the trend path based on years 2010-2015, there will be a small change in the fleet by 2030. In the ultralow emission scenario hydrogen and hybrid vehicles will get a momentum in 2020 and will significantly increase their share by 2050, together exceeding the number of diesel vehicles. It is predicted that there will be about 7000 hydrogen trucks by 2030. That constitutes about 10 percent of the fleet.

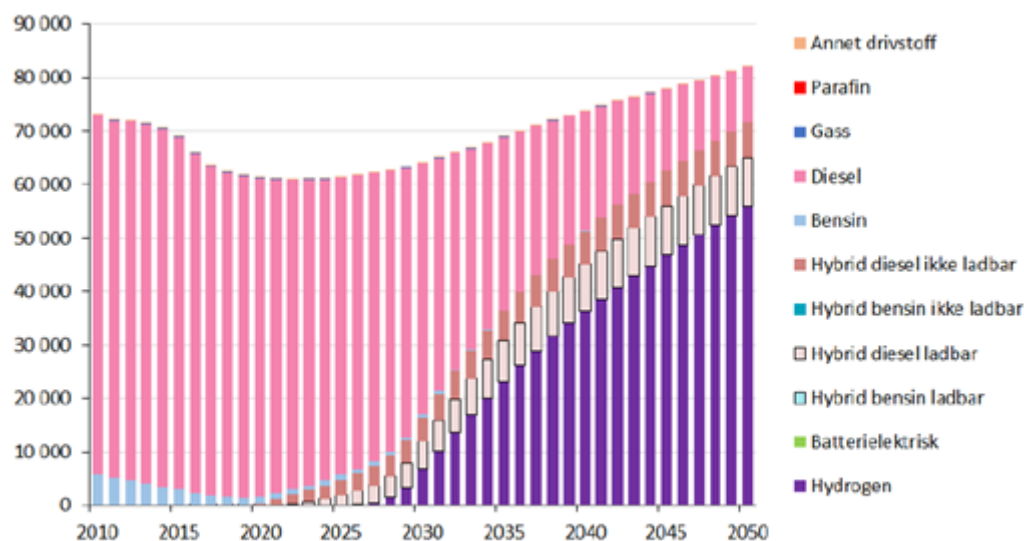
Figure 7: Stock of heavy-duty vehicles, trend path. Observed and predicted stock of heavy-duty vehicles by fuel/ energy carrier. Trend based on observed stock between 2010-2015: Meld. St. 33 (2017)



The share of electric and hybrid private vehicles has been increasing in past years. The development of environmentally-friendly technologies has not gone as far in the heavy-duty vehicle market. Currently, there are few suppliers of commercial heavy-duty vehicles with hydrogen propulsion technology. There are no models in mass production. However, there are a few companies that are in the process of producing their first models, customized for their clients. Thus, the models are very expensive. Moreover, there are only five charging hydrogen stations in Norway, all of them in located in Eastern Norway (Østlandet). The lack of infrastructure discourages investments in hydrogen vehicles (Greensight, 2017).

In the ultralow scenario presented in the TØI report, it is predicted that 55 percent of the new heavy-duty vehicles could be powered by hydrogen by 2050. In the National Transport Plan it is predicted that for trucks, hydrogen is the technology with the biggest long-run potential of reducing greenhouse gas emissions.

Figure 8: Stock of heavy-duty vehicles, ultralow emission path. Observed and predicted stock of heavy-duty vehicles by fuel/ energy carrier. Ultralow emission path in accordance with figure in the National Transport Plan 2018-2029: Meld. St. 33 (2017)



In the light-duty vehicles sector, it is predicted that electric cars will be the biggest contributor to reduction of emissions. For the heavy-duty vehicles, the situation is not so obvious, electric heavy-duty vehicles are not yet produced on a larger scale and introducing hydrogen vehicles is costly.

The prediction of TØI about the light-duty vehicles is that in the more conservative scenario, number of electric vehicles steadily increases and constitutes roughly 50 percent of all the vehicles by 2050 and that most of the remaining vehicles are powered by diesel. In the ultralow emission path, we observe not only a large increase in the stock of electric cars, but also the development of hydrogen driven vehicles. Together the two types almost wipe out all the other types of vehicles from the market.

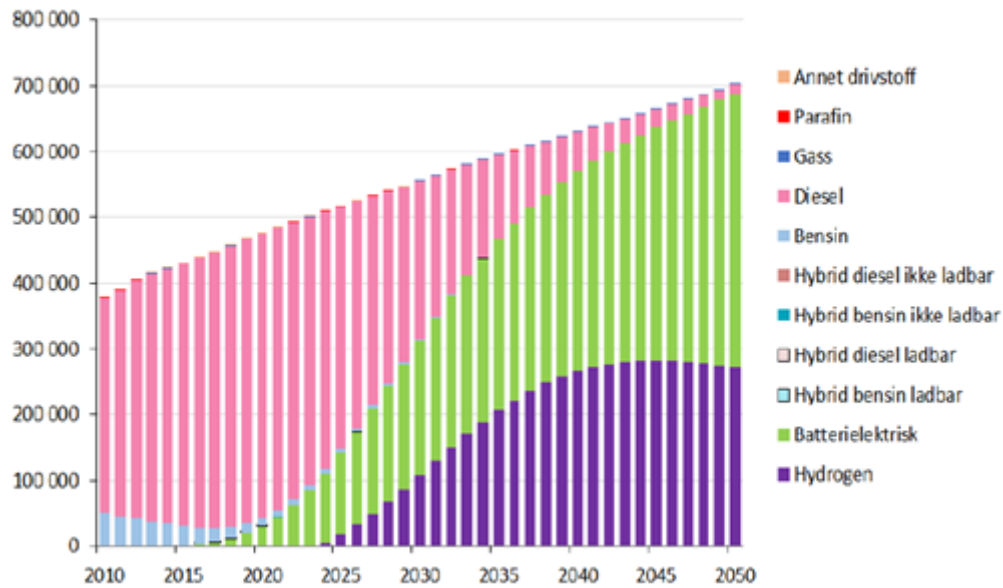
In the report by TØI the prediction is that in the trend path scenario, emissions from light- and heavy-duty vehicles increase.

Figure 9: Stock of light-duty vehicles, trend path. Observed and predicted stock of light-duty vehicles by fuel/ energy carrier. Trend based on observed stock between 2010-2015: Meld. St. 33 (2017)



In the ultralow emission scenario (Figure 10), it is predicted that emissions will continue to increase until 2020, however, after 2021 improvements in vehicle technology will outweigh the increased demand for freight transport and subsequently the emissions from both sectors would be 4.9 million tons lower in 2030 compared to the level in 2015, representing an 18 percent decrease. The ultralow emission scenario also predicts that this decrease will be about 80 percent between 2015 and 2050.

Figure 10: Stock of light-duty vehicles, ultralow emission path. Observed and predicted stock of light-duty vehicles by fuel/ energy carrier. Ultralow emission path in accordance with figure in the National Transport Plan 2018-2029: Meld. St. 33 (2017)



In the following chapter, we present what has been proposed about the CO_2 fund in the national budget in 2017, the subsequent analysis by the TØI, as well as the discussion from the revised national budget in 2017.

4 Proposal for the CO_2 fund for transport

Reducing emissions of CO_2 is possible through either changing the technology or reducing output. Environmental tax is a standard policy instrument aimed to reduce environmentally-harmful activities and incentivize the use of environmentally-friendly alternatives. While increasing the level of the CO_2 tax would increase the cost of transportation and hence potentially lead to a reduction in output, it is difficult to predict the effect on the increase of the level of abatement. This is because the transport industry is dominated by small companies, operating in a highly competitive market with small profit margins. Investing in new technologies, which are not widely available on the market, may not be affordable to small companies, as it involves not only higher costs, but also risk. In addition, it is necessary to invest in costly infrastructure for hydrogen and electrical fast-charging points suitable for trucks (NHO, 2016b, pp. 57).

To reduce the emissions in the freight sector, NHO has proposed to introduce the CO_2 fund for the freight sector. The 2017 national budget stated that the government will consider any concrete proposal from the NHO to create a CO_2 fund based on the existing NO_x fund model to increase fuel charges and that the potential economic and administrative consequences of such a fund would need further investigation (Meld. St. 1, 2016, pp. 81).

The revised national budget in May 2017 presented a few shortcomings of the proposed CO_2 fund. It argued that an environmental agreement like the CO_2 fund would give fewer incentives to reduce the emissions compared to an environmental tax. Another aspect is that introducing a CO_2 fund comes with an opportunity cost. The proceedings from the CO_2 tax, which is part of the budget and could be used to finance some government expenses, would be foregone (Meld. St. 2, 2017, pp. 70). The revised budget also stated that companies have better information about the cost of abatement than the regulator and that such an information asymmetry could result in smaller emissions reductions and higher-than-optimal costs. The environmental agreement would most likely not contribute to reductions in a cost-effective way. Furthermore, the NHO, similar to the authorities, does not have precise knowledge on the future costs and cost allocation between different businesses. Moreover, there is concern over the lack of flexibility in the agreement, namely because the environmental agreement would be in force

for a long period of time (up to ten years) during which it would be challenging to change the regulations. Hence, not only would the agreement have to be created in a way that ensures the environmental objective is reached, but its timespan must also not be too long. Introducing an environmental agreement in addition to environmental tax would increase administrative costs, as it would require creating an additional unit responsible for the implementation of the agreement. This unit would be responsible for processing applications for grants from the fund and ensuring that the grants are used in a desirable way.

The revised 2017 national budget also states that the parliament had not suggested a concrete plan for introducing a CO_2 fund, but that there existed several alternative concepts for designing a CO_2 fund. One alternative would be to have a mechanism similar to the NO_x fund, and another alternative would be based on directly transferring of a portion of the tax revenue to the fund.

The first design, based on the NO_x fund, would be such that the members of the CO_2 fund would not pay the CO_2 tax on diesel, but would instead pay a membership fee to the fund. In time, member companies could apply for a refund from the fund to cover the costs of investing in environmentally-friendly materials and vehicles. Even though there are a lot of similarities between the NO_x fund, the CO_2 fund is facing significant challenges. The number of companies that are members of the NO_x fund is between 900 and 1000. In case of the CO_2 fund, the number of companies could potentially be much higher.

The NHO wants participants from as many sectors in the freight industry as possible to become members of the fund. That means that, in addition to over 450 000 vans and almost 80 000 heavy-duty vehicles, there will be providers of bus transport, ships and construction machinery. The large number of businesses would entail high administrative costs both for businesses and authorities. Not only would all of the existing reporting tasks remain, but number of new tasks would also arise. Companies would have to apply for a tax return from the CO_2 tax and hence document how much taxable fuel they have purchased. The refunds of the CO_2 tax would be handled by the tax office, which would have to distinguish between activities and companies that are eligible for a refund. Companies would subsequently pay a fee to the CO_2 fund and fulfill other potential requirements. In addition, companies would be eligible to apply for grants for investment in abatement technology, and those applications would then be considered by the CO_2 fund, which would decide which projects should get funding.

Finally, the CO_2 fund would have to verify whether companies, following the implementation of eligible projects, are fulfilling the environmental commitment specified in the agreement. Such a CO_2 fund would require significant bureaucratic involvement.

Because freight transport companies that are members of the CO_2 fund would get a refund of the tax, it is estimated that the annual revenue loss would be in the range of 4-4.5 billion NOK. This loss would have to be compensated by either increasing the tax rate for industries not eligible for CO_2 fund membership, or by reducing public spending. Increasing the tax rate would involve a transfer from non-polluting businesses and others who pay for their emissions to companies with significant CO_2 emissions. That would be contrary to the ‘polluter pays’ principle.

The government, by handing the climate policy over to a private CO_2 fund and considering a tax exemption, will no longer be able to influence the incentives of emission reductions through adjusting the CO_2 tax. Thus, the CO_2 tax will no longer play the role of environmental policy instrument for the sectors covered by the CO_2 fund. Hence, if the CO_2 fund is implemented, the environmental impact will ultimately depend on the total emissions of the CO_2 fund’s members.

Another issue is that the tax exemption will be seen as a state aid, which would have to be notified to and subsequently approved by the EFTA Surveillance Authority (ESA), before it can enter into force. The tax exemption from the CO_2 fund would be more extensive than the existing tax exemptions from the NO_x fund. It is therefore uncertain whether such a scheme would be approved by the ESA. If the CO_2 fund was considered to be financed by public funds, it could be limited by the scope of the EEA state aid rules on public support (Meld. St. 2, 2017, pp. 70).

The NHO commissioned the TØI to evaluate the costs and potential emission reductions of the CO_2 fund. The CO_2 fund analyzed by Pinchasik and Hovi resembles the NO_x fund. Participants of the fund are exempt from the CO_2 tax and instead pay a lower per liter participation fee into the fund, proposed to be set at 0.80 NOK per liter diesel (which is about 70 percent of the current CO_2 levy). The proceeds are used to subsidize investment costs of renewable-based propulsion systems (assumed 80 percent subsidy) and infrastructure such as filling stations and charging points (assumed up to 50 percent of subsidy). It is assumed that only new vehicles would be subsidized as it is not cost-effective to modify existing vehicles. In

the analysis, the higher operating costs of renewable-energy-based vehicles and infrastructure are not taken into consideration. Additional investment costs are lowest for biofuels and relatively high for hydrogen and electric vehicles (because of small-scale production and the lack of a critical mass). The costs are expected to decrease during the lifetime of the fund, which is expected to last for 10 years (decrease of 70 percent for the hydrogen and electric vehicles).

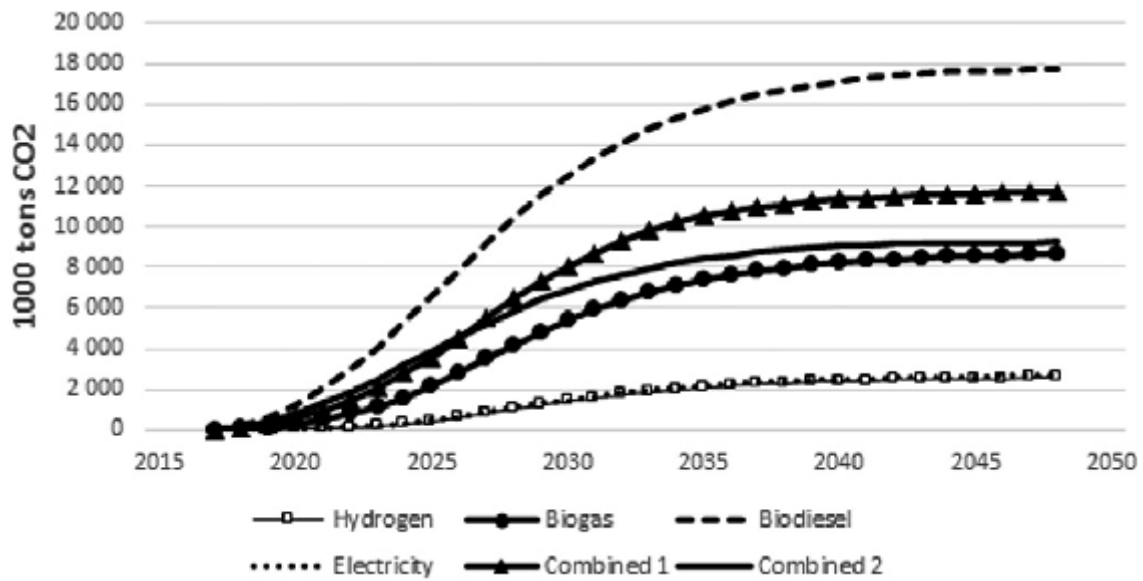
The technologies taken into consideration in the analysis are biofuels (biodiesel or biogas), hydrogen and electricity. The analysis includes six different scenarios with predicted emission reduction, as well as the costs. The assumption made by Pinchasik and Hovi is that in each scenario there is a sufficient amount of sustainable biofuels available to accommodate the subsidies.

