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Sebastian Weber

On the effects of the Swiss Heavy Vehicle Fee

Über die Auswirkungen der Leistungsabhängigen Schwerverkehrsabgabe

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ABSTRACT

Trying to isolate the effect of a singular policy on a highly volatile variable is never an easy feat. Nevertheless, it is the goal that this thesis tries to accomplish. A set of different econometric approaches show that the intended effect of the heavy vehicle fee in Switzerland is not just a political pipe dream but a statistically identifiable mechanism. According to baseline estimates, the HVF implies a cost elasticity of about -1.4 on heavy-duty mileage, which is slightly above related scientific findings. An RDD-Estimation shows that adapting HVF tariffs doesn't imply lower overall mileage values. Instead, the HVF notably shifts road traffic from older, more polluting to newer, cleaner trucks. This might not be in line with the Swiss efforts to shift transport from road to rail. Nonetheless, it contributes to a different goal in transport policy, namely, to internalize some of the negative externalities of heavy-duty traffic.

ZUSAMMENFASSUNG

Anhand dieser Arbeit wird versucht, den Einfluss der Einführung der Schwerverkehrsabgabe 2001 auf den Schwerverkehr in der Schweiz zu schätzen. Eine Reihe verschiedener ökonometrischer Ansätze zeigt, dass die beabsichtigte Wirkung der Schwerverkehrsabgabe in der Schweiz nicht nur ein politischer Wunschtraum ist, sondern ein statistisch identifizierbarer Mechanismus. Nach einer Basisschätzung impliziert die LSVA eine Kostenelastizität von etwa -1,4 auf die Fahrleistung von schweren Nutzfahrzeugen, was leicht über den entsprechenden wissenschaftlichen Erkenntnissen liegt. Eine RDD-Schätzung zeigt, dass die Anpassung der LSVA-Tarife nicht zu niedrigeren Gesamtkilometerwerten führt. Stattdessen kommt es durch die LSVA zu einer deutlichen Verlagerung des Strassenverkehrs von älteren, schadstoffreicheren auf neuere, sauberere Lkw. Dies mag nicht im Einklang mit den Bemühungen der Schweiz stehen, den Verkehr von der Strasse auf die Schiene zu verlagern. Dennoch trägt es zu einem anderen verkehrspolitischen Ziel bei, nämlich der Internalisierung einiger der negativen externen Effekte des Schwerlastverkehrs.

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1 INTRODUCTION

Transportation in general and road transportation specifically are responsible for a large share of global greenhouse gas emissions. According to estimates of the World Resource Institute, transport accounted for 7.9 of the world's 36.7 billion tonnes of CO_2 in 2016 (*Data Explorer | Climate Watch*, 2016). Out of that, road transport is responsible for 74.5% of all emissions, which are split into 45.1% for passenger and 29.4% for freight road transport respectively (*Data Explorer | Climate Watch*, 2016). Next to greenhouse gas emissions, road transport also creates considerable costs for which it does not pay. These are so-called negative externalities in the shape of accidents, degradation of infrastructure, noise, congestion and local air pollution. Operating a truck, train or bus will lead to considerable emission of harmful substances, greenhouse gasses and noise and the costs induced are not borne by the operators but by society as a whole. Such activities create negative externalities, because they impose costs to actors that are external to the action itself. This is a situation where state intervention is a necessity for efficient market performance.

Consequently, policy makers all over the world have attempted to internalize negative externalities by introducing a variety of policies, including fuel taxes, emission targets, low emission zones and mileage fees. Government action of this kind is often justified by evocation of the *polluter pays principle.* The polluter pays principle is a legal principle sustained by many of the world's leading economies, that states that it is the polluters who ought to be responsible to pay for the damage that they create. According to this principle, sovereign action needs to be taken in order to ensure that polluters will have to pay for the external costs they created, as they will not so do unless they are forced to. Successfully doing this means that the external costs have been internalized.

The Swiss Heavy Vehicle Fee (HVF) is a political instrument designed to internalize negative externalities of heavy-duty traffic on Swiss roads by taxing the mileage of all road vehicles above a weight threshold. Internalisation ensures that the true costs of transport are paid. Inefficient transports, which generate more costs than benefits overall, are thus eliminated. One way to determine successful internalisation would therefore be to observe a reduction of the transport mileage of the vehicles concerned, a path this thesis aims to follow.

This thesis concerns itself with the functionalities and effects of the HVF. It sets an empirical focus on the hard-to-isolate implications of the fee that is trying to limit heavy-duty traffic on Swiss roads. Using a specifically compiled data set on mileage and changing tariff rates of heavy-duty traffic in Switzerland, several statistical models are estimated. The aim of this thesis is to answer the fundamental question if the HVF achieves its goal. It contributes to the academic literature by examining whether road pricing schemes, represented here by the archetypical HVF, achieve their policy objectives.

This thesis is structured as follows: After a chapter on the background of the HVF, an overview of the existing economic literature on the workings and successes of road pricing policies such as the HVF will follow. Based on theoretical expectations, hypotheses on the suspected relationship between the HVF and traffic behaviour on Swiss roads are formulated and the data and methodology to test these hypotheses are presented. Subsequently, possible reasons as to why some of the theoretical expectations were partially unmet are discussed as well as potential improvements of the empirical strategy.

2 BACKGROUND

This chapter will give an extensive overview of the historical background, implementation, policy environment and external costs calculations concerning the HVF. It aims to transmit all the information about the HVF that is required to understand the connection between the academic literature and the empirical approach applied in this thesis.

The performance-related Heavy Vehicle Fee (HVF) has been levied in Switzerland since January 2001. It is a key element of Swiss transport policy. The HVF is intended to cover the long-term infrastructure costs and costs attributable to heavy goods vehicles at the expense of the general public, insofar as they are not already covered by other services or fees. It also contributes to improve the general conditions for rail in the transport market and to increase the transport of goods by rail. By increasing costs of road transport, it creates a shift effect from road to rail and is thus a central instrument for shifting heavy goods traffic. Additionally, the Confederation uses its share (two thirds) of the HVF revenue primarily to finance railway infrastructure. The cantons receive the remaining third of the revenue and use it to finance transport projects. By internalising the external costs caused by heavy-duty road transport, the HVF attempts to e$nsure that the costs of road and rail transport are accurately apportioned. In fact, according to calculations of the extent of the negative externalities, rail transport creates comparatively significantly lower external costs than road transport (Federal Office for Spatial Development ARE Switzerland, 2022). The HVF thus aims to correct a previously inadequately distributed costs of transport.

2.1 HISTORICAL AND LEGAL BACKGROUND

In 1994, a majority of the Swiss population voted in favour of a popular initiative dubbed "Alpen-Initiative", which obliged the Swiss Federal Council to adopt measures to protect the Swiss Alps from the negative effects of goods traffic on Swiss roads (Swiss Confederation, 1994). One of the measures developed to achieve this goal is the HVF. In its dispatch on the 11 September 1996, the Federal Council published a first draft of the law that later became the legal basis for the HVF (Swiss Confederation, 1996).

A central aspect of that law were the external costs calculations of heavy-duty traffic that the Federal Council had commissioned and now were used to justify the implementation of the fee (Swiss Confederation, 1996). According to the calculations of the Federal Council, 47 billion tonne kilometres were annually travelled by heavy-duty vehicles on Swiss roads. The total external costs of these tonne kilometres were estimated to be around CHF 1.15 billion (Swiss Confederation, 1996), which amounted to average costs of CHF 0.025 per tonne kilometre. In order to take into account, the different externalities of cleaner and more pollution intensive vehicles, the Federal Council proposed the introduction of three tariff categories, with prices ranging between CHF 0.016 and 0.03 per tonne kilometre.

Based on the Federal Council's dispatch of 11 September 1996, the Swiss Parliament decided to introduce tariffs ranging between CHF 0.006 and 0.025 per tonne kilometre. Members of Parliament justified the negative deviation from the Executive Proposal by arguing that higher tariffs were not affordable for the transport industry (Swiss Confederation, 1997).

With the conclusion of Bilateral Agreements I with the European Union in 1999, Switzerland was able to anchor the non-discriminatory HVF in Article 40 of the Agreement between the Swiss Confederation and the European Community on the Carriage of Goods and Passengers by Rail and Road of 21 June 1999 (Land Transport Agreement, LTA, SR **0.740.72**). The LTA enables a coordinated transport policy between Switzerland and the EU and recognises the Swiss policy of shifting freight transport from road to rail. In return for the introduction of the HVF, Switzerland agreed to a gradual increase in the tonnage limit for heavy goods vehicles. It was raised from 28 tonnes in 2000 to 40 tonnes in 2005. With the weight limit increase, the maximum tariff of the HVF was raised from CHF 0.025 to 0.03 per tonne kilometre.

Nowadays, the HVF has its legal roots in Article 85 of the Swiss Federal Constitution which states that "The Confederation may levy a capacity or mileage-related charge on heavy vehicle traffic where such traffic creates public costs that are not covered by other charges or taxes." (Federal Constitution of the Swiss Confederation, SR **101**). The HVF is further defined in the Heavy Vehicle Fee Act (SVAG, SR **641.81**) and in the Heavy Vehicle Fee Ordinance (SVAV, SR **641.811**).

2.2 IMPLEMENTATION

The HVF is essentially a fee, the tariffs of which depend directly on three factors: the number of kilometres driven, the maximum gross vehicle weight and the tariff class in which the vehicle is located. Vehicles are put into one of three categories according to their EURO emission class, a European Union vehicle standard targeting local pollutant emissions. Since 1 January 2017, tariffs have amounted to CHF 0.0228 (Cat. 3), 0.0269 (Cat. 2) and 0.031 (Cat. 1) per tonne kilometre. The HVF applies to all journeys on the entire Swiss customs road network made by vehicles with a permissible vehicle weight of more than 3.5 tonnes[1]. The public revenue amounts to approximately CHF 1.7 billion per year.

The HVF tariffs have changed over the years since its introduction in 2001. The fee is calculated as follows. The tariff of the category in which the vehicle is located is multiplied by the distance travelled in Switzerland in kilometres and then multiplied by the weight of the vehicle in tonnes. The result in Swiss Francs is the tax to be paid.

$$Tariff * Kilometres * Tonnes = Tax$$

The tax is best illustrated by a standard journey. The highly frequented north-south axis through Switzerland, from Basel to Chiasso, is 300 km long. In 2022, a 40-tonne vehicle in the cheap Category 1 paid a levy of:

$$0.0228 \frac{Swiss\ Francs}{Tonnes * Kilometres} * 300\ Kilometres * 40\ Tonnes = 273.46\ Swiss\ Francs$$

A transport firm who very regularly undertakes such journeys in Switzerland thus easily pays several tens of thousands of francs per vehicle per year. On the other hand, if the firm transported its goods by train or with vehicles that are lighter than 3.5 tonnes, it would not have to pay any mileage-based fee at all. The HVF is therefore a very specific fee

[1] *Hereafter referred to as "heavy-duty vehicles".*

that targets only one of several plausible modes of transport and thus discourages the use of heavy-duty vehicles.

Understanding how the HVF is calculated is crucial to determine its effects on transportation. This chapter was meant to show in which scenarios the HVF is applied and consequently where one would expect it to have an impact. The next chapter will touch upon the tariff changes of the HVF and how these developments can be used to establish an empirical strategy in order to identify the effects of the HVF on heavy-duty mileage. The HVF is essentially a fee, the tariffs of which depend directly on three factors: the number of kilometres driven, the maximum gross vehicle weight and the tariff class in which the vehicle is located. Vehicles are put into one of three categories according to their EURO emission class, a European Union vehicle standard targeting local pollutant emissions. Since 1 January 2017, tariffs have amounted to CHF 0.0228 (Cat. 3), 0.0269 (Cat. 2) and 0.031 (Cat. 1) per tonne kilometre. The HVF applies to all journeys on the entire Swiss customs road network made by vehicles with a permissible vehicle weight of more than 3.5 tonnes[2]. The public revenue amounts to approximately CHF 1.7 billion per year.

