

Evaluation of Bonus-Malus systems for reducing car fleet CO2 emissions in Sweden

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CTS Working Paper 2015:6

Abstract

Early 2014, an official Swedish government investigation report (FFFreport) was released proposing a policy package to promote a Fossil Free Fleet in Sweden by 2050. One objective of this policy package is to design a Bonus-Malus system that pushes the Swedish fleet composition towards the EU objectives of the average CO2 emissions of 95 g/km for new cars by 2021. The proposed scenarios address cars bought by private persons as well as by companies. These scenarios differ in designs for registration tax, vehicle circulation tax, clean car premiums, company car benefits tax and fuel tax. We use the Swedish car fleet model system to predict the effects of the proposed scenarios on the Swedish car fleet composition. Also, we build a simple supply model to predict future supply.

Our model results show that none of the three proposed scenarios is actually successful enough to meet the Swedish average CO2 emissions target of 95 g/km in 2020. The average CO2 emissions in two of these scenarios are actually higher than in the business as usual scenario. Relative to a business as usual scenario the number of ethanol and gas cars is reduced in the other scenarios which is a negative result in terms of fossil fuel independence. Also, the Bonus-Malus system gives a positive net result in terms of budget effects showing that car buyers choose to pay the malus for a car with higher emissions rather than to be attracted by the bonus of a car with lower emissions.

Keywords: Bonus-Malus, CO2 emission policies, car fleet modeling, vehicle supply model

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1 Introduction

The composition of the car fleet determines the energy consumption from car traffic, the oil dependency and the emissions. The Swedish car fleet has since long been dominated by large and highly fuel consuming cars compared to the rest of Europe, and in 2013, the Swedish Government initiated an official investigation to propose which measures should be used to

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bring about a fossil independent vehicle¹fleet by 2030 and a fossil free vehicle fleet by 2050. For the transport sector in Sweden, this vision means that the CO_2 emissions should decrease from more than 20 million tons per year to zero in less than 40 years. The EU has decided on a directive that the average CO_2 emission of new cars should not exceed 130 g/km by 2015 and 95 g/km by 2021². Such radical reduction of emissions of the transport sector, in such a short time perspective, puts a lot of pressure on decision support, planning and political resolution. The adaptation will affect all transport system users and all transport modes and will require important changes in conditions and policies for the transport sector.

The investigation report was released early 2014 and we will refer to it as the FFF-report (Näringsdepartementet, 2013). In the FFF-report, different scenarios are proposed to reach the target of Sweden being fossil fuel independent by 2030. These scenarios combine policies affecting purchase, usage but also assumptions on technology development. The proposed policies address cars bought by private persons as well as by companies and public organizations. In this official report, a CO_2 differentiated Bonus-Malus system is proposed, along with a number of other measures. This system is designed to give a premium (bonus) to car buyers that purchase a car with low CO_2 emissions and to punish (malus) those who buys a car with high CO_2 emissions. A CO_2 emission null-point" is set, where the buyer neither gets a bonus nor a malus. This CO_2 emission null point is supposed to drop over time to push car buyers to buy cars with lower and lower CO_2 emissions. A Bonus-Malus system has already been introduced in France 2008 (WSP, 2013). Potential effects of the different scenarios are estimated in the FFF-report, but are not supported by explicitly modeling the car fleet impact.

In this paper, we will use the Swedish car fleet model system³ as an evaluation tool to predict the effects on the Swedish car fleet composition as an effect of the proposed scenarios. The possibility to predict how different policies will affect the car purchase, the scrapping rates and the usage of the cars, is then of great importance (see e.g. Goldberg, 2003; Ewing and Sarigöllü, 1998; Potoglou and Kanaroglou, 2007; Mabit and Fosgerau, 2011; Mabit, 2014). The Swedish car fleet model system consists of three sub models; a car ownership model, a scrapping model and a model for purchase of new cars. This tool has been used in several policy evaluations (Hugosson et al., 2014) and is continuously updated and further developed. Our model results show that none of the three scenarios proposed in the FFF-report is actually successful enough to meet the Swedish target of average CO_2 emissions of 95 g/km in 2020. The average CO_2 emissions in two of the scenarios are actually higher than the business as usual scenario.

In section 2 of this paper we give an overview of the policy package proposed in the official report initiated by the Swedish Government to bring about a fossil independent vehicle fleet by 2030. Further policy details can be found in appendix A. In section 3 we briefly describe the evaluation tool, the Swedish car fleet model system, used to evaluate the policy packages. We also lay out the settings for handling input data, such as car supply and policies, in the model system. Results are shown in section 4 followed by a discussion and finally conclusions are made in section 5.

¹In this paper we use vehicle and car interchangeably and by both words we mean personal cars.

²The original target year was 2020 but it was changed to 2021 in the negotiation phase. In this paper, the year 2020 is maintained since it is used in the FFF report.

³For extensive review of such models (see e.g. Potoglou and Kanaroglou, 2008; Anowar et al., 2014)

2 FFF scenarios

2.1 Policy description

Early 2014, an official Swedish government investigation report was released proposing a policy package to promote a Fossil Free Fleet (the FFF investigation) in Sweden by 2050. One objective of this policy package is to design a Bonus-Malus system that pushes the Swedish fleet composition towards the EU objectives of CO_2 emissions for new cars which is on the average 130 g/km by 2015 and 95 g/km by 2021. The system is designed to reward (bonus) car buyers who choose to purchase a car with lower CO_2 emissions and penalize (malus) buyers who choose a car with higher CO_2 emissions. The idea is that the system would pay for itself and not rely on public funding. In such a system those who choose to buy a car with higher CO_2 emissions subsidize the purchase of those who choose a car with lower CO_2 emissions. In the FFF policy package different scenarios are proposed. These scenarios differ in setting of a CO_2 emission null point for different segments as well as designs and combinations for registration tax, vehicle circulation tax⁴, clean car premiums and company car benefit tax⁵. These policies are described as follows:

- (A) Business as usual.
- (B) CO₂ differentiated Bonus-Malus system of registration tax and environmental premium.
- (C) CO_2 and weight differentiated Bonus-Malus system of registration tax and environmental premium.
- (D) CO_2 and weight differentiated vehicle circulation and benefit tax and super green car premium.

Table 1 summarizes the FFF scenarios. A detailed description of scenarios can be found in appendix A.

⁴The yearly tax that is paid for CO_2 emission. For the detailed definition refer to appendix A

⁵The benefit value of having a car for private use provided by the employer is taxed as income. For the detailed definition refer to appendix A

Scenario	Registration tax (Bonus-Malus)	Vehicle circulation tax	Environmental premium	Benefit tax for company cars	Super clean cars premium ^[3]	5-year tax exemption for clean cars ^[4]
Α	-	emission based tax	-	reduction of benefit tax until 2016 for AFV ^[1]	until 2015	yes
В	Bonus Malus with fixed CO_2 null point	 for diesel cars, it decreases over the period for the rest it is equal and fixed over the period 	15,000-30,000 SEK ^[2] for AFV emitting less than a limit	 increase in taxable benefit value reduction of bene- fit tax until 2018 for AFV 	-	_
С	Bonus Malus with weight differentiated CO_2 null points	 for diesel cars, it decreases over the period for the rest, it is equal and fixed over the period 	15,000-30,000 SEK for AFV emitting less than a limit	 increase in taxable benefit value reduction of bene- fit tax until 2018 for AFV 	-	-
D	-	weight differentiated emission based tax	-	 weight differenti- ated emission based benefit tax reduction of bene- fit tax for AFV 	higher than today	-

Table 1: Summary of FFF package

¹ Alternative fuel vehicles

² Swedish crowns which is equal to 0.11 Euros on 6th of October 2014.