The first four scenarios estimate the effects of subsidizing one type of technology: either biodiesel, biogas, electricity or hydrogen. Two last scenarios are so-called 'combined scenarios': the fifth scenario analyzes a subsidy which allocates half of the proceeds toward financing biodiesel vehicles and the remaining half equally to hydrogen, electricity and biogas. In the last scenario it is assumed that during the first years of the fund most of the subsidies are spent on biodiesel vehicles and infrastructure, while only some of the fund's proceeds go to investment in electric and hydrogen infrastructure. However, over time as the electric and hydrogen technology matures and becomes cheaper, more funds are directed towards electric and hydrogen infrastructure. In the first four scenarios only one type of infrastructure is needed, thus a larger share of subsidies is used for the rolling stock. In contrast, in the fifth and sixth scenarios a larger share is used to finance several types of infrastructure.

An analysis of emissions reduction consists of two parts. The first part considers emissions reduction resulting from subsidies on rolling stock, while the second part considers emissions reduction from infrastructure. These two are separated due to the greater uncertainty related to investment in infrastructure.

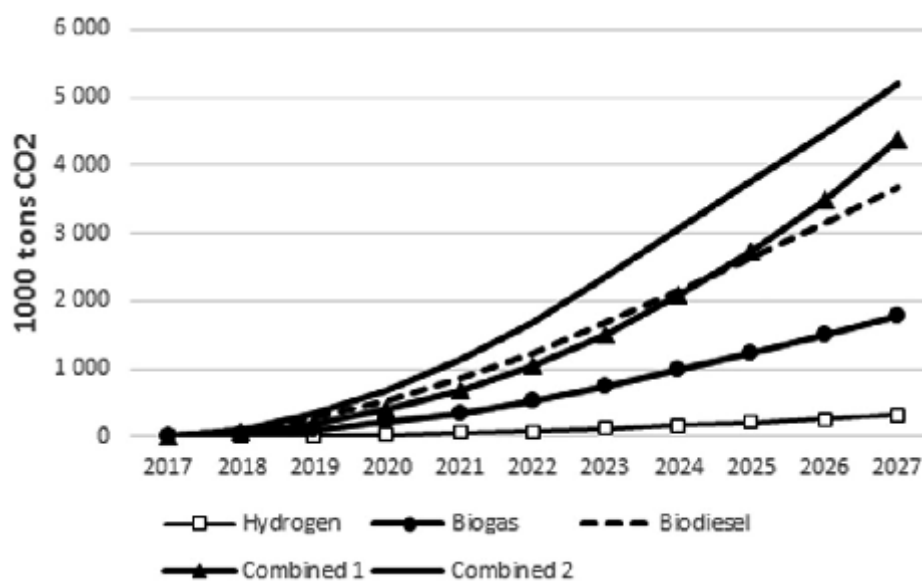
When considering emissions from the rolling stock, emissions reductions are highest in the scenario where only biofuels are subsidized. The reason for this is that biodiesel adaptation is relatively cheap and hence the subsidies are relatively cost-effective. The following most effective scenarios are the combined scenarios, which see a considerable share of subsidies being spent on biodiesel.

Figure 11: Accumulated CO_2 -reduction in each scenario from subsidized rolling stock, relative to 'business as usual': (Pinchasik and Hovi, 2017, pp. 194)



Considering the reduction of emissions from infrastructure, the highest reduction occurs in the two combined scenarios. This is because in these scenarios, a larger share of fund's revenue is allocated to infrastructure. The reduction is highest for the second combined scenario, in which it is assumed that during the first years of the fund most of the subsidies are spent on biodiesel vehicles and infrastructure, and over time as electric and hydrogen technology develops.

Figure 12: Accumulated CO_2 -reduction in each scenario from subsidized infrastructure, relative to 'business as usual'. Electrical infrastructure not included: (Pinchasik and Hovi, 2017, pp. 194)



The assumption made in the paper is that the sufficient infrastructure for heavy vehicles in Norway would include about 60 hydrogen stations, 140 biogas stations 700 biodiesel stations and 500 electrical fast-charging points, suitable for trucks.

As mentioned in chapter 3, biofuel is the most mature technology in the heavy-duty vehicles sector. Thus, the result from Pinchasik and Hovi about biodiesel being the most cost-effective technology is not surprising. It is the cheapest way to reduce emissions by a certain amount. However, subsidizing biofuel is not only contrary to the 'polluter pays' principle, it also results in the polluter getting paid. This completely disrupts the incentives to abate. Moreover, biofuel is sold at petrol stations. Thus, it is unclear what is meant by subsidizing biofuel infrastructure in the report by Pinchasik and Hovi.

The NHO is lobbying for the creation of a CO_2 fund, as it would bring money to the industry. However, taking into consideration all of the costs related to its creation - such as opportunity costs related to how the fund could be used more efficiently using a different design, administrative costs and bureaucracy - it is reasonable that in the revised national budget the potential effects of the CO_2 fund are analyzed from a broader perspective. It is plausible that the government is cautious in administering this policy.

An alternative design of the CO_2 fund would allow the refunds to the members of the fund to come directly from the state budget. Such a system would be comparatively cheaper, as it would not include any additional administrative costs for the business sector and the tax administration, for administering the tax refunds. On top of that, the NHO would not have to bear additional administrative costs for collecting the membership fees and membership management. This means that all the money from the CO_2 fund could be used for processing the applications for support and financing the projects. Additionally, the CO_2 tax would continue to be an effective and flexible climate policy instrument that government uses to achieve the climate policy goals. This model would be in line with the 'polluter pays' principle. Such CO_2 fund will be financed by public funds and thus will be also subject to the EEA state aid rules on public support. There will therefore be limitations on how much support can be given. Transfers to the CO_2 fund would have to be notified to and approved by the ESA before they can be enforced. The duration of notification will depend on the arrangement of the agreement. It is therefore uncertain if and when any CO_2 fund will enter into force. However, such an aid scheme would not differ significantly from the existing Enova support

scheme, which is already approved by the ESA. Assuming this alternative design, it may be possible to get funding by 2020 (Meld. St. 2, 2017, pp. 69-74).

Because of the high costs associated with the CO_2 fund, which would constitute an organization with members, the alternative design, where subsidies come directly from the state budget, will form a basis for the model presented in this thesis. The next chapter presents the literature review, followed by the environmental policy model.

5 Literature review

This section provides a theoretical background on pollution control instruments. The purpose of this section is to introduce issues related to environmental policy. These will provide a basis for justifying the choice of the mechanism in the theoretical model of taxes and subsidies, which is introduced in the subsequent chapter.

First, the textbook theory on pollution control instruments is introduced. Second, policies that combine the emission tax with refunding scheme are described. Then I move on to discuss the issue of commitment when setting environmental policy. Finally, I make a case for the importance of network effects.

In textbook economic theory, environmental taxes are described as an economic (market-based) incentive instrument, which is charged directly based on quantity and/or quality of the pollutant in question. In theory, environmental taxes can not only lead to an efficient level of pollution, and are sufficient in doing that, but they are also doing it in a cost-effective way (Perman et al., 2003). Many economists agree that the most efficient way to address climate change as well as other negative externalities related to the use of fossil fuels is by introducing a carbon tax. The government could establish an economically efficient price for pollution by setting the tax equal to the social cost of pollution to society, hence internalizing the negative externality. Such a tax is not only relatively easy to implement, but also is flexible, less susceptible to arbitrage and raises revenue (Roberts, 2016).

One reason why conventional tax may not yield the optimal choice of technology even if it fully reflects the social cost of carbon could be technological lock-in. “Technological lock-in describes a situation in which a new product that would increase welfare does not successfully diffuse into the market” (Greaker and Heggedal, 2010). The lock-in situation in the market for cars would be due to network externalities. This issue is further discussed in section 5.4.

Another instance where environmental taxation may not be an adequate policy is when there is a resistance from industry lobby groups (Fredriksson and Sterner, 2005, pp. 113). Fredriksson and Sterner (2005) show that the refunded emissions payment program introduced in Sweden could not only reduce lobbying against the environmental tax, but due to the mecha-

nism of the scheme could, in some cases, result in lobbying for a higher level of tax by relatively clean firms.

Hence, cost-effectiveness should not be the only criterion taken into consideration when choosing the optimal policy, as the effect of the environmental tax is not satisfactory in some cases. Other important criteria which could be of importance for the policymaker are long-run effects, dynamic efficiency, ancillary benefits (if there is a potential to achieve double dividend), equity (impact on the distribution on welfare), dependability, flexibility and costs of use under uncertainty and information requirements (Perman et al., 2003).

One alternative to tax could be to use subsidies. However, subsidizing a certain technology necessarily involves so called ‘picking winners and losers’ (Perman et al., 2003). Another option would be to use more complex instruments, which are a combination of a tax or charge and allowance, exemption, refund or subsidy, which Sterner describes as “two-part instruments”.

5.1 Policies combining emission tax with refunding

Sterner and Isaksson (2006) describe the effect of the Refunded Emission Payments (REP) in Sweden. The scheme in Sweden works as follows: Polluters pay a charge on pollution of NO_x and then subsequently the revenues from this charge are returned to the same group of polluters. The magnitude of the repayment is related to the relative output produced by the company (in the Swedish REP scheme it is directly related to the measure of energy produced). Sterner argues that under the scheme, when charges are being refunded to companies, the incentives to abate are not different from the incentives under the tax, when there are many producers. However, the distribution of costs is different, which results in the refunded emission payments to be easier to implement. Even though REP implicitly is a form of ‘subsidy’, in reality it is just a scheme, which redistributes the fees within the sector, as all the refunds come from within the sector. Thus, the fee can be set much higher than would have been acceptable in case of a tax.

Another mechanism, which is a combination of a fee and subsidy, is the NO_x fund in Norway. However, unlike the REP system in Sweden where payback depends on companies’ output, in the NO_x fund, the magnitude of the refund depends on the amount of investment

in abatement technologies incurred by the companies. Hagem et al. (2017) compare the two mechanisms to the standard tax scenario and analyze them in two scenarios: One with the same fee level in both mechanisms and the other with the same target level of abatement. They argue that both mechanisms, unlike the uniform tax, are not cost-effective due to the fact that companies invest too much in abatement technology and relatively little in the reduction of production. However, in some cases such an outcome is desired by policymakers.

The two mechanisms presented in Hagem et al. differ from the model presented in this thesis in the number of stages in the model. In Hagem et al., agents face only one stage. We briefly present a simplified model from Hagem et al..

5.2 Theoretical model of two-part instruments

5.2.1 Standard tax

The objective of the firms is to maximize profits. For each firm we have:

$$\pi = pq - c(q) - my - t(e^0 - a(r, y))$$

Where p is the product price, q is firm's output, $c(q)$ represents production costs, m is the cost per unit of abatement technology (represented by y), t is the level of tax, e^0 is the level of emissions in absence of environmental policy. Function $a(r, y)$ is the emission reduction, which depends on the level of abatement y and the output reduction $r = q^0 - q$.

In chapter 6, the model of optimal environmental policy is presented, where we use a similar profit function for the firms. However, instead of having a constant abatement cost equal to m , we will use a cost function that depends on the level of investment in capital and the level of abatement: $a_t(y, K_t) = \frac{a}{2}y_t^2 - y_t\sqrt{K_t}$. In Hagem et al., the tax revenue is represented as $t(e^0 - a(r, y))$, where the amount of emissions is a function of emissions without environmental policy e^0 , less the reduction of emissions due to abatement, which is a function of a reduction in output r and amount of emissions y . In the model presented in the next chapter, we represent tax revenue as an explicit function of output and abatement: $\tau(x - y)$, where τ is the level of

tax, x is the level of output and y represents the abatement.

From the first-order conditions with respect to y and r :

$$\frac{m}{a'_y(r, y)} = t$$

$$\frac{p - c'}{a'_r(r, y)} = t$$

The left-hand side of the first equation is the marginal cost of reducing emissions through abatement technology and the left-hand side of the second equation is the marginal cost of reducing emissions through output reductions.

For all emission levels the Pigouvian tax yields a cost-effective output reduction and level of abatement technology, assuming that the level of tax represents the true social marginal damage.

5.2.2 Output-Based Refunding Emissions Payments

In this mechanism the fees paid by the firms are subsequently refunded in proportion to the output.

$$\pi = pq - c(q) - my - t(e^0 - a(r, y)) + qt \frac{E}{Q}$$

Where Q is the sum of outputs and E is the sum of emissions of all the firms, which fall under the scheme. We see that the higher the share of firm's output, the higher the refund. The first-order conditions yield:

$$\frac{m}{a'_y(r, y)} = t$$

$$\frac{p - c'}{a'_r(r, y)} = t(1 - \frac{E}{Qa'_r(r, y)})$$

The marginal cost of emissions reduction through abatement technology is equal to the fee paid by the firms, mirroring the standard tax scenario. However, the marginal cost of emissions

reduction through output reductions is weaker than under the standard tax case.

This mechanism has been successful in decreasing the emissions of NO_x in Sweden. It would be unattainable to apply this scheme to the Norwegian commercial transport sector. First of all, it would be necessary to define output of the transport sector. While for the heavy-duty vehicles, it could be related to the km of goods transported, it would be impossible to define output in case of light-duty vehicles, as the variety of services provided is too large. Additionally, the output-based refunding scheme decreases the marginal cost of emissions reduction through output reductions, the cost of driving vehicles would be lower than in the scenario with standard tax. This is an additional argument for why output-based mechanisms are not a suitable policy for the transport sector.

5.2.3 Expenditure-Based Refunding

In this mechanism, the fees paid by the firms are subsequently refunded in proportion to firms' expenditures on abatement equipment.

$$\pi = pq - c(q) - (1 - s)my - t(e^0 - a(r, y))$$

Here s represents the subsidy rate for abatement cost expenditure. The first-order conditions yield:

$$\frac{(1 - s)m}{a'_y(r, y)} = t \quad (5.1)$$

$$\frac{p - c'}{a'_r(r, y)} = t \quad (5.2)$$

The marginal cost of emissions reduction through the output reduction is equal to the fee paid by the firms, similarly to the standard tax case. But in this case, the marginal cost of emissions reduction through abatement technology is lower than in the standard tax scenario. In the expenditure-based refunding firms have strong incentives to invest in abatement technology due to the subsidy.

The Expenditure-Based Refunding in Hagem et al. resembles the model of environmental policy presented in the thesis. The first-order conditions will be the same, which we show in the following chapter.

The conclusion in Hagem et al. is that to achieve a certain level of abatement, the fee level in the output-based (OB) mechanism exceeds the standard tax rate, whereas the fee level in the expenditure-based (EB) mechanism is the lowest. This is because the output-based mechanism has very modest output effect. However, because of the automatic refund from the fund, even though the fee rate is high, the average company pays nothing. The tax rate in the expenditure-based mechanism is lower than under both the standard tax and the output-based mechanism because of the combination of the tax effect and subsidy effect. Under this scheme, the incentives for abatement are very strong. Not only are emissions taxed, but abatement is subsidized.

When comparing standard tax and OB and EB systems, Hagem et al. show that when the fee level is the same under the three systems, we will have that the level of abatement is highest in the EB system, lower under standard tax and lowest in the OB. In practice, the two mechanisms are likely to be used when it is impossible for the government to set a tax above a certain level for political reasons. For instance, it could be the case that it is not desirable for output to fall below a certain level. Moreover, setting tax above a certain threshold could drive some firms out of the market and hence cause a threat to jobs. Thus, the relevant comparison could be between, on the one hand, the standard tax with a low level of t and lower target of abatement and, on the other hand, Output- and Expenditure-Based mechanisms with a relatively high t and high abatement target. “In this case, production might still be higher under the OB and EB systems, but certainly there will be higher expenditures on abatement activities. [...] higher production is often considered desirable by politicians in economies with excess labor capacity. The investments can also create employment and may speed up the development of the abatement industry through scale effects and learning by doing, possibly even creating export opportunities or other strategic advantages for domestic industry” (Hagem et al., 2017, pp. 22).