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2.3 TARIFF AND MILEAGE DEVELOPMENT

Since the implementation of the HVF in 2001, the Swiss Federal Council has repeatedly changed the tariffs of the three categories. It has also changed the categorization of the vehicles into the categories according to their EURO emission norms. Such changes are usually reflected in so called downgrades of some EURO emission norms i.e., vehicles of a certain norms have found themselves replaced in a more expensive category. Table 1 shows tariff changes and downgrades since 2001. The numbers in brackets below the tariff values as well as the grey shading signify the category in which the emission standard was placed at the time. Before 2021, IV and V standard vehicles were in category 2. In 2021, they were downgraded to the more expensive category 1. The downgrading of vehicle types into more expensive tariff categories, even though it is formally under the authority of the Federal Administration, is, due to its heavy impact on the bookkeeping of the transport firms, a very politicized decision.

TABLE 1
HVF-Tariff-Changes between 2001-2021. Source: Swiss Federal Office of Transport.

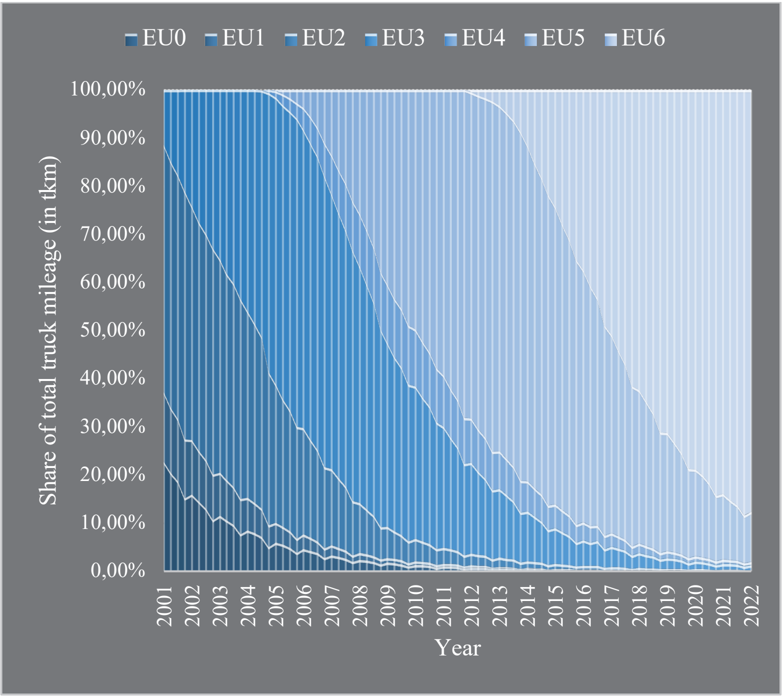
Ct. /tkm	2001	2005	2008	2009	2012	2017	2021
EURO 0	2.00 (1)	2.88 (1)	3.07 (1)	→	3.10 (1)	→	3.10 (1)
EURO I	1.68 (2)	2.88 (1)	3.07 (1)	→	3.10 (1)	→	3.10 (1)
EURO II	1.42 (3)	2.52 (2)	3.07 (1)	→	3.10 (1)	→	3.10 (1)
EURO III	1.42 (3)	2.15 (3)	2.26 (3)	2.66 (2)	2.69 (2)	3.10 (1)	3.10 (1)
EURO IV	-	2.15 (3)	2.26 (3)	→	2.28 (3)	2.69 (2)	3.10 (1)
EURO V	-	2.15 (3)	2.26 (3)	→	2.28 (3)	2.69 (2)	3.10 (1)
EURO VI	-	-	-	-	2.05 (3.5)	2.28 (3)	2.28 (3)

Not all vehicle categories were necessarily downgraded at the same time. Sometimes, the changes affected only one or two categories, while the tariffs for the other categories remained the same. The last downgrade took place in 2021. The EURO VI emission standard had its own category "3.5" as it benefitted from a special discount between 2012 and 2017.

The aim of this thesis is to understand the effect of the HVF on heavy vehicle mileage, in particular how the continuous adaptation of the HVF tariffs has affected heavy vehicle mileage. Since the exact amount of the HVF levied differs according to the EURO category of the vehicle (via the classification into the three tariff categories), it is worth looking at the distribution of the mileage of the EURO categories. Figure 1 shows the distribution of heavy-duty vehicle mileage according to their EURO standard over the years. This graph makes it possible to follow the introduction of standards since 2001 and to see the share in total mileage of each emission standard. It can be seen that when a new standard is introduced, the distribution of vehicles in this emission standard increases until a new standard is introduced. For example, the introduction of the EURO V standard in 2005 was followed by a steep increase in the share of EURO V vehicles that was only stopped by the introduction of the EURO VI standard in 2011. The share of vehicles in the lower standards gradually decreased over time. In 2022, the VI standard was very dominant, while the other standards, except for EURO V, were almost non-existent. The introduction of the EURO VII standard is not foreseen before 2027, which means that a large majority of vehicles will be in the VI standard and thus in the cheapest tariff class until at least 2027 (European Commission, 2022).

As the tariff is directly linked to the EURO emission standard, the HVF has a direct effect within the road transport sector in that the lower-emission vehicles pay a lower levy, thus creating a financial incentive for vehicle owners to invest in cleaner vehicles. It is this exact effect which is currently actively weakened, as most vehicles already are in the cheapest tariff class. As long as this configuration remains intact, the effectiveness of the HVF to promote road vehicles with lower pollution levels is severely limited. This should however not influence the empirical strategy of this thesis as it only uses data until 2017 and before 2017, no EURO emission standard had reached as status as dominant as the one EURO VI had in 2022.

FIGURE 1
**Distribution of Mileage in tonne kilometres by EURO-Categories.
Source: Swiss Federal Office of Transport.**

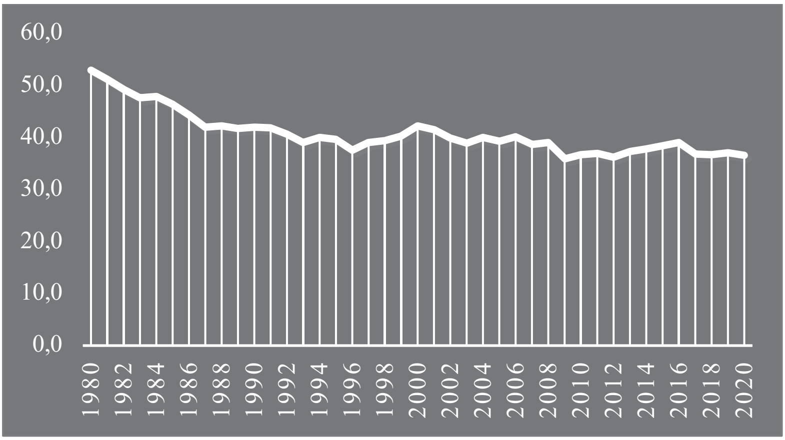


2.4 POLICY ENVIRONMENT OF THE HVF

The Swiss government maintains a number of transport policies that have related goals to the one of the HVF. It is therefore vital to the empirical approach of this thesis to discuss the potentially confounding influence of these policies. Next to the HVF, the Swiss government maintains a number of political instruments, dubbed *Verlagerungspolitik* ("policy of shifting transport from road to rail") to limit heavy-duty road traffic. At the heart of Swiss efforts are the policies designed to reduce traffic on the four alpine crossing points (Gotthard, Simplon, San Bernardino and Grand Saint Bernhard) in Switzerland. It has set itself the statutory target of reducing the number of heavy-duty vehicles crossing the Alps to 650'000 vehicles per year (Article 3, GVVG, **SR 740.1**), a goal that was still unachieved in 2021 (Swiss Federal Office of Transport, 2021). As with the HVF, this goes back to the popular initiative "to protect the Alpine region from transit traffic" which was accepted by the Swiss voting population in 1994 (Swiss Confederation, 1994). With the adoption of the initiative, the expansion of transalpine road capacity became prohibited. To achieve the goals of the popular initiative, Switzerland built the NRLA (New Rail Link through the Alps) and pays lump-sum settlements to any transport firm who is willing to cross the alps by train (Swiss Federal Office of Transport, 2021).

It might be expected that the coexistence of these instruments would make it more difficult to determine the effectiveness of the HVF. As to possible other goals of Swiss transport policy, consider Figure 2, which displays the share of railway of total freight transport.

FIGURE 2
Share of rail freight in total freight. Source: Swiss Federal Office of Transport.



The share of rail freight in the freight transportation modal split has been decreasing slightly since the introduction of the HVF. This goes directly contrary to the belief, that the HVF would decrease the attractiveness of road freight and in turn lead to an increase in rail freight after its implementation in 2001. Of course, this remains a descriptive observation of data – for example, we do not know what would have happened with the modal split if the HVF had not been introduced at all. It, however, implies that the effect of the HVF on the modal split is especially hard to identify. Furthermore, focusing on the modal split would mean to ignore part of the potential consequences that arise when heavy-duty transportation costs increase. Namely, shifting from road to rail is not the only path a transport firm can take. This will be further expanded upon in chapter 3.4.

This small dive into the rail-road modal split discussion shows why it is not fit for further exploration in the scope of this thesis. There is significant benefit to focussing solely on Switzerland's heavy-duty road traffic, as it is a key figure that is clearly defined and directly related to the HVF's levying mechanism.

2.5 THE EXTERNAL COSTS OF HEAVY-DUTY TRAFFIC IN SWITZERLAND

Internalising the external costs of heavy road traffic has always been a central aspect of the HVF (Art. 7 SVAV). In the case of heavy goods vehicles, this refers in particular to the public authorities and people who suffer damage. Just as the Confederation, cantons and municipalities have to cover the deficits of hospitals and social security systems, individual citizens have to pay higher insurance premiums for lung and cardiovascular diseases caused by heavy-duty traffic (Parry, 2008; Suter & Walter, 2001). The owner of a building will have to be content with charging low rents because of the high noise imission or face high costs to combat it. The quality of life of those living along noisy roads also suffers (Federal Office for Spatial Development ARE Switzerland, 2022).

In its yearly publication, the Federal Office for Spatial Development (ARE) calculates the costs and benefits of each transport by mode, including those of heavy-duty vehicles (2022). It reports costs of CHF 3'915 million for heavy-duty vehicles, of which CHF 1'515 million are infrastructure costs and CHF 2'400 million are external costs. On the other hand, ARE reports a total of CHF 2'403 million that were borne by the heavy goods vehicles themselves. Out of these CHF 2'403 million, CHF 1'590 million come from the HVF, the rest from other levies such as the mineral oil tax. This leaves CHF 1'512 million uncovered. The resulting coverage rate of around 61% for 2019 is roughly in line with the level of the last 10 years (between 60% and 65%).

From an economic perspective, this aspect of costs internalisation is highly relevant. By obliging road freight transport to internalise the external costs it causes, an important step is to be taken towards true costs pricing in the transport sector. Due to the increased marginal costs of road transport based on economic theory (more on this in chapter 3.2), a corresponding effect on modal choice in freight transport should be observed. To better understand this effect (or lack thereof), it is worth looking at the decision-making process of a transport company when choosing a mode of transport, which is something that will be examined in detail in chapter 3.4.

This chapter on background offered a broad overview of the functionalities and fundamental ideas of the HVF. It should facilitate understanding of the now following chapter on Literature, especially when it comes to making a connection between the expectations that theory sets for the HVF and the hypotheses that are subsequently postulated.

3 LITERATURE

This chapter aims to present an overview of the existing literature on the external costs of transportation and on political instruments to internalize such externalities. This is done by identifying similarities and differences between the Swiss HVF and similar transport policies that have been or are yet to be adopted. Ultimately, the HVF is to be situated in the economic literature on road pricing. Based on what can be learned from said literature, assumptions can be made about what can be expected from the effectiveness of the HVF. Possible shortcomings in the implementation of the HVF as well as blind spots in the existing literature with regard to the HVF are consequently discussed and incorporated into the research design of this thesis.

