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The vehicle purchase tax as a climate policy instrument

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Abstract

Since 2007, the Norwegian vehicle purchase tax includes a large CO_2 emission component. At the same time, generous tax exemptions and privileges are granted to battery electric vehicles. Continued application of the purchase tax instrument may induce large-scale penetration of electric cars into the passenger car stock, thus halving the fleet's fossil fuel consumption and greenhouse gas emissions within two or three decades. The main tangible cost of this low carbon policy is the extra cost of acquiring novel products with currently small economies of scale. This cost difference will decline over time. The main benefits consist in reduced energy consumption and greenhouse gas emissions.

We calculate the gross and net tangible cost of the low carbon policy in a long-term perspective, i.e. towards the 2050 horizon. A crucial cost determinant is the speed at which the manufacturing costs of battery and plug-in hybrid electric vehicles will fall. Under moderately optimistic assumptions about impending economies of scale, net tangible costs by 2050 come out in the range €48 to 278 per tonne CO_2, depending on the discount rate and on battery replacement costs.

Keywords

Passenger cars
Greenhouse gases
Fiscal incentives
Electric vehicles
Modelling
Policy scenario

1 Introduction

More often than not, transport generates external costs, i.e. costs borne by someone else than the decision-making traveller, shipper or operator. Such externalities include environmental impacts, noise, accidents, congestion, infrastructure wear and tear, as well as visual intrusion and barrier effects.[1]

In principle, externalities may be neutralized through the application of appropriate taxation or pricing systems, such as emission allowance trading, congestion charging, or fuel tax (Pigou, 1920; Baumol and Oates, 1988). The degree to which such measures are applied to transport varies, however, widely between jurisdictions, and between different types of trans- port occurring within the same jurisdiction (Santos et al., 2010b).

Environmental impacts encompass a wide variety of local, regional and global effects, most notably reduced local air qual- ity due to NOx, black carbon and particulate matter emissions, as well as habitat degradation and climate change. The latter problem has given rise to a massive international research effort, as summarized by the United Nations' Intergovernmental Panel on Climate Change (IPCC, 2013, 2014a). According to Stern (2007: xviii), 'climate change is the greatest market failure the world has ever seen'.

Responsible governments and supranational bodies worldwide are considering how to limit and reduce greenhouse gas (GHG) emissions sufficiently to avoid a development adjacent to any of the higher 'Representative Concentration Pathways' – RCP6.0 or RCP8.5 – drawn up by the IPCC (2014b). Through the Paris agreement, all nations have expressed their commit- ment to limit the increase in the global average temperature to less than 2 °C above pre-industrial levels (United Nations, 2015).

In the European Union (EU), an estimated 19 per cent of all greenhouse gas (GHG) emissions originate from transport.[2] Roughly one half of these emissions come from private cars.

In the EU as well as in North America, certain policy measures to combat GHG emissions from cars are already in place. Among regulatory measures, emission standards are the most important. Economic policy measures consist mainly of emis- sions trading schemes and of various fiscal incentives, such as excise taxes, subsidies, and tax credits.

The Corporate Average Fuel Economy (CAFE) regulation requires that

[1] See, e.g., Verhoef (1994), EC (1995), Maddison et al. (1996), Mayeres et al. (1996), de Borger and Proost (2001), Hensher and Button (2003), Quinet (2004), Proost (2011), Delucchi and McCubbin (2011), Friedrich and Quinet (2011), Santos et al. (2010a), Korzhenevych et al. (2014).

passenger cars and light trucks produced for sale in the USA obey, on average, certain minimal fuel economy standards depending on the vehicle's 'footprint', defined as the product of the vehicle's width and its wheelbase. For passenger cars with a footprint below 41 square feet, the 2015 standard is at least 39 miles per gallon (mpg), translating into a CO_2 emission rate of at most 140 g per kilometre (gCO_2/km) for a petrol driven car. For cars with a footprint of over 56 square feet the limit is 30 mpg, or 182 gCO_2/km. For light trucks the standards are more lenient – 33 and 24 mpg, or 165 and 277 gCO_2/km, respectively, although these vehicles are also to a large extent used for passenger transport (NHTSA, 2010).

The European Union (EU, 2014) has mandated maximum CO_2 emission targets for new passenger cars sold in 2015 and 2021, respectively. The targets are 130 gCO_2/km in 2015 and 95 gCO_2/km in 2021, as averaged over all vehicles brought to the EU market. More lenient standards apply to manufacturers producing heavier than average vehicles (ICCT, 2014).

To meet the targets, automobile manufacturers are introducing a widening range of battery and plug-in hybrid electric vehicles (BEVs and PHEVs). Special accounting rules make sure that vehicles with a CO_2 emission below 50 gCO_2/km give rise to 'super-credits' towards the EU targets for 2020–2022.

In addition to regulatory measures, fiscal incentives are being used. In the USA, new plug-in electric vehicles are eligible for a tax credit of up to $ 7500, depending on the battery capacity.

In Europe, the incentives vary between countries. In France, the government has implemented a feebate system, whereby new passenger cars emitting less 110 gCO_2/km receive a subsidy (bonus), whereas a purchase tax (malus) applies to vehicles with type approval CO_2 emissions above 135 gCO_2/km (D'Haultfoeuille et al., 2013).

Most countries in the European Economic Area (EEA)[3] levy an excise tax on fossil fuel, with per litre rates that typically add 100 per cent on top of the pre-tax value. In Norway, e. g., the 2014 rates for petrol and diesel were approximately € 0.69 and € 0.53 per litre, respectively, before 25 per cent value added tax (VAT). In North America, fuel tax levels are generally much lower. A considerable scientific literature exists on the respective merits of vehicle and fuel taxation.[4] Sterner (2007) finds that 'Had Europe not followed a policy of high fuel taxation but had low US taxes, then fuel demand would have been twice as large.' Parry and Small (2005) conclude that '.. .the optimal gasoline tax for the United States is more than double its current rate, while that for the United Kingdom is about half its current rate'. They add, however, that '.. .the fuel tax turns out to be a rather poor means of controlling distance-related externalities like congestion because it is too indirect, causing greater shifts in fuel economy than in amount of travel. A direct tax on amount of travel (vehicle-miles) performs far better.. .'

Thus, although no general consensus exists, many economists would argue that a pigouvian fuel tax, or a carbon cap-and- trade system encompassing road transport, would constitute a near-optimal way of internalising the costs of exhaust emis- sions generated by fossil fuel combustion. A fuel tax would not, however, correctly internalise all other marginal external costs, such as road wear, congestion, noise, accidents, or particulate matter released from tarmac or brake pads. For these externalities, electronic road pricing would be more appropriate.

Also, since households generate no external costs simply by owning a vehicle, only when they use it, most economists would argue that taxing the vehicle as such would be misguided. Some studies have, however, emphasized the apparently greater GHG abatement potential of fiscal incentives directed towards vehicle purchase and ownership.[5]

The remarkable market uptake of low and zero emission vehicles in Norway, brought about by national fiscal and regu- latory incentives, has drawn international attention.[6] Starting, in Section 2, by an examination of the Norwegian experience, we go on to discuss its most important costs and benefits in Section 3. To assess the net costs in relation to the GHG abatement effects obtained, we present, in Section 4, a set of scenario projections on to the 2050 horizon. In Section 5, we discuss the inter- pretation of results and the possible limitations affecting our study. Conclusions are drawn in Section 6.

1. The Norwegian experience

As an EEA[3] member, Norway is bound by the great majority of EU regulations. But since the country is not a full member of the EU, reduced CO_2 emissions from new cars registered in Norway do not count towards the EU mandated targets faced by car manufacturers.

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[2] Source: Eurostat.

[3] The European Union plus Norway, Iceland and Liechtenstein.

[4] See, e.g., Newbery (2005), Parry and Small (2005), Kuhnert and Kuhfeld (2007), Sterner (2007), Small and van Dender (2007), Ryan et al. (2009), Santos et al. (2010b), Fu and Kelly (2012), Mabit (2014).

[5] Johnstone and Karousakis (1999), Greene et al. (2005), Rogan et al. (2011), Brand et al. (2013).

[6] See, e.g., http://en.wikipedia.org/wiki/Plug-in_electric_vehicles_in_Norway and references therein.

However, in their 2008 'climate policy agreement', a large majority in the Norwegian Parliament defined a target for the average type approval CO_2 emission rate of new passenger cars sold in 2020. The target was set at 85 gCO_2/km.

Since there is no domestic car manufacturing, the target does not bind or penalize corporate stakeholders. It is, however, a strong political signal. The main strategy to reach the target is an accelerated market uptake of low and zero emission cars in general and of battery electric vehicles (BEVs) in particular.

The policy appears to work. As of January-October 2016, thanks to a 15.1 per cent BEV market share and a 13.8 per cent PHEV share, the mean type approval rate of CO_2 emissions from new passenger cars registered in Norway was 93 gCO_2/km,[7] equivalent to a fuel economy of 58.5 mpg for a petrol driven car.

The ownership and use of zero emission vehicles – BEVs and fuel cell electric vehicles (FCEVs) – benefit from substantial incentives. These vehicles are exempt of value added tax (VAT), vehicle purchase tax, road tolls and public parking charges. They benefit from strongly reduced annual circulation tax and ferry fares. Moreover, they are generally allowed to travel in the bus lane and may be parked and recharged for free in many public parking lots.

The probably most important incentive in force is the CO_2-graduated initial vehicle registration tax, hereinafter called the *purchase tax*, applicable to all passenger cars equipped with an internal combustion engine (ICE). The purchase tax is a sum of four independent components, calculated on the basis of curb weight, ICE power, and type approval CO_2 and NO_X emission rates, respectively (see Fig. 1). All but the NO_X component are convex, exhibiting increasing marginal tax rates.

For plug-in hybrid vehicles (PHEVs), certain special rules apply. The electric motor is not considered part of the tax base for engine power. Also, so as to leave the standardized weight of the battery pack out of the tax calculation, the taxable curb weight of PHEVs is reduced by 26 per cent.[8]

Since the CO_2 component is negative for cars emitting less than 105 gCO_2/km (as of 2014), light-weight PHEVs may come out with zero of near-zero purchase tax. The purchase tax cannot, however, become negative, as in a feebate system.

BEVs and FCEVs are altogether exempt of purchase tax. Most zero emission vehicles would, however, be subject to zero purchase tax even if the exemption were lifted,[9] as the engine power and NO_X components would be zero, while the negative CO_2 component would more than outweigh the positive weight component, except for the heaviest vehicle models.

Hence, for BEVs the VAT exemption is presently more important than the purchase tax exemption (Steinsland et al., 2016). ICE and hybrid cars are subject to a standard 25 per cent VAT on the price exclusive of purchase tax.

In Fig. 2, we show how the purchase tax system exhibited in Fig. 1 translates into retail prices as averaged for BEVs, hybrids, petrol and diesel vehicles, the latter two segmented by weight class.

For ICE vehicles, the four purchase tax components taken together typically add 50 to 150 per cent on top of the import value – or even higher for the largest and most powerful vehicle models.

Thanks to the tax exemptions, BEVs come out with an average retail price that is lower than for medium sized petrol or diesel driven cars.

For hybrid cars on average, the CO_2 component is negative. This is true also for some of the smaller diesel vehicles.

The CO_2 component of the Norwegian vehicle purchase tax was introduced in 2007. Up until 2006, the purchase tax included a component based on the engine's cylinder volume. Obviously, such a component is relevant for ICEs only. When this component was replaced by a CO_2 component, making the system more technology neutral, the price of diesel cars dropped compared to that of petrol driven cars of similar size, simply because the diesel engine is more energy efficient. The car buyers responded by a massive shift towards diesel driven passenger cars in 2007, as shown in Fig. 3.

In 2010, the issue of NO_2 emissions from diesel cars came to the fore, with the City of Bergen's 'winter of discontent', when unfavourable atmospheric conditions led to prolonged and unprecedented levels of air toxicity in the downtown area (Strand et al., 2010). The fact that similar levels of air pollution are rather more frequent in the capital City of Oslo received less attention at the time, but has become a more hotly debated issue in later years (Aas et al., 2015). Thus, in 2011 the first hints at a possible ban or heavy toll on diesel cars driving into the city centres were made public. Apparently, since 2012, consumers have responded to this by a certain reluctance to buy diesel driven cars, allowing petrol driven cars a certain renaissance. Also, since 2011, BEVs have exhibited rapidly growing market shares, reaching 12.5 per cent in 2014 and a full
17.1 per cent in 2015.