In section 6.5.4, I introduce the theoretical model of the CO_2 fund when there is a regional policy which requires that the demand for freight cannot fall below a certain threshold \bar{x}_t .

As mentioned above, in case of expenditure-based refunding, firms have strong incentives

to invest in abatement technology due to the subsidy. This mechanism resembles the model of subsidy presented in this thesis. Later, I investigate under which circumstances and to what extent the subsidy is desired in the commercial transport sector. Unlike in Hagem et al, my model features two stages, with the subsidy and investment in capital in place only in the first stage. The reason for having two stages is that the purpose of the subsidy on abatement and capital is to give a momentum to help the introduction of new technology and to help building the infrastructure. Once the transition is achieved, the subsidy would be terminated. This is also to mirror the idea behind the CO_2 fund proposed by the government, which has been suggested to be a temporary solution.

5.3 Commitment

Developing the electric and/or heavy- and light-duty vehicles markets in Norway will require a significant amount of investment in infrastructure and technology. Additionally, for the new technologies to be affordable, a certain production volume is necessary (Greensight, 2017). Such a transition will take years and is associated with significant uncertainty. In order for companies to have incentive to invest in environmentally-friendly technologies, it would be ideal that the government announces both current and future policy to stimulate R&D. But it could be the case that after the climate-friendly technologies have been developed, the government may use a policy which differs from the pre-announced policy. Thus, there may be a time inconsistency problem.

Golombek et al. (2010) analyze the difference between the optimal designs of carbon taxes when the government can commit to a certain policy to when there is no commitment. They use a model with two periods, with the technology progress taking place in the first period and being used in both periods, which is similar to the idea of the CO_2 fund. First, they analyze the case where the government can implement the first-best social optimum, which means that it implements both optimal carbon taxes as well as R&D subsidy. They then depart from the scenario of first-best R&D policy and analyze what happens under both pre-commitment and no pre-commitment. Authors argue that when the first-best subsidy is offered to the R&D firms, the first-best outcome will be reached independently of whether government can commit to a certain level of tax or not. However, when the subsidy provided differs from the first-best,

the equilibrium under commitment will be different than the first-best outcome and will be time inconsistent. In particular, when the level of subsidy is lower than the first best, then in each time period the level of tax will exceed the first-best level of tax. If subsidy is higher than the first best, then the tax imposed will be lower than the first best. When time consistency is imposed through sub-game perfectness, the level of the carbon tax will be different in the first-best commitment and no-commitment cases and will depend on the level of the subsidy. If the subsidy level is lower than the first best, then the government would ideally like to implement a high tax in the second period. However, that is not time consistent and hence, when the government is not able to pre-commit to a high tax in the second period, they will implement a high tax in the first period, which exceeds the first-best. On the other hand, when the level of subsidy exceeds the first best, government would ideally like to impose a lower tax in the second period, however, because it cannot commit, in order to compensate for the fact that the ex post tax implemented in the second period is higher, the tax imposed in the first period will be lower.

Thus, the advantage of using two stages in the model of subsidies in the Norwegian commercial transport sector is related not only to the fact that it will reflect the temporary structure of subsidies, but will also enable capturing the issue of commitment.

In my analysis, I analyze two scenarios when government sets subsidies which are different than optimal. One scenario is when government introduces subsidy on capital and the other scenario with subsidy on abatement.

5.4 Network externalities

Another factor which may hinder the development of environmentally-friendly technologies is network externalities. Greaker and Heggedal (2010) investigate the private transport market and the technology choice of firms and consumers when there are two options: internal combustion engine-based technology and hydrogen. Because of network externalities, there may be several market equilibria and it is possible that one of them Pareto dominates the others. Greaker and Heggedal argue that, due to network effect, it is likely to end up in a scenario with a technological lock-in, an equilibrium with only one type of technology. If the technology of hydrogen cars is not mature, the only equilibrium will be the one with combustion engine-based

technology, which yields lower welfare.

The network externality of hydrogen technology lies in the network of services. The more filling stations and automobile repair shops there are and the bigger the market for used cars, the higher the chance that consumers will choose to invest in the hydrogen technology. At the same time, the size of the infrastructure depends on the number of users of the technology. Greaker and Heggedal investigate what factors cause lock-in in the market for private transport and analyze whether there exists a clear case for government intervention in cases where a lock-in occurs.

First, they find that when the costs of introducing hydrogen technology are too high, then the only equilibrium is the one without hydrogen. Alternatively, when there is an equilibrium with lower hydrogen shares under a lock-in situation, it must be the case that the utility that consumers derive from choosing a hydrogen vehicle compared to an alternative must exceed the transition costs of moving to an equilibrium with a bigger share of hydrogen technology. Second, even if a lock-in situation exists, government intervention may not be necessary as long as there are firms that could profit from switching to hydrogen technology. For the government to undertake optimal intervention, it will require information on the cost of technology and transition, benefits for consumers and potential profits for firms.

The current situation of commercial transport in Norway may reflect such a lock-in situation, where most of the vehicles use fossil fuel technology. For the light-duty vehicles, the owners do not have enough incentives to switch to electric vehicles because it is much cheaper to buy vehicles powered by diesel. In absence of a poll of potential consumers who are willing to switch to electric technology, there are no incentives to further develop the infrastructure. On the other hand, it could be the case that because the infrastructure is insufficient, potential buyers are discouraged from investing in electric vehicles. The situation is similar for heavy-duty vehicles. The cost of using a vehicle powered by hydrogen is similar to that of using a standard vehicle that uses fossil fuel, as has been mentioned in the previous chapter. Thus, it is uncertain whether there would be many consumers willing to switch to hydrogen technology if the infrastructure were in place. However, hypothetically, if there were a subsidy on capital to help build the infrastructure and improve the efficiency of hydrogen engines, thus decreasing the cost of driving, a transition could be sparked. After a certain period, with more users, increased production would likely drive the price down, making the transition more attractive

to additional users.

In the following chapter, the model of environmental policy is presented, taking into consideration the issues presented in this chapter. We look at how the inability to commit to a certain level of tax affects the investment decisions of firms. Moreover, the network effect will partially be reflected in the function of abatement cost, which decreases in the level of capital.

6 A model of the environmental policy

A model of environmental policy for the commercial transport sector consists of a combination of a subsidy on abatement s_y , a subsidy on capital s_K and a tax τ_t . We have two periods ($t = 1, 2$). The subsidy is in place only in the first period because, as we argued earlier, subsidies are supposed to be temporary. We think of a two-stage game:

1. In the first stage, the government sets a subsidy for abatement capital investments s_K and subsidy on abatement costs s_y . Moreover, the government sets an emission tax τ_1 . The transport sector chooses an activity level x_1 , capital investment ΔK , and abatement y_1 . Emissions in period 1: e_1 are realized.
2. In the second stage, the government sets an emission tax τ_2 . The transport sector chooses activity level and abatement, such that emissions in period 2: e_2 are realized.

By "activity level", we mean the number of kilometers driven by trucks. Parameters y and ΔK represent factors that contribute to the reduction of emissions. Abatement y describes actions that can be realized in the short run, without much investment in capital or having the capital already in place. For instance, it could be using biodiesel in diesel truck, driving an electric or hydrogen truck, using better logistics (i.e. route optimization and better capacity utilization), as well as decreasing the number of empty kilometers and transferring freight from road to rail or maritime. ΔK represents long-term investments in alternative technologies, like investment in hydrogen or electric vehicles, as well as investments in capital, such as charging stations for hydrogen and electric vehicles. Moreover, ΔK includes investments in capital, which supports abatement y , for instance investments in production of biofuels and investments in digitization systems, which would improve logistics. The tax is set per amount of emissions of CO_2 . In reality, CO_2 tax consists of the CO_2 fee, which is a component of the registration fee, and the road tax on fuel, which differs by type of fuel (see Table 2 in the appendix).

6.1 Transport sector

The representative firm in the road freight sector has demand for its services (activity level) equal to: $x_t = D(p_t) = M - p_t$ (where p_t represents the cost of output and M is a parameter describing the size of the market), and has costs, which are a sum of the cost of transportation and the cost of abatement $c(x_t) + a(y_t, K_t)$. We assume $c_x, c_{xx} > 0$. Further, $a_y, a_{yy} > 0$ and $a_K < 0$, $a_{KK} \geq 0$, $a_{yK} < 0$, where the last inequality is because the marginal cost of abatement decreases with the level of capital and vice versa. Emissions are given $e_t = x_t - y_t$. We can normalize $K_1 = 0$. Thus, for K_t we have:

$$K_1 = 0$$

$$K_2 = K_1 + \Delta K = \Delta K$$

The representative firm maximizes profits π over the two periods. In the first period, the profit is maximized with respect to x_1 , y_1 and ΔK . In the second period, the profit is maximized with respect to x_2 , y_2 . We assume no discounting between the two periods.

We can write the problem of the firm as a sum of profit maximizations over the two periods:

$$\begin{aligned} \max_{x_1, y_1, \Delta K, x_2, y_2} \pi = & p_1 x_1 - c(x_1) - \tau_1 e(x_1, y_1) - (1 - s_y) a(y_1, 0) - (1 - s_k) \Delta K \\ & + p_2 x_2 - c(x_2) - \tau_2 e(x_2, y_2) - a(y_2, \Delta K) \end{aligned}$$

The 5 first-order conditions are:

$$\frac{\partial \pi}{\partial x_1} = p_1 - c_{x_1}(x_1) - \tau_1 e_{x_1}(x_1, y_1) = 0 \quad (6.1)$$

$$\frac{\partial \pi}{\partial y_1} = -\tau_1 e_{y_1}(x_1, y_1) - (1 - s_y) a_{y_1}(y_1, 0) = 0 \quad (6.2)$$

$$\frac{\partial \pi}{\partial \Delta K} = -(1 - s_k) - a_{\Delta K}(y_2, \Delta K) = 0 \quad (6.3)$$

$$\frac{\partial \pi}{\partial x_2} = p_2 - c_{x_2}(x_2) - \tau_2 e_{x_2}(x_2, y_2) = 0 \quad (6.4)$$

$$\frac{\partial \pi}{\partial y_2} = -\tau_2 e_{y_2}(x_2, y_2) - a_{y_2}(y_2, \Delta K) = 0 \quad (6.5)$$

From 6.1 and 6.4 we have that:

$$p_t = c_{x_t}(x_t) + \tau_t e_{x_t}(x_t, y_t) \quad (6.6)$$

In both stages, firms will produce until the marginal costs are equal to price. By rearranging equation 6.2 and 6.6 we get the following result, which mirrors equations 5.1 and 5.2 from the Expenditure-Based Refunding from section 5.2.3:

$$\frac{(1 - s_y)a_y(y, K_0)}{e_y(x, y)} = t \quad (6.7)$$

$$\frac{p - c_x(x)}{e_x(x, y)} = t \quad (6.8)$$

We do not solve the model analytically, as the equations become too complex. Thus, to illustrate the results, we use some functional forms, which represent costs of output, costs of demand and emissions of the representative firm. These form the basis for the numerical simulation in Microsoft Excel, which is presented later in the chapter.

6.2 Solving the model

We set:

$$c_t(x) = \frac{c}{2}x_t^2 \quad (6.9)$$

$$a_t(y, K_t) = \frac{a}{2}y_t^2 - y_t\sqrt{K_t} \quad (6.10)$$

$$e_t = x_t - y_t \quad (6.11)$$

The first function is a standard cost function, in which cost increases with the activity level at an increasing rate. This is to reflect the increasing cost due to expanding capacity, increasing costs of depreciation of the fleet, as well as costs related to increased traffic.

The second function represents the cost of abatement. A similar form has been used by Greiner and Hagem (2013). This functional form reflects the increasing cost of abatement at higher levels of emission reduction (Perman et al., 2003, pp. 146). The cost of abatement decreases with the level of capital, e.g. by having more hydrogen or electric trucks in the fleet, it is much cheaper to abate. Moreover, the decrease in the cost of abatement could be due to the network effect. For instance, the more charging stations there are, the cheaper it is to use electric vehicles, as it decreases the distance to the nearest charging point. Another example could be related to decreasing the costs of technology due to economics of scale (e.g. more efficient fuel cells in hydrogen vehicles).

The level of investment is bounded such that $ay_t \geq 2\sqrt{K_t}$ to ensure that $a_t(y, K_t) \geq 0$.

6.3 Firms

By plugging in the functional forms 6.9- 6.11 in the first-order conditions 6.1- 6.5 (section A in appendix), we find that the representative firm chooses output, level of abatement and capital such that:

$$x_1^* = \frac{M - \tau_1}{1 + c} \quad (6.12)$$

$$x_2^* = \frac{M - \tau_2}{1 + c} \quad (6.13)$$

The output increases with the size of the market M and decreases with the level of tax $\frac{\partial x}{\partial \tau} < 0$ and the level of costs c . The output of the companies does not depend on the level of s_y or s_K . Hence, the level of output can be influenced by the government only through the level of tax.

$$y_1^* = \left(\frac{\tau_1}{1 - s_y} \right) \frac{1}{a} \quad (6.14)$$

We have that $\frac{\partial y_1}{\partial s_y} > 0$ and $\frac{\partial y_1}{\partial \tau_1} > 0$, level of abatement in the first period increases with the level of tax and the level of subsidy on abatement.

$$y_2^* = \frac{\tau_2 + \sqrt{\Delta K}}{a} = \frac{2(1 - s_K)\tau_2}{2a(1 - s_K) - 1} \quad (6.15)$$

We have that $\frac{\partial y_2}{\partial \tau_2} > 0$, $\frac{\partial y_2}{\partial s_K} > 0$, level of abatement in the second period increases with the level of tax and the level of subsidy on capital.

$$\Delta K^* = \left(\frac{\tau_2}{2a(1 - s_K) - 1} \right)^2 \quad (6.16)$$

The level of abatement in the second period depends on the level of investment in capital in the first period $\frac{\partial y_2}{\partial \Delta K} > 0$ (see section A in the appendix). The level of capital in turn depends on the level of subsidy on capital, hence $\frac{\partial y_2}{\partial \Delta K} \frac{\partial \Delta K}{\partial s_K} > 0$. This is because the marginal cost of abatement decreases with the level of capital $\frac{\partial a(y, \Delta K)}{\partial \Delta K} > 0$. Thus, we expect that a high subsidy on capital in the first stage would spur further investment in abatement in the second stage, after the subsidies are no longer in place.

In addition, we have the following equilibrium condition for the representative firm:

$x_t = D(p_t) = M - p_t$, $t = 1, 2$, where $x_t = x_t(p_t)$ follows from the first-order condition (A).

The level of capital in which companies invest depends on the level of the tax in the second period. However, in our model, companies invest in capital in the first period. That is the reason why it is important to consider the effect of the government not being able to commit to a certain level of tax in the second period. Companies will make costly investments in the first periods only if they expect the tight regulations to be enforced in the following

period. It would be plausible for the government to be able to pre-commit to a particular level of taxes in period 2. Gersbach (2002) argues that the inability to commit to a certain regulatory scheme prevents firms from investing. In case companies do not invest in the first stage, the government may face political pressure and hence find the enforcement costly in the second period and, ultimately, choose not to implement the tight policy. Hence, the regulator's threat of tight regulation is not credible; firms foresee this and find it more plausible not to invest.

Later, in section 6.5.3, we discuss a scenario in which the government cannot commit to a certain level of tax in the second period and companies choose ΔK strategically.

6.4 Government

The objective of the government is to choose a level of tax and subsidies that maximize social welfare. Social welfare is a sum of the consumer surplus, producer surplus, less the costs of abatement technology and environmental damage, which we incorporate as a shadow price on emissions δ . The tax paid by the company does not enter the welfare function, as it merely represents the redistribution of welfare between the firm and the government.