Road pricing, charges or fees levied for the use of roads, is an often-discussed subject in economics. A majority of the academic papers focus on the public acceptance and implementation challenges of road pricing policies (cf. Baranzini et al., 2021; Duncan et al., 2017, 2020). A few articles focus on the effects of road pricing, most notably in the shape of congestion charges, in the cities of London and Stockholm (Eliasson et al., 2009; Leape, 2006; Schmutzler, 2011; Sørensen et al., 2014). However, academic literature on the Swiss HVF or on closely related policies, is scarce. The main point of orientation of this thesis is an article by Luechinger & Roth (2016) on the effects of the HVF on road traffic which, while examining the same phenomenon, laid a strong focus on the implementation period and only briefly attempted to estimate any effects that are beyond the immediate. Suter & Walter (2001) wrote a theory-oriented article, examining if the implementation of the HVF bodes well with what would be considered "ideal" from an economic perspective. Besides those two articles, the academic evidence on the subject at hand can be considered anecdotal. This is perhaps due to the fact that the HVF could be considered as a sort of outlier from what is usually discussed in road pricing literature. It cannot be considered as a congestion charge because it is not limited to one geographical location, nor is its official goal to reduce congestion. It also cannot be considered as a toll because it applies to all roads in Switzerland. Furthermore, it does not primarily exist to finance road infrastructure, as a toll usually does. Instead, as elaborated in chapter 2, it was designed to limit heavy-duty traffic in Switzerland. In economic terms, the Swiss HVF does this by internalizing the externalities of heavy-duty traffic. While most of the academic literature focusses on the internalization of externalities, chapter 3.4 contains a conceptual separation of internalization and traffic reduction.

3.1 EXTERNAL COSTS OF TRANSPORT

The existence of external costs is one of the key reasons for the need of government regulation in the transport sector. Transportation, due to its heavy reliance on infrastructure and fuel, is responsible for large amounts of pollutants and greenhouse gas emissions, as well as accidents, congestion and noise (Pigou, 1932). However, the transport sector does not automatically bear the costs of these measures, as they are borne by a wider public. Government policy is therefore needed to ensure that the creation of external costs is appropriately priced so that external costs can be regarded as internalized (Pigou, 1932).

The notion of internalization of external costs, though it only applies to heavy-duty traffic, lies at the core of the HVF. As discussed in chapter 2.4, the Swiss Government has conducted and mandated various research projects on the extent and impact of (positive and negative) externalities created by transportation (Federal Office for Spatial Development ARE Switzerland, 2007, 2015 & 2022). According to their estimates, transportation in Switzerland generated CHF 14 billion in externalities in 2019 of which 72 percent are attributed to road traffic. The biggest cost items are air pollution, noise, greenhouse gasses, and congestion (Federal Office for Spatial Development ARE Switzerland, 2022, p.13). The measurement of external costs is notoriously difficult and based on a plethora of assumptions (Vasallo et al., 2012). For example, calculating external costs of the greenhouse gas emissions is heavily politically influenced, especially when it comes to setting a discount factor for future damages. Furthermore, research in this area is often hard to compare because it focuses on different units or situations. Some scientists focus on heavy-duty traffic, while others analyse household traffic (cf. Parry, 2008; Zhang & Lu, 2012).

According to ARE and several scientific sources, motorised individual transport generates significantly higher external costs than public transport on road or railway would (Federal Office for Spatial Development ARE Switzerland, 2022; Poulikakos et al., 2016; Lalive et al., 2013). Similarly, freight transport produces considerably more externalities on the road than by railway or ship. According to Poulikakos et al. (2016) road freight traffic in Switzerland accounted for CHF 0.071 per tonne kilometre, whereas it was only 0.028 cents and 0.005 cents per tonne kilometre for railway and ship transport respectively. According to Lalive et al. (2013), who examined the effects of increased service frequency of railway transport, improved access to passenger railways in Germany lead to significantly decreases in severe road accidents, nitric oxide emissions and infant mortality rates. The case of Lalive et al. (2013) shows not only that road traffic is significantly more detrimental to public welfare but also that targeted measures (which do not necessarily have to come in the form of road pricing) can correct behaviour and lead to more desirable outcomes for society. Comparatively higher costs of road transportation can either be achieved by subsidizing the more desirable transport modes or by penalizing the less desirable ones, possibly in the shape of road pricing. Parry (2008), who estimated externalities of heavy road traffic in the US, separated them into fuel-related and mileage-related costs and calculated an optimal fuel tax and a truck charge to internalize both of them. Including cost points such as congestion, accident, noise, local and global pollution which are standard additions to such calculations, Perry (2008) presented estimations of externalities of only USD 0.69 per gallon and a truck charge spanning between USD 0.07 and 0.33 per mile. In comparison Zhang & Lu (2012) estimated an average external costs of household traffic numbering between USD 0.077 and 0.091 cents per mile.

In summary, the existence of transportation externalities finds a lot of scientific support. This thesis will from now on only thematize those externalities which are created by road transport, for it is those costs who are also targeted by the HVF. Nevertheless, Vasallo et al., (2012) do well in pointing out that other modes of transport, such as trains, are also causers of external costs. Consequently, should a perfect market allocation be the goal of the policy maker, railway and ship transport should also be subject to a mileage or fuel-based fee, and not be subsidized.

3.2 INTERNALIZING EXTERNALITIES THROUGH REGULATION

Considerable scientific work has been conducted on the effect of public policies on internalizing externalities of transport specifically and on environmental outcomes in general. The potential success of such policies is clear. A survey experiment conducted in the US showed that, if all externalities of private household road traffic were entirely internalized, private household road traffic would decrease by 27.1 percent (Zhang & Lu, 2012).

Schmutzler (2011) divides such policies into subsidies, road pricing and driving restrictions. Subsidies encompass schemes that, for example, fund public transportation networks to incentivize the use of low emission transport modes as opposed to motorized private transport. Driving restrictions on the other hand consist of measures that inconvenience those modes of transport who are more polluting, by imposing speed limits or closing off certain areas completely.

Schmutzler (2011, p. 527) calls policies road pricing if they attempt to disincentivize a certain non-desirable behaviour by imposing costs in the form of taxes, charges, or fees. Road pricing can be applied locally, as it is the case in London, where its main goal is to reduce time costs in form of congestion (Leape, 2006). When it comes to road pricing, it is important to differentiate between policies that have an actual behavioural (and hopefully environmental) impact and policies, that solely aim to finance infrastructure, such as toll roads. Road tolls' main goal is to finance the infrastructure for the use of which the toll is levied, which does not imply any behavioural change. The HVF is a particular case in the sense that it is not applied locally, i.e. it does not intend to reduce congestion in one singular area, nor is it solely designed to finance road infrastructure (Federal Office for Spatial Development ARE Switzerland, 2015).

In economic literature, road pricing is generally thought of as a theoretically well-developed, suitable instrument to internalize externalities of road transport (Sørensen et al., 2014; Suter & Walter, 2001). The causal mechanisms of road pricing are so evident that the impact chain through which the policy aims to disincentivise a certain type of behaviour is barely ever elaborated upon (cf. Luechinger & Roth, 2016; Schmutzler, 2011). Although easily summarized under the overarching goal of internalizing external costs, the design of road pricing policies can have a lot of nuances. Mileage-based road pricing will be most effective to reduce mileage-based externalities, such as noise or congestion, whereas fuel-based taxes will be most effective at reducing greenhouse gas emissions (Parry, 2008). Congestion charges will target traffic in small and pre-defined areas, whereas nation-wide road fees will have less-easily localizable effects (Glaister & Graham, 2005). Defining the "price" in road-pricing is also something to be heavily considered. Obviously, setting it as close as possible to the monetary value of the external costs of every single vehicle-trip is ideal, but this is technically impossible.

A large part of the existing literature on road pricing either highlights the political and technical difficulties of its implementation or sets a focus of the mostly negative effects of congestion charges on road transport externalities. According to Suter & Walter (2001), road pricing policies in the transport sector are generally rare, because they are hindered by technical implementation problems as well as limited political acceptance. Despite the fact that technology has come far since then and technical implementation problems probably have diminished significantly, the political climate has not changed much. According to Duncan et al. (2017, 2020), road pricing is still very unpopular which requires policy makers to adopt strategies aimed at increasing acceptance of such measures. This may lead to political compromises that are imperfect from a theoretical perspective. Despite their unpopularity, a number of road pricing policies have been successfully implemented, a number of which are presented in the following.

Leape (2006) paints a broad picture of the London congestion charge, a flat charge paid by any car that moves within a pre-defined zone that consists of the central boroughs of London. The introduction of the congestion charge was reportedly very effective as it leads to a decline in the number of incoming car traffic by around 33 percent (Transport for

London, 2005). Similarly, Eliasson et al. (2009) found that the 2006 congestion charge in the heart of Stockholm found great success. Traffic crossing the cordon of the charge reportedly decreased by 22 percent during the 6-month trial period and total traffic in terms of kilometres in the inner city decreased by 15 percent. As the average charge paid in Stockholm was about half of what was paid in London, 5£ and 28 SEK per vehicle and day, elasticities to the charge regarding the decrease in kilometres driven seem to be very similar in both locations (Eliasson et al., 2009). Interestingly, as the Stockholm congestion charge was only temporary, it was possible to observe how traffic would behave after the congestion charge was abolished. Traffic rose again significantly, but stayed around 8 percent below old levels, implying that the charge had a lingering effect. The remarkable success of the Stockholm congestion charge then swayed public opinion on the matter in such a way that a referendum in 2006 lead to permanent reinstatement. (Transport & Environment, 2006). Further congestion charges exist in the Norwegian cities of Oslo, Bergen and Trondheim and in Singapore, with reported similar successes as those in Stockholm and London (Ieromonachou et al., 2006; Schmutzler, 2011; Tvinnereim et al., 2020). Ison & Rye (2005) mention trials for congestion charges in Hong Kong and Cambridge, which were not implemented successfully due to a lack of political support.

Generally speaking, the existing literature highlights that road pricing is highly unpopular and therefore hard to implement. This is why implementations of road pricing are often not ideal from a theoretical perspective. Instead, they are a compromise between what is optimal based on economic theory, and what is feasible according to public support. The Swiss HVF fits well into that because, even though theory would argue for an ubiquitous implementation, it only applies to heavy-duty vehicles above 3.5 tonnes. This coincides well with the literature, because the exemption of camionettes and passenger cars from the HVF embodies the sort of compromise that is needed to make the political implementation of road-pricing work.

3.3 SETTING EXPECTATIONS FOR THE SWISS HVF

There are some academic papers which analysed or at least took note of the existence of the HVF. Combining their findings and the generalizable expectations from other applications of road pricing such as those in London and Stockholm, this chapter aims to condense expectations for the success of the HVF.

When they analysed it at the time of its implementation in 2001, Suter & Walter concluded that the HVF was an "imperfect but sufficient implementation of environmental pricing", that it was supposedly one of the best applications of theoretical suggestions and that it would consequently set appropriate incentives to reduce heavy-duty traffic on Swiss roads (Suter & Walter, 2001, p.395). Other scientists offer a more critical view. Vasallo et al. (2012) suggest that it is undesirable that the HVF only targets vehicles above 3.5 tonnes, thereby leaving a majority of road vehicles untouched, despite those vehicles also creating negative externalities. This has important implications which will be discussed in chapter 3.4. Also worth talking about is what Eliasson et al. (2009) listed as accompanying measures to make sure that sufficient alternatives would be open to people who would like to switch away from private road transportation as a result of the implementation of the Stockholm congestion charge. At the time, the Stockholm municipality introduced 16 new public bus lines, stocked up on the existing ones, increased local railway capacity and improved the existing Park and Ride facilities around the city's outskirts. When Germany introduced its highway truck charge in 2005, the lack of an effect on traffic was attributed to a lack of suitable alternatives, and the charge instead contributed to a swifter renewable of the trucking fleet and consequently to better emission standards (Broaddus & Gertz, 2008).