^{3,4} for the definition of clean cars and super clean cars refer to appendix A

Table 2 shows examples of economic impacts of different scenarios in 2015. It includes different cars operating on different fuels to show how different policies differ in terms of taxes and premiums. In this table bonus is shown as positive and malus is shown as negative. As an example Volkswagen TSI 105 running on petrol is an example of a car that gets a bonus in scenario B since its CO_2 emission level is lower than the allowable limit of 120 g/km in year 2015 but gets a malus in scenario C since the emission level for its weight is 106 g/km in this scenario. It also shows that it is not subject to tax in scenario A since it emits less than allowable level of emission for taxation i.e. 117 g/km, but the taxation of 1,500 SEK is fixed in scenario B and C. This car is subject to even higher tax in scenario D i.e. 1,692 SEK where the allowable emission level is 87 g/km. This example also shows how allowable levels of CO_2 emission different taxes in different scenarios.

Toyota Auris 1,4 D-4D running on diesel and Volkswagen Golf TSI 122 running on E85 are two other examples of small cars subject to bonus in scenario B and to malus in scenario C. Volvo V70 AFV Bi-Fuel is an example of a car running on gas and considered as a clean car. Therefore it is exempted from vehicle circulation tax in scenario A and is subject to the lowest amount of vehicle circulation tax in scenario D i.e. 360 SEK but gets a malus in both scenarios B and C. Moreover, in these scenarios it is subject to a 1,500 SEK vehicle circulation tax as all other non-diesel cars while getting 15,000 SEK premium at the same time. The trend for all clean cars is that they are subject to minimum tax in scenarios A and D which is less than 1,500 SEK or 2,760 SEK for non-diesel and diesel cars respectively. In all cases the value of benefit taxes in scenarios B and C are higher than in scenarios A and D.

Make/		~ ~	~ .	Bonus-Malus	Vehicle	Environmental	Benefit	Super	5-year tax
model/	Weight	CO_2	Scenario	effect	circulation	premium	tax	clean cars	exemption for
Tuel-type	(Kg)	(g/km)		0	tax	•	17500	premium	clean cars
VW Golf	1205	114	A	0	360	-	17532	0	no
TSI 105			В	2 400	1 500	0	23044	-	-
Petrol			С	-3 376	1 500	0	23548	-	-
			D	0	1 692	-	17853	0	-
Toyota Auris	1270	109	А	0	1 089	-	18098	0	yes
1,4 D-4D			В	4 400	1 500	0	24175	-	-
Diesel			С	-188	1 500	0	23738	-	-
			D	0	2 599	-	18663	0	-
Volvo V70	1760	157	А	0	760	-	16262	0	yes
AFV Bi-Fuel			В	-14 800	1 500	15000	26561	-	-
Gas			С	-10 431	1 500	15000	26124	-	-
			D	0	360	-	23597	0	-
VW Passat	1598	117	А	0	360	-	13742	0	yes
TSI 150			В	1 200	1 500	15000	21286	-	-
Gas			С	2 608	1 500	15000	21162	-	-
			D	0	360	-	19550	0	-
VW Golf	1279	119	А	0	360	-	18461	0	yes
TSI 122			В	400	1 500	15000	23358	-	-
E85			С	-4 024	1 500	15000	23738	-	-
			D	0	360	-	16793	0	-
Volvo V60	2058	48	А	0	360	0	19431	0	yes
D6 2.4 TD			В	28 800	1 500	15000	29574	-	-
Plug_in petrol			С	38 616	1 500	15000	28510	-	-
			D	0	360	-	16193	50 000	-
Toyota Prius	1495	89	А	0	360	-	19985	0	no
Prius			В	12 400	1 500	0	26062	-	-
Electric hybrid			С	11 925	1 500	0	26062	-	-
			D	0	360	-	18561	0	-
Citroen	1195	0	А	0	360	-	8136	0	yes
C-Zero			В	48 000	1 500	15000	7286	-	-
Electric			С	42 041	1 500	15000	7599	-	-
			D	0	360	-	4068	70 000	-

Table 2: Example of economic impacts of different scenarios in 2015

The following figures show how the scenario policies for 2015 will affect average purchase prices including Bonus-Malus and premiums, and average tax costs for the whole car supply, where the car supply has been divided into seven CO_2 ranges. The policies are compared by each component, as in figure 1. In figure 1a, it can be seen that the policies mainly differ in the tails of the price curves. Low emission cars are subsidized in scenarios B, C and D, and high emission cars are penalized in scenario B and C. But most car alternatives are in between, and the price differences are small there. In figure 1b, scenario A shows the lowest CO_2 sensitivity regarding the benefit tax. Scenarios B and C (scenario C is overlapping scenario B) show higher benefit tax values compared to scenario D. In figure 1c, vehicle circulation taxes are shown. Scenarios B and C (scenario C again overlapping scenario B) are quite neutral, scenario A is penalizing cars with CO_2 over 120 g/km, and scenario D has the most CO_2 sensitive profile. Table B1 in appendix B will show the scenario specific average prices and taxes for different CO_2 emission classes.



(a) Car price (including Bonus-Malus and premiums) by scenario and CO_2 class



(b) Benefit tax by scenario and CO_2 class



(c) Vehicle circulation tax by scenario and CO_2 class

Figure 1: The effects on scenarios on the average purchase prices and average tax costs of the car supply

2.2 Fuel tax

In Sweden, fuel taxes include two parts: energy tax and CO_2 tax. Currently, the energy tax for diesel is lower than for petrol. The FFF policy package proposes to treat petrol and diesel tax equally from an energy perspective. Therefore, FFF proposes that the energy tax on diesel fuel is increased in three stages such that the total energy and CO_2 tax of diesel reaches the same level as of petrol in 2020. In accordance with the energy tax increase, the annual vehicle circulation tax on diesel cars should be gradually reduced. Moreover, the CO_2 tax for natural gas and liquefied petroleum gas (LPG) should no longer be differentiated from the CO_2 tax on petrol. Gas (bio gas) should remain CO_2 tax free at least until 2022. The proposed fuel taxes are applied in all above mentioned scenarios, except scenario A. Figure 2 shows the development of fuel price including VAT in different scenarios. The fuel prices without taxes are based on a forecast made by the Swedish Energy Authority (Energimyndigheten, 2013).