6.5 Solutions

In section 5.3, we discussed the issue of commitment. Moreover, it could be the case that there is a regional policy that ensures that the load transported does not fall below a certain threshold. We analyze six different scenarios. The first 3 scenarios present first-best solutions. In the first scenario, the government can commit to τ_2 , while in the second and third scenarios, the government cannot commit to the level of τ_2 in the first period, and firms either do not act strategically or act strategically. Subsequently, we analyze 3 more scenarios that present second-best solutions.

Hence, we solve for:

1. First-best solution with commitment (6.5.1)

2. First-best solution without commitment, no strategic behavior by firms (6.5.2)
3. First-best solution without commitment, strategic behavior by firms (6.5.3)
4. Second-best solution with commitment with regional policy: $x_t \geq \bar{x}_t$ (6.5.4)
5. Second-best solution with subsidy on abatement (6.5.5)
6. Second-best solution with subsidy on capital (6.5.6)

As mentioned before, we do not solve the problem analytically. This is because the equations get very complex. Instead, to find the optimal level of tax τ_1^* , τ_2^* and the level of subsidy for abatement capital investments s_K^* and subsidy on rolling stock s_y^* , we simulate a model. The simulation is done using the Microsoft Excel Solver Add-in. In order to do this, we use equations derived from the first-order conditions from sections 6.1, 6.2 and A in the appendix. Moreover, we choose some parameters a , c , M , δ_1 , δ_2 , such that $ay \geq 2\sqrt{\Delta K}$.

It is very challenging to set meaningful parameters in the simulation because the model is simplified. In reality, the costs of abatement would be different for different types of technology. Additionally, costs would depend on the volume of production of certain types of vehicles. Moreover, the costs would likely change during the lifetime of the fund. Hence, we will choose some parameters to be able to observe how the level of tax and subsidy behaves in different scenarios.

We analyze 12 scenarios in which the cost of environmental damage δ ranges from 5 to 14.27 and increases by 10 percent in each scenario. Our parameters of choice are as follows: $a = 30$, $c = 0.3$, $M = 100$, $\delta \in [5; 14.27]$.

We use these parameters in all scenarios. Each section includes an explanation of the parameters, which have been set in Excel. For every scenario, we plot the relationship between the level of cost of environmental damage, the level of tax and the level of investment in capital.

6.5.1 First-best solution with commitment

We now analyze a scenario in which the government can pre-commit to the level of tax τ_1 and τ_2 . Then, in period 1, the government maximizes social welfare with respect to the level of subsidy on capital and abatement technology and with respect to tax in period 1 and period 2.

$$\begin{aligned}
\max_{s_y, s_K, \tau_1, \tau_2} \omega_1 + \omega_2 = & \underbrace{\frac{(M - p_1)^2}{2}}_{\text{consumer surplus}} + \underbrace{p_1 x_1 - c(x_1) - (1 - s_y)a(y_1, 0) - (1 - s_K)\Delta K}_{\text{producer surplus}} + \underbrace{-\delta_1 e_1}_{\text{environmental damage}} \\
& + \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \Delta K) - \delta_2 e_2 + \underbrace{-s_y a(y_1, 0) - s_K \Delta K}_{\text{subsidies payed by the government}}
\end{aligned}$$

The subsidy on abatement and the subsidy on capital enter the function twice, once in the producer surplus, which is the firm's profit maximization, and again as a subsidy paid by the government. They cancel out from the welfare function, as they merely represent a redistribution of welfare between the representative firm and the government, thus we can write:

$$\begin{aligned}
\max_{s_y, s_K, \tau_1, \tau_2} \omega_1 + \omega_2 = & \frac{(M - p_1)^2}{2} + p_1 x_1 - c(x_1) - a(y_1, 0) - \Delta K - \delta_1 e_1 \\
& + \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \Delta K) - \delta_2 e_2
\end{aligned}$$

By inserting $x_1^*, y_1^*, x_2^*, y_2^*$ and ΔK^* in the maximization problem (equations 6.12-6.16), we get that $\omega_1 + \omega_2$ is a function of τ_1, τ_2, s_K, s_y and parameters a, c, M, δ_1 and δ_2 . The functions for $x_1^*, y_1^*, x_2^*, y_2^*$ and ΔK^* come from the profit maximization of the firm. From the four first-order conditions ($\frac{\partial \omega_1 + \omega_2}{\partial \tau_1}, \frac{\partial \omega_1 + \omega_2}{\partial \tau_2}, \frac{\partial \omega_1 + \omega_2}{\partial s_K}$ and $\frac{\partial \omega_1 + \omega_2}{\partial s_y}$), we get the functions of $\tau_1(s_y), \tau_2(s_K), s_K(\tau_2), s_y(\tau_1)$. Having four equations and four unknowns (τ_1, τ_2, s_K and s_y), it is possible to find the optimal level of $\tau_1^*, \tau_2^*, s_K^*, s_y^*$, which maximize welfare.

Our prediction is that at the optimum, the tax in both periods should be set equal to the cost of environmental damage (the shadow price on emission), thus: $\tau_1^* = \delta_1$ and $\tau_2^* = \delta_2$. We also expect that $s_y = 0$ and $s_K = 0$

We now move to the simulation of results from Excel Solver.

Solver maximization

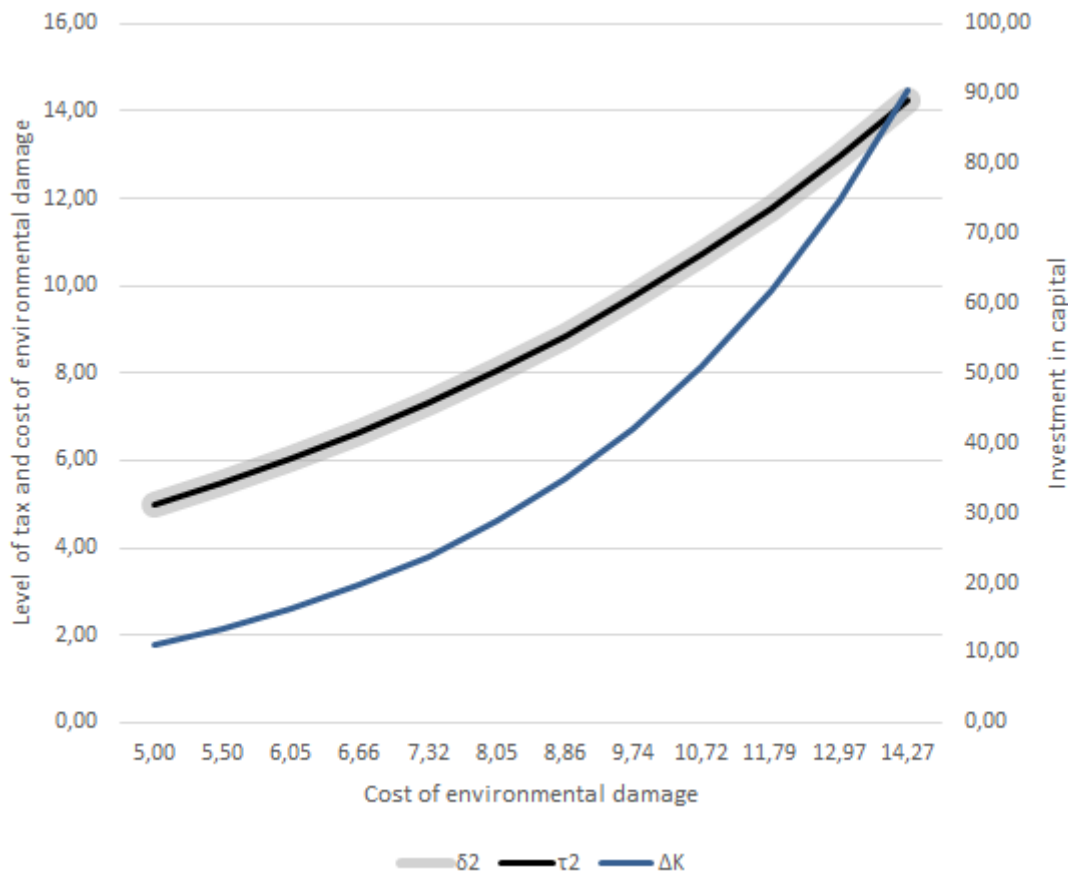
1. Set: $x_1^*, x_2^*, y_1^*, y_2^*, \Delta K^*$: from the firms profit maximization (equations 6.12- 6.16).
2. Maximize $\omega_1 + \omega_2$, subject to: τ_1, τ_2, s_y and s_K .

3. There are no other constraints.

The result that we obtain is that the sum of welfares is maximized when the level of tax is in line with the social cost of environmental damage, thus: $\tau_1^* = \delta_1$ and $\tau_2^* = \delta_2 \forall \delta_1, \delta_2$ of our choice. We also get that $s_y = 0$ and $s_K = 0$. Hence, welfare is maximized when neither abatement nor infrastructure is subsidized. This result is not surprising, since in theory, the tax, which is equal to the social environmental damage, should be a sufficient instrument to maximize social welfare.

The level of investment in capital and the level of abatement both increase with the level of tax and social cost of environmental damage. In the figure, we see that tax is equal to the cost of environmental damage and that investment in capital ΔK increases with the level of tax.

Figure 13: First-best solution with commitment



From the simulation we get that the demand x decreases with the level of the tax. This reflects what we would call abatement due to output reduction. The price of transportation

increases with the level of tax.

All in all, the tax is sufficient to induce a reduction in emissions both by increasing the level of abatement and by reducing output.

6.5.2 First-best solution without commitment, no strategic action by firms

As mentioned previously, we solve the problem by setting parameters and simulating the results in Excel, because solving the theoretical model is complex. However, before moving to the results of the simulation, I will first outline the method of solving the theoretical model.

In this scenario, the government in the first period cannot commit to a certain level of tax in the second period. The level of tax in the second period will thus be chosen in the second stage, after the level of investment in capital ΔK is already known, which we will denote as $\overline{\Delta K}$. The problem will be solved by backward induction. The government in period 2 maximizes welfare in period 2 with respect to tax in period 2, knowing the level of capital $\overline{\Delta K}$:

$$\max_{\tau_2} \omega_2 = \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \overline{\Delta K}) - \delta_2 e_2$$

By inserting x_2^* , y_2^* , $\overline{\Delta K}$ in the maximization problem (equations 6.12-6.16), we get that ω_2 is a function of τ_2 , s_K and parameters a , c , M and δ_2 . The functions for x_2^* , y_2^* , $\overline{\Delta K}$ come from the profit maximization of the firm. While x_2^* , y_2^* depend on τ_2 and s_K , which are known in the second period, the amount of investment in capital by the representative firm in the first period depends on the level of tax in the second period. Thus, the representative firm's choice of ΔK is based on the expected level of tax in the second period. Thus, we have that:

$$\Delta K^* = \left(\frac{E[\tau_2]}{2a(1 - s_K) - 1} \right)^2 \quad (6.17)$$

We assume that the representative firm has correct expectations about the level of the tax in the second period. In the second period, the government observes the actual level of

investment $\overline{\Delta K}$.

From the first-order condition $\frac{\partial \omega_2}{\partial \tau_2} = 0$ of the welfare maximization, we get the optimal level of tax in the second period, as a function of the level of investment in capital $\overline{\Delta K}$ and the level of subsidy on capital s_K (see section C in the appendix):

$$\tau_2^*(\overline{\Delta K}, s_K) = \frac{\delta_2 \left(\frac{1}{1+c} + \frac{2(1-s_K)}{2a(1-s_K)-1} \right) + \sqrt{\overline{\Delta K}} \frac{2(1-s_K)}{2a(1-s_K)-1}}{\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2}} \quad (6.18)$$

Subsequently, in period 1 the government maximizes the sum of welfare $\omega_1 + \omega_2$ using the optimal tax $\tau_2^*(\overline{\Delta K}, s_K)$ derived by backward induction.

$$\begin{aligned} \max_{s_y, s_K, \tau_1} \omega_1 + \omega_2 &= \frac{(M - p_1)^2}{2} + p_1 x_1 - c(x_1) - (1 - s_y)a(y_1, 0) - (1 - s_K)\overline{\Delta K} - \delta_1 e_1 \\ &+ \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \Delta K) - \delta_2 e_2 - s_y a(y_1, 0) - s_K \overline{\Delta K} \end{aligned}$$

By inserting $x_1^*, y_1^*, x_2^*, y_2^*$ and $\overline{\Delta K}$ in the maximization problem (see section A in the appendix), we get that $\omega_1 + \omega_2$ is a function of τ_1, τ_2, s_K, s_y and parameters a, c, M, δ_1 and δ_2 . The functions for $x_1^*, y_1^*, x_2^*, y_2^*$ and $\overline{\Delta K}$ come from the profit maximization of the firm. From the first order conditions of the welfare maximization, we get the functions of $\tau_1(s_y), s_K(\tau_2^*), s_y(\tau_1)$. Having three equations and three unknowns (τ_1, s_y and s_K) it is possible to find the optimal level of τ_1^*, s_K^*, s_y^* , which maximize the welfare.

We now move to the numerical simulation of the model. In the simulation, we do not maximize welfares sequentially. Rather, we program the results from the maximization of ω_2 , which we obtained through backward induction, and maximize the sum of welfare $\omega_1 + \omega_2$.

Solver maximization

1. Set: $x_1^*, x_2^*, y_1^*, y_2^*$ from the firms' profit maximization (equations 6.12- 6.15).
2. Maximize $\omega_1 + \omega_2$, with respect to: $\Delta K, \tau_1, \tau_2, s_y$ and s_K .

3. Subject to two constraints:

$$\begin{aligned}\tau_2^*(\overline{\Delta K}, s_K) - \tau_2 &= 0 \\ \Delta K^*(E[\tau_2], s_K) - \Delta K &= 0\end{aligned}$$

Where the first constraint comes from the maximization of ω_2 by backward induction by the government, and where the τ_2^* is a function of $\overline{\Delta K}$ and s_K . The second constraint represents the amount of investment in capital, taken from the representative firm's profit maximization, given the correct expectation of the level of tax in the second period $E[\tau_2]$ and the level of s_K .