The research project most similar to this thesis is an article published in 2016 by Luechiger and Roth. They find that with the introduction of the HVF, the number of trucks on Swiss roads declined by 4 – 6 percent, using a regression discontinuity design (Luechinger & Roth, 2016). They find "no significant effects on car traffic, on time-shifted placebo policy changes or for traffic diversion to neighbouring countries, but suggestive evidence for an increase in rail freight traffic." (Luechinger & Roth, 2016, p.2)

They address the simultaneously happened increase of the maximum permissible total weight for trucks from 28 t to 34 t to 40 t. They also state that "In interpreting our results, it is important to note that the increase of the permissible total weight is likely to have strengthened any negative effects of the heavy vehicle fee on traffic volume." (Luechinger & Roth, 2016, p.3) This is probably due to the fact that they measured traffic volume in the number of trucks that were active on any given day. This is a weakness in their approach, as the HVF tariffs are calculated using tonne kilometres, meaning heavier vehicles pay a higher tax. When measuring the effectiveness of the HVF, using tonne kilometres instead of vehicle numbers would therefore be a more precise approach. Additionally, Luechiger and Roth (2016, p. 7) did not manage to filter out vans from their data meaning that their outcome variable, mileage, is diluted by vehicles that are not subject to the HVF.

Since their use of a regression discontinuity design only addresses short-term responses to a policy shift and can be biased by anticipation effects (Lee & Lemieux, 2010), Luechiger and Roth (2016) complement their analysis with estimates based on the synthetic control method. There, they find a negative effect of the mileage tax on heavy-duty traffic density that is similar to the regression discontinuity estimates. However, with placebo tests, they find, that this effect is not statistically significant. In sum, their two approaches (RDD and Synthetic Control Design) yield weakly significant and insignificant reductions in traffic of around 5 percent. In sum, their approach led to some fruitful results concerning the introduction of the HVF in 2001 but not concerning the time after that. This is thus the area where this thesis aims to make a scientific contribution.

3.4 WHY THE HVF MIGHT STILL FAIL

This chapter serves to discuss the theoretical implications that have been presented the previous chapters. It concerns the expectations it sets for the success of the HVF. It also includes an expansion of some reflections that were only briefly touched on by the literature but still are very important when it comes to hypothesizing, how well and in what ways the HVF had an impact on heavy-duty mileage in Switzerland.

The existing and further above elaborated scientific literature is rather shallow when it comes to exploring adaption strategies for private actors due to institutional change. For example, Leape, (2006) would go into considerable detail on how the London congestion charge was designed and enforced, but he does not discuss how the incentive effect of the charge *works*. Luechinger & Roth (2016) provide fascinating insight into the economic repercussions of the introduction of the HVF, but do not barely deliberate, why the HVF would lead to decreased heavy-duty mileage in the first place. Instead, the underlying model on the effect of a charge on behaviour is implicitly included. Of course, activity of X will decrease when the cost of X increases. However, this assumption is not sufficient for a detailed analysis of the decision-making process influenced by the HVF. The following paragraphs aim to shed light on the decision that truck holders in Switzerland were faced with when they learned of an increase in the tariff of one or several emission categories.

From a macroeconomic perspective, any increase in costs of a certain activity should lead, everything else held constant, to a decrease in said activity. While this should certainly be true for the HVF and heavy-duty mileage in Switzerland, lots can be learned by exploring how the HVF functions, i.e., how any concerned actor can possibly react to it. The increase in the marginal costs of heavy-duty road transport, which we observe with both the introduction of the HVF and any declassification of one or several tariff categories, can basically have three consequences for any given transport service, determined by the decision of the service provider:

1) The provider shifts the service away from heavy-duty trucks.

2) The provider continues to provide the service on heavy-duty trucks despite the increased costs.

3) The provider no longer provides the service at all.

Two of the three options listed here lead to a decrease heavy-duty traffic, one of the three does not. Under what circumstances do we arrive at which option?

Option 1 – Successful reduction of heavy-duty mileage

Based on the political intentions of the HVF, the reduction of heavy-duty traffic, option 1 represents the desired outcome. While it is hard to draw a universally applicable solution, in most of these cases the fee presumably does what it is supposed to do: It corrects the marginal costs of road transport in such a way that external costs are sufficiently internalized and other transport modes are now cheaper. However, this represents a narrow point of analysis – as option the following elaborations on options 2 and 3 will show, it is entirely feasible for the HVF to work as intended, without actually reducing heavy-duty mileage.

The HVF is also reduces heavy-duty traffic when actors switch from trucks to camionettes. Camionettes are loosely defined as cargo transportation vehicles weighing below 3.5 tonnes. They are not subject to the HVF, though there was an inconclusive parliamentary debate on the subject (Swiss Parliament, 2020). They of course still produce external costs and are, especially for shorter distances, a very valid alternative to trucks. Any shift from trucks to camionettes can thus be described as undesirable, as even though the amount of trucks decreases, the internalization of external costs suffers (Vasallo et al., 2012). Camionettes create externalities, too, but without having to internalize them. Broaddus and Gertz (2008) observed a similar phenomenon in Germany, where the number of vehicles just below the cut-off for the truck toll skyrocketed after its introduction. There is however no data on the prevalence of camionettes in Switzerland – though the Federal Statistical Office is presently on it (2022) – which means any shift towards them cannot be accounted for.

Option 2 – Unchanged heavy-duty traffic

Cases that end up in option 2, are those instances in which any given service is continuously provided on the road. One would think that the HVF has, in this case, failed. This is not necessarily true – depending on the configuration of the case, it is economically justifiable and comprehensible, that no change in mode would occur. In other words, the HVF might have successfully internalized the external costs, without changing behaviour.

One has to keep in mind that such a shift of mode is not always possible. Even though Switzerland's rail network is comparatively dense, it does not span to all parts of the country. Furthermore, rail capacity is not endless, in fact, the Swiss railway network is very densely utilized, especially along the main transport (Swiss Federal Railways, 2022). These factors also influence the comparative costs of rail and road transports – if, for example, rail transport is only possible to a place that is nearby but not exactly where the transported goods should go, and consequently, the goods would need to be transferred to road vehicles to cover the last mile, resulting in overall higher costs of transport than if the entire distance had been covered by road vehicles.

Thus, it is entirely feasible that the external costs of road transport are successfully internalized, i.e., market prices have been adequately corrected but the road remains cheaper than rail. While it remains debatable that the internalization of the external costs truly worked out (per the calculations of the ARE, the HVF only covers about 62 percent of them, see chapter 2.5), we end up with cases in which the HVF did what it could but to no avail, as the transport service remains to be provided on the road.

Then, as mentioned in chapter 2.3, HVF tariffs depend directly on the EURO norm of the corresponding vehicle. In 2022, companies in possession of vehicles of the EURO 0 – V standards could invest into cleaner EURO VI vehicles to reduce the fee they pay by roughly 30 percent. In other terms, the HVF might not necessarily prompt companies to shift to rail transport but instead to cleaner road transport. Looking at it from an external costs perspective, this is a desirable outcome as cleaner vehicles effectively produce lower external costs. It would also be consistent with what Broaddus & Gertz (2008, p. 111) meant, when they found that, in Germany, the truck toll lead to a "clear shift (…) toward trucks with better emission standards." When asking the question whether increased marginal costs for road transport through the implementation of a fee successfully reduces road transport and/or increases rail transport, this constitutes a confounding factor. It does not necessarily mean that the HVF is an ineffective policy instrument. It could however mean, that it does not work in the way it was intended.

By now, two major arguments have been made, why the HVF may not lead to the desired result (being option 1) whilst not being entirely ineffective. There also exist cases in which the HVF is entirely ineffective. As mentioned earlier, the HVF does not do a perfect job at internalizing external costs. Per the calculations of the ARE, only about 62 percent of all external costs created by heavy-duty road traffic are covered by the fees (Federal Office for Spatial Development ARE Switzerland, 2022). While hard to estimate, this leaves a theoretical bundle of cases that would have shifted to rail transport, had the remaining 38 percent of the external costs been internalized as well. This could very well happen in a case where a modal shift is neither hampered by lack of rail infrastructure, nor is the steering effect absorbed by a change of vehicle (because, for example, the company already uses vehicles of the cleanest EURO norm). When, in later chapters of this thesis, a price elasticity on heavy-duty mileage is estimated, it will be possible to estimate, just how big the potential of a modal split is, if the HVF tariffs were raised to a degree that 100 percent of the external costs are internalized.

Option 3 – Suspension of the service

A third option lies within the suspension of the service. The service is no longer provided as the possibility of modal shift is not available to it for certain reasons and continuing to provide the service by road no longer generates a profitable result. As these services cease to exist without showing up in data on either road or rail traffic, they are hard to identify. While they do not represent the initially intended outcome of the HVF, from an economic perspective they can still be considered a success. Being services that were only provided due to an imperfect market configuration, their omission is economically desirable. When it comes to methodology and results of this thesis, whatever possible will be done to account for these cases.

The service, if it is not domestic, can also to cease to lead through Switzerland but instead lead through a neighbouring country. Spatial diversion is a serious confounder when the target of the fee is long-distance transportation with well-defined alternative routes. It is less of an issue with local road pricing such as London or Singapore (Schmutzler, 2011), which explains why it was not mentioned in the literature but very much is an issue here. From a holistic and European perspective, this should be considered the outcome of the policy that is least desired. There is no change in transport mode nor are there investments into cleaner vehicles. Instead, the service presumably follows a route that is longer yet cheaper, in turn leading to a more inefficient market with higher external costs.

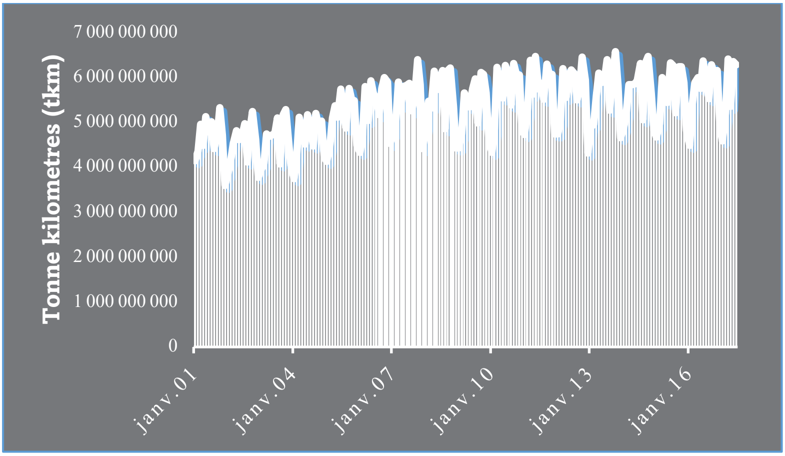
Lastly, not nearly every transportation company in Switzerland can be described to have a disposition that allows them to quickly adapt to changes in the institutional environment. Specifically small companies, only in command of a few trucks, will only be able to adapt their behaviour every few years. The service life of a vehicle is about 8 years, so if a company owns 4 vehicles, it will buy a new truck approximately every other year. Those companies are thus not able to adapt their behaviour in a pace that one would expect. Small truck holders might not have the resources to strategically plan ahead for tariff changes and are therefore not as responsive to changes in policy as we would expect. To go even further, small transport companies face serious financially challenges with the implementation of a charge and may, partially, disappear from the market (Doll & Schaffer, 2007).

These lines were meant to illustrate the difficulty in creating an unambiguous and successful HVF. There is a handful of reasons why a simple increase in marginal costs of heavy-duty transport will not necessarily lead to a decrease in heavy-duty mileage. These considerations must be kept in mind when it comes to understanding empirical estimates of the effect of the HVF.