(a) Development of fuel price in scenario A

(b) Development of fuel price in FFF

Figure 2: Development of fuel price including VAT in different scenarios

3 Evaluation tool - the Swedish car fleet model

The Swedish car fleet model was developed in 2006 and further evolved and updated several times. It is a cohort model which annually updates the stock of the cars by subtracting scrapped cars and adding new cars (Transek (2006) and Hugosson et al. (2014)). Figure 3 shows the Swedish car fleet model system The car fleet model system is composed of three different sub-models as follows:

- A total fleet size model, car ownership model
- A scrapping model
- A car type choice model (for new cars)

The total fleet size model is a simple cohort model based on the probabilities that a person not owning a car will become a car owner and a car owner will sell his/her car and stop being a car owner, (VTI, 2002). The number of car owners is annually updated. Included variables are income, GNP growth, fuel price, age, share of leased cars, retirement dummy and a time factor.



Figure 3: Swedish car fleet model system

The scrapping model is a simple model giving the percentages of a car make of a certain age that should be removed from the stock each year.

The car type choice model is a nested logit model, which calculates the probability that a certain car will be purchased among available vehicles. Included variables in the model are car price or benefit tax, brand, size class, fuel type, tank volume, rust protection guarantee, running cost (fuel and vehicle circulation tax), safety (NCAP classification), engine power (hp), and share of fuel stations with alternative fuel (E85 and gas). In the estimation process, a choice set of more than 300 different car alternatives was established. The new car type model is segmented into three consumer groups. These consumer segments value cars attributes differently. One segment represents private car buyers and the two other segments represent company car buyers with or without a leasing arrangement. The leased company car segment is typically the fringe benefit car segment, although such cars can also be used as a shared car by the company (Hugosson and Algers, 2012). The non-leased car segment comprises typically cars that are used for work, but may also contain fringe benefit cars. The classification based on the existence of a leasing arrangement is not ideal from a modeling perspective, but is used as it is the only indicator in the car register (on which the models were estimated). The shares of privately bought or company bought cars each year are exogenous in the model. In 2013, the private car share was 45 percent, the non-private leased car share was 34 percent and the non-private non-leased share was 22 percent.

In order to understand policy effects, it is also of interest to show the distribution on the available car models on the market, and its demand. In figure 4 the distribution of the supply and its demand for the three model segments is shown for the model calibration year 2013. Figure 4 shows that the market shares of different CO_2 classes are different among different demand segments. The supply is dominated by cars emitting more than 150 g/km. The leased company cars have the highest market share in the 96-120 gr/km CO_2 class, whereas the nonleased company cars and the private car segment have their highest market share in the 151-120 gr/km CO_2 class. It shows that demand is more concentrated over some CO_2 emission classes than others. This can give an idea about how to design a Bonus-Malus system. Right now, the Bonus-Malus is designed linear over all CO_2 emission classes. Another way to design such a system would be to design an S-shape function in which the steeper part, that is more



Figure 4: Supply and demand for car alternatives distributed on CO_2 emission classes

sensitive to CO_2 emission changes, can be used over emission classes with higher demand and the flatter parts that is less sensitive to CO_2 emission changes, can be used over emission classes with lower demand. The linear design provides very little incentive to transfer to cars with a marginally lower CO_2 emission.

3.1 Simple car supply model

When making a forecast of the car fleet, it is necessary to handle the future supply of cars available on the market (see Hugosson et al., 2014; Sprei et al., 2008). Regarding relatively new technologies like electric cars, electric hybrids and plug in hybrids, it is difficult to predict when such cars will enter the market and what properties they will have. In this study we use a simple but systematic method to create a scenario for future supply of these technologies.

First, the 50 top-selling car models in the Swedish new car sale 2013⁶ are grouped according to their size class (9 classes). They represent 75% of the new car sales. For each group we identify existing electric cars, electric hybrids and plug in hybrids that are approximately in the same size class. The properties of these cars are then replicated as new cars for all the brands within the same size class. For instance one of the 50-top selling cars in Sweden is Volkswagen Golf. In its size class, the electric car Nissan Leaf, the electric hybrid Toyota Auris and the plug-in hybrid Toyota Prius are available on the market. Thus in the future we assume that Volkswagen will develop and sell cars with properties like Nissan Leaf, Toyota Auris and Toyota Prius plug-in respectively. The same goes for e.g. BMW, Ford and Audi. It is also assumed that the replicated car will enter the market some years after the last model generation of the respective model was released. In our scenario we assume that electric hybrids enter the market after 2 years while electric cars and plug-in hybrids enter after 3 years. For example, Volkswagen Golf's last model generation was released in 2013. Thus, the so-called "Volkswagen Auris" will enter the market in 2015 and the so-called "Volkswagen Leaf" and so-called "Volkswagen Prius" in 2016. For car models where the last generation was released a relatively long time ago, it is assumed that a new model generation is released every 6th year. This is based on statistics for the top 50 selling car models in Sweden. Using the descriptions

⁶Source:www.bilsweden.se

above, the following conditions and formulas are used:

If $Year_{LG} + \Delta T \leq Year_s \longrightarrow$ Introduction year = $Year_{LG} + \Delta M + \Delta T$ If $Year_{LG} + \Delta T > Year_s \longrightarrow$ Introduction year = $Year_{LG} + \Delta T$

where,

 $Year_S$ - starting year (i.e. 2013) $Year_{LG}$ - Last model generation year ΔT - Number of years until a new technology will enter the market ΔM - Number of years between model generations (i.e. 6 years).

Today electric cars, electric hybrids and plug in hybrids are relatively expensive compared to conventional cars. The price differences are believed to decrease over time. In this study we assume that the extra cost for the new technologies will be reduced by half during the period 2014-2020. An analysis of the market in 2013 shows that electric cars cost 95,000 SEK more than conventional cars, and that electric hybrids and plug in hybrids cost 75,000 SEK and 175,000 SEK more, respectively. In addition, we assume that all cars that are available on the Swedish market today (2013) will exist in the future. However we assume that diesel cars get 1% more energy efficient each year and petrol and ethanol (E85) cars get 2% more energy efficient per year. Moreover, since automakers must meet the requirements of Euro 6 which has a stronger regulation on diesel cars and emission of nitrogen oxides we assume that diesel cars will get 15,000 SEK more expensive from 2015 and onwards. In the FFF-investigation's reference scenario, it is assumed that the energy efficiency is approximately 1% per year, though it is also believed that the efficiency difference between diesel and petrol cars will decrease. Moreover, it is assumed that diesel cars will get more expensive because of the Euro 6 requirements and that electric vehicles and plug in hybrids will have a high purchase price in the beginning of the forecast period (2012 till 2050). Overall we believe that our assumptions on vehicle development and price are in line with the reasoning in the FFF-investigation.

3.2 Using the model for FFF scenario evaluation

Previous use of the model shows that the results are quite sensitive to supply assumptions (Hugosson et al., 2014). This is the reason why we have specifically developed a systematic procedure to make assumptions on future supply. Another issue is that the model alternatives are brand specific, and the nesting structure is such that choice elasticities between brands are lower. Supply uncertainty will of course increase over time, and brand loyalty may also change over time, introducing more uncertainty in the results. We therefore have chosen to model the development of the car fleet only up to the year 2020, although the FFF scenarios main goals are for 2030 and 2050. The FFF also contains intermediate goals for 2020, allowing us to get a good indication of how well the different scenarios will comply with the desired long term development of CO_2 emissions.