As mentioned above, we assume that the representative firm has correct expectations about the level of tax in the second period. Hence, we can write: $E[\tau_2] = \tau_2$

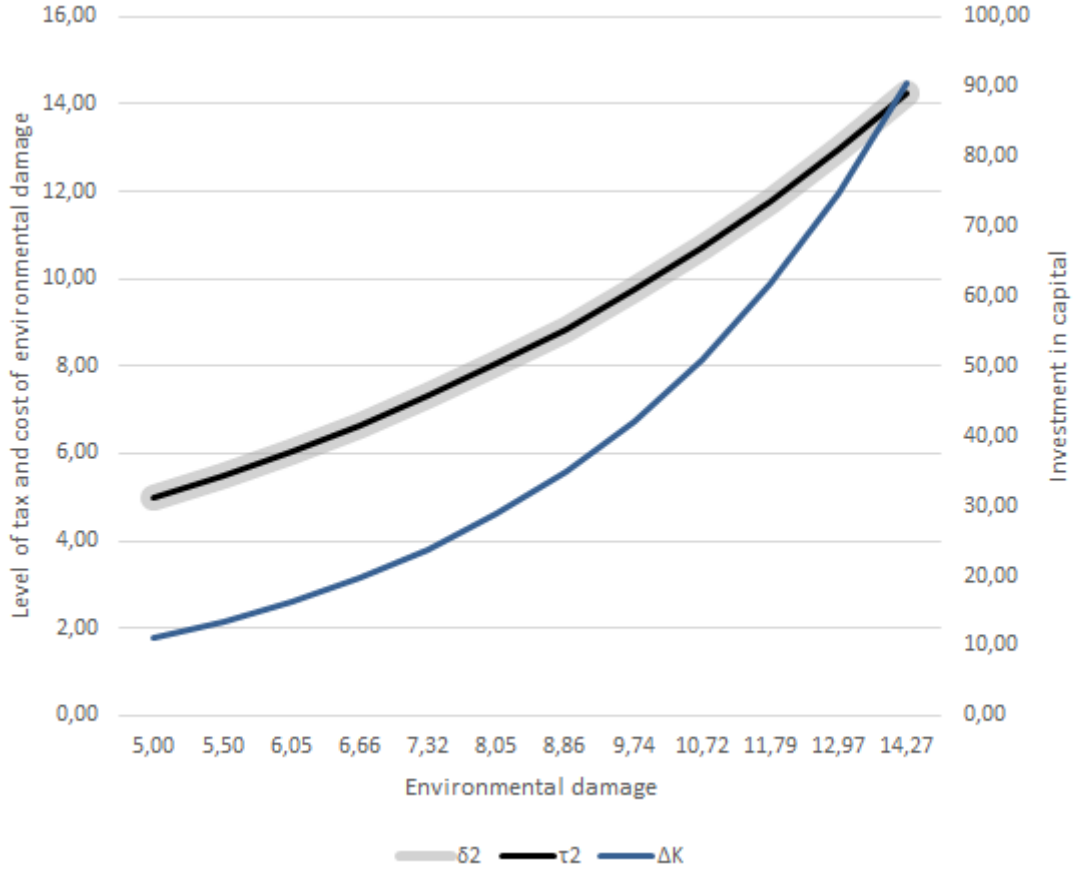
Thus, plugging in 6.17 and 6.18, the two constraints are:

$$\begin{aligned}\frac{\delta_2 \left(\frac{1}{1+c} + \frac{2(1-s_K)}{2a(1-s_K)-1} \right) + \sqrt{\overline{\Delta K}} \frac{2(1-s_K)}{2a(1-s_K)-1}}{\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2}} - \tau_2 &= 0 \\ \left(\frac{\tau_2}{2a(1-s_K)-1} \right)^2 - \Delta K &= 0\end{aligned}$$

The first constraint reflects that the level of τ_2 cannot be chosen freely, but is a function of $\overline{\Delta K}$. The second constraint ensures that the level of ΔK chosen by the firm is optimal, given the correct expectation of the tax level in the second period, $E[\tau_2] = \tau_2$.

In this scenario, firms do not undertake strategic action. We assume that the government anticipates this fact, knowing the profit maximization function of the firms. Because we assume that the representative firm has correct expectations about the level of tax in the second period, and that there are no other market imperfections, the result we obtain is the same as in the commitment case. This can be seen in the figure below.

Figure 14: First-best solution without commitment, no strategic action of the firms



Thus, even though the government cannot commit to a certain level of tax in the second stage, when firms do not undertake strategic action, have correct expectations about the level of tax in the second period and in absence of any other market imperfections, we have (by backward induction) the same result as in the commitment case. In the final chapter, we discuss how the result changes when firms systematically underestimate the level of tax in the future.

6.5.3 First-best solution without commitment, strategic action of the firms

In this scenario, as in the previous section, the government cannot commit to a certain level of tax in the second period in the first stage. Moreover, in this scenario, firms undertake a strategic action. More specifically, firms anticipate that they can influence the level of tax in the second period by choosing a certain level of investment in capital, ΔK . The level of tax

chosen in the second period will thus depend on the level of strategic investment in capital ΔK , which is known in the second period, and which we denote as $\widehat{\Delta K}$, to distinguish it from the previous case.

The problem will again be solved by backward induction. The objective of the government is to maximize the social welfare over the two periods. The government in period 2 maximizes welfare in period 2 with respect to tax in period 2, knowing the level of capital $\widehat{\Delta K}$.

$$\max_{\tau_2} \omega_2 = \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \widehat{\Delta K}) - \delta_2 e_2$$

By inserting x_2^* , y_2^* , $\widehat{\Delta K}$ in the maximization problem (see section A in the appendix), we get that ω_2 is a function of τ_2 , s_K and parameters a , c , M and δ_2 . The functions for x_2^* , y_2^* , $\widehat{\Delta K}$ come from the profit maximization of the firm. As before, x_2^* , y_2^* depend on τ_2 and s_K , which are known in the second period. In the previous case, we had that the level of investment of capital depended on firms' expectations of the level of tax $\Delta K(E[\tau_2])$. However, now the choice of ΔK is strategic. Later in this section, we will present the level of strategic investment $\widehat{\Delta K}$.

From the welfare maximization of the government we obtain the level of tax, which has the same form as in the previous section and is a function of the level of subsidy on capital s_K .

From the first-order condition $\frac{\partial \omega_2}{\partial \tau_2} = 0$:

$$\tau_2^*(\widehat{\Delta K}, s_K) = \frac{\delta_2 \left(\frac{1}{1+c} + \frac{2(1-s_K)}{2a(1-s_K)-1} \right) + \sqrt{\widehat{\Delta K}} \frac{2(1-s_K)}{2a(1-s_K)-1}}{\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2}} \quad (6.19)$$

Now we move on to deriving the choice of $\widehat{\Delta K}$ by the firm.

In the previous section, the representative firm did not choose the level of investment in capital strategically - rather, the firm chose ΔK based on the expectation of what the tax level would be in the second period $E[\tau_2]$. In the present scenario, the firm is strategic, and thus chooses ΔK while keeping in mind that the level of tax can be induced by the level of investment $\widehat{\Delta K}$ as follows:

$$\frac{\partial \tau_2}{\partial \Delta K} = \frac{\frac{2(1-s_K)}{2a(1-s_K)-1}}{2\sqrt{\Delta K} \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)} \geq 0$$

This effect will be incorporated in the profit maximization of the firm. Now, instead of maximizing the profit with respect to the expectation of τ_2 , the representative firm maximizes profit with respect to the level of tax, which is a function of ΔK .

And thus, the profit function of the representative firm looks as follows:

$$\begin{aligned} \max_{x_1, y_1, \Delta K, x_2, y_2} \pi = & p_1 x_1 - c(x_1) - \tau_1 e(x_1, y_1) - (1 - s_y) a(y_1, 0) - (1 - s_K) \Delta K \\ & + p_2 x_2 - c(x_2) - \tau_2(\Delta K) e(x_2, y_2) - a(y_2, \Delta K) \end{aligned}$$

In the previous scenario when firms were not strategic, we had a the following first-order condition:

$$\frac{\partial \pi}{\partial \Delta K} = -(1 - s_K) - a_{\Delta K}(y_2, \Delta K) = 0$$

Now, taking into consideration that τ_2 is strategically influenced by the level of ΔK , we have that the representative firm's first-order condition, with respect to ΔK , has an additional term $\frac{\partial \tau_2}{\partial \Delta K}$, and is equal to:

$$\frac{\partial \pi}{\partial \Delta K} = -(1 - s_K) - a_{\Delta K}(y_2, \Delta K) - \frac{\partial \tau_2}{\partial \Delta K} e(x_2, y_2) = 0$$

From this first-order condition, we find the value of $\Delta K^*(\tau_2, s_K)$, which is different from the function from the previous section. In section D in the appendix we find that:

$$\Delta K^*(\tau_2, s_K) = \left(\frac{\tau_2}{2a(1-s_K)-1} - \frac{\frac{M-\tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}}{(2a(1-s_K)-1) \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)} \right)^2 \quad (6.20)$$

The level of $\Delta K^*(\tau_2, s_K)$ is such that the condition $\frac{\partial \pi}{\partial \Delta K} = 0$ is satisfied.

Back to the welfare maximization of the government. Subsequently, in period 1 the gov-

ernment maximizes the sum of welfare $\omega_1 + \omega_2$, however now, using the optimal tax $\tau_2^*(\widehat{\Delta K}, s_K)$, which is again derived by backward induction.

$$\begin{aligned} \max_{s_y, s_K, \tau_1} \omega_1 + \omega_2 = & \frac{(M - p_1)^2}{2} + p_1 x_1 - c(x_1) - (1 - s_y)a(y_1, 0) - (1 - s_K)\widehat{\Delta K} - \delta_1 e_1 \\ & + \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \Delta K) - \delta_2 e_2 - s_y a(y_1, 0) - s_K \widehat{\Delta K} \end{aligned}$$

Similarly to the previous case, by inserting $x_1^*, y_1^*, x_2^*, y_2^*$ (equations 6.12- 6.15) and $\widehat{\Delta K}$ in the maximization problem, we get that $\omega_1 + \omega_2$ is a function of τ_1, τ_2, s_K, s_y and parameters a, c, M, δ_1 and δ_2 . The functions for $x_1^*, y_1^*, x_2^*, y_2^*$ and $\widehat{\Delta K}$ come from the profit maximization of the firm. From the first-order conditions of welfare maximization, we get the functions of $\tau_1(s_y), s_K(\tau_2^*), s_y(\tau_1)$. With three equations and three unknowns (τ_1, s_y and s_K), it is possible to find the optimal level of τ_1^*, s_K^*, s_y^* that maximize welfare.

In this scenario, it is difficult to predict what would happen just by looking at the theoretical model, because the problem becomes very complex. Firms try to influence the level of tax in the second period by choosing a certain level of capital. However, companies' choice of investment in capital depends on the level of subsidy. The optimal level of tax in the second period depends both on the level of investment in capital by the firms, as well as the level of subsidy on capital chosen by the government in the first period.

Firms anticipate that they can influence the level of taxes in the second period by choosing a certain level of investment in capital ΔK . Specifically, we have that $\frac{\partial \tau_2}{\partial \Delta K} \geq 0$. Thus, we predict that firms will choose to invest little in capital in the first period to ensure that the government sets a low tax in the second period.

Again, we will not solve the model parametrically, because the problem is too complex. Thus, the simulation in Excel will be very insightful. We now move to the numerical simulation of the model. As in the previous section, in the simulation, we do not maximize welfares sequentially. Rather, we program the results from the maximization of ω_2 , which we got by backward induction, and maximize the sum of welfare $\omega_1 + \omega_2$.

Solver maximization

1. Set: $x_1^*, x_2^*, y_1^*, y_2^*$ from the firms profit maximization (A. in appendix).
2. Maximize $\omega_1 + \omega_2$, subject to: $\Delta K, \tau_1, \tau_2, s_y$ and s_K .
3. Subject to constraints:

$$\begin{aligned}\tau_2^*(\widehat{\Delta K}, s_K) - \tau_2 &= 0 \\ \Delta K^*(\tau_2, s_K) - \Delta K &= 0\end{aligned}$$

Thus, the first constraint is the same as in 6.5.2, except for the different level of ΔK chosen by the firms. However, now the ΔK^* will be different than in 6.5.2 because firms anticipate that their choice of ΔK affects $\tau_2(\Delta K)$.

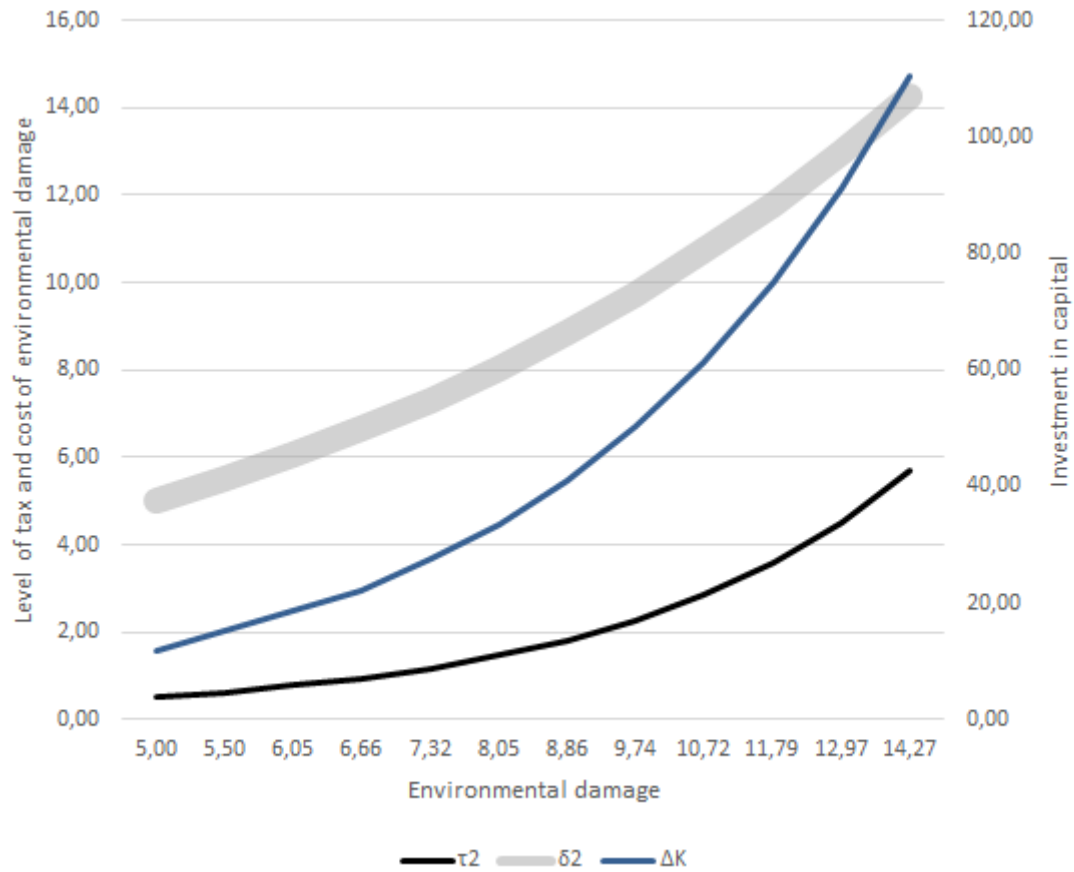
Thus, plugging in 6.19 and 6.20, the two constraints are:

$$\begin{aligned}\frac{\delta_2 \left(\frac{1}{1+c} + \frac{2(1-s_K)}{2a(1-s_K)-1} \right) + \sqrt{\widehat{\Delta K}} \frac{2(1-s_K)}{2a(1-s_K)-1}}{\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2}} - \tau_2 &= 0 \\ \left(\frac{\tau_2}{2a(1-s_K)-1} - \frac{\frac{M-\tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}}{(2a(1-s_K)-1) \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)} \right)^2 - \Delta K &= 0\end{aligned}$$

The first constraint reflects that the level of τ_2 cannot be chosen freely, but is a function of investment in capital in the first period, $\widehat{\Delta K}$. The second constraint ensures that the level of ΔK chosen by the firm in the first period maximizes the profit, thus $\frac{\partial \pi}{\partial \Delta K} = 0$, given the effect that $\widehat{\Delta K}$ has on the tax level in the second period.