The introduction of the CO_2 tax component in 2007 and the subsequent sharpening made gradually during 2008–2016 seem to have had a considerable impact on the behaviour of Norwegian car buyers. Thus, from 2006 to 2016, the mean type approval rate of CO_2 emission among new petrol and diesel driven cars registered in Norway has fallen by 45 and 26 per cent, respectively. When BEVs are included in the calculation, the drop is 47 per cent (dotted blue[10] line in Fig. 4).

Real world emissions have gone down less than the type approval values, which are based on the NEDC[11] laboratory tests mandated by the European Commission. According to Tietge et al. (2016), the discrepancy between on-the-road and type approval emission rates has grown from an estimated 9 per cent in 2001 to a full 42 per cent for the 2015 cohort of passenger car models.

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[7] *Source:* http://www.ofvas.no/bilsalget-i-oktober/category702.html.

[8] As of 2015–2016, up from 15 per cent in 2014.

[9] Assuming that BEVs would then be subject to the same tax rules as PHEVs.

[10] For interpretation of color in Fig. 4, the reader is referred to the web version of this article.

[11] New European Driving Cycle.

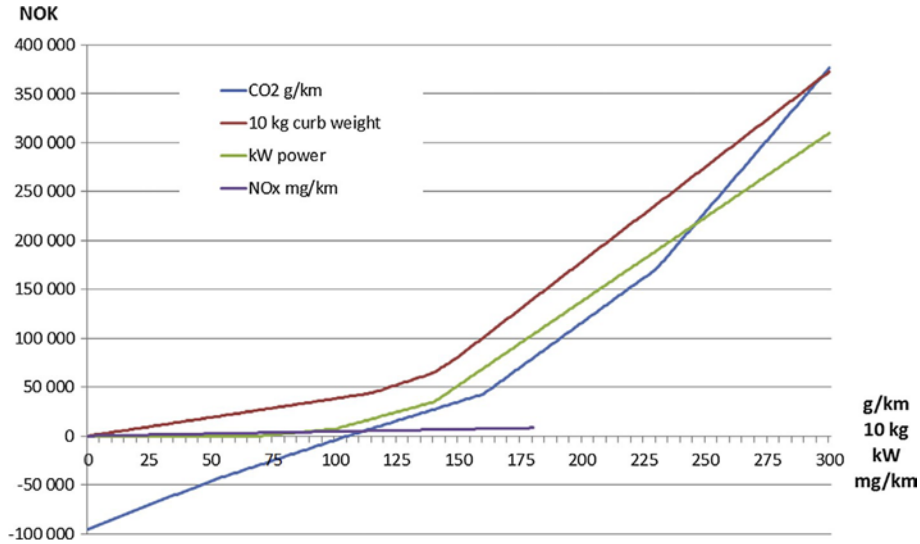

Fig. 1. Vehicle purchase tax as a function of curb weight, combustion engine power, and type approval CO2 and NOX emission rates, in Norway 2014. (NOK = Norwegian kroner. As of 1 July 2014, € 1 = NOK 8.43). *Source:* Fridstrøm et al. (2014).

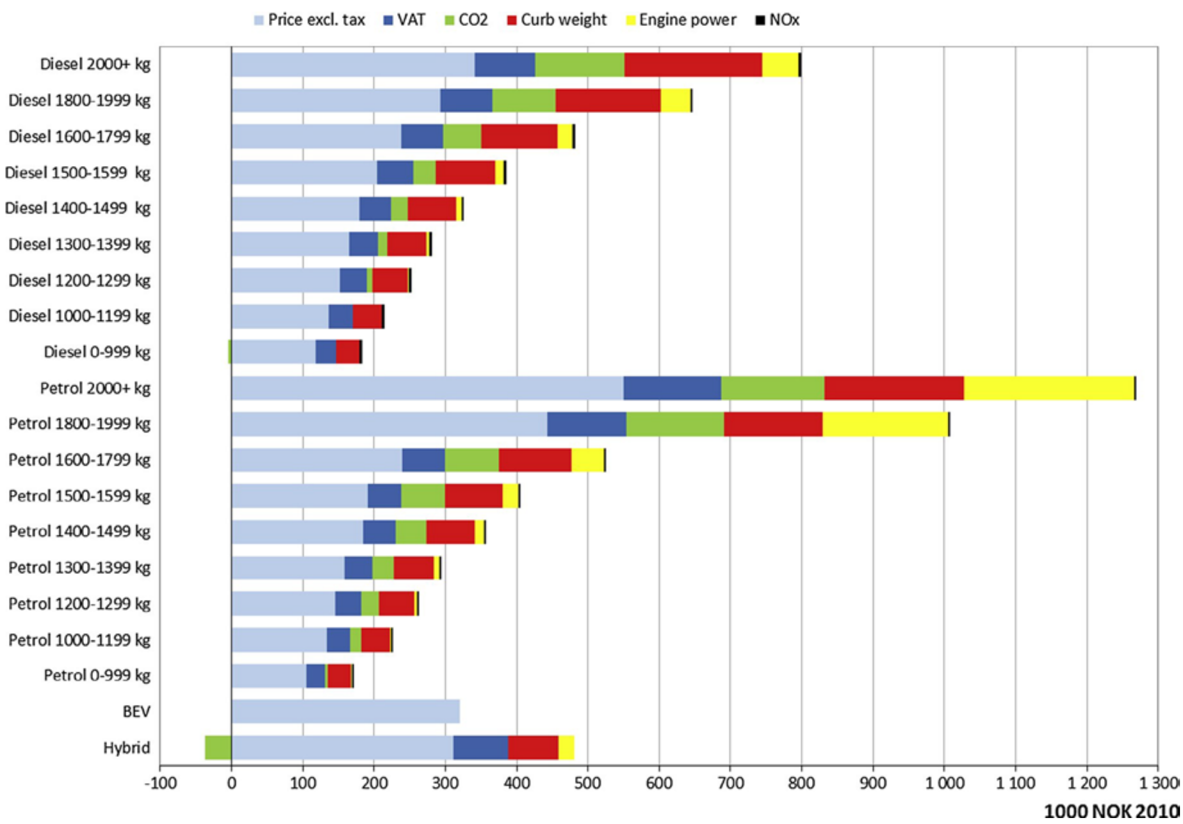

Fig. 2. Estimated average automobile prices and tax components, by fuel type and curb weight, in Norway 2014.

When correction is made for this growing divergence, on-the-road emissions from new, Norwegian registered petrol and diesel cars are seen to have fallen by only 18 and 4 per cent, respectively, between 2006 and 2015 (solid red and green lines in Fig. 4). The overall mean, which includes BEVs, has come down by 29 per cent (solid blue line), meaning that 33 per cent of the 2006 to 2015 improvement according to type approval figures is fictitious. One may note in passing that in the EU, the

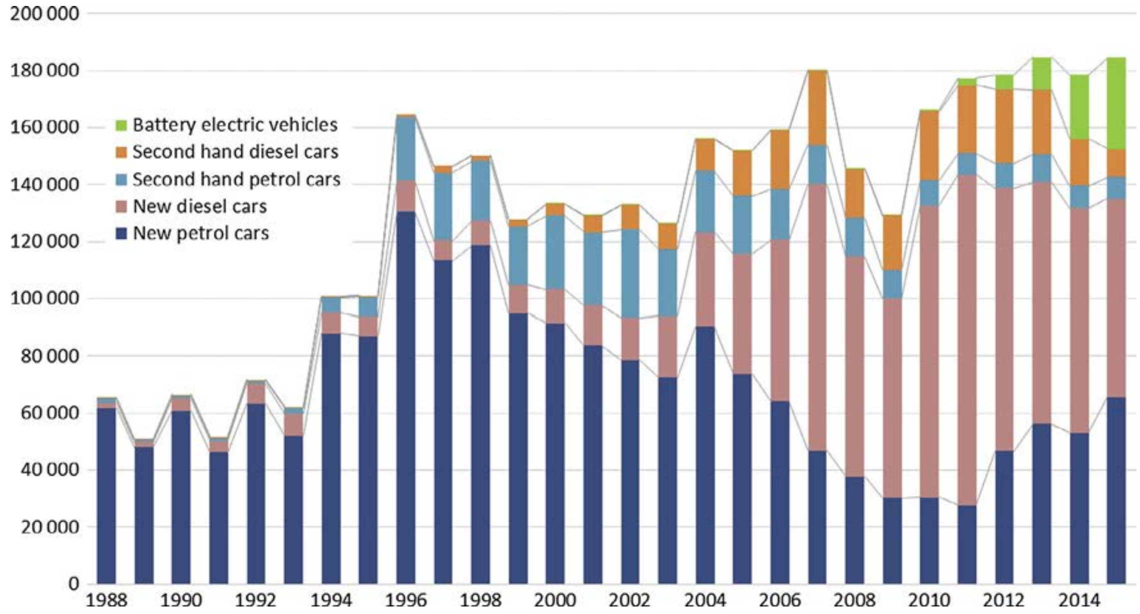

Fig. 3. Passenger cars imported to Norway 1988–2015, by engine technology. Hybrids are included in petrol/diesel category. *Source:* Statistics Norway.

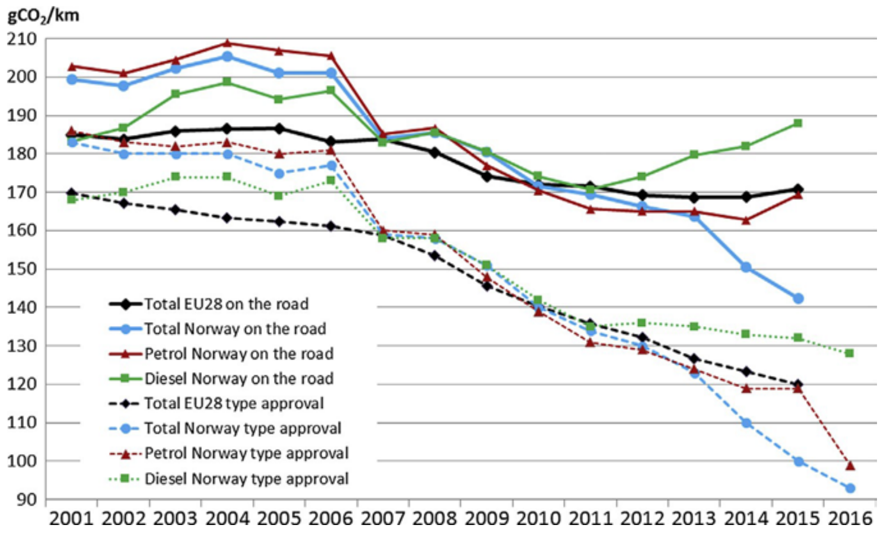

Fig. 4. Average type approval and estimated on-the-road rates of CO2 emission from new cars registered in Norway, by fuel type, and in EU28. Figures for 2016 pertain to January-October.[7] *Sources:* Fridstrøm et al. (2014), EEA (2015), Mock et al. (2013, 2014), Tietge et al. (2015, 2016), ICCT (2016).

inconsistency is more than twice as bad: No less than 74 per cent of the relative improvement 'recorded' between 2006 and 2015 is fictitious (compare solid and dotted black lines in Fig. 4).

One notes that in Norway, the downward trend for type approval emission rates continues in 2016, thanks to increasing BEV and PHEV market shares. PHEVs are included in the 'petrol' or 'diesel' vehicle categories, as the case may be.

2. A taxonomy of cost and benefits

The costs of Norway's policy for low and zero emission vehicles, and in particular the generous incentives for BEVs, is a widely discussed issue in Norwegian public debate.[12] With the article by Holtsmark and Skonhoft (2014), hereinafter called H&S, the discourse has also reached the international research community.

[12] See, e.g., Miljødirektoratet (2010), Figenbaum et al. (2014), Greaker and Kverndokk (2014), Bentzrød (2014).

2.1. *Fiscal costs*

H&S focus on the revenue loss incurred by the public treasury, on account of the exemptions from purchase tax, road toll, parking charges, and road use tax (embedded in the fuel tax) enjoyed by zero emission vehicles. For an example Nissan LEAF owner, they add up the values of these exemptions, arriving at US$ 8100 per annum. They assume an annual mileage of 7500 km, of which 5600 km are thought to replace trips made by a Toyota Prius, whose type approval emission rate is 110 gCO_2/km. From this, they calculate the annual CO_2 emissions savings at 600 kg. This results in a 'cost per tonne CO_2' of US$ 13,500.

