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From innovation to penetration: Calculating the energy transition time lag for motor vehicles

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ABSTRACT

To meet the targets laid down in the Paris agreement and in the European Union's climate policy documents, road vehicle fleets will have to undergo a massive energy transition in the decades ahead. New vehicles acquired need to be distinctly superior to the old vehicles scrapped, in terms of their energy efficiency and/or carbon intensity.

To keep track of the process of vehicle fleet renewal and assess its time scale and potential for energy conservation and greenhouse gas mitigation, stock-flow modeling is a useful tool. The bottom-up stock-flow cohort model ensures coherence between the stock in any given year and the annual flows of scrapping, deregistration, new vehicle acquisitions, and second-hand vehicle import and export. It can be constructed from a few years' segmented data on the vehicle stocks and their annual mileage.

As evidenced by our stock-flow model for Norwegian registered vehicles, it may take 5–25 years, in some cases even longer, before innovations affecting the flow of new vehicles have penetrated similarly into the stock. This energy transition time lag would tend to increase with the speed of innovation and with the target level of penetration, but decrease with the velocity of vehicle turnover.

1. Introduction

In its 2030 climate and energy framework (EU, 2011a), the European Union has laid down ambitious targets. In 2030, greenhouse gas (GHG) emissions are to be at least 40 per cent lower than in 1990. It is suggested that, compared to 2005, emissions should decrease by 43 per cent within the European emissions trading system (ETS) and by 30 per cent in the non-ETS sector.

Transportation represents a large and growing share of European and global GHG emissions. With a few exceptions,[1] transportation is not covered by ETS. Vehicle electrification will, however, amount to moving an important source of emissions into the cap-and-trade system.

According to the so-called *avoid-shift-improve* paradigm, there are in essence three possible ways to combat GHG emissions in transportation. One can either (i) reduce the total amount of transportation (*avoid*), (ii) shift travel and freight to more efficient and/or less carbon-intensive modes (*shift*), or (iii) replace the energy technology of vehicles, vessels and crafts by more efficient and/or less carbon-intensive alternatives (*improve*).

The difficulty of cutting GHG emissions through reduced mobility of people and goods (*avoid*) is explicitly recognized in the EU (2011b) white paper 'Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system', which (in para. 18) states bluntly that: "Curbing mobility is not an option." Apparently, the most realistic strategy towards transport demand reduction is enhanced urban planning and densification, which could allow for generally shorter commutes and more competitive mass transit, bicycling and walking. But this strategy would yield results only in the very long term, as it takes time to reshape a city and its land use. At the same time, numerous other drivers, such as income and population growth, increased international trade and specialization, and falling energy costs of travel, would tend to pull car ownership and transport demand in the opposite direction.

In the short and medium term, ride sharing, car sharing etc. may seem to carry more promise. Modern information technology may reduce the barriers against these more collective arrangements. Even so, it seems unlikely that these schemes could reduce the volume of traffic by more than a few percentage points. There is a reason why, up until now, the overwhelming majority of households in western industrialized societies have come to prefer to own and use their own individual car.

The *shift* strategy is not very much more promising. Although mode shift – from road to sea and rail – has been part of the official policy for

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[1] Electrically driven means of transportation receive their energy from power plants covered by the European cap-and-trade system (EU ETS). Also, since January 2012, intra-EEA aviation is included in the ETS. (EEA = European Economic Area = EU plus Norway, Iceland and Liechtenstein.).

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decades, at the EU level as well as in individual member states, little has happened in terms of travel and freight market shares. According to Eurostat, road transportation's share of freight ton kilometers in EU28 has hardly changed between 2001 and 2014, being stable between 74 and 77 per cent. As for the travel market, a comprehensive modeling study for Norway (Fridstrøm and Alfsen, 2014) examined a large number of radical policy options, including 50 per cent higher fuel prices, 50 per cent higher toll rates, drastically improved public transit, 50 per cent reduced transit fares, and/or 25 per cent higher air fares. Even if all of these measures were implemented together, they would, according to the study, reduce GHG emissions from short and long distance domestic travel by no more than 16 and 5 per cent, respectively. Apparently, the competition between modes is not strong enough for politically feasible policy measures to bring about massive changes in the choices made by travelers and shippers (Brand et al., 2013).

This leaves us with the *improve* strategy, in other words *energy transition*, as the most promising path forward. When demand cannot be capped or shifted away from the road mode, the road vehicles themselves, or possibly their fuel, need to be transformed.