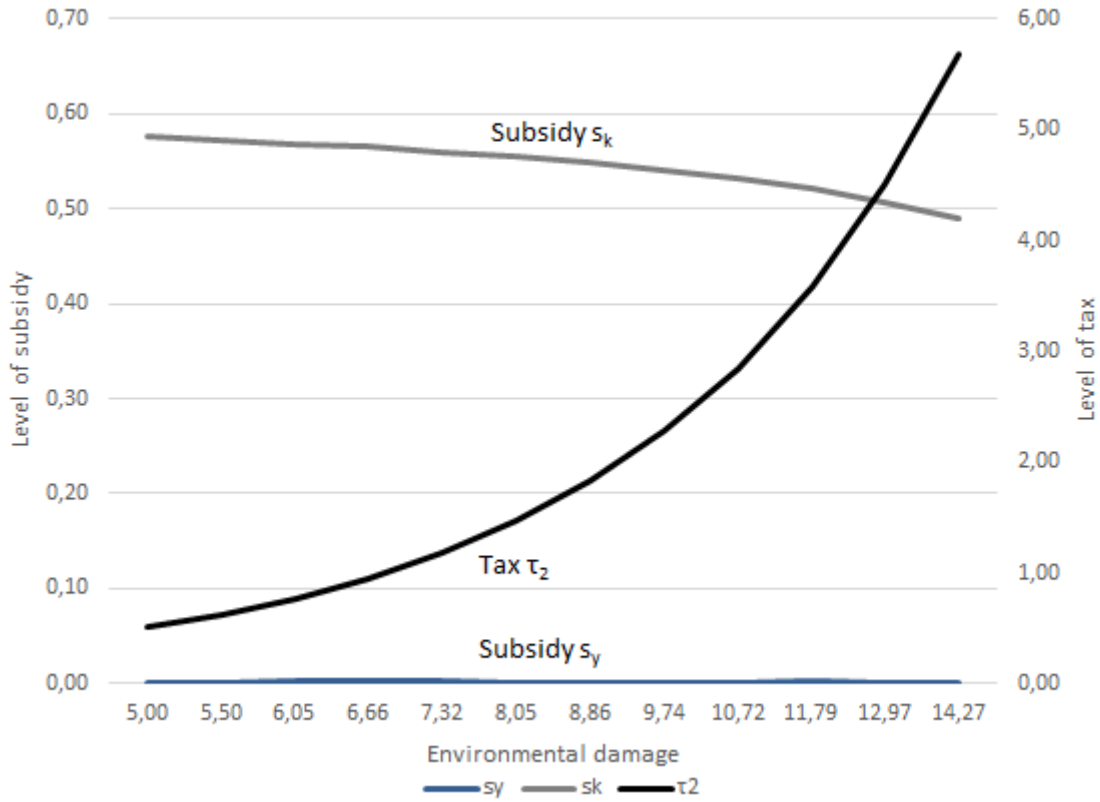
From the solver simulation, we find that the tax set by the government is lower for all the levels of cost of environmental damage than in the previous scenarios, and that it increases with the cost of environmental damage. This can be seen on the graph.

Figure 15: First-best solution without commitment, strategic action of the firms



Additionally, government sets a subsidy on capital. The level of subsidy decreases with the level of tax. This could be explained by the fact that tax and subsidy are substitutes. The higher the tax, the bigger the incentive to invest in capital, thus the lower subsidy is needed. On the contrary, the lower the tax, the lower the incentive to invest in capital, thus, the higher subsidy is needed. This complementary feature of tax and subsidy is represented in the figure 16.

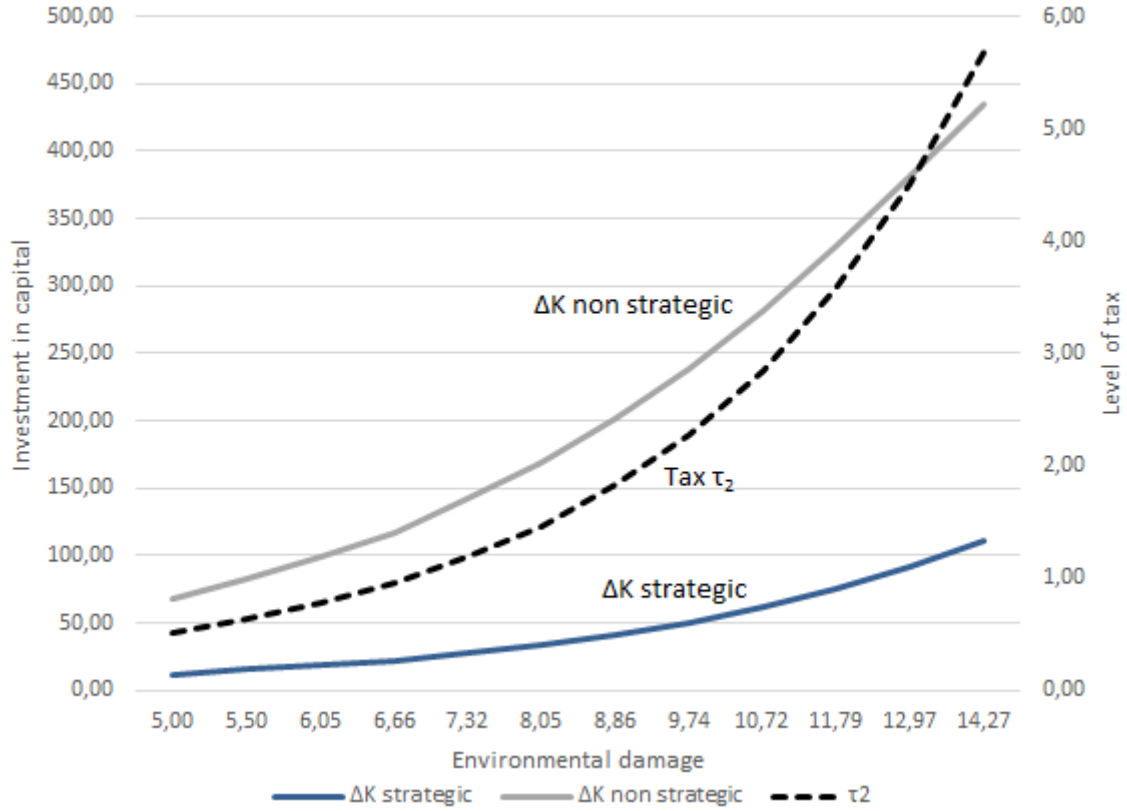
Figure 16: Government's policy as a function of environmental damage



It is difficult to compare the level of capital in the scenario with and without strategic action by firms because the level of tax in the second period is completely different in the two scenarios. Moreover, subsidy on capital is introduced in the second scenario. What we have is that for all the levels of costs of environmental damage, the level of capital is higher in the strategic scenario.

Thus, it is worth comparing the level of investment in capital in scenarios with strategic action to a hypothetical scenario with the same level of tax in the second period and the same level of subsidy and no strategic action. This comparison will prove our hypothesis, that when firms undertake strategic action, they will indeed choose to invest less in capital to induce lower tax in the second period. That is why government introduces subsidy on capital, to counteract an excessive decrease of capital investment (figure 17).

Figure 17: Comparison of ΔK investment for strategic vs. non strategic firm



6.5.4 Second-best solution with commitment with regional policy:

$$x_t \geq \bar{x}_t$$

In this scenario, we assume that there is a regional policy requiring that the demand for freight does not fall below a certain threshold \bar{x}_t . In addition, we assume that the government can commit to the level of tax in the second period. In this case we will have that: $x_1^* \geq \bar{x}_1$ and $x_2^* \geq \bar{x}_2$

Earlier, we showed that:

$$x_1^* = \frac{M - \tau_1}{1 + c}$$

$$x_2^* = \frac{M - \tau_2}{1 + c}$$

So we will have that:

$$\frac{M - \tau_1}{1 + c} = x_1^* = \bar{x}_1 \quad \text{and} \quad \frac{M - \tau_2}{1 + c} = x_2^* = \bar{x}_2$$

And so, the level of tax that the government can implement will have an upper bound such that:

$$\tau_1 \leq \frac{M}{\bar{x}_1(1 + c)} \quad \text{and} \quad \tau_2 \leq \frac{M}{\bar{x}_2(1 + c)}$$

We present a result from the simulation in Excel. The result we get is that whenever the demand x_1^* and x_2^* would have been lower than \bar{x}_1 and \bar{x}_2 , thus not complying with regional policy, the government lowers the taxes to ensure that x_1^* and x_2^* do not fall below \bar{x}_1 and \bar{x}_2 . Additionally, government introduces a subsidy on capital and abatement. However, since the tax on emission is lower, companies choose a level of abatement which is lower than in the case without a regional policy, in which the tax is equal to the cost of environmental damage.

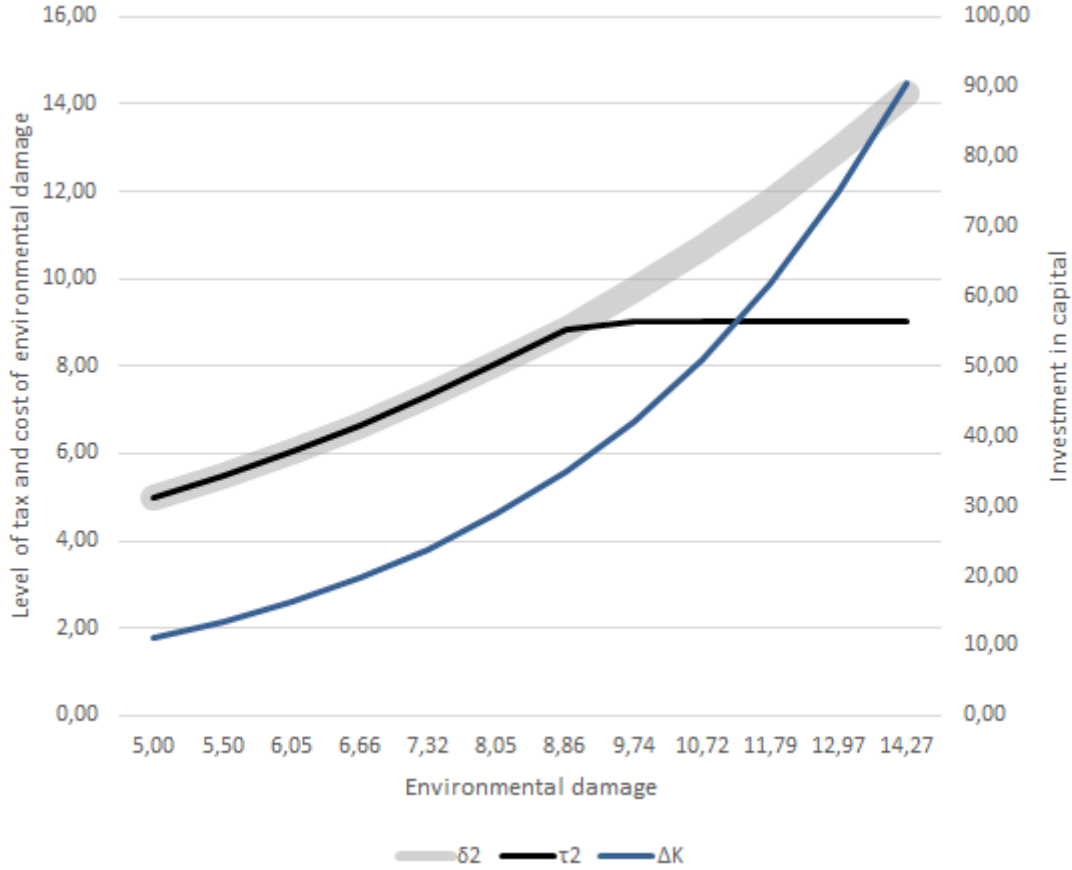
In our simulation, we assume that the regional policy is such that the demands cannot fall below $\bar{x}_1 = 70$ and $\bar{x}_2 = 70$

Solver maximization

1. Set: $x_1^*, x_2^*, y_1^*, y_2^*, \Delta K^*$: from the firms profit maximization (section A in the appendix).
2. Maximize $\omega_1 + \omega_2$, subject to: τ_1, τ_2, s_y and s_K .
3. subject to constraints $x_1^* = 70$ and $x_2^* = 70$

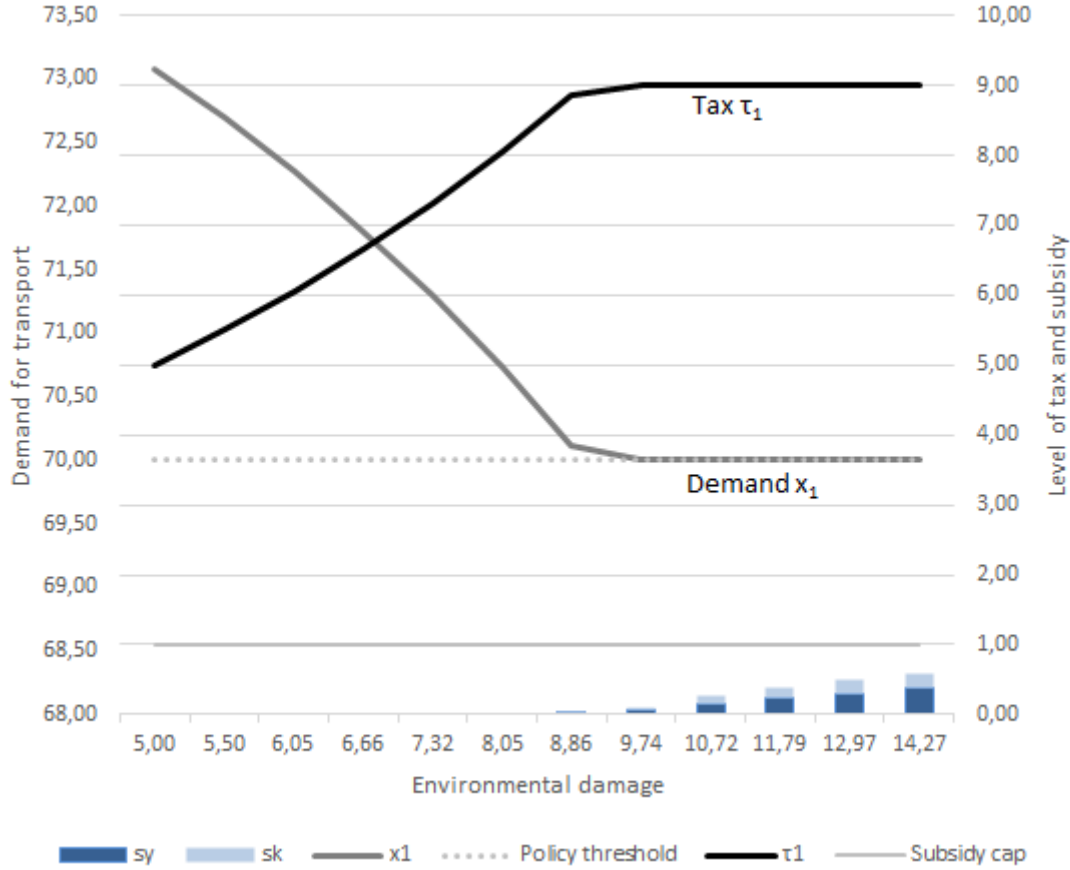
In the commitment case, the level of tax was in line with the level of cost of environmental damage. In this subsection, we find the same result whenever the tax does not exceed the level that induces demand to fall below the threshold set by the regional policy. When the cost of environmental damage exceeds a certain point, the government cannot set a tax equal to the cost of environmental damage because it would result in demand being lower than the regional policy boundary. Thus, whenever demand x_1^* and x_2^* would have been lower than \bar{x}_1 and \bar{x}_2 , thus not complying with regional policy, the government sets lower than optimal tax to ensure that x_1^* and x_2^* do not fall below 1 and 2. This can be seen in figure 18.

Figure 18: Regional policy when $\bar{x}_t = 70$



Moreover, in the simulation we get that the government introduces a subsidy on capital and abatement. Figure 19 represents our finding. On the horizontal axis we have the cost of environmental damage. We see that the level of tax increases with the cost of environmental damage and as a result the demand falls. There is no subsidy. This continues until demand falls to the minimum level dictated by the regional policy, thus $x_1^* = \bar{x}_1 = 70$. After that, the level of tax stays the same to ensure that demand does not fall below the threshold. At the same time, the subsidy on abatement and capital is introduced. The level of abatement and capital increases with the cost of environmental damage. The subsidy is introduced as a substitute of the tax, to incentivize companies to abate and invest in capital despite the fact that it is cheaper to pollute due to relatively lower level of tax.

Figure 19: Regional policy when $\bar{x}_t = 70$



What we expect is that when subsidies are introduced, firms increase the level of abatement and investment in capital. However, in the results we find that even though the government increases the level of subsidy on abatement, the level of abatement remains the same in the first period and decreases in the second period. This is because the effect from the decrease in the tax level is stronger than the effect from the subsidy. It is relatively cheaper to pollute. Thus, increasing the level of subsidy may not necessarily increase the level of abatement if the tax is not sufficiently high.