But according to Nissan's own telematics system, the average annual distance driven by European LEAF vehicles is 16,500 km.[13] Figenbaum et al. (2014) confirm that modern BEVs in Norway are driven 14–15,000 km per year – just about as much as the average, new petrol driven car. Also, a more realistic comparison would be against the average new, Norwegian registered petrol car, which in 2014 emitted 163 g CO_2 per km (Fig. 4). Using these inputs, the resulting CO_2 savings come out at 2689 kg per annum, implying a 'cost per tonne' of US$ 3012 – less than one fourth of the figure calculated by H&S.

More importantly, the interpretation of tax, toll and parking charge exemptions as 'costs' is seriously flawed. Far from being costs in the standard economic sense, these money flows are simply redistributive transfers between the private and the public sector, or between different segments of private consumers and businesses. Their economic significance, if any, is bounded by the marginal cost of public funds, i.e. by the assumed economic efficiency cost of raising an extra unit of revenue for the public treasury, as first noted by Pigou (1948).[14] We revert to this in Section 3.7 below.

To come to grips with the costs involved in Norway's policy for low and zero emission vehicles, a much broader approach is, in our view, called for. While not presenting a full cost-benefit analysis, we aim to identify and quantify the most impor- tant tangible costs and benefits that enter the picture. The fiscal revenue implications of our various policy scenarios are cov- ered in Section 4.5.

2.2. *Manufacturing costs*

The main economic cost connected with the gradual substitution of low and zero emission vehicles for conventional ICE cars is the extra price paid for the former vehicles compared to the latter. With a history of just about 100 years of mass pro- duction, the manufacturing of ICE vehicles has accumulated huge amounts of technological knowhow and reaped vast economies of scale and scope. For BEVs, PHEVs and FCEVs this innovation process is just in its dawn, with unit production costs presently exceeding those of ICE vehicles. There is, however, reason to believe that the manufacturing and operating costs of electric cars will gradually converge to those of conventional ICE vehicles (Fulton and Bremson, 2014).

Since there is no domestic car manufacturing in Norway, the foreign trade statistics can be used to draw a fairly complete picture of the unit costs involved. In Fig. 5, we show deflated, average pre-tax prices of new[15] passenger cars imported to Norway 1988–2015, as reckoned in Norwegian kroner (NOK 2014). To get rid of seasonality, we show 12-month moving averages.

The black and red curves, representing petrol and diesel driven cars, respectively, are seen to be trending upwards since the early 1990s.[16] In fact, this development masks the fact that the average size of cars within each fuel segment has increased. A more detailed scrutiny reveals that within most weight classes, real prices have actually fallen.

By the same token, the average price of all ICE vehicles (the pink curve, until 2012 hidden behind the thick blue curve) has risen, mostly because the more expensive diesel driven cars have acquired increasing market shares, as shown in Fig. 3.

The average price of new and second hand BEVs is shown by the green curve. While in the early stages of BEV market uptake (1999–2008), electric vehicles were generally small, simple and relatively inexpensive, holding very small market shares, from 2009 onwards we see an upsurge in the market share as well as in the average cost of BEVs, as full size and compact vehicles like the Nissan LEAF entered the market. Another upsurge occurred from August 2013, when the Tesla Model S was launched in Norway, boosting the average price of BEVs sold.

The thick blue curve represents he overall mean price of all new cars imported, including second hand BEVs. Prior to 2009, the BEVs pull the average price down, but almost imperceptibly so, since their market share is so small. From 2012 onwards, the market share of BEVs is large enough, and their price high enough, to visibly pull the overall average up from that of ICE cars, opening a gap between the blue and pink curves. One can interpret this gap as a rough indication of the extra costs paid by Norwegian society for the substitution of BEVs for ICE vehicles. The indication is 'rough' because it does not take into account the differences in attributes between BEVs, petrol and diesel driven cars (see Section 3.3 below).

More precisely, this is the *tangible* cost incurred – the incremental cash expenditure that manifests itself in the gross domestic product and in the wallets, books and bank accounts of private households and companies.

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13 See, e.g., http://www.greencarcongress.com/2015/01/20150119-leaf.html or http://www.newsroom.nissan-europe.com/uk/en-gb/Media/Media.aspx?mediaid=128587.

14 For more recent expositions, see Diamond and Mirrlees (1971), Stiglitz and Dasgupta (1971), Atkinson and Stern (1974), Browning (1976) or Dahlby (2008).

15 The foreign trade statistics do not distinguish between new and second hand BEVs imported. Thus, second hand BEVs are included in the overall average. In 2012, 2013 and 2014, second hand vehicles represented 7, 21 and 14 per cent, respectively, of the

BEVs imported (source: www.ofv.no).

16 During 2014–2015, the Norwegian currency has weakened considerably towards the Euro and the US dollar. This partly explains the stiff price increases visible after 2013.

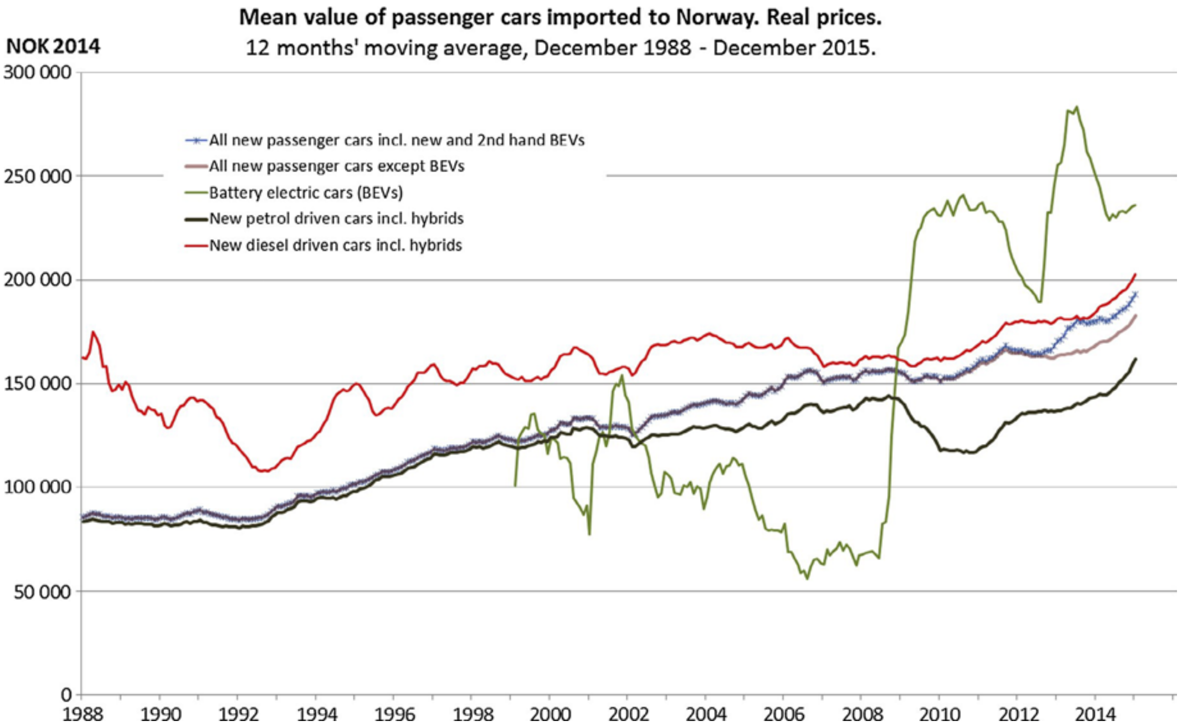

Fig. 5. Average real pre-tax value of passenger cars imported to Norway 1988–2015, by engine technology. *Source:* Statistics Norway.

Aggregating over all months between January 1988 and December 2015, we calculate at NOK 4923 million (= approx. € 585 million) the extra expenditure paid for all new cars (plus second-hand BEVs) compared to the hypothetical cost of importing an equal number of averagely priced ICE vehicles. During 2015 alone, the corresponding cost differential is NOK 1725 million (= € 205 million) – an about 5.6 per cent margin embedded in the annual outlay of NOK 33 billion (= approx. €4.0 billion).

2.3. *Welfare costs*

In addition to this observable, objective cost, there is a subjective, *intangible* cost involved, determined by changes in the consumer surplus. In the context of automobile choice, if buyers are induced to choose zero and low emission vehicles over larger and more powerful ICE cars, because the former are cheaper after tax, they are left with a car fleet that differs from the 'initial' one in several respects. Limited range electric vehicles have supplanted conventional cars, without the cost of range anxiety or range limitations showing up anywhere as a tangible cash flow. The fact, however, that an estimated 78 per cent of Norwegian BEV owners belong to two-car or multi-car households (Figenbaum et al., 2014: 18) is likely to limit the per- ceived disutility of vehicle range constraints.

Another intangible welfare cost is the uncertainty associated with the second hand value and life expectancy of novel products, such as BEVs.

In a full cost-benefit analysis, changes in the consumer surplus, i.e. in the subjective willingness-to-pay for quality over and above what the consumer has actually paid, would have to be taken into account. To accurately calculate the full welfare costs of automobile taxation one would have to integrate under the hedonic vehicle demand surface as defined in *n*- dimensional space, *n* being the number of choices (vehicle models) available to the buyers. Such an analysis has been beyond the scope of this study. We therefore limit our attention to the (most important) tangible cost and benefits.

In a simplified partial analysis of the fiscal incentives benefiting Norwegian BEV owners, Bjertnæs (2016) calculates the subsidy received by the *marginal* (i.e., last) BEV buyer in 2015 at NOK 280,000. Assuming that the *average* BEV buyer receives just about half as large a subsidy, and given a BEV sale of around 25,000 units in 2015, Bjertnæs' estimate is consistent with a total annual economic cost – or 'deadweight loss' – of NOK 140,000 $\times$ 25,000 = NOK 3.5 billion. Although crude, Bjertnæs' assessment suggests that the total gross economic cost of the BEV incentives could be about twice as large as the tangible costs computed in this paper, in other words that the *intangible* welfare cost involved is on a par with the *tangible* cost cal- culable from the import expenditure statistics.

2.4. *Energy consumption*

What are the tangible benefits of the low carbon fiscal policy? First and foremost, they relate to energy costs. While ICE vehicles at best exploit 30–45 per cent of the energy contained in their fuel, and at start-up and low speed much less, BEVs are remarkably energy efficient, exploiting 85–90 per cent of the energy already from the first metre driven. On the average, BEVs are at least three times as energy efficient as comparable ICE cars.

Even if the unit cost of energy would be the same for electricity and petrol/diesel, there is thus a potential for saving two thirds of the energy costs.

What are the relative prices of electricity versus fossil fuel? The spot price of electricity in Norway is of the order of € 0.030–0.035 per kWh excluding surtax[17] and VAT. The energy content of one litre of petrol being about 9 kWh, with a pre- tax price hovering around € 0.6, one notes that, before taking account of grid costs, the resource cost of electricity in Norway is only about half as high as for fossil fuel.

In our scenario projections, an energy consumption rate of 0.2 kWh/km[18] is assumed for BEVs, while PHEVs are assumed to consume an average of 0.1 kWh of grid electricity per km. Under Norwegian conditions, this translates into a BEV energy cost of about NOK 0.20 per km including tax, versus roughly NOK 1.00 (= € 0.12) per km for an average petrol driven car.

2.5. *Life expectancy of electric vehicles and batteries*

A third, tangible cost element is vehicle maintenance, in particular battery replacement. The batteries of some BEVs may not outlast the vehicle itself. In our scenario projections, it is foreseen that all or some BEVs have their batteries replaced in their 10th life year, at an average cost of NOK 50,000 per vehicle (= € 5 931). For PHEVs, a unit battery replacement cost of NOK 20,000 is assumed.

Other maintenance and depreciation costs are unlikely to differ greatly between BEVs, PHEVs and ICE vehicles. In our sce- narios, BEVs and hybrids are assumed to exhibit life expectancies and lifetime mileages comparable to those of ICE vehicles. The average life expectancy of a passenger car in Norway is around 17 years (Fridstrøm et al., 2016).

2.6. *Infrastructure*

A fourth element is recharging infrastructure. While most BEV owners will charge their vehicle through an outlet at home, for BEVs to become the preferred option of a majority of car buyers, public charging stations should become available along major travel corridors, as well as for those who cannot park their vehicles anywhere but in the street.