4 RESEARCH DESIGN

When looking at the total heavy-duty mileage expressed in tonne kilometres, one cannot help but jump to the conclusion that the HVF had no visible effect on traffic volume at all or even made it increase. Yearly tonne kilometres increased from about 55 billion in 2001 to about 69 billion in 2017 (Figure 3).

FIGURE 3
Evolution of Tonne kilometres over the period of 2001 to 2017. Source: Swiss Federal Office of Transport.



As Luechinger & Roth (2016) wrote, traffic volume, expressed in the amount of cars on the road, decreased by about 5 percent with the introduction of the HVF. Ever since, the amount of tonne kilometres travelled by trucks has slowly increased. Does this mean that the HVF is not working properly? Probably not and not only because we do not know how traffic numbers would have been in these past 20 years, had the HVF not been introduced. A plethora of other factors also influence the development of road mileage, not just the introduction and modification of the HVF. This is why the regression discontinuity design computed by Luechinger & Roth (2016) was an elegant solution. Thanks to their statistical approach, they were able to isolate the effect of the introduction of the HVF at the cut-off point in the data.

However, this thesis does not concentrate on the singular effect of the HVF at its introduction as this question has been sufficiently answered by Luechinger & Roth (2016). Instead, the focus lies at the question, whether the measurements of the Swiss Government, i.e., the downgrading of certain emission standards, that were taken ever since the introduction of the HVF have had an effect on traffic mileage, too. Also, as discussed in chapter 3.4, ceasing to transport on the road is not the only feasible reaction to increased transportation costs. Interestingly, investing in cleaner vehicles to reduce the HVF-payments is also an option. Cleaner vehicles are identified by their EURO emissions standards. This is why this thesis will also try to find out if the downgrading of emission standards leads to a cleaner truck fleet.

Hypotheses

Is the HVF an effective instrument to reduce heavy-duty mileage on Swiss roads? The subject at hand offers several pathways into exploring effectiveness of the mileage fee. Economic theory predicts that internalizing external costs will increase marginal costs of road transport so that instead other modes of transport that embody a societally more desirable outcome will be chosen (Pigou, 1932). It is also possible that an existing transport route will be abolished because it turns out to be unprofitable. Said outcome is not necessarily an unwanted side effect of the mileage tax as the internalization of external costs actually corrects a behaviour that was economically undesirable, as because it netted lower profits than it induced costs. This leads to the first hypothesis:

H1: The HVF has a negative effect on heavy-duty mileage on Swiss roads.

This hypothesis concerns the general relationship between the HVF and heavy-duty mileage on Swiss roads. It does not differentiate between tariff classes and it does not focus on specific time periods, as the next two hypotheses do.

The vehicles obligated to pay the HVF are separated into different categories whose tariffs changed over time, though not necessarily at the same time. In other words, there is considerable variation in the relationship between heavy-duty mileage and tariff levels, and said variation conveniently appears at different points in time for the different tariff categories. As a matter of fact, after 2001, HVF tariffs underwent significant price changes. These would sometimes happen across the board (i.e., for all tariff classes) and sometimes just a fraction of the tariff classes would be concerned. These changes all signified changes in marginal costs for road transport and should consequently have affected heavy-duty mileage, too. This leads to the second hypothesis:

H2: An increase in tariff in any of the tariff classes will reduce heavy-duty mileage of that tariff class.

Identification of the effect of the HVF on heavy-duty mileage is challenging, as there are various confounding mechanisms that need to be identified and extracted from the analysis. For example, if the tariffs of only a fraction of the tariff class change, truck holders will not necessarily be inclined to move towards other modes of transport but instead invest in trucks of other, comparatively more profitable tariff categories. At the same time, it is hard to imagine that such a shift would go towards categories that consist of older, dirtier trucks and are therefore more expensive. Instead, truck holders will most likely invest in newer vehicles that are placed in cheaper categories. This is why a third hypothesis is postulated:

H3: *A change in tariff will shift heavy-duty mileage from the now more expensive tariff classes towards cheaper tariff classes.*

5 METHODOLOGY

The aforementioned hypotheses are to be tested using a set of various econometric approaches. The available data suggests conducting a linear regression using a fixed-effects estimator to account for unobservable, time-unvarying factors of the EURO categories of trucks. But due to the existence of several moments in time, where an alteration of the HVF induces a change of tariffs for some or for all trucks, using a RDD (Regression Discontinuity Design) also seems viable. Thus, several attempts at capturing the effect of the HVF on heavy-duty mileage will be made and subsequently weighted against each-other.

However, some points have to be made to ensure that the present approach is not tautological. Evidently, there are other reasons for private actors to invest into newer vehicles apart from lower HVF fees. More precisely, vehicles belonging to newer EURO Norms (and consequently pay lower HVF tariffs) will enjoy higher purchases because such vehicles are also cheaper to maintain, use less fuel and offer more functionalities and comfort for their drivers. The effect of a change in HVF tariffs on the number of kilometres travelled by vehicles in a specific tariff class should be especially observable in the years in which tariff changes happened, and factoring in anticipation effects, slightly before the change as well.

First, however, the various economic instruments and general aspects of regression analysis will be discussed.

5.1 LINEAR REGRESSION WITH FIXED-EFFECTS

Estimating a linear regression with fixed-effects is the most straightforward approach to identify an effect of the HVF tariffs on heavy-duty mileage. Using fixed-effects is quintessential to this approach. The empirical strategy of this thesis builds on the assumption that traffic mileage numbers in the various tariff categories, which serve as entities in the panel data, are behaving similarly, except for the fact that their tariffs change at different times and that their behaviour is time lagged. In other words, mileage data of any emission category follow a similar trajectory that reacts similarly to price shocks, it just happens to be that these trajectories are shifted in time. When estimating the impact of the

HVF on traffic, it is therefore vital that the different tariff categories are considered separately. For this reason, unit fixed effects will be included in the regression design.

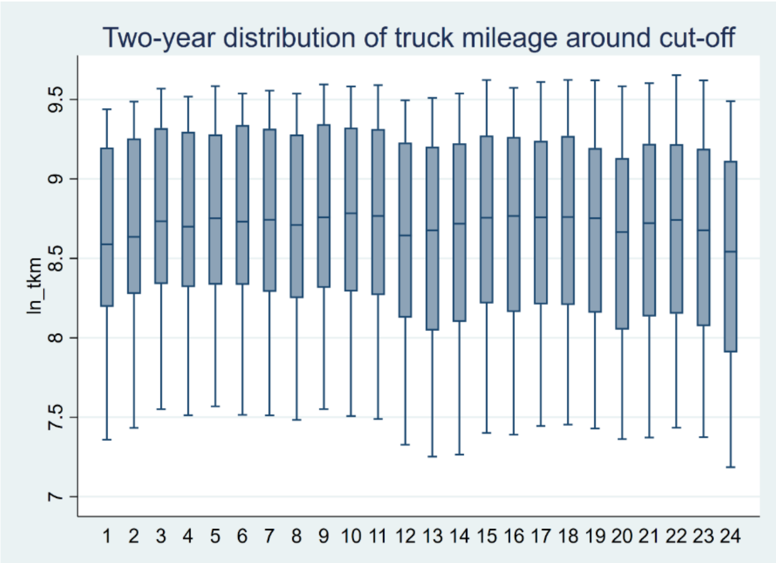
Fixed-effects do not only address the issue of time-lagged trajectories across entities, they also have other benefits. By including them, it is possible to control for factors that vary between units but do not vary over time. These could for example be systematic ascertainment errors for certain EURO categories. Some of these factors might be unobserved or unmeasured and could therefore not be included in the regression at all.

5.2 REGRESSION DISCONTINUITY DESIGN

The idea to use an RDD to estimate the effect of the HVF on heavy-duty mileage is not entirely new. Roth and Luechiger (2016) use it to study the cut-off point created by the introduction of the HVF in 2001. Though a sensible choice, 2001 is not the only point in time, where RDD can be applied. After all, there exist 6 other time stamps, where the HVF tariffs were changed for some or all emission standards. These time stamps can serve as cut-off points for the vehicles that were in emission standards that saw their tariffs change. Using RDD makes the most sense where the possibility of self-selection for truck holders is the lowest. Those points in time where tariffs were increased across the board are less sensitive to self-selection as the possibility of investing into trucks that belong to more "attractive" categories is lower. Figure 4 shows the distribution of tonne kilometres, over the course of two years. The first dozen of months represent the year before a tariff change, the second dozen of months the year after a tariff change. Only data on the emission standards that were affected by a tariff change was included.

Using RDD is very helpful when it comes to addressing the fact that heavy-duty traffic expressed in mileage has steadily increased over the last 20 years. As HVF tariffs have only been on the increase over the same time span, it is difficult to estimate a casual effect of the tariffs on mileage with an OLS regression. Even more so, the estimates of said regression might come out with a positive correlation between tariffs and mileage, which would go directly contrary to what hypothesized. Instead, the inclusion of an RDD makes it possible to isolate the hypothesized negative effect of a costs increase in the form of tariffs on heavy-duty mileage.

FIGURE 4
Distribution of heavy-duty mileage over the year before and the year after a tariff change. Source: Swiss Federal Office of Transport.



There are two caveats to this procedure. The data on heavy-duty mileage is only available for month quarter of the year, which means that the cut-off can only be defined in between two of such months, and not be more narrowly defined. This is not necessarily an issue however, because, as mentioned in chapter 3.4, truck owners are expected to react rather slowly to costs changes, mainly because they cannot quickly renew their entire vehicle fleet. In other words, even if it had been possible to calculate an RDD that only encompasses a few days before and after the change in tariffs, it is unlikely that one would find a substantial effect on heavy-duty mileage. The other caveat lies with the fact that heavy-duty mileage over the course of a year follows a modestly visible cyclicality, which was displayed in Figure 4. There is a considerable uptick in mileage some of the months, while mileage for other months is far below the average. With the mileage for the few last months before new-year being visible higher than for the first months of the new year, an RDD with just these months will essentially be meaningless, because it will always yield a decrease in mileage for every year, no matter if there was a tariff change or not. Instead, to account for both the cyclicality and the slow adaption processes of truck holders, the RDD is calculated comparing each month of the year before the tariff change with each month of the year after the change. This way, one tariff change provides for twelve cut-offs for the twelve month-dyads. The cut-offs between the month-dyads are normalized to generate one big cut-off and estimate an average local treatment effect of a change in tariffs. Monthly rather than quarterly data are used to best reflect the cyclical nature of heavy-duty mileage.

To use RDD, two assumptions have to hold:

(1) Entities on either side of the cut-off have to be similar, which means that aside from the treatment, they should have similar baseline characteristics. This could be tested by doing a regression discontinuity graph with a pre-treatment characteristic on the y-axis and time on the x-axis. This is not an issue in the present approach, however, because the entities on both sides of the coefficient are the same.

(2) There is no sorting around the cut-off, meaning that entities do not manipulate the cut-off to get the treatment. This is highly unlikely in this example because the cut-off is across time, meaning that the only way of manipulation is by highly concentrating your activities on the quarter of the year before the cut-off so that you do not need to do them after the cut-off. Again, this is unlikely to happen to transportation companies as they are often not responsible for the planning of their activities and instead work on a contract basis.

5.3 CONTROL VARIABLES

Control variables are included in linear regression models to control for the influence of other variables that might be related to both the dependent variable and the independent variables of interest. This serves primarily to isolate the presumed relationship between the chosen set of variables. Due to the usage of fixed effects, some confounding influence of omitted variables is already addressed. With the inclusion of fixed-effects, if an omitted variable does not change over time, then any changes in Y over time cannot be caused by the omitted variable.