3.2.1 Sensitivity analysis of supply assumptions

As has been said before, the model is sensitive to supply assumptions. We have therefore made some sensitivity analysis of some supply assumptions. We have tested the following assumptions:

- No increase in the efficiency of conventional cars
- Shorter model cycle
- Increased supply of electrical cars

An assumption made in the FFF investigation is that conventional drive lines will become more efficient over time i.e. 1% per year. It is also assumed that the efficiency difference between diesel and petrol cars will decrease. This assumption is not quantified in the FFF report, but we need to quantify the effect to be able to analyse it in our model. The assumption we have made is that conventional cars will become less fuel consuming at a rate of 1% per year for diesel cars and 2% for petrol cars. When the model is run without this assumption, then CO_2 emissions of new cars will go up on the average (relative to the case with the assumption). The lack of fuel efficiency for diesel and petrol cars will make them less competitive on the market (higher fuels costs), and therefore the number of non-conventional cars will go up. This may seem contradictory, but the vast majority of new cars sold are petrol and diesel cars, and the increase in non-conventional cars is not enough to compensate for the lack of fuel efficiency increase in this case. The impact of the assumption is larger compared to the differences between the policy scenarios A, B, C and D. It turns out that the difference between the average CO_2 emission of new cars in scenario A with and without the increase in conventional cars fuel consumption is 9 g/km, whereas the corresponding difference between the most successful scenario (D) and scenario A is 4 g/km. For the whole fleet, the assumption of no fossil fuel efficiency improvement in Scenario A implies a 2% increase in fossil fuel consumption(5% increase in diesel and 1% decrease in petrol).

The simple supply model described above assumes a model cycle where new technology is introduced with a delay of three years. The second sensitivity test was to assume a faster model cycle with only one year delay. This has a very small impact, giving less than a half percent decrease in fossil fuel consumption.

The third sensitivity test was to double the supply of electrical vehicles (pure electrical, hybrids and plug-ins). The effect was marginal also in this case, giving less than a half percent decrease in fossil fuel consumption.



Figure 5: The supply sensitivity analysis for scenario A

As can be seen from figure 5, the sensitivity tests performed show that the assumption of technological development of conventional technology is quite important for the model results, and that differences in assumptions on faster model cycle and the number of electrical cars have marginal effects only.

3.2.2 Model limitations

All models have limitations, and so has the Swedish vehicle fleet model. We want in particular to specify two structural weaknesses of the model one should be aware of in order to better judge the model results. These limitations are the shares of company and private segments being exogenous and the fact that the model does not explicitly consider the specific choice set that companies provide for their employees. The exogenous segment shares imply that policies having the effect that people will not find a benefit car worthwhile and buy cars privately instead cannot be modelled. This may happen if policies are too harsh towards company cars. Larger companies and public organisations often have car policies reflecting economic and environmental constraints on benefit takers' choice of car. By not explicitly defining company car choice sets, our model cannot model the company car policy changes that may happen in the company cars choice sets as a response to policy changes. Currently there is an ongoing project to estimate a vehicle fleet model that does not have these weaknesses.

4 Results and discussion

In this section some of the main model results of the different scenarios are presented and compared with scenario A which is business as usual. Figure 6 shows the average CO_2 emission of new cars in different scenarios. As can be seen the average level of CO_2 emission is higher



Figure 6: The average CO_2 emission of new cars under different scenarios

in scenarios B and C and lower in scenario D compared to scenario A. The lowest level of CO_2 emission in year 2020 is acquired in scenario D with 120 g/km. This is higher than the target of the FFF package which is 95 g/km for 2020. In the rest of this section, we present more detailed results to discuss the reasons why not only the target is not met but also the average value of CO_2 emission is higher in scenarios B and C compared to scenario A.

4.1 Policy effects on CO₂ emissions distribution for new cars

In addition to the mean CO_2 emission values, we can also show the CO_2 emission distribution by plotting the cumulative market shares of all car alternatives in increasing CO_2 emission order (a CO_2 cumulative density function (CDF) for new cars). This will show where changes take place.

Figure 7 shows the CDF of CO_2 emissions of new cars under different scenarios in year 2020. As can be seen in figure 7a, approximately 10% of the cars emit less than 100 g/km in scenarios B and C while this number increases to nearly 20% in scenarios A and D. The more the CDF curves move towards left the less CO_2 is emitted. The CDF curves of scenarios B and C are to the right of scenario A whereas the curve of scenario D locates to the left of A showing that more CO_2 is emitted in scenarios B and C compared to A while the least is emitted in scenario D. As can be seen in figure 7b there is not a big difference between different CDF



(c) CDF of CO_2 emission of leased company cars (d) CDF of CO_2 emission of not-leased company cars

Figure 7: CDF of CO_2 emission of new cars under different scenarios in year 2020

of CO_2 emission of different scenarios in the private segment. The difference exists only in

the range of 100-120 g/km. The percentage of the cars that emits less than 100 g/km of CO_2 increases from 5% in scenarios B up to 10% in scenario D while the percentage of cars that emit less than 120 g/km increases approximately from 10% in scenario B up to 20% in scenario D. No new car in the private segment emits less than 75 g/km.

In the leased company cars segment, as can be seen from figure 5c, the difference between different scenarios is bigger. Approximately, 10% of the cars emit less than 100 g/km in scenarios B and C and this number increases to 25% in scenarios A and D. The number of cars that emit less than 50 g/km is 5% in scenario A, B and C and 10% in scenario D. In this segment, the percentage of the cars that emit less than 95 g/km is 10% in scenario D while for the same scenario this value drops to 5% in the private segment as can be seen in figure 7b. The cumulative curve of scenario A is closer to scenarios B and C for emissions less than 95 g/km and gets closer to the curve of scenario D afterwards.

In the not-leased company cars segment, as can be seen in figure 7d, the number of cars that emit less than 100 g/km is 10% in scenario A, B and C and 20% in scenario D. Overall the curve of Scenario A is very close to that of scenarios B and C. In general, the different scenarios affect company cars more strongly. It can be seen that scenario D has equal or positive impact towards decreasing CO_2 emission compared to scenario A while scenarios B and C have equal or negative impact on company cars segment compared to scenario A. This can be explained by the fact that benefit taxes in scenarios B and C are higher than in A but not CO_2 differentiated. Therefore, individuals will choose the less expensive cars that might emit more CO_2 . It should also be taken into account that company cars are on average heavier than cars bought in the private segment. Finally, the market share of different segments is also given exogenously. This assumption also needs to be relaxed since the share of different segments is influenced by different policies as well.

Different policies may affect the choice of the weight of the sold cars in different segments in similar way. However, the result shows that different scenarios do not change the weight distribution of chosen cars.

4.2 Policy effects on fuel types for the whole fleet

Figure 8 and 9 show the development of the total number of cars for different fuel types in the whole fleet in scenarios A to D. The total number of the cars in the fleet is almost the same in all scenarios as well as ownership rate and scrapping rate. The reason is that the car ownership package sub-model only includes fuel price as policy variables and fuel price is the same in scenarios B, C and D and the differences with respect to scenario A is very marginal (see figure 2). The scrapping sub-model is not a policy sensitive model and thus is not influenced by policy change.