In an appraisal, the costs of developing and operating a recharging infrastructure must be balanced against the savings made on fossil fuel distribution, as steadily fewer vehicles are propelled by petrol or diesel. In our calculations, we have made the simplifying assumption that these cost items cancel out.

2.7. *External costs*

In addition to the tangible and intangible private costs involved in the policy for low and zero emission vehicles, several external effects arise. Indeed, the very rationale for this policy is to limit certain externalities, notably the exhaust emission of greenhouse gases (GHGs) and of locally toxic substances, such as particulate matter (PM) and nitrogen dioxide (NO_2).

These costs are also intangible. They can, however, be assessed to the extent that a unit monetary value has been assigned to them. Thune-Larsen et al. (2016) provide up-to-date monetary values for a wide range of local pollutants originating from Norwegian road transport. Korzhenevych et al. (2014) present valuations made for the various EU countries.

The need to balance the government budget is a real constraint in many European countries, whence it makes sense to confer extra value to a unit of public money. The marginal cost of public funds (cf. Section 3.1) is thus another external cost, for which there exists a government mandated statutory value. According to the Norwegian Ministry of Finance (2014), the extra cost of public funds should be set uniformly at NOK 0.20 per NOK 1 expenditure or revenue. However, Sandmo (1998) notes that unless the taxation system is already optimally designed as seen from a welfare economics point of view, the mar-
ginal cost of public funds depends on the tax instrument. Bjertnæs (2015) concludes, in a recent general equilibrium analysis of the Norwegian economy, that the rate is only 0.05 for general income taxation and VAT, but possibly as high as 0.20 for taxes on capital dividends and corporate profits. Accordingly, the economic costs of the direct and indirect subsidies aimed at zero emission vehicles in Norway is somewhere between 1/20 and 1/5 of the nominal amounts of tax revenue foregone. This brings the gross cost reported by H&S down to US$ 150–600 per tonne CO_2, before the energy savings and other long-term benefits are taken into account (see Sections 4.4 and 4.5 below).

17 As of 2014, the electricity tax was NOK 0.1239 per kWh = € 0.0147.

18 This average masks a certain variation by season and vehicle size. In Norway, BEV energy consumption is noticeably higher in winter (Figenbaum et al., 2015).

3. Scenario projections

To assess the outcome of a policy, one has to judge it against some alternative. Standard cost-benefit analysis (CBA) is based on the comparison between two or more possible paths of development, one of which – the 'business-as-usual' or 'do-nothing' alternative – is typically labelled the 'reference path' or 'benchmark'.

If one were, however, to calculate the cost of Norway's policy for low and zero emission vehicles up to and including, say, 2015, one quickly runs into the challenge of specifying a meaningful benchmark. Rather than performing a counterfactual analysis of past developments, we have made use of a dynamic stock-flow cohort model of the car fleet to simulate a set of hypothetical futures, differing in terms of fiscal policy and in certain other determinants.

3.1. *Reference paths and modelling framework*

A key input to any scenario projection for the passenger car fleet and its GHG emissions is the relative prices between competing vehicle models, and in particular the prices of low and zero emission vehicles as opposed to conventional cars. This development is uncertain. To account for this uncertainly, two sets of projections have been made, one assuming 'quick convergence' between the manufacturing costs of BEVs and ICE vehicles, respectively, and another based on 'slow conver- gence'. The two cases are shown in Figs. 6 and 7.

For petrol, diesel and battery electric vehicles, both paths develop from the average prices observed during the 12-month period from July 2013 to June 2014 (see Fig. 5). For hybrid vehicles, since no data are available from the foreign trade statis- tics, certain discretionary estimates have been made for the plug-in and ordinary hybrid vehicle segments, respectively.

In the quick convergence case, the price of BEVs is cut into half from 2014 to 2022. In the slow convergence case, the same does not happen until 2035. In both cases, the prices of ordinary and plug-in hybrids are assumed to come down more slowly than those of BEVs. PHEVs are assumed to remain more expensive than petrol driven ICE cars throughout the projection period.

For each of these two cases, we have defined a reference path, where the Norwegian vehicle purchase tax does not change between 2014 and 2050. For realism, however, we assume that most other privileges enjoyed by BEVs are successively abol- ished. The road toll and ferry charge exemptions are assumed to end on 1 January 2018, the purchase tax exemption on 1 January 2020, and the VAT exemption[19] on 1 January 2022.

Energy efficiency improvements are assumed to take place for all ICE and hybrid vehicles. The mean type approval rate of fuel consumption of new petrol and diesel driven cars is assumed to drop by 1 per cent per year throughout the period 2014– 2050. For hybrid vehicles, the rate is set at 3 per cent per year, reflecting an assumption than an increasing share of these vehicles will be plug-in hybrids.

On top of the improvements in fuel economy and manufacturing costs, BEVs are also assumed to undergo gradual quality improvements (e. g., extended range), valued at NOK 100,000 (= € 11,862) per vehicle by 2022 and another NOK 60,000 by 2050. For hybrid vehicles, half as large an improvement is assumed.

To predict the composition of new car sales under these assumptions, we make use of a nested logit model estimated on the basis of exhaustive, disaggregate passenger car sales data covering the period between January 1996 and July 2011 (see companion paper by Østli et al., 2016). A 5-digit number of different vehicle models have been identified and their annual sales recorded. Independent variables include the retail list price, tax, fuel type, make, type approval fuel mileage, curb weight, utility load, engine power, width, length, traction, and number of doors and seats. As a proxy for all those quality attributes that are not explicitly accounted for, we use the share of the retail price that does *not* consist in purchase tax or VAT.

The model predictions are sensitive to changes in the purchase tax. Since the discrete choice model is entirely generic, we may use it to predict the demand for hypothetical new car models, in particular the demand for low and zero emission vehi- cles, such as BEVs and PHEVs.

To account for the long-term changes in the car fleet, the new car sales are fed into a dynamic spreadsheet model, in which each cohort of cars is followed through its life span. In this cohort model, each year's *stock* of cars is calculated from that of the preceding year, as modified by the *flows* of new car sales, second hand import, scrapping, and deregistration (com- panion paper by Fridstrøm et al., 2016).

The car fleet is divided into 22 segments and 31 age classes. There are nine segments for petrol driven cars and nine for diesel driven ones, each fuel class being subdivided into weight classes. In addition, there is one segment for hybrid vehicles, one for BEVs, one for FCEVs,[20] and one for vehicles using other energy carriers (compressed natural gas, ethanol, etc). All but the last two of these segments are exhibited in Fig. 2 above.

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[19] By Council Directive 2010/88/EU, the minimal VAT rate is 15 per cent. Since Norway is not an EU member, EU Directives are enforced by the EFTA Surveillance Authority (2015), which, in its decision of 21 April 2015, accepted the tax exemptions etc. for electric vehicles as State aid compatible with the EEA agreement. Since this decision stands only until 31 December 2017, our scenarios presuppose that an at least four-year extension be granted.

[20] Since there are virtually no market data available on FCEVs, we cannot at present assess their future demand. Hence these vehicles are not separately accounted of in our projections. Instead, since FCEVs and BEVs have identical tax regimes and on-the-road emission characteristics, one may choose to interpret the BEV category as including all zero emission vehicles.

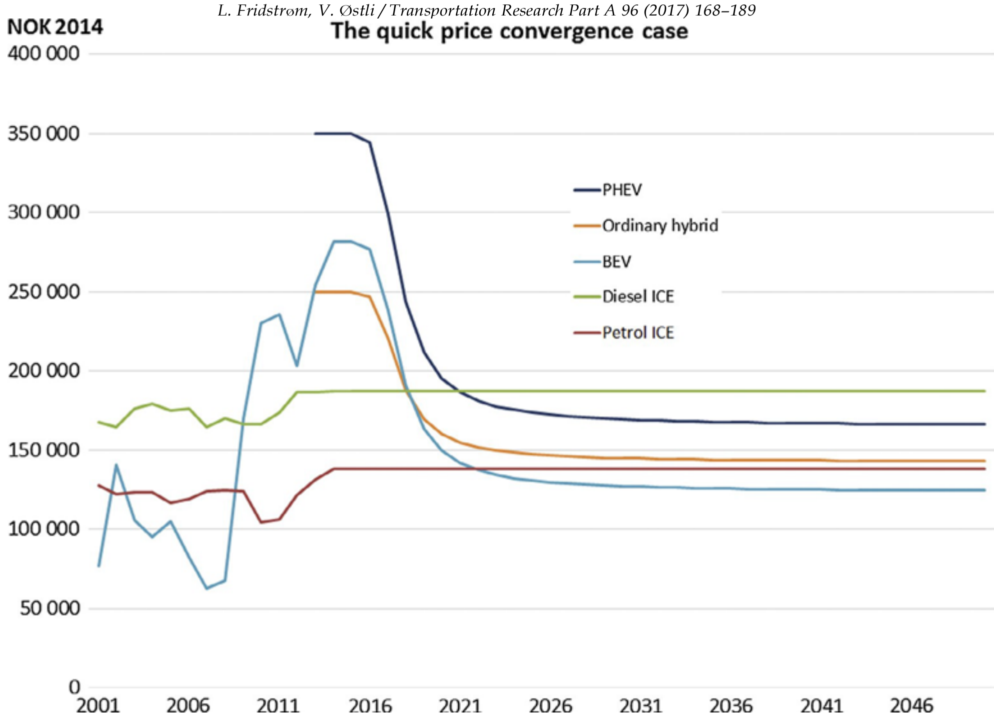

Fig. 6. Assumed real price development for new passenger cars imported to Norway, under quick price convergence. Pre-tax averages for five vehicle segments.

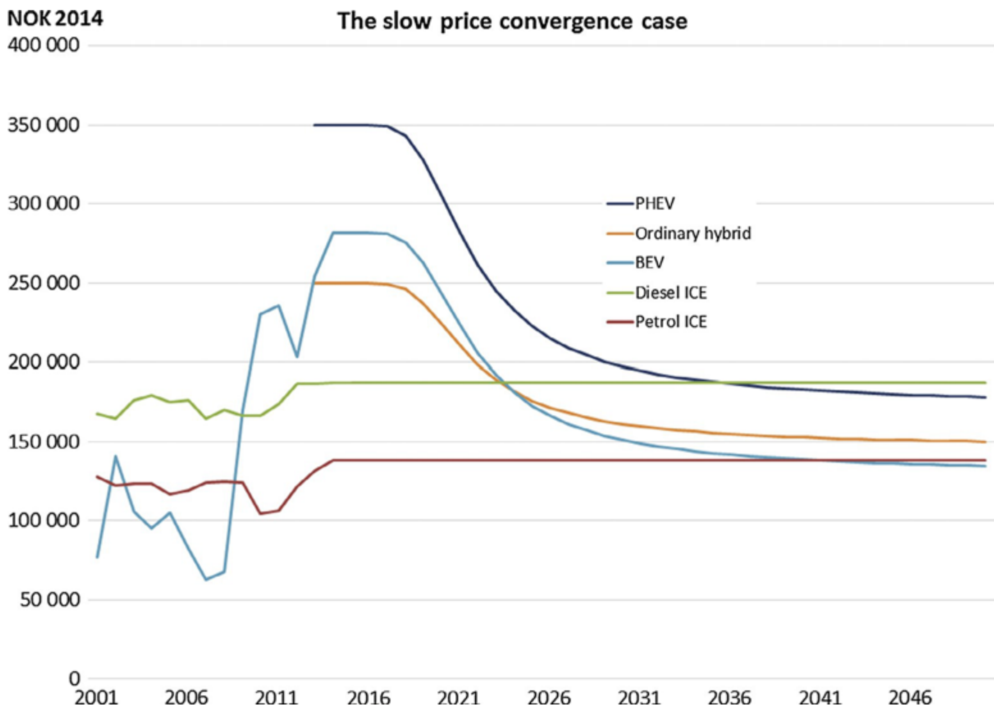

Fig. 7. Assumed real price development for new passenger cars imported to Norway, under slow price convergence. Pre-tax averages for five vehicle segments.

To each cell in the 22 x 31 matrix of the car fleet, various attributes are assigned, such as mean type approval fuel con- sumption per km, mean NO_X emission rates, mean annual distance driven, annual rate of scrapping, and an annual rate of second hand import. There is also a residual outflow of vehicles defined, with its own annual rate, covering second hand export and net temporary or permanent deregistration.

Using this framework, we have simulated several paths of development, differing in terms of vehicle taxation, until the 2050 horizon. One set of projections assumes quick price convergence, another applies to the slow convergence case.