6.5.5 Second-best solution with subsidy on abatement

In this section we briefly analyze what happens, when the government introduces subsidy on abatement, $s_y > 0$, despite the fact that it is not optimal to do so, as we found in section 6.5.1. We assume that the government can commit to a certain tax level in the second stage. The result we get is that the higher the level of subsidy on abatement, the lower the optimal

tax in the first stage, as tax and subsidy are substitute policies. The subsidy on abatement results in an increased level of abatement y_1 . However, at the same time, lower tax results in increased output x_1 . Hence, two effects are observed: an abatement effect and an output effect. The abatement effect increases the level of abatement due to the higher level of subsidy. The output effect is a result of a decrease in the tax level. The lower the tax, the higher the output, as it is relatively cheaper to pollute. Moreover, a lower level of tax makes abatement less attractive to the firms. Both the abatement effect and output effect impact the level of emissions. Depending on the cost parameters a and c that we choose, we will have that one effect dominates the other. If the output effect is stronger, we will get an increase in emissions. If abatement effect is stronger, emissions will decrease. The result we get is that the higher the level of subsidy, the lower the welfare. Thus, the highest welfare is achieved when $s_y = 0$, which is the first-best solution in section 6.5.1. This confirms our discussion that it is not plausible to subsidize abatement.

6.5.6 Second-best solution with subsidy on capital

In this section we analyze a second-best solution, which is when the government introduces subsidy on capital, thus $s_K > 0$, despite the fact that it is not optimal to do so. We analyze it for a scenario in which the government can commit to a certain tax level in the second stage. The result is that the higher the level of subsidy on capital, the lower the optimal tax in the second stage. The higher the subsidy, the more investment in capital. However, as the tax decreases with the level of subsidy, what we get is that even though the investment in capital increases, the level of abatement in the second period decreases, as it is relatively cheaper to pollute, hence making abatement relatively less attractive. This results in the amount of emissions in the second period being higher, the higher the level of subsidy on capital. However, welfare in the second period increases with the level of s_K , due to the higher profits of the representative firm, because of higher level of optimal output x_2 . At the same time, welfare in the first period decreases with the level of subsidy on capital, because the higher the subsidy, the more investment in capital, which is costly. All in all, the result we get is that the highest welfare over the two periods is achieved when there is no subsidy on capital, which is again represented by the first-best solution in section 6.5.1.

In all the scenarios that we analyzed, the level of abatement in the second period was

higher than in the first period due to the investment in capital undertaken in the first period, which made abatement cheaper in the second period.

In the next section we conclude the main findings of the thesis.

7 Conclusion

In the thesis, we analyzed the optimal environmental policy for the commercial transport sector in Norway, considering the recent discussion about creating a CO_2 fund for the commercial transport sector. The analysis was based on a theoretical model, with two stages, with potential subsidies in place only in the first stage. The result from the numerical simulation indicates that when the government can commit to the level of tax in the future, or when there is no strategic action of the firms in case of government's non-commitment, the subsidy for the commercial transport sector in Norway is not a cost-effective climate policy and that the tax on CO_2 emissions is more desirable. This corresponds to the economic literature. Taxes ensure that polluters bear the cost of environmental damage.

However, as a result of analyzing the model as a two stage game, we found special cases, when introducing subsidy increases social welfare.

We found the same result in case the government cannot commit to the level of tax in the future and firms do not act strategically. Again the optimal level of subsidy on both abatement and capital was equal to 0. However, what we assumed was that the representative firm has correct expectations about the level of tax in the future. In reality, it could be the case that firms systematically underestimate the level of tax in the future and as a result systematically invest less than optimal. Because of low level of investment, the government may be pressured to lower the level of tax in the future. Hence, it could be plausible to introduce a subsidy, when there is an issue of incorrect firms' expectations of the level of tax in the future.

Another case we analyzed was when we assumed that the government was not able to commit to a certain level of tax in the future and firms acted strategically. The result was that the optimal policy involved a subsidy on capital. When companies act strategically, they try to influence the level of tax in the future. In particular, by investing little in capital, they induce a lower optimal level of tax in the future. To counterbalance this effect, the government should introduce subsidy on capital, to incentivize investment in capital.

For the firms to undertake a strategic action, they must anticipate that they can influence the level of tax in the second period, by choosing a certain level of investment in capital ΔK .

Let us discuss whether that is likely. The concentration of the market is relatively low- there are about 9200 firms within the road transport sector. We assume that firms could undertake strategic action, if they coordinated their actions. There exists Norwegian Truck owners' federation¹, which is a politically independent business and employers' organization for truck owners who carry out professional freight in Norway. It represents about 3200 companies, which operate approximately 20 000 trucks and 23 000 employees. Every other year, the federation organizes congress, where decision-making body, representatives of regions and employees partake to discuss interests of the sector. Thus, there exists a platform, which gives an opportunity to discuss the interests of heavy-duty vehicles owners in Norway. Moreover, this coordination could happen without the explicit discussion of strategy. For instance, firms would invest in ΔK less than optimal, when the investment in capital is too costly and when firms coexist in technological lock-in with fossil fuels (see 5.4).

In reality, when companies do not invest in environmentally friendly technologies, it could be the case that in the future the government would face a political pressure of not introducing a too high tax.

Finally, we discussed three scenarios with second best solutions, when government introduces the subsidy. The first scenario analyzed an optimal policy when there is a regional policy, according to which the number of kilometers performed cannot fall below a certain level. In that case there is a cap on the level of the tax. With the government being unable to enforce a certain level of tax, in order to maximize the social welfare, subsidy on capital is introduced. That ensures that companies invest in abatement more, than they would have, has there not been subsidy. The second and third scenario briefly analyzed the effect of introducing subsidy on abatement and capital on the social welfare. In both cases introducing subsidy decreased the social welfare, which proved that the first best solution is when there are no subsidies and the environmental policy is regulated solely by the tax.

Subsequently, we discussed the differences between light-duty and heavy-duty vehicles market. Because of the difference in their characteristics, it seems that it would be optimal to tailor the policy for both sectors. The sector of light-duty vehicles has a great potential to reduce the emissions of CO_2 by switching to electric vehicles. We have showed that the current structure of the tax for the Category 2 vans with green plates does not incentivize investments

¹Norges Lastebileier-Forbund (NLF)

in electric vans. It seems that instead of subsidizing this sector, the most efficient solution would be to increase the registration fee, so that the structure of the tax resembles the one for personal vehicles. In case of heavy-duty vehicles, the alternative zero-emission technologies like hydrogen and electric vehicles are not yet mature. thus, subsidy on capital would speed up the diffusion of alternative technologies. Moreover, introducing subsidy could be desirable whenever government does not want to increase the tax above a certain level due to political pressure from the industry or when too high tax would cause a decrease of output.

Another result of the thesis is that only long term investments should be subsidized. This is because long term investments decrease the marginal cost of abatement, thus making abatement cheaper even after the first stage is over and subsidies are no longer in place. Subsidizing short term investments is costly and does not contribute to the reduction of emissions in the future.

Some limitations of the model:

- We did not assume discounting and we treated both periods as if they were of the same length.
- We use simple quadratic cost function.
- When we fix the level of ΔK , we have that the cost of abatement will increase quadratically. It is possible that the more investment in certain technology there is, the cheaper the technology becomes; hence the average cost of abatement could start to decrease after certain volume is achieved at a certain level of capital.
- We assume that all the investment in capital occurs in the first stage.
- We do not take into consideration that the cost of capital could decrease with development of technology.

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A Appendix

A Representative firm

Calculations:

Firm, profit maximization.

$$\begin{aligned} \max_{x_1, y_1, \Delta K, x_2, y_2} \pi = & p_1 x_1 - c(x_1) - \tau_1 e(x_1, y_1) - (1 - s_y) a(y_1, 0) - (1 - s_K) \Delta K \\ & + p_2 x_2 - c(x_2) - \tau_2 e(x_2, y_2) - a(y_2, \Delta K) \end{aligned}$$

FOC:

$$\frac{\partial \pi}{\partial x_1} = p_1 - c_{x_1}(x_1) - \tau_1 e_{x_1}(x_1, y_1) = 0$$

$$\frac{\partial \pi}{\partial y_1} = -\tau_1 e_{y_1}(x_1, y_1) - (1 - s_y) a_{y_1}(y_1, 0) = 0$$

$$\frac{\partial \pi}{\partial \Delta K} = -(1 - s_K) - a_{\Delta K}(y_2, \Delta K) = 0$$

$$\frac{\partial \pi}{\partial x_2} = p_2 - c_{x_2}(x_2) - \tau_2 e_{x_2}(x_2, y_2) = 0$$

$$\frac{\partial \pi}{\partial y_2} = -\tau_2 e_{y_2}(x_2, y_2) - a_{y_2}(y_2, \Delta K) = 0$$

Set:

$$c_t(x) = \frac{c}{2}x_t^2$$

$$a_t(y, K_t) = \frac{a}{2}y_t^2 - y_t\sqrt{K_t}$$

$$e_t = x_t - y_t$$

Plugging in functional forms to FOC:

$$\frac{\partial \pi}{\partial x_1} = p_1 - cx_1 - \tau_1 = 0 \quad (1)$$

$$\frac{\partial \pi}{\partial y_1} = \tau_1 - (1 - s_y)ay_1 = 0 \quad (2)$$

$$\frac{\partial \pi}{\partial \Delta K} = -(1 - s_K) + \frac{y_2}{2\sqrt{\Delta K}} = 0 \quad (3)$$

$$\frac{\partial \pi}{\partial x_2} = p_2 - cx_2 - \tau_2 = 0 \quad (4)$$

$$\frac{\partial \pi}{\partial y_2} = \tau_2 - (ay_2 - \sqrt{\Delta K}) = 0 \quad (5)$$

From 3 we have:

$$y_2 = 2\sqrt{\Delta K}(1 - s_K)$$

and thus,

$$\Delta K = \left(\frac{y_2}{2(1 - s_K)} \right)^2$$

Combining 3 and 5 we get:

$$\Delta K = \left(\frac{\tau_2}{2a(1 - s_K) - 1} \right)^2$$

We know that $x_t = D(p_t) = M - p_t$, hence $p_t = M - x_t = M - \frac{p_t - \tau_t}{c}$ we get that:

$$p_t = \frac{cM + \tau_t}{1 + c}$$

$$x_1 = \frac{p_1 - \tau_1}{c} = \frac{M - \tau_1}{1 + c}$$

$$x_2 = \frac{p_2 - \tau_2}{c} = \frac{M - \tau_2}{1 + c}$$

$$y_1 = \left(\frac{\tau_1}{1 - s_y} \right) \frac{1}{a}$$

$$\begin{aligned} y_2 &= (\tau_2 + \sqrt{\Delta K}) \frac{1}{a} = \left(\tau_2 + \sqrt{\left(\frac{\tau_2}{2a(1 - s_K) - 1} \right)^2} \right) \frac{1}{a} \\ &= \left(\tau_2 + \frac{\tau_2}{2a(1 - s_K) - 1} \right) \frac{1}{a} = \frac{2(1 - s_K)\tau_2}{2a(1 - s_K) - 1} \end{aligned}$$

B Pre-commitment:

Firm as in A

Government maximizes sum of welfares.

$$\begin{aligned} \max_{s_y, s_k, \tau_1, \tau_2} \omega_1 + \omega_2 &= \frac{(M - p_1)^2}{2} + p_1 x_1 - c(x_1) - a(y_1, 0) - \Delta K - \delta_1 e_1 \\ &\quad + \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \Delta K) - \delta_2 e_2 \end{aligned}$$

By inserting x_1^* , x_2^* , y_1^* , y_2^* and $\overline{\Delta K}$ from A:

$$\begin{aligned}
\max_{s_y, s_K, \tau_1, \tau_2} \omega_1 + \omega_2 = & \frac{\left(\frac{M-\tau_1}{1+c}\right)^2}{2} + \frac{cM + \tau_1}{1+c} \frac{M - \tau_1}{1+c} - \frac{c}{2} \left(\frac{M - \tau_1}{1+c}\right)^2 \\
& - \frac{a}{2} \left(\frac{\tau_1}{1-s_y} \frac{1}{a}\right)^2 - \Delta K - \delta_1 \left(\frac{M - \tau_1}{1+c} - \frac{\tau_1}{1-s_y} \frac{1}{a}\right) \\
& + \frac{\left(\frac{M-\tau_2}{1+c}\right)^2}{2} + \frac{cM + \tau_2}{1+c} \frac{M - \tau_2}{1+c} - \frac{c}{2} \left(\frac{M - \tau_2}{1+c}\right)^2 \\
& - \left(\frac{a}{2} \left(\frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}\right)^2 - \frac{2(1-s_K)\tau_2\sqrt{\Delta K}}{2a(1-s_K)-1}\right) \\
& - \delta_2 \left(\frac{M - \tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}\right)
\end{aligned}$$

C No pre-commitment, no strategic action:

Firm as in A

Government, second stage, $\overline{\Delta K}$ given.

$$\max_{\tau_2} \omega_2 = \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \overline{\Delta K}) - \delta_2 e_2$$

By inserting x_2^*, y_2^* from A:

$$\begin{aligned}
\max_{\tau_2} \omega_2 = & \frac{\left(\frac{M-\tau_2}{1+c}\right)^2}{2} + \frac{cM + \tau_2}{1+c} \frac{M - \tau_2}{1+c} - \frac{c}{2} \left(\frac{M - \tau_2}{1+c}\right)^2 - \left(\frac{a}{2} \left(\frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}\right)^2 - \frac{2(1-s_K)\tau_2\sqrt{\Delta K}}{2a(1-s_K)-1}\right) \\
& - \delta_2 \left(\frac{M - \tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}\right)
\end{aligned}$$

$$\frac{\partial \omega_2}{\partial \tau_2} = -\frac{\tau_2}{1+c} - \tau_2 \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} + \sqrt{\Delta K} \frac{2(1-s_K)}{2a(1-s_K)-1} + \frac{\delta_2}{1+c} + \delta_2 \frac{2(1-s_K)}{2a(1-s_K)-1}$$

$$= -\tau_2 \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right) + \sqrt{\Delta K} \frac{2(1-s_K)}{2a(1-s_K)-1} + \delta_2 \left(\frac{1}{1+c} + \frac{2(1-s_K)}{2a(1-s_K)-1} \right) = 0$$

$$\tau_2 \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right) = \delta_2 \left(\frac{1}{1+c} + \frac{2(1-s_K)}{2a(1-s_K)-1} \right) + \sqrt{\Delta K} \frac{2(1-s_K)}{2a(1-s_K)-1} = 0$$

$$\tau_2^*(\overline{\Delta K}) = \frac{\delta_2 \left(\frac{1}{1+c} + \frac{2(1-s_K)}{2a(1-s_K)-1} \right) + \sqrt{\overline{\Delta K}} \frac{2(1-s_K)}{2a(1-s_K)-1}}{\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2}}$$

Government, first stage, τ_2^* and $\overline{\Delta K} = \Delta K(\tau_2)$ given.

$$\begin{aligned} \max_{s_y, s_K, \tau_1} \omega_1 + \omega_2 &= \frac{(M-p_1)^2}{2} + p_1 x_1 - c(x_1) - (1-s_y)a(y_1, 0) - (1-s_K)\Delta K - \delta_1 e_1 \\ &+ \frac{(M-p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \Delta K) - \delta_2 e_2 - s_y a(y_1, 0) - s_K \Delta K \end{aligned}$$