As can be seen in all scenarios, the number of petrol cars decreases in favor of diesel cars, electric hybrid and plug-in cars. The increase in the number of diesel, electric and plug-in cars is higher in scenario D as well as the decrease in the number of petrol cars. Figure 9b shows a sharper increase in the number of plug-in cars from 2017. At the same time the number of ethanol (E85) cars decreases sharply. The explanation is that ethanol cars that had entered the fleet earlier start to be scrapped around 2017 and that plug-in cars will be more attractive because of more competitive prices. Finally the number of gas cars will be increased slightly from 2015-2020 in all scenarios. Table 3 shows the percentage changes in the number of cars by fuel types in all scenarios relative to scenario A in year 2020. The relative change in the



(a) Total number of petrol cars

(b) Total number of diesel cars

Figure 8: Total number of petrol and diesel cars in scenario A-D



(a) Total number of electric cars

(b) Total number of plug in cars

Figure 9: Total number of electric and plug in cars in scenario A-D

number of petrol cars is the same in scenarios B and C (i.e. 1%) while it is slightly decreasing (i.e. 3%) in scenario D. The percentage change in number of diesel cars do not increase in scenarios B and C compared to scenario A while it slightly increases in scenario D, i.e. 2%. The relative decrease of the number of electric hybrid cars in scenarios B and C are almost 40% while the relative number of electric hybrid cars in scenario D is increased 18%. The numbers of electric and plug-in cars increases in all scenarios while the number of ethanol (E85) and gas cars decreases in all scenario D is higher, 76% and 155% respectively. One reason is the super green car premium that is introduced in scenario D. This premium mainly covers these two groups of the cars and is much stronger than the environmental premium introduced in scenarios B and C. The number of gas and ethanol (E85) cars decreases is probably due to the increase of vehicle circulation tax for alternative fuel vehicles in scenario B, C and D compared to scenario A, as can be seen in table 2. In general it can be observed that in scenario D, the demand is relatively more shifted towards environmental friendly cars.

Fuel type	Scer	nario B	Scer	nario C	Scenario D		
	Number	Percentage	Number	Percentage	Number	Percentage	
Petrol	28800	1	21000	1	-71700	-3	
Diesel	-9500	0	-600	0	45300	2	
Electric	2100	21	1900	19	7500	76	
Gas	-1400	-3	-1400	-3	-3400	-1	
Electric hybrid	-9300	-39	-9900	-39	3700	18	
E85	-13100	-6	-13600	-6	-3400	-1	
Plug-in	2300	18	2600	20	22300	155	

Table 3: The percentage changes in the number of cars by fuel types in all scenarios relative to scenario A in year 2020

4.3 Total fuel consumption

Total fuel consumption is calculated for the whole fleet by using statistics on the average number of km driven by car age, by using fuel consumption information on car age and fuel type, and also by regarding fuel cost using an elasticity of -0.3. Therefore, the changes in the fuel consumption are caused by the number of different car types and their fuel economy. From the results, it is observed that the fuel consumption trend is nearly the same as that of the number of cars by fuel type. Petrol consumption is decreased while diesel consumption is increased. The consumption of ethanol (E85) and plug-in cars (electricity) also follow the similar pattern as the number of these cars. There is a decrease in ethanol usage from 2017 that continues till 2020. This decrease is associated with the decrease in the number of ethanol cars in these years. Also, there is a sharper increase in the consumption of plug-in cars starting from 2017 which is also in connection with the higher increase in number of these cars starting 2017.

Table 4 shows the percentage changes in total fuel consumption in all scenarios relative to scenario A in year 2020. As can be seen, the general trend of percentage change in fuel con-

Fuel type	Scenario B	Scenario C	Scenario D
Petrol	1	1	-3
Diesel	1	2	2
Electric	23	21	83
Gas	-3	-3	-1
El hybrid	-39	-38	19
E85	-5	-5	-1
Plug-in	14	17	137

Table 4: The percentage changes in total fuel consumption (billion liter) in all scenarios relative to scenario A in year 2020

sumption relative to scenario A is very similar to the percentage change in the number of cars by fuel type shown in table 3. The total consumption of petrol and diesel is slightly increased in scenarios B and C (1-2%) While in scenario D, petrol consumption is slightly decreased (i.e. -3%), unlike diesel consumption that is slightly increased (i.e. 2%). The consumption of electricity increases in all scenarios while the consumption of ethanol (E85) and gas decrease in all scenarios relative to scenario A. These results are in accordance with the relative number

of cars by these fuel types in respective scenarios.

4.4 Fleet average fuel costs

Fleet average fuel costs are depending on car fleet fuel efficiency as well as on fuel prices. The result show that the relative changes are very small in different scenarios compared to scenario A. The average cost of running on electricity increases 2% in scenarios B and C and 4% in scenario D relative to scenario A. The average cost of running on diesel increases 2% in scenarios B and C and decreases 1% in scenario D compared to scenario A. The average cost of gas increases 1% in scenario D relative to A and the average cost of running on ethanol (E85) increases 1% in scenario B and C compared to scenario A.

4.5 Policy effects on government budget

Budget effects of different policies are of course important for policy decision makers. Figures 10 shows the cumulative distribution of Bonus-Malus paid by car buyers (private or companies) in scenarios B and C. In these figures, bonus is shown as negative (as a cost for the Government) and malus as positive. As can be seen in both scenarios, less than 10% of car



Figure 10: CDF of Bonus-Malus in scenarios B and C in year 2020

buyers are receiving a bonus. In both scenarios the private segment is more willing to pay the malus for their choice of car compared to the company cars segment. The percentage of buyers paying the malus is higher in scenario C.

4.5.1 Private car buyers

Table 5 shows budget effects of different scenarios in the private segment relative to scenario A. As for the figure 10, bonus and malus are shown from the government perspective. The relative value of total Bonus-Malus and premium paid are the same in scenarios B and C and increases from 900 to 2000 million SEK between years 2015-2020. Since there is no Bonus-Malus system introduced for registration tax in scenario D, the figures shown in table 5 are

Scenario B								
Year	BM + premium	Vehicle circulation tax	Fuel tax	Sum				
2015	900	100	0	1000				
2018	1000	100	0	1100				
2020	2000	100	0	2100				
Scenario C								
Year	BM + premium	Vehicle circulation tax	Fuel tax	Sum				
2015	900	100	10	1010				
2018	1000	100	0	1100				
2020	2000	100	0	2100				
Scenario D								
Year	BM + premium	Vehicle circulation tax	Fuel tax	Sum				
2015	-40	200	-10	150				
2018	-60	100	-10	30				
2020	-60	100	-10	30				

Table 5: Budget effects of different scenarios (in million SEK) for new cars in the private segment relative to scenario A

negative expressing only premium paid for super green cars. The paid premium relative to scenario A increases from 40 million SEK in 2015 to 60 million SEK in 2018 and remains constant till 2020. The values of total vehicle circulation taxes are the same in scenarios B and C for the different years. The relative value of the total vehicle circulation tax in scenario D is twice as high as in scenarios B and C in the year 2015 and the corresponding values of the three scenarios are the same in 2018 and 2020. The value of the total fuel tax in scenario B is equal to scenario A in the years 2015 and 2018. The corresponding value in scenario C is 10 million SEK in year 2015 relative to scenario A and equal to scenario A. However, the relative values of total budget effect is positive in all scenarios relative to scenario D. The relative total budget effect increases in scenarios B and C from 2015 to 2020 while it decreases in scenario D for these years. The difference is mainly due to the Bonus-Malus system. The total budget value is the same in scenarios B and C in different years.