3.2. *Low carbon fiscal policy scenario*

In addition to the reference path, we specify a rather forceful fiscal scenario, where the CO_2 component of the vehicle pur- chase tax is assumed to increase by NOK 75 per gCO_2/km each year from 2015 on, while the deduction applicable to cars emitting less than 105 gCO_2/km is doubled from 2016 on (Fig. 8).

Apart from the changes in the purchase tax, the low carbon policy scenario is based on the same assumptions as the ref- erence scenario.

3.3. *Policy impact on car fleet and emissions*

3.3.1. *The quick price convergence case*

The projected new car registrations under quick price convergence are depicted in Fig. 9. The reference scenario is shown to the left, and the low carbon policy scenario to the right.

In the latter case, our nested logit model of car choice predicts a massive shift towards hybrid and battery electric cars. In the reference scenario, however, the market growth period for BEVs lasts only as long as the VAT exemption (2022).

The mean type approval rates of CO_2 emission from new cars in the two scenarios are shown as dotted lines in Fig. 10. In the reference path, the rate comes down from 110 gCO_2/km in 2014 to 95 gCO_2/km in 2020, 88 gCO_2/km in 2030, and 75 gCO_2/km in 2050. In the low carbon policy scenario, the corresponding levels are 80, 59 and 37 gCO_2/km, respectively. The composition of the car fleet and its emission characteristics change more slowly. In the low carbon policy scenario, although hybrid and battery electric vehicles will represent more than 50 per cent of new car registrations in 2025, it will take until 2039 before the same is true of the car stock (Fig. 11).

By the same token, the car fleet's emissions on the road will come down only slowly. In the low carbon policy scenario, real-world emissions are seen to drop by 18 per cent (to 160 gCO_2/km) by 2020, by 42 per cent (to 113 gCO_2/km) by 2030, and by 67 per cent (to 65 gCO_2/km) by 2050 (solid red line in Fig. 10).[21]

On account of the gradual substitution of new vehicles for older ones, the CO_2 emissions from the car fleet will come down even in the 'do-nothing' scenario – by 15 per cent by 2020, 31 per cent by 2030 and 44 per cent by 2050 (solid green line in Fig. 10).

In terms of absolute CO_2 emission cutbacks, the low carbon policy scenario saves an estimated 1.8 million tonnes in 2050 compared to the reference path, and a full 4.1 million tonnes compared to the 2014 level.

3.3.2. *The slow price convergence case*

In the case where the future price of BEVs converges only slowly to that of ICE vehicles, BEV fleet penetration and CO_2 emissions reduction will be slower, in the reference as well as in the low carbon policy scenario. But as judged from Figs. 12 and 13 compared to Figs. 10 and 11, the difference is not appalling. In the long run, say by 2050, the results are very similar. In the medium term, the difference is more noticeable. Consider the type approval CO_2 emission rate of new cars under the low carbon policy scenario. While, in the case of quick price convergence, it drops below 80 gCO_2/km in 2021, it takes until 2024 before the same happens under slow price convergence (compare Figs. 10 and 12). Also, while under quick price con- vergence, the number of BEVs and hybrid vehicles surpasses one million in 2029, it does so two years later if prices converge slowly (compare Figs. 11 and 13).

4.4. *Differential tangible costs*

4.4.1. *Year-by-year forecasts*

While the end result in terms of GHG abatement and passenger car fleet composition is only marginally different between the quick and slow convergence scenarios, the same is not true of their respective economic costs. In Figs. 14 and 15, we show differential expenditures incurred under the low carbon policy scenario as compared to the reference path. Benefits, or cash savings, are shown as bars below the horizontal axis.

The main tangible cost element is the extra outlay on car acquisition, which reaches NOK 2.5 billion (= € 0.297 billion) in 2016 and 2017 under quick price convergence, before gradually tapering off as hybrid and battery electric cars become cheaper. A slight increase in car purchase expenditure occurs between 2025 and 2050, as the more expensive plug-in hybrids are projected, in the low carbon policy scenario, to replace ordinary hybrids and petrol driven cars. In general, however, dif- ferential car acquisition expenditures peak in the early phase of the process.

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[21] Here, we have made the conservative assumption that for future car generations, the discrepancy between type approval and real-world emissions does not increase from the 2011 level of 28 per cent. For vehicle cohorts prior to 2011, we use correction factors consistent with Mock et al. (2013).

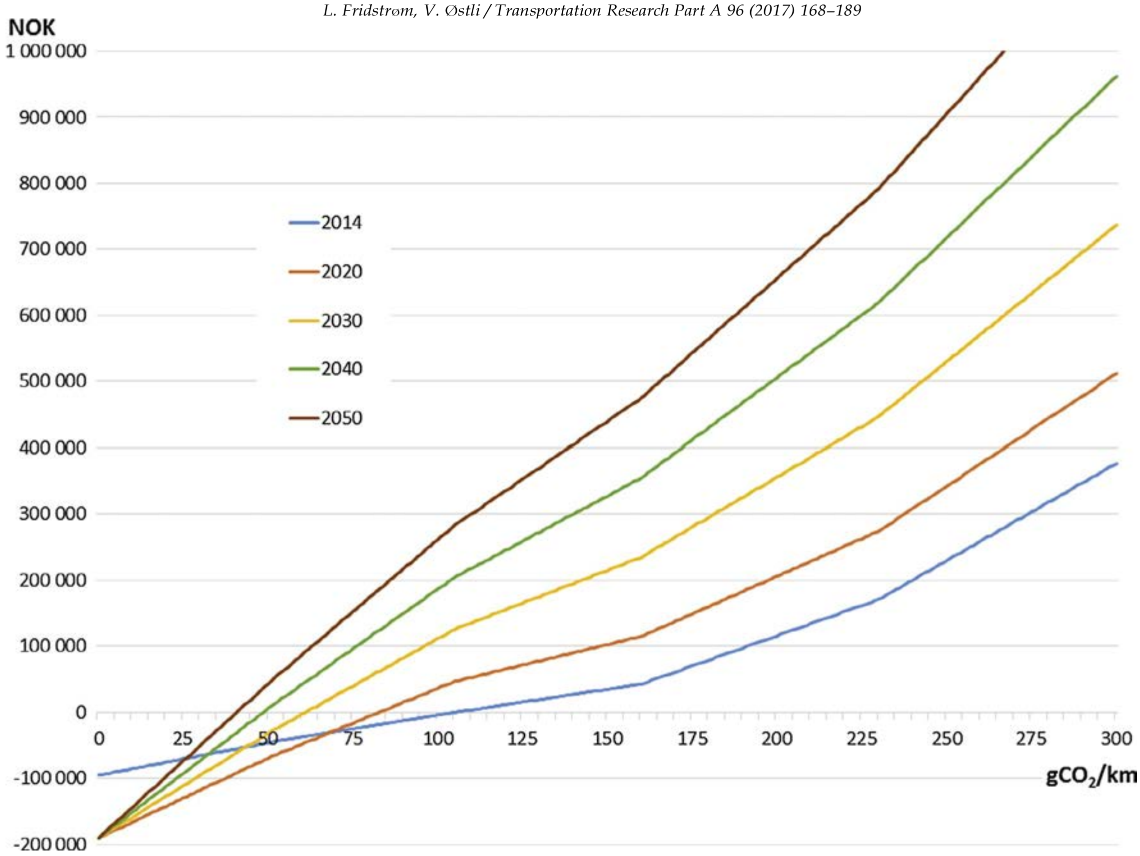

Fig. 8. Assumed development of the CO2 component of the vehicle purchase tax under the low carbon fiscal policy scenario.

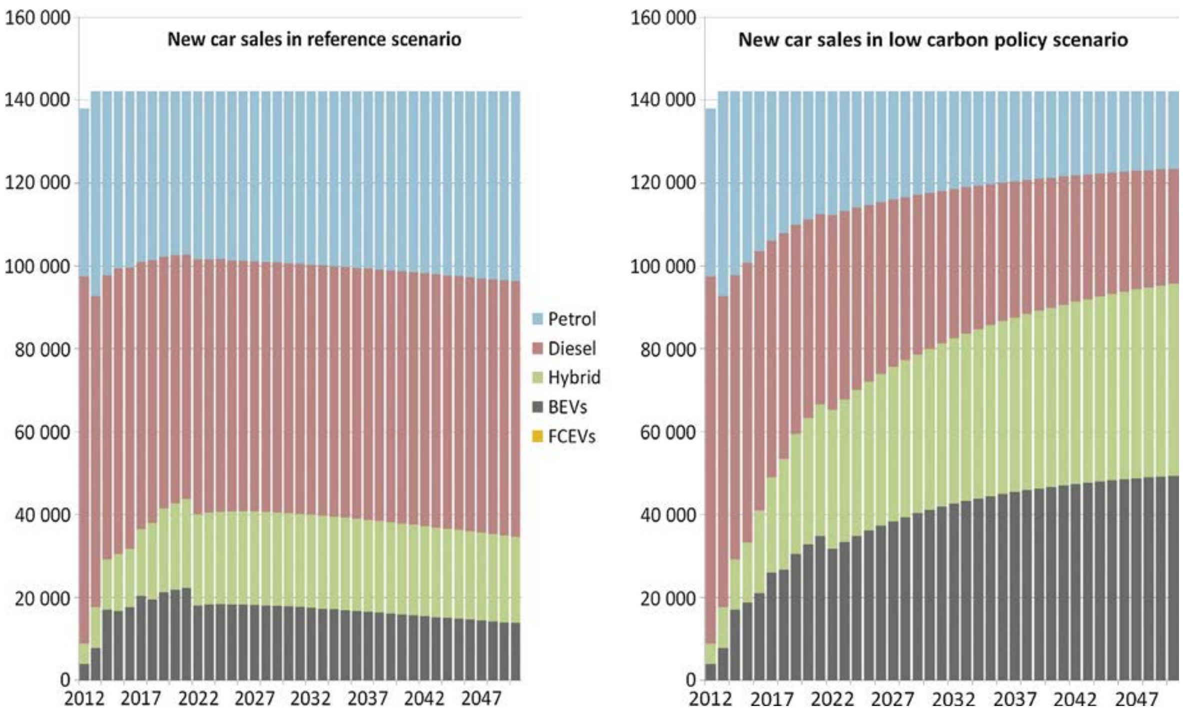

Fig. 9. New car sales 2012–2050 under reference and low carbon policy scenarios, assuming quick price convergence.

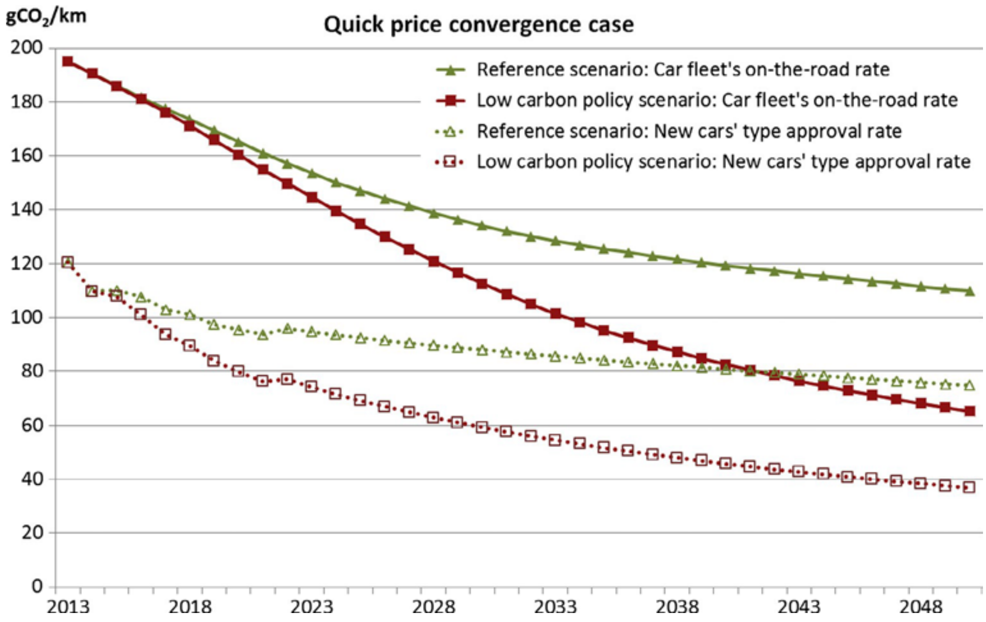

Fig. 10. Mean type approval and estimated on-the-road CO2 emission rates of Norwegian passenger cars 2013–2050, under quick price convergence. Reference and low carbon policy scenarios.