Omitted variable bias occurs when the relationship between dependent and independent variables is either under- or overestimated due to an under-specification of the regression model (Angrist & Pischke 2009, p. 46). If the omitted variable holds significant influence over both X and Y, the influence that the omitted variable holds over Y will instead be attributed to X. Depending on whether the effect of the omitted variable on X and on Y, and the effect of X on Y is positive or negative, the estimated effect on X on Y will be upward or downward biased. Regression models can easily be over specified, meaning that a regression model is composed of too many variables. Bad controls, which are variables that should rather be considered as outcome variables in the model at hand, are often the cause of overspecification (Angrist & Pischke 2009, p. 47). In the present empirical approach, a good example of a potentially bad control would be fuel prices. Even though it is a credible assumption that fuel prices do have an effect on heavy-duty mileage, it is also feasible to assume that higher fees will decrease mileage and, in turn, lead to lower fuel prices due to decreased demand. In such a case, fuel prices are endogenous to the relationship between fee changes and heavy-duty mileage and will introduce possible collinearity issues. This is contrary to Roth and Luechiger (2016), who nonetheless opted to include fuel prices as controls.

Subsequently, a number of further variables that could potentially cause omitted variable bias will be discussed. Economic Indicators such as GDP, industrial production, unemployment rates are not useful in the chosen empirical approach since their influence is highly likely to be constant across tariff categories. To add to that, due to the close relationship between transport activity and economic growth, the inclusion of variables such as GDP may absorb most of the effect that is to be isolated. Weather conditions, as used by Roth and Luechiger (2016) are important determinants of traffic, but they mostly cause daily fluctuations. Since the data used was collected monthly data, weather should not play an influential role. Lastly, time-related variables to capture time trends or cyclical patterns in traffic behaviour are already accounted by the RDD design that specifically addresses the cyclicality of heavy-duty mileage across a year.

5.4 REJECTED METHOD: DIFFERENCE-IN-DIFFERENCE DESIGN

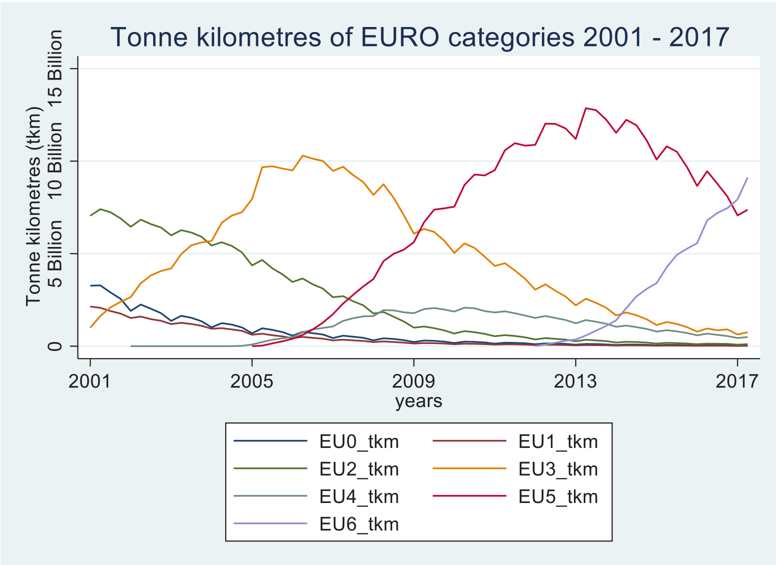
At first sight, applying a difference-in-difference model to estimate the effect of the HVF on heavy-duty mileage appears to be a sensible approach. Mileage numbers of the EURO standard categories follow parallel trends, lagged by a few years. Any effect of a change to tariffs could then be identified by a deterioration from the trend. The issue to this idea is that there is never a control group. It is always all vehicles of an emission standard who are targeted by a tariff change and most of the time, all emission standards were targeted by a tariff change at the same time (as seen in Table 1). Hence, the parallelism is never broken, and the application of a diff-in-diff is not feasible.

6 DATA

The data used in this thesis was provided by the Swiss Federal Office of Transport. It was initially collected by the Federal Office for Customs and Border Security FOCBS Switzerland who is responsible for the implementation and the levying of the HVF. Consequently, the data is directly derived from all the HVF payments that were made by private actors. This is very satisfactory source because, even though there might be some rogue trucks on Swiss roads who do not pay the HVF, the available data consists of exactly those payments that were made and therefore should have had an effect on mileage.

The data is available for the years 2001 (introduction of the HVF) – mid-2017. It contains information on the mileage of the seven different EURO categories of heavy-duty trucks and is available monthly. It can therefore be treated as a panel data set with the seven entities EURO 0 – VI during a time span of January 2001–June 2017. The panel is not balanced as the EURO IV emission standard was only introduced in 2002, EURO V in 2006 and EURO VI in 2015. Mileage in the data is available in both vehicle and tonne kilometres. For vehicle kilometres, the data is however only available from 2005–2017. Figure 5 displays the recorded tonne kilometres of the seven EURO categories over the entire timespan of the data.

FIGURE 5
Tonne kilometres of EURO categories from 2001–2017. Source: Swiss Federal Office of Transport.



In addition, a second data set of the tariff prices of the seven EURO categories across the time span of the data was collected. This was done using the bi-annually published "Verlagerungsbericht" of the Federal Office for Transport OFT Switzerland where all changes in tariffs were published (cf. Swiss Federal Office of Transport, 2021). All mileage values were transformed into their logarithmic form as their numbers easily reach billions and are consequently hard to grasp. In order to conduct an RDD, a variable called "Cut-off" was created, which takes "0" when the observation is within 12 months before a cut-off, "1" if the observation is within 12 months after a cut-off and no value if the observation is further than 12 months away from a cut-off. Luckily, no emission standard saw its tariffs changed more than once within the same 24 months, which means that there is no observation for which the variable "Cut-off" would have to take two separate values.

6.1 DISCUSSING DEPENDANT VARIABLES

When it comes to measuring the effectiveness of the HVF in reaching its goals, one needs to define those goals first and it is not an entirely unambiguous thing to do. Surely, the HVF aims to reducing heavy-duty traffic. But the idea behind reducing heavy-duty traffic is also linked to the reduction of external costs.

Starting out with the reduction of heavy traffic, the choice of which variable to measure it with is not obvious. Traffic can be measured in several ways. Perhaps the most obvious choice is to look at the formulated political target: to reduce the annual number of vehicles crossing the alps below 650’000 – a key value that is published every other year by the OFT in its reports on the effectiveness of the “Verlagerungspolitik” (Swiss Federal Office of Transport, 2021). Using this measurement comes with two main flaws. Firstly, it only includes traffic crossing the alps. The HVF however also covers voyages made through any parts of Switzerland that do not include any of the four main alpine crossing points (Grand St. Bernard, Simplon, Gotthard, and San Bernardino) and those voyages are not included in the 650’000. Parts of the effectiveness of the tax are therefore excluded if this measurement was to be used. Secondly, it only covers parts of the economic considerations made by private actors when deciding whether they transport by rail or road and furthermore which vehicle type they deploy. Since the tax is calculated not only based on kilometres but also on weight and emission category of the vehicle, the effect of the tax can also be captured by the decision to use heavier trucks (up to 40 tonnes are allowed) or trucks generating less harmful emissions (up to EURO 6). That is to say the tax can, to a certain extent, have an effect despite the total amount of alpine crossings staying the same, as was also elaborated upon in chapter 3.4. To add to this, the HVF is not a flat charge that, for example, is paid by every truck crossing the Alps but is instead a mileage-based fee. It would therefore be more fitting to operationalize the density of heavy traffic with a mileage-based variable.

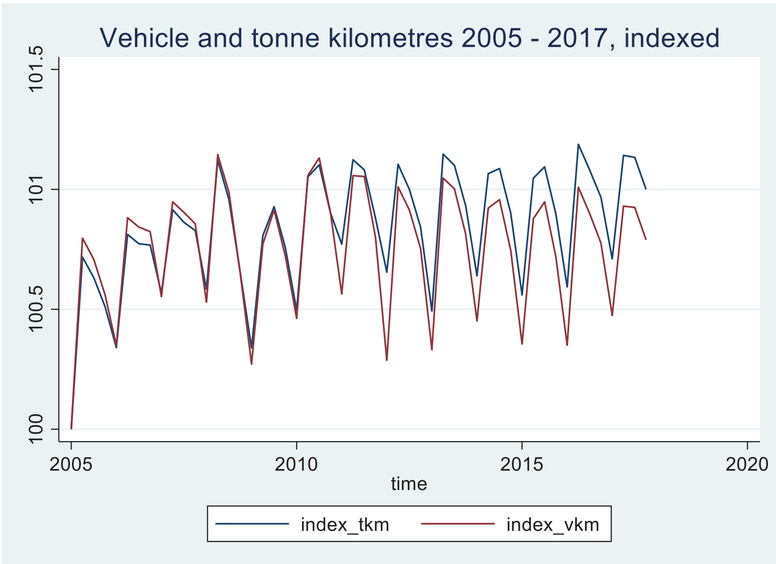
Furthermore, when discussing the effectiveness of the HVF and specifically the choice of the dependent variable to operationalize said effectiveness, one must not neglect factors stemming from external costs. For example, the number of truck trips is not completely unfit as a dependent variable if you want to approximate accidents or traffic congestion costs of truck transports. A much better approximation, however, is the number of kilometres covered by trucks as it essentially a more precise estimate of the same thing – if you assume, that the amount of air pollution, noise, accidents etc. increases linearly with the amount of distance travelled by trucks. According to calculations made by Swiss Authorities, this is a reasonable assumption to make, if one accounts for the emission standards of the vehicles (Federal Office for Spatial Development ARE Switzerland, 2022).

6.2 TONNE KILOMETRES V. VEHICLE KILOMETRES

Having discussed as to why simply considering the total amount of heavy vehicle trips taken through the Swiss Alps falls short of answering the question at hand, we will turn to mileage-based variables, of which there exist two variants: tonne and vehicle kilometres. Vehicle kilometres are defined by the amount of distance a vehicle travelled, whereas tonne kilometres are defined by the distance travelled times the weight of the vehicle. Both iterations address the previously stated problems of not covering all vehicle trips made in Switzerland. It is however only the measurement in tonne kilometres that will also capture a potential trend towards the use of heavier trucks. It is also tonne kilometres that the calculation of the tax is based upon. Economically, it is hence the variable that should be most directly influenced by a change in tax. Vehicle kilometres on the other hand are a more precise measurement of the cause of external costs as especially accidents and traffic congestion are not as much increasing with the weight of the vehicle as they are with the increased distance travelled. Nevertheless, due to the close relationship between tonne kilometres and the HVF, it appears to be the variable that is most suited to estimate the effect of the policy.

In Figure 6, using data between 2005–2017, the proportional relationship between vehicle kilometres and tonne kilometres is shown. While both vehicle kilometres and tonne kilometres are generally rising, tonne kilometres are showing a proportionally stronger increase. This implies that the average weight of trucks is increasing, too, which in turn means that tonne kilometres as a candidate for our dependant variable capture important variation that vehicle kilometres cannot. On the other hand, vehicle kilometres do a better job of capturing the change in external costs generated by heavy-duty traffic. Thus, vehicle both kilometres and tonne kilometres will be included in the analysis. The results on vehicle kilometres will have a control function for those on tonne kilometres because they should at least react very similarly to external stimuli.

FIGURE 6
Comparison of indexed vehicle and tonne kilometres over the years 2005 – 2017. Source: Swiss Federal Office of Transport.



6.3 MAX WEIGHT OF TRUCKS V. WEIGHT OF FREIGHT

In the HVF data set provided by the Federal Office for Customs and Border Security FOCBS Switzerland the weight of the trucks and consequently the measure of tonne kilometres is based on the maximum, not the actual, weight of the vehicle. The tax is then calculated with that same value, irrespective of the fact, how heavy the vehicle actually is. This method of calculation corresponds to Article 6.1 of the Heavy-duty Tax Act (**SR** 641.81). The aim of said law is to incentivize truck owners to transport as much weight as possible for you pay the lowest amount of money per tonne kilometre if your vehicle is loaded to max capacity.