4.5.2 Company car buyers

Table 6 shows budget effects of different scenarios in the company cars segments relative to scenario A. Bonus-Malus and vehicle circulation tax are paid by companies which are subject to the same rules and regulations as the private segment (except for the bonus part, which is maximized to 35 percent of the car price). Benefit tax is the tax that benefit takers (employees) should pay due to having access to company cars for the private usage. As can be seen, the relative total tax incomes of scenario D is negative. The relative total value of Bonus-Malus and premium paid increases towards 2020 in scenarios B and C. Again, since there is no Bonus-Malus system introduced for registration tax in scenario D, these figures are negative expressing only premium paid for super green cars and this paid premium increases from 2015 to 2020. The trend is similar to that of the private segment. In fact the relative values of total

Scenario B										
Year	BM + premium	Benefit tax	Vehicle circulation tax	Fuel tax	Sum					
2015	800	2000	200	-500	2500					
2018	1000	2000	100	40	3140					
2020	2000	2000	100	90	4190					
Scenario C										
Year	BM + premium	Benefit tax	Vehicle circulation tax	Fuel tax	Sum					
2015	500	2000	200	100	2800					
2018	1000	2000	100	40	3140					
2020	2000	2000	100	90	4190					
		Sce	enario D							
Year	BM + premium	Benefit tax	Vehicle circulation tax	Fuel tax	Sum					
2015	-300	-30	200	-100	-230					
2018	-700	-30	100	-200	-830					
2020	-700	60	100	-200	-640					

Table 6: Budget effects of different scenarios (in million SEK) for new cars in the company car segments relative to scenario A

Bonus-Malus and premium paid are nearly the same in the private and company sectors in scenarios B and C in years 2015-2020 except for 2015 where company cars have lower Bonus-Malus tax in 2015 compared to the private segment. In scenario D, the relative amount of paid premium is higher than their equivalent values in the private segment showing more super green cars in the choice of company cars. The relative benefit tax values are positive and equal in scenarios B and C and in all years. The respective values in scenario D are lower than in scenario A in years 2015 and 2018 and higher in year 2020. The relative vehicle circulation taxes are the same in all scenarios and decreases from 200 million SEK in 2015 to 100 million SEK in 2018 and 2020. vehicle circulation taxes are paid by the companies, and do not directly affect the taxable benefit values. The relative values of total fuel tax in scenarios B and C are the same and higher than in scenario A in the years 2018 and 2020. However, in scenario B the relative value of fuel tax in year 2015, is lower than in scenario A and equal to 500 million SEK while in scenario C the respective value is higher than in scenario A and equal to 100 million SEK. The values of total fuel tax in scenario D are lower than in scenario A and the relative values are decreasing from -100 million SEK to -200 million SEK. The relative values of total fuel tax are higher in the company cars segments compared to private segments and the reason to that is the exogenous assumption that company cars on the average are driven more in a year relative to private cars.

Finally, table 7 shows the total budget effects of the private and company cars segments relative to scenario A. As it can be seen the total budget effect is negative in scenario D in all years and the negative value increases from 2015 to 2020 relative to scenario A. For scenario B and C the relative budget effect is positive and equal in all years (except for 2015) and increases from 2015 to 2020 as well.

Scenario B					Scenario C		Scenario D			
Year	Private	Company cars	Sum	Private	Company cars	Sum	Private	Company cars	Sum	
2015	1000	2500	3500	1010	2800	3810	150	-230	-80	
2018	1100	3140	4240	1100	3140	4240	30	-830	-800	
2020	2100	4190	6290	2100	4190	6290	30	-740	-710	

Table 7: The total budget effect (in million SEK) of new cars in the private and company car segments relative to scenario A

4.5.3 Comparison of the budget effects of the model with that of FFF

Compared to the reasoning in the FFF investigation, our model results show greater budget effects of the Bonus-Malus system and environmental premiums in scenario B and scenario C. The FFF investigation believe that the system will give a budget effect of approximately plus minus a few hundred million SEK in the year 2020, whereas our results show a positive budget effect of a few billion SEK for scenarios B and C. The difference is mainly related to the extent of electrification of the car fleet. The FFF investigation's calculations is based on assumptions on the shares of electric cars and plug in hybrids that are higher than our model results. However the FFF investigation states that it is difficult to predict if the systems will be self-financed. This is one of the reasons why the investigation suggest that so called control stations should be made continuously where the system's effects are evaluated.

In scenario D, FFF assumes that beneficiaries and companies will adjust to the stronger proposed regulations. In that case the system will not affect the tax incomes from car benefits. This means that the company car segment will include more clean cars. We can not model this dynamic since as mentioned before the share of the company cars is exogenous to the model and we do not consider company specific choice sets. However, our model results also show that scenario D has a large effect towards increasing the number of clean cars in company car segment.

4.5.4 Comparing yearly cost with purchase price

Finally, to be able to compare the effect of each policy, we need to compare yearly costs with a purchase price. One way is to calculate it from a customer (private or company) perspective. A rational consumer would do such a comparison based on the expected second hand car price, expected fuel costs and expected taxes over a defined period of time, possibly regarding uncertainties in these expected values. We have no information on this, and have to assume that these considerations are reflected in the estimated values of purchase price and yearly cost parameters in the model. From the model we can calculate the exchange rate of operating cost (fuel cost + vehicle circulation tax) to purchase price for the private car segment which is 30.72. This means that 1 SEK of change in operating cost, by changing in fuel cost or vehicle cost, is valued as 30.72 SEK in purchase price⁷. As example from table 2, Volvo V70 AFV Bi-Fuel is taxed 1,500 SEK yearly in scenarios B and C compared to being tax free in scenario A in 2015. Therefore, the total value of bonus plus additional premium should be equal to 46,000 SEK (converted to purchase price) to keep this car equally attractive. Currently, the bonus is 200 SEK in scenario B and 4,500 SEK in scenario C. This explains partly why in scenario B

 $^{^{7}\}beta_{\text{purchase price}} = -0.009473 \text{ (1000 SEK)}$ and $\beta_{\text{operating cost}} = -0.000291 \text{ (Transek, 2006)}$

and C, the number of clean cars decreased while consequently CO_2 emission is increased. To compare benefit tax with operating cost for the company segment, the exchange rate of benefit tax to operating cost is acquired from the company car model which is 0.25^8 (this is the average of the values for company cars with and without lease). Therefore, 1 SEK change in benefit tax and fuel cost should be the same, but the model is estimated under the assumption of a fixed driven distance per year which may vary a lot, and does also not consider that a share of this distance may be driven for work and therefore not a cost for the employee. Remuneration rules for work travel may also affect the parameter value. The benefit tax is also based on an assumption on marginal tax rate which may also vary between employees. The differences in coefficient values can at least to some extent be seen as corrections for differences between reality and model assumptions.