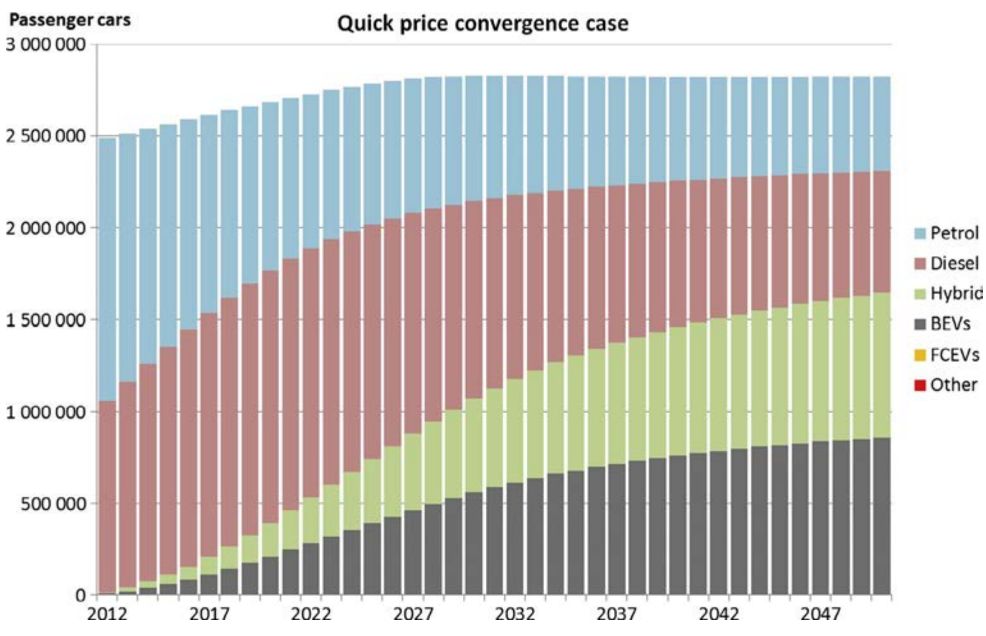

Fig. 11. Norwegian passenger car fleet 2012–2050 under low carbon policy scenario and quick price convergence.

The opposite is true of fuel costs. As long as low and zero emission vehicles make up only a few per cent of the car fleet, fuel savings are modest. But when, under the low carbon policy scenario in 2039, BEVs and hybrids make up more than 50 per cent of the car fleet, annual fuel savings amount to NOK 3.25 billion (= € 0.386 billion), as evaluated at pre-tax prices under the quick price convergence assumption.

Expenditure on electricity will, of course, go up as more and more vehicles become electrified. As of 2039, differential electricity expenditures are projected to reach NOK 0.944

billion (= € 0.112 billion) under quick price convergence, less than one third of the corresponding fossil fuel cost savings.

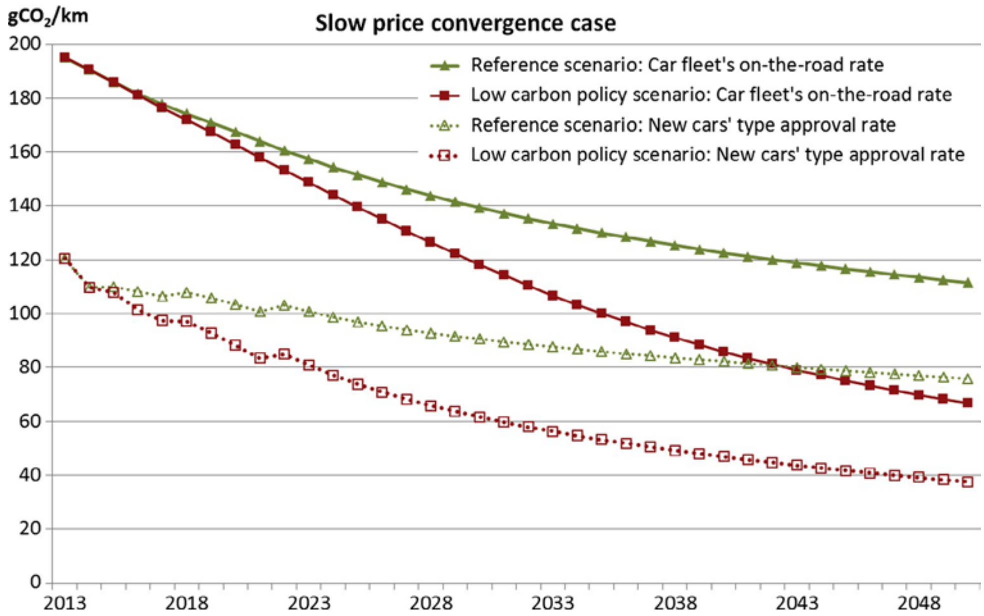

Fig. 12. Mean type approval and estimated on-the-road CO2 emission rates of Norwegian passenger cars 2013–2050, under slow price convergence. Reference and low carbon policy scenarios.

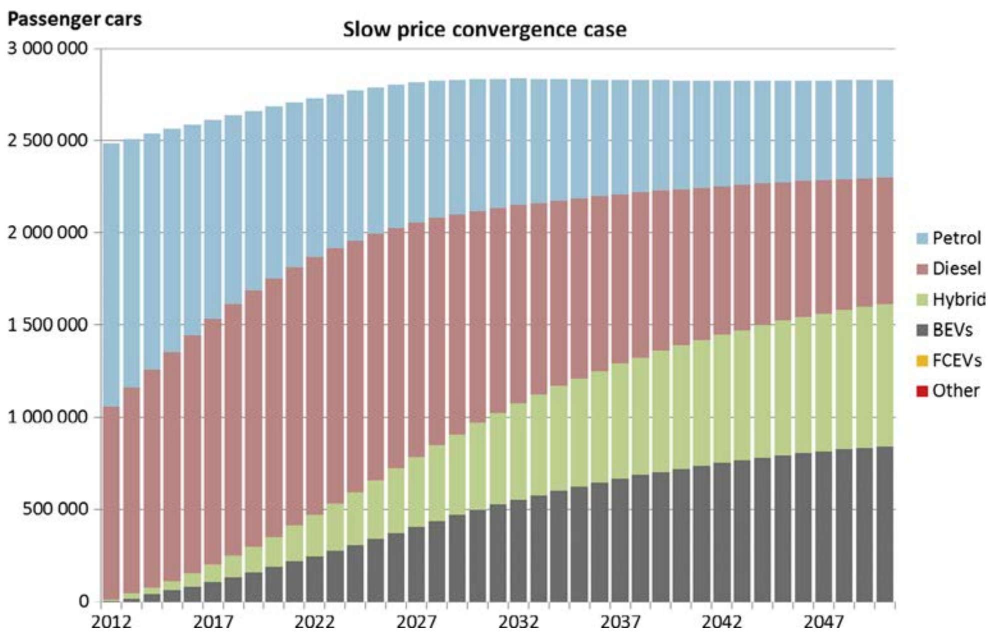

Fig. 13. Norwegian passenger car fleet 2012–2050 under low carbon policy scenario and slow price convergence.

Battery replacement, if applicable to all BEVs and PHEVs in their 10th life year, is in

2039 projected to cost NOK 1.141 billion (= € 0.135 billion) more under the low carbon policy scenario than under the reference scenario, assuming – again – quick price convergence.

Under slow price convergence, the tangible costs are seen to be considerably higher (Fig. 15). The extra expenditure on new vehicle acquisitions is seen to peak as late as 2020, with more than NOK 4 billion.

4.4.2. *The discount rate*

When future cost and benefits are to be compared, the discount rate plays a critical role, especially when the time horizon extends over several generations. It is a contentious issue, politically as well as scientifically. Harrison (2010: 36) cites ten

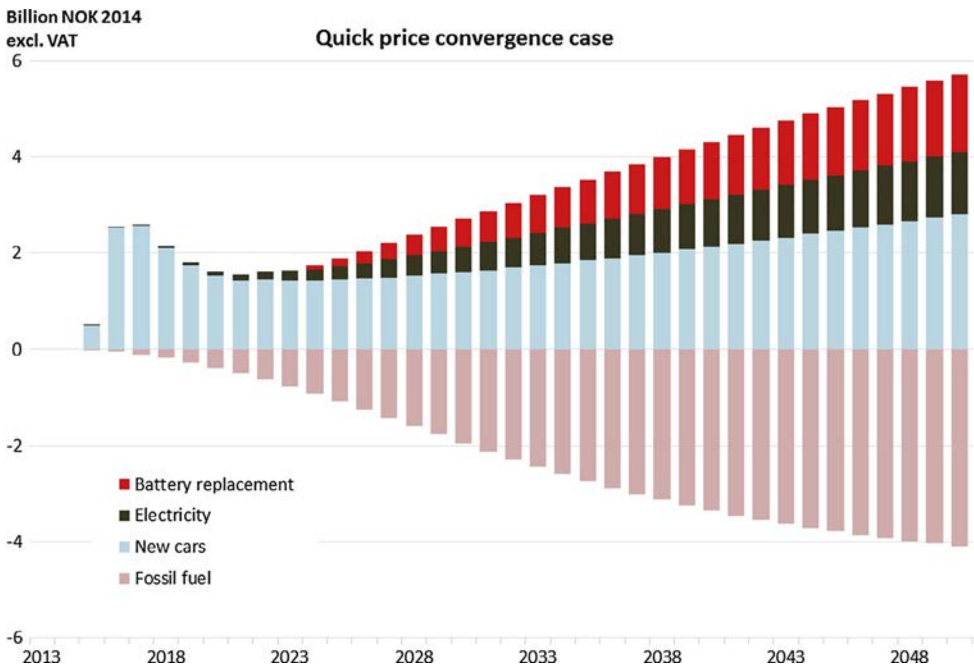

Fig. 14. Differential tangible economic costs (expenditure) between low carbon policy and reference scenarios, assuming quick price convergence.

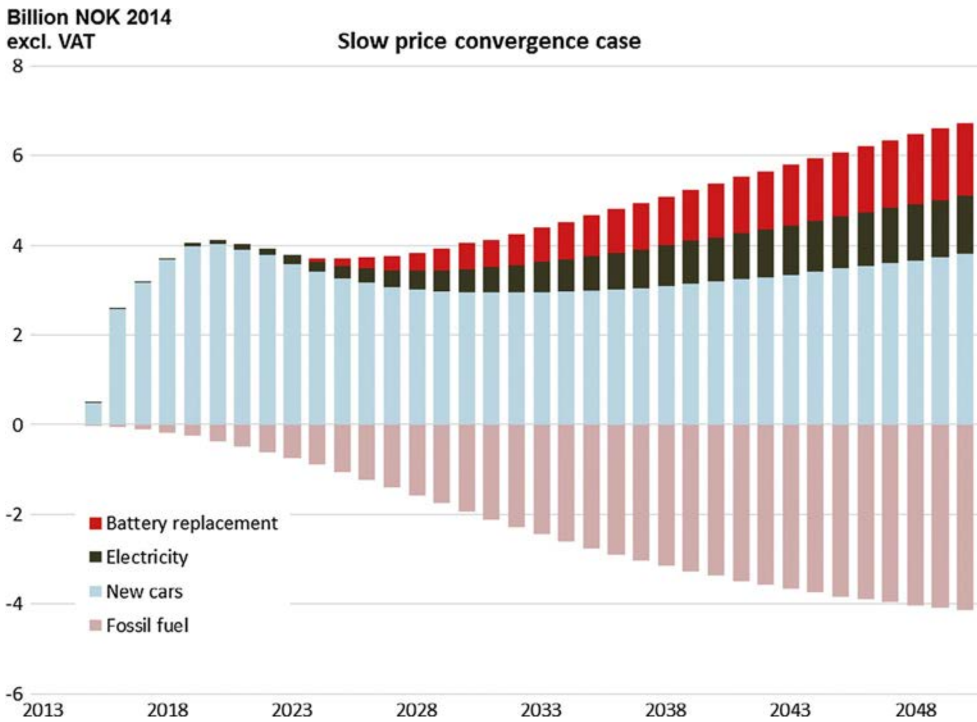

Fig. 15. Differential tangible economic costs (expenditure) between low carbon policy and reference scenarios, assuming slow price convergence.

different studies suggesting annual discount rates ranging from 1.4 to 8 per cent, all of them based on the renowned Ramsey formula, whereby the risk-free, 'pure rate of time preference' is augmented by an additive term given by the consumption growth rate weighted by (minus) the elasticity of marginal utility with respect to consumption. The idea behind the second term is that if consumption growth is positive, future generations will be more affluent, hence their consumption should count relatively less (i.e., be discounted at a higher rate), as long as utility is a concave function of consumption. Arguing, like Ramsey (1928: 543), that pure time discounting is 'ethically indefensible' as it amounts to valuing the welfare of future generations at a lower rate than the current, Stern (2007) uses a near-zero (0.1) annual rate of time preference, a logarithmic utility function (implying a unit elasticity) and a 1.3 per cent consumption growth rate, resulting in a 1.4 discount rate. Remarking that Stern's policy conclusions 'will not survive the substitution of assumptions that are more consistent with today's marketplace real interest rates and savings rates', Nordhaus (2007) shows how a 1.5 per cent time preference, a 2 per cent growth rate and a consumption elasticity of 2, yielding a 5.5 per cent discount rate, would completely change the economics of climate change mitigation.