The urgency of climate change mitigation, as recognized in the Paris agreement (United Nations, 2015), has brought the speed of energy transitions to the attention of researchers. Examining several centuries of energy innovation and diffusion in various sectors, Fouquet (2010) concludes (i) that the main drivers for energy transition were the opportunities to produce cheaper or better services, (ii) that government intervention may be needed for low carbon technologies to overcome early competitive disadvantages, and (iii) that “a complete transition to a low carbon economy is likely to be very slow”. Solomon and Krishna (2011) conclude in a similar vein, however stating that for certain sectors “it is possible to transition between major energy sources within a few decades if government recognizes a national imperative”. Grubler (2012) concludes that “energy transitions take a long time, many decades” and that “innovation efforts need to be persistent and continuous, aligned and balanced”. Sovacool (2016) points out that “some transitions were quick because they were managed or incentivized”. Kern and Rogge (2016) add that “quicker transitions have happened in the past and may therefore also be possible in the future globally”, but that “at the heart of the pace of low carbon energy transitions is the firm political commitment at all levels of governance”. Warning, however, against “wishful thinking”, Smil (2016) contends that “even the fastest conceivable adoption of non-carbon energies will fall far short from eliminating fossil fuel combustion by the middle of the 21st century”, and that energy transition will be particularly challenging within transportation: “Replacing thermal electricity generation by new renewables is much easier than displacing liquid fossil fuels in transportation”.

Few researchers have explicitly addressed the speed of future energy transitions within road transportation, or the methods to assess it. This is where our paper is intended to fill a gap.

The degree to which existing vehicles can be retrofitted and thus improved in terms of their energy use and climate footprint is very limited indeed. But over the years, new vehicles acquired can and should be distinctly superior to the old vehicles scrapped, in terms of their energy efficiency and/or carbon intensity. Hence this paper focuses on *vehicle fleet renewal*.

2. The Norwegian policy experiment

The Norwegian government has implemented strong incentives to bring down the GHG emissions from cars. The probably most important one is the CO_2-graduated *vehicle purchase tax*, payable upon first registration of any passenger car or cargo van equipped with an internal combustion engine (ICE). As of 2016, the purchase tax was 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. Steinsland et al. (2016) have calculated the elasticity of new cars’ mean type approval CO_2 emission rate with respect to the CO_2, weight and engine power components, respectively, at −0.11, −0.11, and −0.012. Thus, the weight and CO_2 components are just about equally effective CO_2 abatement instruments, while the engine power component has a lesser impact. As of 2017, this component has been abolished.

For plug-in hybrid vehicles (PHEVs), certain special rules apply. 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. Since the CO_2 component is generally negative for cars emitting less than 75 gCO_2/km (as of 2017, down from 95 gCO_2/km in 2016), light-weight PHEVs may come out with zero of near-zero purchase tax. The purchase tax cannot, however, become negative, as in a the French feebate system (D’Haultfoeuille et al., 2013).

Particularly strong incentives apply to zero emission vehicles (ZEVs), be they battery or fuel cell electric. ZEVs are *exempt of 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 *recharged for free* in many public parking lots. Last, but not least, while ICE and hybrid cars are subject to a standard 25 per cent value added tax (VAT) on the price exclusive of purchase tax, ZEVs are *exempt of VAT*.

For ICE vehicles, the VAT and purchase tax taken together typically add 50–100 per cent on top of the import value – or even higher for the largest and least energy efficient vehicle models (Fridstrøm and Østli, 2017). Thanks to the tax exemptions, battery electric vehicles (BEVs) come out with a mean retail price in Norway that is lower than for medium sized gasoline or diesel cars.

The incentives appear to work (Figenbaum and Kolbenstvedt, 2015, 2016). Thanks to a 15.7 per cent BEV market share and a 13.4 per cent PHEV share,[2] the mean type approval rate of CO_2 emissions from new passenger cars registered in Norway in 2016 was 93 gCO_2/km, equivalent to a fuel economy of 58.5 miles per gallon (mpg) for a gasoline driven car. In January-May 2017, the BEV and PHEV market shares reached 17.1 and 16.2 per cent[2], respectively, bringing the average type approval emission rate down to 88 gCO_2/km, corresponding to 61.9 mpg.

For light duty freight vehicles (LDVs, or ‘cargo vans’), the same kind of incentives apply, however with less force, since in this case the purchase tax is less than 25 per cent of the rate applicable to passenger cars. Yet, in 2015, 2.1 per cent of all new cargo vans registered were BEVs. For 2017, an extraordinary scrapping premium of NOK 13,000 (= appr. US$ 1550) is being implemented, benefiting those who replace their old LDV by a new battery or fuel cell electric cargo van.

A fairly general consensus exists between the political parties to continue and reinforce the incentives for zero and low emission vehicles, so as to drastically reduce the CO_2 emissions from new vehicles at the 2025 and 2030 horizons. Thus, the development of the Norwegian vehicle fleet provides a convenient case study in energy transition, in essence a natural experiment, on account of (i) the country's record rapid uptake of BEVs and PHEVs, and (ii) its unusually ambitious targets for clean passenger and freight vehicle sales in the not so distant future (see Section 4.2 below). If these targets are reached, how fast will the energy transition take place and the GHG emissions from road transportation come down?

3. The stock-flow modeling approach

A vehicle fleet is an inert matter. The life expectancy of Norwegian registered passenger cars ranges between 13 and 22 years, depending, inter alia, on make, energy carrier, size and price (Fridstrøm et al.,

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[2] Source: www.ofvas.no.