4.6 Effects of model limitations

As mentioned above, the limitations of our model include the exogenous shares of company and private segments and the fact that the model does not consider the specific choice set that companies will provide for their employees. We believe that the effects of these limitations are that the Bonus-Malus effects in scenario B and C will be somewhat underestimated because high emitting cars (suffering malus penalties) will to some extent no longer be included in the benefit takers choice set because of the purchase price constraint. This applies also to scenario D. The generally less favorable conditions for company cars may also make some employees choose having a private car instead of a company car. It is not clear what the emission implication will be. These limitations concern mainly one segment (leased company cars), and not all companies have binding benefit car policies. Almost half of the benefit takers are self-employed and are not subject to company car policies (Transek, 2006). We therefore do not expect these limitations to have a major impact on the model results, but they are likely to underestimate effects to some extent.

5 Conclusion

In the FFF policy package different scenarios are introduced to reach the target of a fossil independent vehicle fleet by 2030 in Sweden. The scenarios combine policies affecting purchase, usage and also technology development. These scenarios differ in designs for registration tax, vehicle circulation tax, clean car premiums and car benefits. The package includes four scenarios A, B, C and D. Scenario A is business as usual, scenario B is a CO_2 differentiated Bonus-Malus scheme for registration tax, scenario C is a CO_2 and weight differentiated Bonus-Malus registration tax and scenario D is a CO_2 and weight differentiated vehicle circulation and benefit tax. In all scenarios, except scenario A, diesel tax increases gradually to reach the same level as petrol tax and in connection with this increase, the vehicle circulation tax on diesel cars is also decreased gradually. To evaluate these scenarios, we use the Swedish car fleet model and calibrate it for the year 2013. Also, we build a simple supply model to predict future supply.

 $^{{}^8\}beta_{\text{taxable benefit}}/\beta_{\text{operating cost}} = -0.095515/ - 0.000354 = 0.27$ for company cars with lease and $\beta_{\text{taxable benefit}}/\beta_{\text{operating cost}} = -0.083094/ - 0.000364 = 0.23$ for company cars without lease.

Our model results show that none of the FFF scenarios is likely to lead to the desired goal of 95 g/km of CO_2 emission of new cars on average, by 2020. The average CO_2 emission has the lowest value in scenario D in 2020 which is 120 g/km. The average CO_2 emissions in scenarios B and C are actually higher than in the business as usual scenario. In the FFF investigation it is suggested to continuously follow up the effect of the policies in so called control stations. A result of the control stations might be to tune the system in one way or the other or add new policies. The first control station would be in 2018. Our model results indicate that it would be appropriate to tune the suggested policies already today.

The number of alternative fuel cars (E85 and gas) is reduced in all scenarios compared to scenario A which is a negative result in terms of fossil fuel independence. The probable reason is the higher vehicle circulation taxes for these cars in the respective scenarios. Although the percentage of super green cars increases strongly in the scenarios compared to scenario A, the introduction pace seems quite insufficient for the long term goal of fossil fuel independence. If 70 000 (in scenario D) super green cars are introduced in five years, it is only 2% of the total car fleet in Sweden. The Bonus-Malus system gives a positive net result in terms of budget effects. The car buyers choose to pay the malus for a car with higher emissions rather than to be attracted by the bonus of a car with lower emissions. The scenarios affect company car segments more strongly. They motivate company car users towards lower CO_2 emission cars in scenario D and towards higher CO_2 emission cars in scenarios B and C. The reason can be that the higher benefit tax that is introduced in scenarios B and C, is not CO_2 differentiated. The separate analysis of different policies introduced in scenarios B and C shows that only introducing Bonus-Malus system has more effect on reducing the average CO_2 emission than combining it with vehicle circulation tax or benefit tax and the reason is these taxes are not CO_2 differentiated and actually lead the market towards the purchase of higher CO_2 emission cars.

Finally, the result of our study calls for stronger policies to be implemented and for the modification of proposed policies. One approach is modify the proposed policy is to optimize the current Bonus-Malus system such that it pays for itself. One way to do this is to use an S-shape function for Bonus-Malus as discussed before. Another way is to combine current scenarios such that we combine their strong points that are CO_2 differentiated policies. Another approach can also be to use the budget gained from different policies to invest in other policies that motivate purchase and use of the clean cars.

At the end we should mention that there are policies available in FFF policy package that target the use of the cars and the final target of average CO_2 emission is set based on the whole policies together while in this study we only evaluate the purchase of the new cars.

Acknowledgments

We would like to acknowledge the Center for Transport Studies in Stockholm that provided the resources for this study. We would also like to acknowledge Ronny Svensson who generously put the Ynnor database on vehicle attributes at our disposal.

Appendix A

In scenario A, the current tax on fuels and on vehicles are assumed to be continued. Currently, the vehicle circulation tax consists of two parts; a basic amount and a CO_2 component. The CO_2 component of vehicle circulation tax is calculated based on the amount of CO_2 emitted over 117 g/km. Additionally, diesel cars have a fuel factor and an environmental addition. The fuel factor is justified because of diesel being less taxed than petrol. The formulation is as follows:

Petrol cars:

$$360 \text{ SEK} + \max(0, (co_2 \text{ emission} - 117)) \times 20 \text{ SEK/gr}$$

Diesel cars:

 $2.33 \times [360 \text{ SEK} + \max(0, (co_2 \text{ emission} - 117)) \times 20 \text{ SEK/gr}] + \text{environmental addition}$

Alternative fuels:

$$360 \text{ SEK} + \max(0, (co_2 \text{ emission} - 117)) \times 10 \text{ SEK/gr}$$

Clean cars are exempted from this tax for five years after first registration. The definition of clean cars in Sweden has changed in 2013 towards weight differentiated allowable emissions i.e. a car running on petrol with a curb weight of 1372 kg, should emit 95 g/km of CO_2 to be defined as a clean car. If it runs on ethanol (E85) or gas, the limit is 150 g/km. Heavier cars can emit 0.0457 gram more emission per 1 kg additional weight. Moreover, a super green car premium exists in which a premium of maximum 40,000 SEK is assigned to the cars that emit maximum 50 g/km. Finally, employees that have cars for the private use provided by the employer are benefit taxed. The benefit value is based on the prices of the new cars and interest rate of each year which is calculated by the tax authorities and taxed as income. Alternative fuel cars except ethanol (E85) cars will get a reduction of this tax.