Arguing that future rates of time preference are uncertain, Weitzman (1998) advocated the use of falling discount rates. Gollier (2004, 2009), on the other hand, came to the opposite conclusion – that discount rates should be increasing, to reflect a growing uncertainty concerning the future growth rate. Gollier and Weitzman (2010) later came to the common conclu- sion that 'When future discount rates are uncertain but have a permanent component, then the "effective" discount rate must decline over time towards its lowest possible value.'

This principle has now been put into practice by the governments of France and the United Kingdom (Arrow et al., 2014), as well as in Norway. The Norwegian Ministry of Finance (2014, see also NOU 2012:16) has mandated discount rates for use in cost-benefit analysis of 4 per cent per annum over the first 40 years, 3 per cent over the next 35 years, and 2 per cent after 75 years, as reckoned from the date when the cost-benefit assessment is made.

As judged against current marketplace interest rates, these discount rates may seem to be on the high side. Statistics Norway (2015) estimates the real after-tax lending rate from banks at 0.1 per cent per annum in 2015 and expects the rate to drop below zero in years to come. Since most Norwegian families own their own home, the after-tax mortgage rate could be seen as a reasonable proxy for the households' opportunity cost of capital.

Resolving the issue of long-term social discount rates is beyond the scope of this paper. However, to shed light on the uncertainty connected to it, we have calculated the present value of tangible costs and benefits under three alternative assumptions: 0, 4 or 8 per cent annual discount rate.

4.4.3. *Present value of accumulated benefits and costs*

The present value of accumulated net differential costs per tonne of CO_2 emissions avoided is shown in Table 1, under varying assumptions concerning the discount rate, the speed of price convergence and the need for battery replacement in BEVs and PHEVs. In Fig. 16, costs with and without battery replacement under quick price convergence are compared among the 0, 4 and 8 per cent discount rates. In Fig. 17, we show variation across the speed of price convergence under a 4 per cent discount rate.

When all BEVs with a life longer than 10 years are assumed to have their battery replaced, the net present value of tan- gible costs accumulated until 2050 comes out at NOK 1166 (= approx. € 138) per tonne CO_2 under quick price convergence and a zero discount rate. If we disregard battery replacement costs, assuming that the batteries of future BEVs and PHEVs will outlast the vehicles themselves, the cost per tonne CO_2 comes down to NOK 402 (= approx. € 48) at the 2050 horizon.

When a 4 per cent discount rate is used, the corresponding per tonne CO_2 tangible cost estimates come out at NOK 1608 (= approx. € 190) and NOK 903 (= approx. € 107) with and without battery replacement, respectively. Here, the CO_2 emis- sions have been discounted as well, although, according to IPCC (2013), the long term climate impact of GHG emissions depends on their aggregate amount over time rather than on when emissions occur.

At an 8 per cent discount rates, even higher estimates ensue: NOK 2346 and 1712, or € 278 and 203, as evaluated at the 2050 horizon.

Under slow price convergence, net tangible costs at the 2050 horizon come out roughly two to four times higher than if price convergence is quick.

Obviously, the accumulated per tonne cost of the low carbon policy is going to depend on the time scale. In the short term, the costs largely outweigh the benefits. As of 2025, for instance, the net accumulated expenditure exceeds € 800 per tonne CO_2 even in the best of cases. Since, however, the full benefit of improved energy efficiency is not harvested until the vehicle is scrapped, a 'fair' cost assessment would have to look at least one vehicle generation ahead, preferably several generations. In this perspective, only the 2040 or 2050 figures should be seen as carrying much weight.

4.5. Differential fiscal revenues

The fiscal revenue implications of our low carbon policy, as compared to the reference scenario under quick price conver- gence, are shown in Fig. 18.

Since many consumers and companies will continue to buy ICE vehicles, the long-term fiscal impact of a steadily sharp- ened CO_2 taxation on new cars will be positive, as viewed by the public treasury.

Fuel tax revenue will, however, relentlessly go down in the low carbon policy scenario, in line with fossil fuel consump- tion. As of 2039, the fuel tax difference between the low carbon policy and reference scenarios is NOK 2.674 billion.[22]

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[22] When this amount is added to the pre-tax fuel cost savings shown in Fig. 14 (NOK 3.25 billion), the gross fuel expenditure reduction enjoyed by car owners in 2039, between the low carbon policy scenario and the reference path, can be calculated at NOK 5.82 billion = approx. € 0.69 billion exclusive of VAT, or approx. € 300 per passenger car including 25 per cent VAT.

Table 1

Accumulated net tangible economic costs per tonne of CO_2 avoided at the 2020, 2030, 2040 and 2050 horizons. Figures in NOK 2014.

	2020	2030	2040	2050
	Quick price convergence, zero discount rate			
Without battery	24 157	2922	857	402
With battery replacement	24 157	3340	1519	1166
	Quick price convergence, 4 per cent discount rate			
Without battery	25 458	3709	1453	903
With battery replacement	25 458	4094	2067	1608
	Quick price convergence, 8 per cent discount rate			
Without battery	26 795	4670	2295	1712
With battery replacement	26 795	5021	2853	2346
	Slow price convergence, zero discount rate			
Without battery	41 984	7614	2964	1774
With battery replacement	41 984	8026	3619	2535
	Slow price convergence, 4 per cent discount rate			
Without battery	43 238	8962	4126	2827
With battery replacement	43 238	9341	4733	3529
	Slow price convergence, 8 per cent discount rate			
Without battery	44 518	10 534	5677	4402
With battery replacement	44,518	10,879	6229	5032

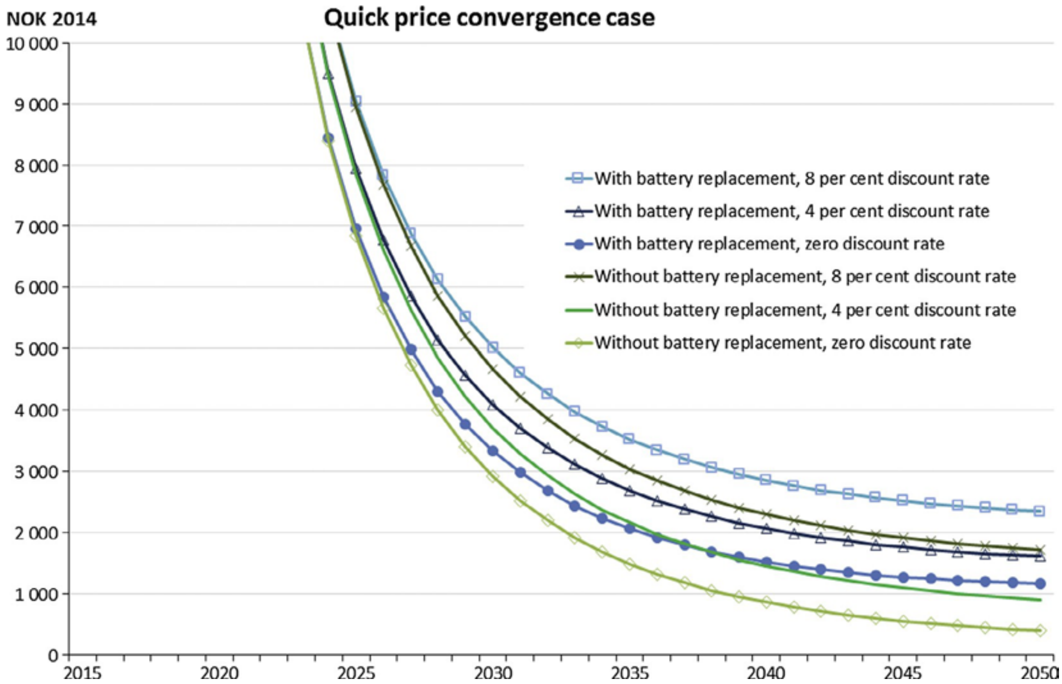

Fig. 16. Accumulated net tangible economic costs per avoided tonne of CO2 under low carbon policy against reference scenario, assuming quick price convergence.

Assuming that the lower rate of annual circulation tax applicable to BEVs will persist, even this tax revenue will shrink. Value added tax (VAT) is levied on vehicles, electricity and fuel. The differential VAT revenues from these three sources are seen to more or less cancel each other out, however with a long-term tendency for fuel VAT reductions to more than offset the extra VAT revenue from electricity and vehicles. Note that in the reference as well as in the low carbon scenario, the aggregate number of new car registrations is kept constant. Thus the VAT revenue from new vehicles changes only in response to the vehicle *mix* being different between the low carbon and reference scenarios. To the extent that buyers switch to less costly vehicles, as measured before purchase tax, VAT revenues from vehicle sales will go down.

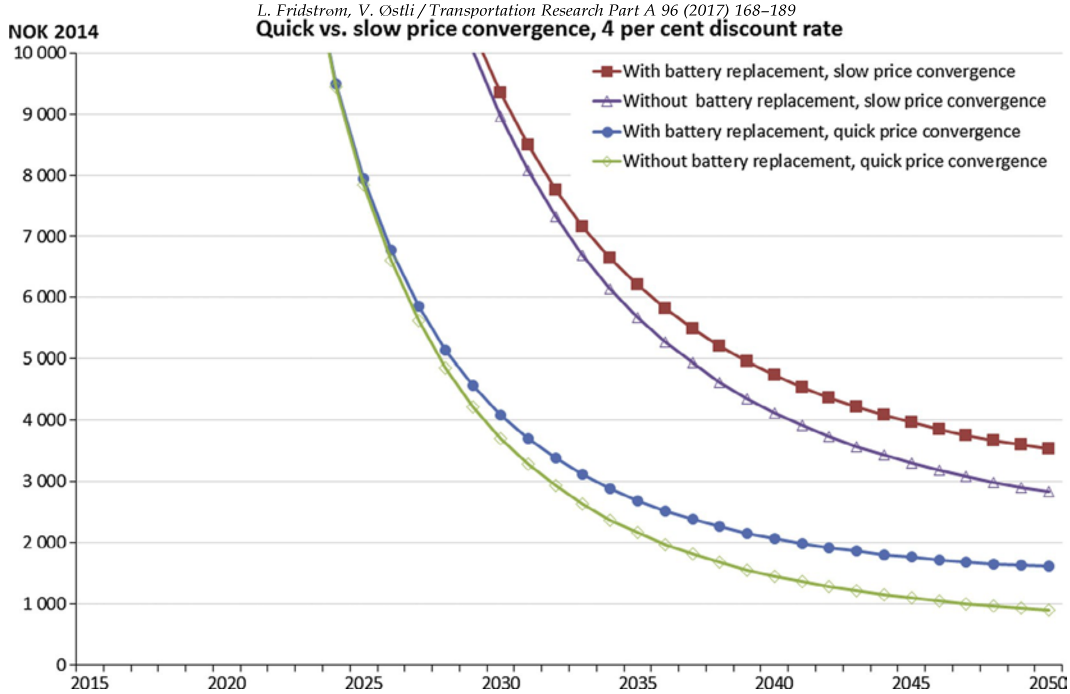

Fig. 17. Accumulated net tangible economic costs per avoided tonne of CO_2 under quick vs. slow price convergence. 4 per cent discount rate assumed.