By inserting $x_1^*, x_2^*, y_1^*, y_2^*$ from A and $\overline{\Delta K}$:

$$\begin{aligned} \max_{s_y, s_K, \tau_1} \omega_1 + \omega_2 &= \frac{\left(\frac{M-\tau_1}{1+c}\right)^2}{2} + \frac{cM + \tau_1}{1+c} \frac{M - \tau_1}{1+c} - \frac{c}{2} \left(\frac{M - \tau_1}{1+c} \right)^2 \\ &- \frac{a}{2} \left(\frac{\tau_1}{1-s_y} \frac{1}{a} \right)^2 - \overline{\Delta K} - \delta_1 \left(\frac{M - \tau_1}{1+c} - \frac{\tau_1}{1-s_y} \frac{1}{a} \right) \\ &+ \frac{\left(\frac{M-\tau_2^*}{1+c}\right)^2}{2} + \frac{cM + \tau_2^*}{1+c} \frac{M - \tau_2^*}{1+c} - \frac{c}{2} \left(\frac{M - \tau_2^*}{1+c} \right)^2 \\ &- \left(\frac{a}{2} \left(\frac{2(1-s_K)\tau_2^*}{2a(1-s_K)-1} \right)^2 - \frac{2(1-s_K)\tau_2^* \sqrt{\overline{\Delta K}}}{2a(1-s_K)-1} \right) \\ &- \delta_2 \left(\frac{M - \tau_2^*}{1+c} - \frac{2(1-s_K)\tau_2^*}{2a(1-s_K)-1} \right) \end{aligned}$$

Solver maximization

$$\begin{aligned}
\max_{s_y, s_K, \tau_1, \tau_2} \omega_1 + \omega_2 = & \frac{\left(\frac{M-\tau_1}{1+c}\right)^2}{2} + \frac{cM + \tau_1}{1+c} \frac{M - \tau_1}{1+c} - \frac{c}{2} \left(\frac{M - \tau_1}{1+c}\right)^2 \\
& - \frac{a}{2} \left(\frac{\tau_1}{1-s_y} \frac{1}{a}\right)^2 - \overline{\Delta K} - \delta_1 \left(\frac{M - \tau_1}{1+c} - \frac{\tau_1}{1-s_y} \frac{1}{a}\right) \\
& + \frac{\left(\frac{M-\tau_2}{1+c}\right)^2}{2} + \frac{cM + \tau_2}{1+c} \frac{M - \tau_2}{1+c} - \frac{c}{2} \left(\frac{M - \tau_2}{1+c}\right)^2 \\
& - \left(\frac{a}{2} \left(\frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}\right)^2 - \frac{2(1-s_K)\tau_2\sqrt{\overline{\Delta K}}}{2a(1-s_K)-1}\right) \\
& - \delta_2 \left(\frac{M - \tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}\right)
\end{aligned}$$

Two constraints:

$$\tau_2^*(\overline{\Delta K}, s_K) - \tau_2 = 0$$

$$\Delta K^*(E[\tau_2], s_K) - \Delta K = 0$$

We assume $E[\tau_2] = \tau_2$. Plugging in, we get:

$$\frac{\delta_2 \left(\frac{1}{1+c} + \frac{2(1-s_K)}{2a(1-s_K)-1}\right) + \sqrt{\overline{\Delta K}} \frac{2(1-s_K)}{2a(1-s_K)-1}}{\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2}} - \tau_2 = 0$$

$$\left(\frac{\tau_2}{2a(1-s_K)-1}\right)^2 - \Delta K = 0$$

D No pre-commitment, strategic action:

Firm, profit maximization with $\tau_2(\Delta K)$.

$$\begin{aligned}
\max_{x_1, y_1, \Delta K, x_2, y_2} \pi = & p_1 x_1 - c(x_1) - \tau_1 e(x_1, y_1) - (1-s_y)a(y_1, 0) - (1-s_K)\Delta K \\
& + p_2 x_2 - c(x_2) - \tau_2(\Delta K)e(x_2, y_2) - a(y_2, \Delta K)
\end{aligned}$$

$$\begin{aligned}
\frac{\partial \pi}{\partial \Delta K} &= -(1 - s_K) - a_{\Delta K}(y_2, \Delta K) - \frac{\partial \tau_2}{\partial \Delta K}(x_2 - y_2) \\
&= -(1 - s_K) + \frac{y_2}{2\sqrt{\Delta K}} - \frac{\frac{2(1-s_K)}{2a(1-s_K)-1}}{2\sqrt{\Delta K} \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)} (x_2 - y_2) = 0
\end{aligned}$$

As in A

$$\begin{aligned}
x_2^* &= \frac{p_2 - \tau_2}{c} = \frac{M - \tau_2}{1 + c} \\
y_2^* &= \frac{2(1 - s_K)\tau_2}{2a(1 - s_K) - 1}
\end{aligned}$$

Plugging in x_2^* , y_2^* and $\frac{\partial \tau_2}{\partial \Delta K}$:

$$-(1 - s_K) + \frac{\frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}}{2\sqrt{\Delta K}} - \frac{\frac{2(1-s_K)}{2a(1-s_K)-1}}{2\sqrt{\Delta K} \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)} \left(\frac{M - \tau_2}{1 + c} - \frac{2(1 - s_K)\tau_2}{2a(1 - s_K) - 1} \right) = 0$$

$$-(1 - s_K) + \frac{\frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}}{2\sqrt{\Delta K}} - \frac{2(1 - s_K) \left(\frac{M - \tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1} \right)}{2(2a(1 - s_K) - 1)\sqrt{\Delta K} \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)} = 0$$

$$-(1 - s_K)\sqrt{\Delta K} + \frac{(1 - s_K)\tau_2}{2a(1 - s_K) - 1} - \frac{(1 - s_K) \left(\frac{M - \tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1} \right)}{(2a(1 - s_K) - 1) \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)} = 0$$

$$\sqrt{\Delta K} = \frac{\tau_2}{2a(1 - s_K) - 1} - \frac{\frac{M - \tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}}{(2a(1 - s_K) - 1) \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)}$$

$$\Delta K^*(\tau_2, s_K) = \left(\frac{\tau_2}{2a(1 - s_K) - 1} - \frac{\frac{M - \tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}}{(2a(1 - s_K) - 1) \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)} \right)^2$$

As in section C

Government, second stage, $\widehat{\Delta K}$ given.

$$\max_{\tau_2} \omega_2 = \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \widehat{\Delta K}) - \delta_2 e_2$$

By inserting x_2^*, y_2^* from A:

$$\begin{aligned} \max_{\tau_2} \omega_2 &= \frac{\left(\frac{M - \tau_2}{1 + c}\right)^2}{2} + \frac{cM + \tau_2}{1 + c} \frac{M - \tau_2}{1 + c} - \frac{c}{2} \left(\frac{M - \tau_2}{1 + c}\right)^2 - \left(\frac{a}{2} \left(\frac{2(1 - s_K)\tau_2}{2a(1 - s_K) - 1}\right)^2 - \frac{2(1 - s_K)\tau_2 \sqrt{\widehat{\Delta K}}}{2a(1 - s_K) - 1}\right) \\ &\quad - \delta_2 \left(\frac{M - \tau_2}{1 + c} - \frac{2(1 - s_K)\tau_2}{2a(1 - s_K) - 1}\right) \end{aligned}$$

$$\begin{aligned} \frac{\partial \omega_2}{\partial \tau_2} &= -\frac{\tau_2}{1 + c} - \tau_2 \frac{a(2(1 - s_K))^2}{(2a(1 - s_K) - 1)^2} + \sqrt{\widehat{\Delta K}} \frac{2(1 - s_K)}{2a(1 - s_K) - 1} + \frac{\delta_2}{1 + c} + \delta_2 \frac{2(1 - s_K)}{2a(1 - s_K) - 1} \\ &= -\tau_2 \left(\frac{1}{1 + c} + \frac{a(2(1 - s_K))^2}{(2a(1 - s_K) - 1)^2}\right) + \sqrt{\widehat{\Delta K}} \frac{2(1 - s_K)}{2a(1 - s_K) - 1} + \delta_2 \left(\frac{1}{1 + c} + \frac{2(1 - s_K)}{2a(1 - s_K) - 1}\right) = 0 \end{aligned}$$

$$\tau_2 \left(\frac{1}{1 + c} + \frac{a(2(1 - s_K))^2}{(2a(1 - s_K) - 1)^2}\right) = \delta_2 \left(\frac{1}{1 + c} + \frac{2(1 - s_K)}{2a(1 - s_K) - 1}\right) + \sqrt{\widehat{\Delta K}} \frac{2(1 - s_K)}{2a(1 - s_K) - 1} 0$$

$$\tau_2^*(\widehat{\Delta K}) = \frac{\delta_2 \left(\frac{1}{1 + c} + \frac{2(1 - s_K)}{2a(1 - s_K) - 1}\right) + \sqrt{\widehat{\Delta K}} \frac{2(1 - s_K)}{2a(1 - s_K) - 1}}{\frac{1}{1 + c} + \frac{a(2(1 - s_K))^2}{(2a(1 - s_K) - 1)^2}}$$

Derivative:

$$\frac{\partial \tau_2^*}{\partial \widehat{\Delta K}} = \frac{\frac{2(1 - s_K)}{2a(1 - s_K) - 1}}{2\sqrt{\widehat{\Delta K}} \left(\frac{1}{1 + c} + \frac{a(2(1 - s_K))^2}{(2a(1 - s_K) - 1)^2}\right)} \geq 0$$

Government, first stage, τ_2^* and $\widehat{\Delta K} = \Delta K(\tau_2, s_K)$ given.

$$\begin{aligned} \max_{s_y, s_K, \tau_1} \omega_1 + \omega_2 &= \frac{(M - p_1)^2}{2} + p_1 x_1 - c(x_1) - (1 - s_y)a(y_1, 0) - (1 - s_K)\widehat{\Delta K} - \delta_1 e_1 \\ &\quad + \frac{(M - p_2)^2}{2} + p_2 x_2 - c(x_2) - a(y_2, \widehat{\Delta K}) - \delta_2 e_2 - s_y a(y_1, 0) - s_K \widehat{\Delta K} \end{aligned}$$

By inserting $x_1^*, x_2^*, y_1^*, y_2^*$ from A and $\widehat{\Delta K}$:

$$\begin{aligned} \max_{s_y, s_K, \tau_1} \omega_1 + \omega_2 &= \frac{\left(\frac{M - \tau_1}{1 + c}\right)^2}{2} + \frac{cM + \tau_1}{1 + c} \frac{M - \tau_1}{1 + c} - \frac{c}{2} \left(\frac{M - \tau_1}{1 + c}\right)^2 \\ &\quad - \frac{a}{2} \left(\frac{\tau_1}{1 - s_y} \frac{1}{a}\right)^2 - \widehat{\Delta K} - \delta_1 \left(\frac{M - \tau_1}{1 + c} - \frac{\tau_1}{1 - s_y} \frac{1}{a}\right) \\ &\quad + \frac{\left(\frac{M - \tau_2^*}{1 + c}\right)^2}{2} + \frac{cM + \tau_2^*}{1 + c} \frac{M - \tau_2^*}{1 + c} - \frac{c}{2} \left(\frac{M - \tau_2^*}{1 + c}\right)^2 \\ &\quad - \left(\frac{a}{2} \left(\frac{2(1 - s_K)\tau_2^*}{2a(1 - s_K) - 1}\right)^2 - \frac{2(1 - s_K)\tau_2^* \sqrt{\widehat{\Delta K}}}{2a(1 - s_K) - 1}\right) \\ &\quad - \delta_2 \left(\frac{M - \tau_2^*}{1 + c} - \frac{2(1 - s_K)\tau_2^*}{2a(1 - s_K) - 1}\right) \end{aligned}$$

Solver maximization

$$\begin{aligned} \max_{s_y, s_K, \tau_1, \tau_2} \omega_1 + \omega_2 &= \frac{\left(\frac{M - \tau_1}{1 + c}\right)^2}{2} + \frac{cM + \tau_1}{1 + c} \frac{M - \tau_1}{1 + c} - \frac{c}{2} \left(\frac{M - \tau_1}{1 + c}\right)^2 \\ &\quad - \frac{a}{2} \left(\frac{\tau_1}{1 - s_y} \frac{1}{a}\right)^2 - \widehat{\Delta K} - \delta_1 \left(\frac{M - \tau_1}{1 + c} - \frac{\tau_1}{1 - s_y} \frac{1}{a}\right) \\ &\quad + \frac{\left(\frac{M - \tau_2}{1 + c}\right)^2}{2} + \frac{cM + \tau_2}{1 + c} \frac{M - \tau_2}{1 + c} - \frac{c}{2} \left(\frac{M - \tau_2}{1 + c}\right)^2 \\ &\quad - \left(\frac{a}{2} \left(\frac{2(1 - s_K)\tau_2}{2a(1 - s_K) - 1}\right)^2 - \frac{2(1 - s_K)\tau_2 \sqrt{\widehat{\Delta K}}}{2a(1 - s_K) - 1}\right) \\ &\quad - \delta_2 \left(\frac{M - \tau_2}{1 + c} - \frac{2(1 - s_K)\tau_2}{2a(1 - s_K) - 1}\right) \end{aligned}$$

Subject to two constraints:

$$\tau_2^*(\widehat{\Delta K}, s_K) - \tau_2 = 0$$

$$\Delta K^*(\tau_2, s_K) - \Delta K = 0$$

Where the second constraint ensures that firms maximize the profits with respect to the level of capital: $\frac{\partial \pi}{\partial \Delta K} = 0$

Plugging in:

$$\frac{\delta_2 \left(\frac{1}{1+c} + \frac{2(1-s_K)}{2a(1-s_K)-1} \right) + \sqrt{\Delta K} \frac{2(1-s_K)}{2a(1-s_K)-1}}{\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2}} - \tau_2 = 0$$

$$\left(\frac{\tau_2}{2a(1-s_K)-1} - \frac{\frac{M-\tau_2}{1+c} - \frac{2(1-s_K)\tau_2}{2a(1-s_K)-1}}{(2a(1-s_K)-1) \left(\frac{1}{1+c} + \frac{a(2(1-s_K))^2}{(2a(1-s_K)-1)^2} \right)} \right)^2 - \Delta K = 0$$

Table 2: Taxes on vehicles in 2017

REGISTRATION TAX (Engangsavgift)	
<i>Private cars, Category 1 vans, tax category a</i>	
Weight of the vehicle	
first 350 kg (150 kg in 2016)	0
next 850 kg (1000 kg in 2016)	26,51
next 200 kg (250 kg in 2016)	66,05
next 100 kg	206,41
the rest	240,06
NOX-emissions, kr per mg/km	70,93
CO2-emissions, kr per g/km	
first 75 g/km (95 g/km i 2016)	0
next 25 g/km (15 g/km i 2016)	914,7
next 30 g/km	995,49
next 70 g/km	2685,98
the rest	3449,8
deduction for emission under 75 g/km (95 g/km in 2016)	937,2
deduction for emission under 40 g/km	1102,65
<i>Category 2 van, tax category b</i>	
Weight of the vehicle, percentage of tax on private cars	20
NOX-emission, percentage of tax on private cars	75
CO2-emission, percentage of tax on private cars	varies
ANNUAL MOTOR VEHICLE TAX , kr/year (Årsavgift, kr/år)	
Petrol cars and diesel cars with factory-fitted particle filter	2820
Diesel cars without factory-fitted particle filter	3290
Electric cars	455
ANNUAL WEIGHT-BASED MOTOR VEHICLE TAX (for over 7500kg) (Vektårsavgift, kr/år)	
	varies
RE-REGISTRATION FEE (Omregistreringsavgift)	
	varies
ROAD TAX ON FUEL (Veibruksavgift på drivstoff)	
Petrol, kr/liter	5,19
Autodiesel, kr/liter	3,8
Bioethanol covered by turnover requirement, kr/liter	5,19
Biodiesel covered by turnover requirement, kr/liter	3,8
Natural gas, kr/Sm3	0
LPG, kr/kg	1,43
Fee on electrical power, øre/kWh	
General rate	16,32
Reduced rate	0,48
CO2-FEE	
Mineral oil general rate, kr/liter	1,2
Mineral oil added road tax, kr/liter	1,2
Autodiesel, kr/liter	1,2
Petrol, kr/liter	1,04
Natural gas, kr/Sm3	0,9
LPG, kr/kg	1,35
Reduced rate for natural gas, kr/Sm3	0,057