Consequently, data on tonne kilometres provided by the FOCBS differ strongly from the data the FSO (Federal Statistical Office) offers as the FSO collects data on the actual weight of goods transported in Switzerland. Because max weight is a direct component of tax calculation, using it is however a much closer fit to the chosen empirical approach.

6.4 ADAPTIONS MADE TO THE DATA

For any newly introduced emission standard, the values of the first year were dropped. These values were huge outliers towards the bottom of the distribution which bring a lot of confusion to the data. Every single one of the emission standards saw steep increases in mileage within the first year of their introduction but stabilized afterwards. For the regression displayed in Table 5, the values of the first year of each emission standard were not omitted, because that would have left very little data.

7 RESULTS

This chapter contains the key findings of this thesis. The results were procured by using inferential statistics and are presented in an order that shows the increasing complexity of the statistical tools used. As written in chapter 4, three distinct hypotheses are to be tested, which are inherently connected but try to test progressively more nuanced relationships between certain aspects of the HVF and the resulting heavy vehicle mileage on Swiss roads.

7.1 FIXED-EFFECTS REGRESSION

As a sort of baseline regression, a standard fixed-effects model that uses all the full bandwidth of the panel data was calculated. The estimation equation is as follows:

$$Log(Kilometres)_{i,t} = \beta_0 + \beta_1 Tariff_{i,t} + \alpha_i + \lambda_t + \varepsilon_{i,t}$$

The dependent variables are, which will be recurring items, both tonne and vehicle kilometres driven by trucks. Time fixed-effects λ_t are months of the year whereas unit fixed-effects α_i are the EURO emission standards. The results of the fixed-effects regression are displayed in. They paint a clear picture of a statistically highly significant negative effect of HVF tariffs on heavy-duty mileage. According to the estimates, an average increase of one percent in tariffs will lead to a decrease in tonne kilometres and vehicle kilometres by about 1.45 percent and 1.37 percent respectively. For the observed time period, tariffs varied between CHF 0.0142 and 0.003. This effect is slightly stronger than the ones who were measured for other road pricing policies such as those in Stockholm or London, which reported a price elasticity of about -0.8 (Eliasson et al., 2009). The coefficient on vehicle kilometres is slightly lower than the one on tonne kilometres, but a t-test yields that there is no significant difference between the two coefficients and therefore no statement on differences between the two measurements two be made.

TABLE 2
Baseline Fixed-effects (within) regression

	(1)	(2)

	Log(tkm)	Log(vkm)
Log(HVF-Tariff)	-1.453***	-1.371***
	(0.0521)	(0.0501)
_cons	9.825***	8.350***
	(0.0474)	(0.0455)
N	1122	1122
adj. R^2	0.407	0.399

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Source: Own calculations based on data from the Swiss Federal Office of Transport and the Swiss Federal Office for Customs and Border

Even though the results are significant and a negative correlation between tariffs and heavy-duty mileage is believable from a theoretical perspective, the OLS fixed-effects regression is rather crude when it comes to isolating a causal effect of the HVF. There are simply too many confounders to this approach, which can hardly be accounted for with a model such as this. There is, for example, the issue of external shocks which affect all emission categories equally, such as the 2007-2008 financial crisis, gasoline price fluctuations or a change in transport policy in Switzerland or neighbouring countries such as changes to the Brenner Maut in Austria or the 2016 total revision of the Swiss cargo railway regulative. Due to these issues, a more refined statistical approach is required.

7.2 REGRESSION DISCONTINUITY DESIGN

The fact that the HVF tariffs were changed several times over the last 20 years offers an opportunity to apply more nuanced identification strategies than "just" an OLS fixed-effects model. As there is a clear cut-off at several year transitions and data available on both sides of it, a regression discontinuity design finds a lot of use. To calculate the RDD, all the changes on tariffs were normalized to generate one single cut-off. Hence, every month of a year before a tariff change is considered non-treated, whereas every month of a year after a tariff change is considered treated. Months in years that were not directly before or after a tariff change are therefore excluded from the analysis, which cuts down the number of observations from 1122 to 456. Due to the fact that unit and time fixed-effects are again used for EURO emission standards and for months, the yearly cyclicality that heavy vehicle mileage goes through is directly accounted for. The estimation equation is as follows:

$$Log(Kilometres)_{i,t} = \beta_0 + \beta_1 Time_{i,t} + \beta_2 Cut\_Off_{i,t} + \beta_3 Time_{i,t} * Cut_{Off}{}_{i,t} + \alpha_i + \lambda_t + \varepsilon_{i,t}$$

The RDD estimator is the coefficient β_2 , which displays the effect of the tariff change on tonne and vehicle kilometres. An interaction term of the running variable, time, and the cut-off is included to allow for the relationship between time and kilometres to be flexible. The results of the RDD are displayed in Table 3.

TABLE 3
Regression discontinuity design with unit and time fixed-effects, on treated emission categories

	(1)	(2)
	Log(tkm)	Log(vkm)
Months	-0.00657***	-0.00599***
	(0.000366)	(0.000358)
Cut-off	-0.499^{+}	-0.530^{+}
	(0.298)	(0.292)

Months#Cut-off	0.000799	0.000848^{+}
	(0.000495)	(0.000484)
_cons	12.63***	10.87***
	(0.219)	(0.214)
N	456	456
adj. R^2	0.505	0.466

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Source: Own calculations based on data from the Swiss Federal Office of Transport and the Swiss Federal Office for Customs and Border

Unfortunately, the coefficient on "Cut-off" is only significant on the 90% confidence level, which is to be interpreted in the sense that around the cut-off, which was defined by a change in HVF tariffs, no strong statistically significant change in heavy-duty mileage could be identified. However, the sign on the coefficient on "Cut-off" is negative, which aligns with the expectations. For each time that the tariffs were adjusted, the model therefore suggests that, when comparing the dyad of the same month in the year before and in the year after the change, there is a negative effect on the heavy-duty mileage for all the emission standards that were affected by the change. Neglecting the only weakly significance of this effect, the RDD model suggests that a change in tariffs will successfully lower heavy-duty mileage in those categories that were targeted by the policy change. This effect exists for both vehicle kilometres and tonne kilometres, but it is of equal low significance. It is thus hard to judge whether the tariff change had any effect on the weight of the average cargo load of an affected heavy-duty vehicle. Only finding weak effects is, according to Lehe & Devunuri (2022), not entirely a surprise. They found that the introduction of a road pricing scheme implies a higher cost elasticity on mileage than the increase in tariffs of the same scheme.

In the spirit of counterfactual analysis, a second RDD was calculated, which included only those points in time where tariff changes happened, but this time including all the observations for the emission categories that were *not* affected by any tariff changes. The estimation equation of this model is as follows:

$$Log(Kilometres)_{i,t} = \beta_0 + \beta_1 Time_{i,t} + \beta_2 Cut\_Off_{i,t} + \beta_3 Time_{i,t} * Cut_{Off_{i,t}} + \alpha_i + \lambda_t + \varepsilon_{i,t}$$

The results of this model are displayed in Table 4.

TABLE 4
Regression discontinuity design with unit and time fixed-effects, on untreated emission categories

	(1)	(2)
	Log(tkm)	Log(vkm)
Months	-0.00961***	-0.00920***
	(0.000256)	(0.000244)
Cut-off	0.626*	0.626**
	(0.244)	(0.232)
Months#Cut-off	-0.000970*	-0.000963*
	(0.000394)	(0.000375)
_cons	14.13***	12.49***
	(0.159)	(0.151)
N	198	198
adj. R^2	0.919	0.920

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Source: Own calculations based on data from the Swiss Federal Office of Transport and the Swiss Federal Office for Customs and Border

The positive and statistically significant coefficient on "Cut-off", conveying the discontinuity of the cut-off, confirms the previous RDD results. If mileage in those emission categories, who were not affected by the tariff change, did not decrease (and more so, increased), the negative effect that was identified in Table 3 should stem from the tariff change itself and not any other external shock that happened at the same time. The fact that mileage even increased for the untreated categories might suggest a shift in mileage from treated to untreated groups. This possibility will be examined in the next chapter. What is slightly confusing about the RDD results on both the treated and untreated emission groups is that the coefficient on "time" is highly significantly negative, when the total heavy-duty mileage over the duration of the data increased. This is probably due to the fact that the older emission categories, that have been on the decline for decades, are "overrepresented" in the data because there is one data point per emission standard for every quarter of the year, but the EURO norm VI has values much higher than EURO norm II. This issue will be brought up again in the Discussion part of the thesis.

7.3 ESTIMATES ON NEWEST CATEGORY

While the RDD design was able to show that a change in HVF tariffs can successfully influence traffic levels for those vehicles that were affected by the change, it cannot show what happens to those categories that were unaffected by a tariff change. This is an issue, because one has to consider the possibility of a shift from heavy-duty vehicles not only to rail- or waterway transport, but also towards other, now comparatively cheaper road transport possibilities. Next to camionettes, for which the available data cannot account for, such transport possibilities are made from those emission categories, which were less or entirely unaffected by the changes in tariff. As discussed and hypothesized in chapters 3 and 4, a behavioural change due to the HVF can not only manifest itself in lower heavy-duty mileage numbers, it can also show in a decrease of mileage numbers for more polluting and therefore expensive emission norms with an increase of mileage numbers for cheaper emission norms in parallel. Any increase in tariffs will therefore not necessarily cause a decrease in total heavy-duty mileage, but it could potentially change the mileage distribution among the different vehicle categories. Since an investment in vehicles of, the at the time newest, and therefore cheapest, category, seems the most sensible behaviour, a regression of the effect of tariff changes in lower emission categories on the mileage of the newest emission category was calculated. The estimation equation for this model is the same as for the previous two:

$$Log(Kilometres)_{i,t} = \beta_0 + \beta_1 Time_{i,t} + \beta_2 Cut\_Off_{i,t} + \beta_3 Time_{i,t} * Cut_{Off_{i,t}} + \alpha_i + \lambda_t + \varepsilon_{i,t}$$

The results of said regression are displayed in Table 5.

The coefficient on "Cut-off" is positive and highly significant. This implies that tariff changes really had a significant positive effect on the mileage of the emission category, that was the newest at the time of the change. Consequently, the negative effect on mileage that was found in the RDD in chapter 6.2 went at least partially into the newest emission category and did therefore not only fuel the effort to reduce heavy-duty mileage, but also promote the use of newer vehicles. To complement this, data on the registration of new trucks shows that the number of newly registered EURO V trucks has relatively quickly receded with the introduction of EURO VI: While there were still 25'822 newly registered EURO V trucks in 2015 (vs. 4'842 EURO VI trucks), there were only 2'020 and 296 newly registered EURO V trucks in 2017 and 2018 respectively as opposed to 30'024 and 32'813 newly registered EURO VI trucks (Federal Statistical Office Switzerland, 2022).

This effect, next to it being an official goal by the authorities, is not entirely undesirable, because, due to the cleaner engines of the newer vehicles, it reduces the external costs generated by road freight traffic. It presumably does not reduce them as much as if the shift had entirely gone towards rail- and waterways, however. These results can however not be taken entirely for granted. The values of the first year of each, in the time frame newly introduced emission standard were not omitted, in order to have a bigger sample size. Since the values of the second year of each emission standard tend to be comparatively higher than the values of the first year – and in this case, the cut-off is between the first and the second year, the estimated impact is probably overestimated.