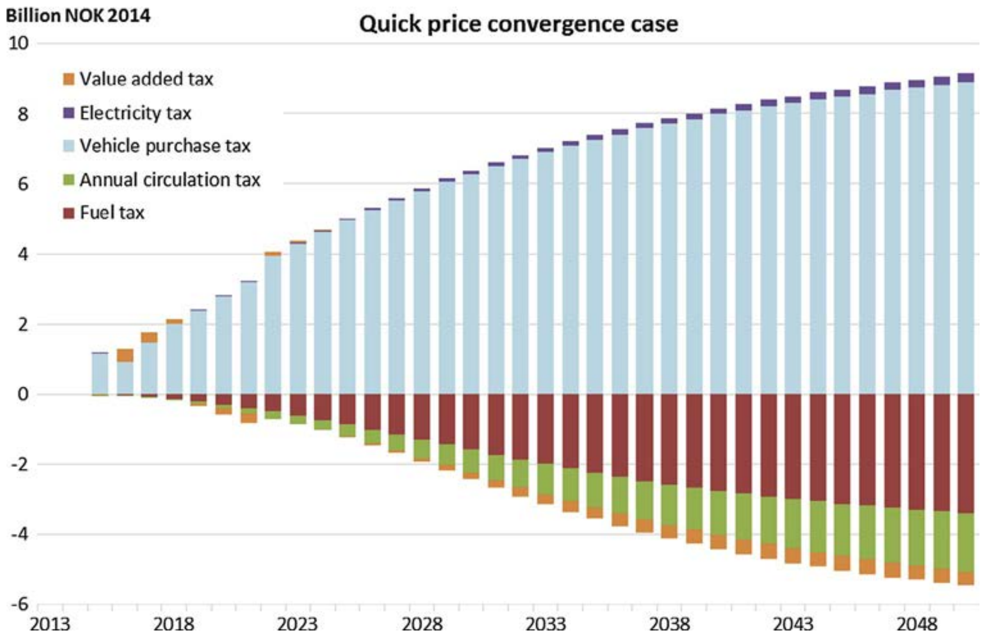

Fig. 18. Differential fiscal revenue under low carbon policy vs. reference scenario, assuming quick price convergence.

4. Discussion

Like any modelling exercise, our calculations are subject to uncertainty and some qualifications.

4.1. *Energy source and carbon footprint*

The CO2 emissions calculated in either scenario are those occurring on Norwegian territory only. A life cycle analysis (LCA) of the vehicles would necessarily include emissions in the countries of manufacturing. Battery production being a rather energy demanding process, a life cycle analysis of Norway's low carbon fiscal policy would result in widely varying assess- ments of the climate footprint depending on the energy mix at the site of battery production.

Our approach is in line with the principles of the Kyoto protocol and Paris agreement, by which each signatory country is accountable for emissions on its own territory. If one were to take into account production effects in other countries, it would be logical to also consider the international impact of Norway's accelerated market uptake of BEVs, which may help bring about economies of scale in BEV manufacturing, to the benefit of buyers worldwide. Such an extended perspective would, however, quickly become intractable, and we have therefore chosen to disregard life cycle and other international effects. A second issue bearing on international relations is the climate footprint of increased electricity use.

In our calculations, the CO2 emission generated by a marginal kWh of electricity consumption is set to zero. While this may appear reasonable given Norway's almost 100 per cent hydropower based electricity system, power exchange with other northern European countries means that the energy mix is not entirely fossil free even in Norway.[23] Some would argue that the marginal kWh originates from a thermal plant. However, since all power plants in the European Economic Area[3] (EEA) are covered by the European Trading System (EU ETS), an extra tonne of CO2 emitted from a power plant simply replaces a corresponding amount of emissions elsewhere. At least this will be true from the time when the cap on emissions becomes effective. Until then, increased demand for electricity to power BEVs and PHEVs will serve to boost the price of emission allowances and enhance the incentives for energy conservation and renewable energy production throughout the economy.

Yet, the power market impact of vehicle electrification should not be overstated. Six per cent of Norway's domestic hydro- power output would be sufficient to operate the country's entire passenger car fleet, if completely electrified.

Obviously, the climate impact of vehicle electrification will, in general, depend on the grid energy source and on the pres- ence or not of effective allowance trading systems. In the European Economic Area, automobile electrification means moving car use into the emissions trading system (EU ETS).

4.2. *BEV and PHEV market development*

The assumption, made under the 'quick convergence' scenario, that the manufacturing costs of BEVs will undercut that of petrol driven vehicles from 2023 onwards may seem optimistic. On the other hand, the most recent data available from Nor- way's foreign trade statistics (January to December 2015) suggest that the BEV to ICE vehicle price differential is already coming down at a rate faster than assumed in our 'quick convergence' scenario projections. If such a development continues, our cost estimates are likely to be on the high side. Under favourable circumstances, it is conceivable that the long-term net tangible cost of the low carbon fiscal policy could drop below zero, yielding a net benefit even before GHG abatement effects. The market uptake of BEVs and PHEVs will depend, not only on their average prices, but also on the variety of models offered. The more models become available in the market, the higher their aggregate market share will be. It is possible, and indeed likely, that our scenario assumptions are too conservative in this respect. This translates into an upward bias in our CO_2 emission estimates under both scenarios. The impact on *differential* CO_2 emissions and cost per tonne CO_2, between the two scenarios, is, however, hard to tell.

4.3. *Externalities and tax*

While large parts of the political debate on Norway's generous BEV incentives are focused on the purported large indirect subsidies, our scenario projections show that a forceful low carbon fiscal policy can be made to have the opposite long-term effect, bringing extra revenue into the public treasury (Fig. 18). When – as in Norway – none of the vehicle, fuel, electricity or circulation taxes are earmarked, changes in their mix are of no big concern to the public treasury.

Such a reshuffling does, however, affect the externalities of road use. If and when low and zero emission vehicles make up a large share of the car fleet, the private marginal cost of car use will go down, spurring demand. This is the so-called rebound effect.[24] Fridstrøm et al. (2014) calculated that a 50 per cent reduction in the per km fuel consumption would lead to 15 per cent more car use on short haul trips, but a 42 per cent reduction in CO_2 emissions, all modes considered. On long haul trips, the car rebound effect was found to be a full 48 per cent in terms of vehicle kilometres travelled, but quite small in terms of overall CO_2 emissions. This is so because, under Norwegian conditions, cars compete primarily against the air mode rather than against long distance coach or rail. When car use becomes cheaper, fewer people choose to fly.

Later studies (Madslien and Kwong, 2015) based on updated models suggest much smaller rebound effects, less than half as large as found by Fridstrøm et al. (2014).

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[23] According to the Norwegian Water Resources and Energy Directorate (NVE) the Norwegian energy mix corresponds to an emission of 10 g CO_2 per kWh, while the 'Nordic energy mix' is equivalent to 175 g/kWh. The latter figure translates into 35 gCO_2/km for a BEV consuming 0.2 kWh per km, equivalent to 157 mpg for a petrol driven car.

[24] See, e.g., Schipper and Grugg (2000) or Small and van Dender (2005).

As of today, European levels of fuel tax serve to internalise a major part of the road use externalities – more so, though, for petrol than for diesel driven vehicles (Thune-Larsen et al., 2016). The concern, held by many, that vehicle electrification may undermine the most important market correction mechanism presently at work, is a valid one. To counteract the growth in car use, with its associated increased congestion, road wear and other externalities, novel forms of market correction, such as generalised GPS-based road pricing (see, e. g., Meurs et al., 2013), might become necessary.

To the extent that the future car fleet includes a large share of plug-in hybrid or battery electric vehicles, certain infras- tructure investments will be necessary. The grid itself may need to be strengthened, households must invest in charging points,[25] and more public charging points will become necessary as well. These tangible costs are not explicitly accounted for in our assessment. However, the unit pre-tax price of electricity used in our calculations – NOK 0.6761 (= approx. € 0.08) per kWh – leaves room for considerable grid and infrastructure costs on top of the current spot price of € 0.030–0.035, without our assumptions becoming overly optimistic.

Our analysis is focused on one single policy instrument – the purchase tax. Some – and a majority of economists – would say that this instrument is far from ideal, since emissions are caused by car *use* rather than by ownership. As argued in our introduction, a fuel tax might be more appropriate for the purpose of GHG abatement.

But the elasticity of demand for fossil fuel seems to be too small (in absolute value) for politically feasible levels of fuel taxation to bring about sizeable GHG emission cuts (Brand et al., 2013). The large, upfront expenditure involved in buying a (more expensive) car is more likely to affect consumer behaviour than the relatively marginal extra cost caused by a fuel tax. Thus, Brand et al. (2013) find, in a comprehensive analysis of UK incentives, that '... car purchase feebate policies are shown to be the most effective in accelerating low carbon technology uptake, reducing life cycle gas emissions .. .' Their conclusion is corroborated by our findings.

Also, it may be argued that, next to residential choice, the acquisition of a car represents the most basic and long-term decision bearing on travel behaviour that is ever made by the typical private household, whose choice of vehicle model affects society's GHG emissions for the coming 15–20 years, regardless of whether the vehicle remains at the hands of its first owner, or is traded second hand. In this perspective, it makes as much sense to tax the car at its acquisition as when it is driven.

The high initial levels of VAT, purchase tax, toll rates and ferry fares in Norway make it possible to create strong incentives without introducing direct subsidies. This experience cannot readily be transferred to other countries. But steep feebates could possibly do the same trick (Lindgren and Fridstrøm, 2015).

4.4. *Emission cuts in other sectors*

In 2010, the Norwegian Environment Agency (NEA) published a report on policy measures and instruments for GHG abatement across all sectors of the Norwegian economy – the so-called 'Klimakur' report. A tentative marginal abatement cost (MAC) curve was compiled (Miljødirektoratet, 2010: 7). It suggests that 7–8 per cent of the country's 54 mtCO2e annual GHG emissions can be cut through measures with zero or negative economic costs. Another 10–12 per cent can, according to the report, be cut at a cost of no more than NOK 1000 (= € 119) per tonne CO2.

In the transport sector, only a few measures – congestion charging, optimized sea vessel speed, shore power to ships at berth – come out as more cost efficient than automobile electrification, which is deemed by NEA to have a negative abate- ment cost at the 2030 horizon. More importantly, automobile electrification is estimated to have a far larger abatement potential than the cheaper measures. Halving the on-the-road emissions of the automobile fleet would alone represent a 5–6 per cent cut in total national GHG emissions.

5. Conclusions

Vehicle purchase taxes and feebates have a large potential for GHG abatement. Such taxes can be designed as fiscally neu- tral or even revenue generating for the public treasury.

The merit of a feebate or purchase tax system should be judged, not by its impact on the public treasury, but primarily by its tangible and intangible costs to all sectors of society, as in a cost-benefit analysis. The main economic cost of an incentive scheme for low and zero emission vehicles is the extra cost of manufacturing technologically immature products with cur- rently small economies of scale. This cost differential is likely to be in large part temporary.

A conversion to low and zero emission vehicles will entail large energy savings in the long term. Since these savings occur much later than the incremental manufacturing cost, it is essential that the policy be assessed in a long-term perspective. The policy itself must be long-term, too, since the car fleet is an inert matter. Converting to a low emission car fleet will require political perseverance over several decades. To reap the benefits without incurring excessive costs, an informed, res- olute and stable long-term policy is called for.

In the European Economic Area, automobile electrification means moving an important source of emissions into the cap- and-trade system (EU ETS).

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[25] Crist (2012) suggests a cost per home charging point of € 1200, or € 0.03 per kWh if divided by a single vehicle life time mileage of 200,000 km at 0.2 kWh/km. Figenbaum and Amundsen (2013) state a cost interval of NOK 3000–16000, roughly € 350–1900, under Norwegian conditions.

The accumulated, net tangible costs of a forceful policy for low emission passenger cars in Norway has been calculated at NOK 402 to 1166 (= € 48–138) per tonne CO2 avoided by 2050, under a zero discount rate and moderately favourable assumptions regarding the impending economies of scale in BEV and PHEV technology. In the shorter perspective, if a 4 or 8 per cent discount rate is applied, and/or if the price of BEVs converges only slowly to that of conventional cars, the cost per tonne will be considerably higher.

The intangible parts of the changes in consumer welfare have, however, not been taken into account in our analysis. One such cost is the limited range of BEVs and the associated range anxiety. Certain simplified partial analyses suggest that this welfare cost may be of the same order of magnitude as the gross tangible cost. To assess these cost elements in a reliable manner, further research will be needed.

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