In scenario B, the CO_2 differentiated registration tax of Bonus-Malus is introduced. The Bonus-Malus registration tax is defined as a tax that newly registered cars should pay for the CO_2 level they emit above an allowed or null point. The null point is defined slightly below the EU determined target of average emissions. The reason for lowering EU target is that Sweden has relatively heavy car fleet and it is needed to ensure that the EU target will be reached. For the years 2015 and 2020, the null point is set at 120 g/km and 90 g/km, respectively, associated with EU targets of 130 g/km and 95 g/km of CO_2 average emission. The null point is reduced by 6 g/km per year from year 2015 to reach 90 g/km in 2020. Each reduction of CO_2 by one g/km is rewarded by 400 SEK. This is based on the premium assigned for zero emission cars in 2015, i.e. 48,000 SEK. Therefore, the premium for zero emission cars will be decreased accordingly over time, and in 2020, the zero emission cars receive a premium of 36,000 SEK. This scenario assigns a supplementary premium of 15,000 SEK for alternative fuel cars (i.e. plug-in hybrids, E85, gas and electric hybrid vehicles) for both private and company cars segments. This premium is assigned to flexible fuel cars (i.e. ethanol and gas) that emit maximum 55 g/km of CO₂over the null point of each year and to plug in-hybrid and electrichybrid cars if they emit maximum 50 g/km of CO_2 . For cars that can run on two alternative fuels twice the additional premium is applied i.e. 30,000 SEK. To avoid successive subsidies, the total amount of premiums and Bonus-Malus tax are limited to a maximum of 25 percent of the cars' new price. In connection with the introduction of the additional premium, the super green car premium is removed. In this scenario, the vehicle circulation tax for new cars is assigned to be 1,500 SEK per year for all cars except for diesel cars that is 2,760 SEK in 2015 and decreases to 1997 SEK in 2020. Moreover, the benefit tax of company cars becomes stronger.

In scenario C, the idea of CO_2 and weight differentiated registration tax is proposed. Sweden has relatively large and heavy car fleet compared to the rest of the EU. The CO_2 differentiated tax of Bonus-Malus system will therefore drift the demand towards low CO_2 emission as well as smaller cars. Thus, the bonus for a small car can be relatively large compared to the purchase price. On the other hand, among 10 top car brands with higher market shares in Sweden between 2011-2012, Volvo had the highest mean curb weight. Therefore, a system pushing towards smaller cars, will risk major negative consequences for Volvo (FFF-report, 2013). It will also affect the households needing big cars negatively. To get around these problems, the system of a CO_2 and weight differentiated registration tax is proposed in this scenario. The objective for the development of an alternative design of CO_2 and weight differentiated registration tax (scenario C) does not differ from the system containing no weight differentiation (scenario B). The objective is still that the average CO_2 emission from new cars in 2020 in Sweden, should be a maximum of 95 g/km. To achieve this goal, the null point should be set at 120 g/km in 2015 and at 90 g/km in 2020 for a car with average curb weight. An annual reduction of the null point by 6 g/km is the same between as before. The difference is that in scenario C instead of a null point we have a null line which is dependent on the curb weight of the car. The relation is defined

$$CO_2 = b + a \times (M - M_0)$$

Where,

M, is the car's curb weight,

 M_0 , the average curb weight of the new cars in Sweden assumed to be 1521 kg^a during the years 2015-2016.

a and b are constant for different registration years. (see table A1).

As can be seen in figure A1, the slope of the line is chosen to be the same as in the EU system.

	2015	2016	2017	2018	2019	2020
a	0.0457	0.0432	0.0417	0.0407	0.0398	0.0333
b	120	114	108	102	96	90

Table A1: a,b coefficients for different registration years

However, the line lies 17 g/km lower than EU line in 2015 regardless of the weight. The reason for this is that the null point is 120 g/km instead of 130 g/km. The environmental premium, vehicle and benefit tax are the same as for scenario B. Again, the super green car premium is removed in connection with introduction of additional premiums. In scenario D, a weight differentiated vehicle circulation tax is proposed as well as CO_2 and weight differentiated benefit tax for company cars. The new vehicle circulation tax is in line with the allowable weight differentiated emission for clean cars in Sweden. The formulation is described as follows: Petrol cars:

 $360 \text{ SEK} + (\max(0, (co_2 \text{ emission} - (95 + 0.0457 \times (\text{curb weight} - 1372))))) \times 50 \text{ SEK/gr}$

^aWe assume the same value for the average curb weight for the next years as well



Figure A1: The null line for Bonus-Malus system with and without weight differentiated tax for diesel and petrol cars

Diesel cars:

fuel factor× $[360 \max (0, (co_2 \text{ emission} - (95 + 0.0457 \times (\text{curb weight} - 1372))))] \times 50 \text{ SEK/gr}$

Alternative fuels:

360SEK + (max (0, (co_2 emission - ($150 + 0.0457 \times ($ curb weight - 1372))))) × 25 SEK/gr

In this scenario, the proposed vehicle circulation tax is combined with an increase of the current super clean car premium from 40,000 SEK to 70,000 SEK for zero emission cars and 50,000 SEK for plug-in hybrids and other cars with emissions between 0 g/km and 50 g/km. For both of these cases the total amount of premium cannot be higher than 25% of the new car price. For company cars, the current benefit tax is increased for emissions over the allowed weight differentiated null point as described in scenario C. There will also be a tax reduction for alternative fuel vehicles. The formulation of change in benefit tax is as follows:

For conventional cars:

 $[4\% \times (co_2 \text{ emission} - \text{weight diffrentiated null point (as in scenario C)}] \times \text{new car price}$

For gas and ethanol (E85) cars:

 $[4\% \times (co_2 \text{ emission} - \text{weight diffrentiated break point (as in scenario C)}) - 2\%] \times \text{new car price}$

For electrical vehicles:

 $(1-50\%) \times$ new car price

For electrical vehicles:

 $(1-70\%) \times$ new car price

The reductions are limited to 20,000 SEK for plug-in vehicles and 28,000 SEK for electrical vehicles (currently 16,000 SEK for both).

Appendix B

Supply CO ₂ class averages	0 - 50 g/km	51 - 95 g/km	96 - 120 g/km	121 - 135 g/km	136 - 150 g/km	151 - 200 g/km	201 - g/km	All cars
CO ₂ g/km	23	86	107	128	142	167	233	145
Scenario A								
Price (1000 sek)	349	250	262	244	276	313	522	294
vehicle circulation tax SEK/years	0	0	139	947	1333	1840	3099	1361
Benefit tax (1000 SEK/year)	23	34	40	38	43	48	90	45
Scenario B								
Price (1000 sek)	301	237	256	246	283	329	562	302
vehicle circulation tax SEK/years	1528	1823	2188	1911	1898	1769	1592	1849
Benefit tax(1000 SEK/year)	29	45	54	53	60	70	129	64
Scenario C								
Price (1000 sek)	300	240	255	246	282	327	554	301
vehicle circulation tax SEK/years	1528	1823	2188	1911	1898	1769	1592	1849
Benefit tax(1000 SEK/year)	29	46	54	53	60	69	127	64
Scenario D								
Price (1000 sek)	297	250	261	244	276	313	522	293
vehicle circulation tax SEK/years	376	461	921	2161	2739	3785	6024	2896
Benefit tax(1000 SEK/year)	15	32	38	39	44	53	109	48

Table B1: The scenario specific average prices and taxes for different CO_2 emission classes

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