TABLE 5
Regression discontinuity design with unit and time fixed-effects, including only the newest emission category

	(1)	(2)
	Log(tkm_newest)	Log(vkm_newest)
Months	0.0247***	0.0235***
	(0.00296)	(0.00261)
Cut-off	9.002***	8.027***
	(1.265)	(1.115)
Months#Cut-off	-0.0140***	-0.0125***
	(0.00211)	(0.00186)
_cons	-6.533***	-7.254***
	(1.783)	(1.572)
N	90	90
adj. R^2	0.561	0.583

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Source: Own calculations based on data from the Swiss Federal Office of Transport and the Swiss Federal Office for Customs and Border

7.4 RESULTS SUMMARY

As for the three hypotheses postulated in chapter 4, the empirical results provide some support for hypothesis 1 - the proposed negative correlation between mileage and tariff levels. The regression displayed in Table 2 suggests a negative cost elasticity of roughly -1.45 which is higher than what researchers have found for the congestion charges in London and Stockholm (Leape, 2006; Eliasson et al., 2009). Considering the fact that only 62% of the external costs of heavy-duty vehicles are internalized by the HVF, a hypothetical increase of HVF tariffs by roughly 60%, thereby reaching full internalization, would per these estimates reduce heavy-duty mileage in Switzerland by about 89%. This result is both hard to believe and astounding, because if it holds true, it means that most of heavy-duty transportation in Switzerland is inefficient. However, there is considerable evidence that the elasticity calculated in Table 2 is overestimated. This will be discussed in chapter 8.

The results in Tables 3 and 4 offer weak evidence for hypothesis 2 which had presumed that a change in tariffs would have immediate negative consequences for the mileage of those tariff classes who were affected by the change. The conducted RDDs did not show a significant negative effect on the mileage of the affected vehicles. However, they showed that the mileage of the unaffected tariff classes increased, which implies a shift from the affected towards the unaffected classes.

For hypothesis 3, which concerned specifically the effect of tariff changes on the at-the-time-cheapest tariff category, there was a lot of statistical evidence. The results of the RDD displayed in Table 5 showed strong evidence that indeed the cheapest tariff class would see its mileage numbers rise heavily with an increase in tariffs in any other class.

The difference in estimates between vehicle and tonne kilometres is always very marginal. This means that the HVF has not resulted in trucks being better or less well filled with goods. So, no efficiency gains were made in this respect.

8 DISCUSSION

The econometric analysis conducted in the previous chapter lead to reasonable, yet not entirely conclusive results. The main hypothesis was able to be confirmed: Using road pricing in the shape of a mileage fee is a viable instrument to reduce the amount of road freight traffic. Nevertheless, the estimated effects were not always as strong, or even significant, as theory and existing literature would have expected them to be. This is not entirely surprising, as there are a number of confounding factors to the empirical strategy, which will be discussed in this chapter. Part of what is mentioned here already was a part of the considerations presented in chapter 3.4, where some of the theoretical expectations for the success of the HVF road pricing scheme were dampened. The important difference between then and now is the deliberation over the question to what extent these concerns held true. To round off this chapter, some ideas as to where future research on this topic could go and how it could address some of the issues that the approach struggled with are presented

The without a doubt most confounding factor lies with confounded the dependant variable, heavy-duty mileage, is. Confounding are several factors, most notably the strong dependency of mileage on economic growth, the yearly cyclicality with the busier summer and the less busy winter, weather or human-made events that can lead to the closure of certain roads or railways and the introduction of policies with implications for road transport other than the one policy that was scrutinized. These issues were addressed and neutralised with the introduction of unit- and time-fixed-effects as well as the application of a Regression Discontinuity Design, which was only possible due to the access to panel data.

This data however, brought new issues. The RDD of mileage on time yielded that mileage over time is declining. This is not true, as the total of tonne kilometres has, on average, risen steadily over the last 20 years. The issue stems from the fact that the lower emission standards are "overrepresented" in the sample, meaning that even though there are much higher mileage values for EURO norms 5 and 6, which are still increasing, every EURO norm in the sample, no matter how busy it still is, gets one observation per month of the year. This means that there are five emission standards (EURO 0 – IV) who have been steadily on the decline for years, albeit on a low level, which overshadow the growth that has been seen in EURO Norms V and VI. This might also be a possible explanation for the comparatively stronger effect of the HVF compared to other road pricing measures. Each emission standard from EURO 0 to EURO VI has one observation per month, but there is no category that captures the total amount of mileage. In other words, if mileage decreases in most of the categories or even shifts towards the other categories, the OLS fixed-effect regression would overestimate the overall effect of tariffs on traffic. This issue is partially addressed by the fixed-effects applied for each emission category, but the overrepresentation of the lower, ever-declining emission categories remains an issue. A possible solution is to use different data, i.e., the data from the HVF-scanners along the highways which register every vehicle that is obliged to pay the fee. This would mean that one would have one observation for each trip that was undertaken by a heavy-duty vehicle, which would leave no emission category "underrepresented". Another possible solution would be grouping several of the lower emission categories together to form one category. This would however severely weaken the statistical power of the data and also hinder an interpretation of the data that respects the possible differences between the emission categories who would have been grouped together. Therefore, the chosen approach, despite being imperfect, constitutes measure to interpret the data sensibly.

Both an identification issue and a fascinating find is the fact that some of the effort of reducing heavy-duty mileage does, for the older emission categories, mean a shift towards the newer emission categories, instead of rail- or waterways. Whenever marginal costs in the more expensive tariff categories rise, some of the decrease in mileage of that category will be shifted to cheaper categories, especially to the cheapest one, as new purchases of trucks are probably mainly done of trucks of the corresponding newest EURO norm. The regression model displayed in Table 5 suggested positive evidence for this assumption. Those numbers are not unsurprising when you consider the fact that tariffs for said EURO categories, in 2017, were adapted insofar that the difference in cost between them became nearly twice as big as it was before. Nevertheless, these numbers offer support for the assumption that spillover effects towards cheaper tariff categories happen mostly to the cheapest tariff class. Such developments, from the point of view of the policymaker, are only semi-optimal, because they only fulfil the goal of reducing road traffic emissions but not the goal of shifting traffic towards rail. One possible solution to this issue would have been omitting the cheapest category for each point in time. This would however have led to too big a loss of statistical power and information.

Where is the heavy-duty traffic shifted to? This question was explored on a theoretical level, but the data at hand did not allow to understand, which alternative mode of transport “benefitted” the most. As rail- and waterway transport are not very flexible transportation means, it is a feasible assumption that a considerable amount of the shifting effort goes towards delivery vans. As these are not subject to the HVF, this embodies a unsatisfactory outcome as the external costs generated by delivery vans is substantial (Federal Office for Spatial Development ARE Switzerland, 2022). If further research could show that indeed a significant portion of the efforts by the Swiss Confederation to shift freight transport from road to rail ends up being foregone by truck holders by investing into delivery vans, policy makers should look into introducing a performance-based fee for lighter vehicles.

As for the case of Switzerland, road and mobility pricing are slowly gathering attention. Baranzini et al. (2021) examined the possibility of a congestion charge in Geneva. According to their findings, the implementation would take a lot of convincing of the local populace. The authors have identified a clear trade-off between the acceptability and efficiency of the policy – people favour low charges with lots of exemptions, whereas from a theoretical perspective, no exemptions would be ideal. People also do not offer support for dynamic pricing, although again, it would be favourable from a theoretical perspective. Lately, there has been a lot of talk about a toll on the Gotthard tunnel. In fact, the Swiss parliament very recently refused a parliamentary motion to probe a road toll through the Gotthard due to the fact that the Swiss government is already working on it.

9 CONCLUSION

The official aim of the Swiss Governments policies to shift traffic from road to rail is to reduce the number of trucks that cross the Alps at 4 distinct crossings to no more than 650'000 vehicles per year. With the HVF not being a flat vehicle tax but mileage-based, there is a mismatch between goal and policy. With the policy targeting mileage, there is no guarantee the number of vehicles will ever fall below 650'000 – theoretically, the size of the vehicles might just get smaller instead. However, over the observational span of this analysis, weight limits for trucks in Switzerland have been on the rise (28t to 34t in 2001, further increase to 40t in 2005) (Swiss Federal Office of Transport, 2004) and the average amount of tonne kilometres per registered truck has also increased. In turn, attaining a number of 650'000 trucks per year now is not so desirable a result as it may seem, for how much worth is an arbitrary number if the weight of the trucks is not fixed? Having 650'000 trucks weighing 28 tonnes cross the alps every year is certainly not the same thing as having 650'000 trucks weighing 40 tonnes doing the same. It is therefore more appropriate to focus on tonne-kilometres rather than the number of trucks, as this analysis does. Additionally, the HVF is also designed to internalize external costs of heavy-duty traffic, through which it hopes to reduce heavy-duty traffic. As laid out in chapter 3.4, there are theoretical cases in which the internalization effort is successful, while the reduction effort is not. In sum, there are several barely harmonizable goals in the Swiss transport policy efforts.

This thesis tried to isolate the effect of a singular policy on a highly volatile variable, heavy vehicle mileage. Despite it being a difficult approach, it was not entirely without merit. The results show that the hypothesised effect of the heavy vehicle fee in Switzerland is a statistically identifiable phenomenon. According to the empirical estimates, the HVF implies a cost elasticity of about -1.4 on heavy-duty mileage, which is slightly above related scientific findings, though this estimation is confounded by identification issues. To complement this result, RDD-Estimates showed that adapting HVF tariffs leads to a noticeable decrease in mileage in the following year for the affected vehicles. However, there is no evidence that this decrease in mileage can be considered a shift towards rail- or waterway transport. Instead, the HVF notably shifts road traffic from older, more polluting to newer, cleaner trucks. This might not be in line with the Swiss efforts to shift transport from road to rail, but it nonetheless contributes to the other goal in transport policy, to internalize some the negative externalities of heavy-duty traffic.

These are promising results, both for the future of the Swiss HVF and for road pricing schemes all over the world. It provides encouragement for policymakers in Switzerland to continuously adapt and increase HVF tariffs to not only support efforts to reduce heavy-duty mileage, but also to internalize as much as possible externalities of heavy-duty traffic. And beyond that, it promotes the use of road pricing in other sectors who themselves generate significant external costs.

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GLOSSARY

ARE	Federal Office for Spatial Development
CHF	Swiss Francs
FOCBS	Federal Office for Customs and Border Security
FSO	Federal Statistical Office
GDP	Gross Domestic Products
HVF	Heavy Vehicle Fee
LTA	Land Transport Agreement
NRLA	New Rail Link through the Alps
OFT	Federal Office of Transport
OLS	Ordinary Least Squares
RDD	Regression Discontinuity Design
SVAG	Heavy Vehicle Fee Act
SVAV	Heavy Vehicle Fee Ordinance

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Trying to isolate the effect of a singular policy on a highly volatile variable is never an easy feat. Nevertheless, it is the goal that this thesis tries to accomplish. Econometric analysis shows that the heavy vehicle fee in Switzerland causes statistically identifiable effects. According to baseline estimates, the HVF implies a cost elasticity of about -1.4 on heavy-duty mileage. An RDD-Estimation shows that adapting HVF tariffs doesn't imply lower overall mileage values. Instead, the HVF shifts road traffic from older, more polluting to newer, cleaner trucks. This might not be in line with the Swiss efforts to shift transport from road to rail. Nonetheless, it contributes to a different goal in transport policy, namely, to internalize the negative externalities of road traffic.

Anhand dieser Arbeit wird versucht, den Einfluss der Einführung der Schwerverkehrsabgabe 2001 auf den Schwerverkehr in der Schweiz zu schätzen. Nach einer Basisschätzung impliziert die LSVA eine Kostenelastizität von etwa -1,4 auf die Fahrleistung von schweren Nutzfahrzeugen. Eine RDD-Schätzung zeigt, dass die Anpassung der LSVA-Tarife nicht zu niedrigeren Gesamtkilometerwerten führt. Stattdessen kommt es durch die LSVA zu einer deutlichen Verlagerung des Straßenverkehrs von älteren, schadstoffreicheren auf neuere, sauberere Lkw. Dies entspricht nicht der Absicht, den Verkehr von der Straße auf die Schiene zu verlagern. Dennoch trägt es zu einem anderen verkehrspolitischen Ziel bei, nämlich der Internalisierung einiger der negativen externen Effekte des Schwerlastverkehrs.