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The Fallacies of Energy Efficiency: The Rebound Effect?

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Abstract:
This paper reviews current and important parts of the literature on the rebound effect. It concludes that the rebound effect with its focus on a pure price mechanism to explain why energy efficiency measures does not give the anticipated results, is too narrow. There must exist other relations between eco-efficiency and succeding growth in consumption. This is discussed in relation to several empirical examples, especially concerning the historical development in the fuel economy of cars in the US. Energy efficiency gains are apparently not only used on more cars and more passenger kilometres, but also on comfort and safety devices, accompanied by increased weight and increased direct energy use of cars on the market. The rebound effect may be a contributing, but not the only, cause of this trade-off. But it addresses the use-phase of technology which is crucial to realize the potential efficiency of technology. "Efficiency of use" is proposed as a concept to develop a more complete understanding of how growth in consumption offset energy efficiency gains. Ecological modernisation theories and theories of ordinary consumption will be important parts in developing the concept further.

Introduction

In this paper central parts of the literature on the rebound effect are reviewed. The theory is discussed in the light of empirical data, especially concerning the historical development of fuel economy in cars on the American market. We also investigate the technological development of one certain car model. Finally conclusions are drawn on the usefulness of the theory to explain the empirical findings.

The Rebound Effect

It has been observed that energy efficiency measures result in less than expected energy savings. This is usually ascribed to the so-called rebound effect. The rebound effect can be quantified as the difference between the mechanically derived energy saving resulting from an increase in efficiency and the actual energy savings (Musters, 1995; VTPI, 2002). In other words:

Rebound Effect = Potential savings – Actual savings

Khazzom (1980) describes the effect in a well-known article, although he does not actually use the term "rebound effect". He critizes the idea that energy savings of mandated efficiency standards can be derived mechanically: If standards raise the efficiency of a car with 1%, fuel demand is expected to drop 1%.

Those who expect such one-to-one relationships overlook according to Khazzom (1980) that changes in energy efficiency of appliances have a "price content". If you buy an appliance that is twice as efficient as your old one, the effective price of fuel is reduced to a half. As long as the elasticity of energy demand with respect to energy price is not zero, as would be quite unreasonable, there will be a pressure on energy demand. This pressure will at least partly offset the mechanically derived energy savings.

In a response to a paper in the journal Energy Policy, concerning nuclear energy and energy efficiency, Len Brookes writes an answer on the issues of energy efficiency, *The greenhouse effect: the fallacies in the energy efficiency solution* (Brookes, 1990), from which this paper has it's title. Here he repeats and develops Khazzoms arguments: " ...there is no evidence that using energy more efficiently reduces the demand for it" (Brookes, 1990). The conversion factor of fuels to useful energy has improved drastically over the last 100 years, he claims, and yet we now consume more energy both in total and per capita. A simple explanation to this is that the implicit price for the commodity "energy" have been reduced due to the efficiency development, and the demand have responded to the falling prices.

His article sets off a heated debate in the journal. After Brookes' fifth (!) contribution, the editors draw the line for the debate, concluding that it was clear that the various authors cannot come to a common understanding on the issue (Musters, 1995).

It is common to differentiate between three types of rebound effects (Binswanger 2001): First there is the *direct rebound effect*, which is the one we have discussed so far. This would be what economists would call a substitution effect: the increased use, substitution, of an energy service set off by the reduction in its price due to increase efficiency. Second, you have the *indirect rebound effect*: by reducing the cost of one energy service, the household will have more money to spend on other goods and services. This is what economists would call an income effect. Lastly we have the *general equlibrium effect*. Changes in the price of one service may have repercussions throughout the economy, shifting the equilibrium of that economy, since there is an interrelationship between prices and outputs in a market. Greening et al. (2000) suggest even a fourth type, *Tranformational effects*: the changes in technology that leads to the energy efficiency, may in itself change the consumers' preferences, alter the society's social institutions and develop the way production is organized.

In a survey of the rebound effect, Greening et al. (2000) claim that an increased demand for an energy service, not countered by an increase in the fuel price, can diminish technological efficiency gains. Although this is firmly rooted in neoclassical economic theory, which is controversial in itself, the real controversy concerns the identification of sources and the size of the rebound effect, says the authors. Several empirical studies have tried to estimate the elasticities of changes in energy prices to quantify the rebound effect (Greene et al., 1999; Puller and Greening, 1999). Greening et al. (2000) provides a review of this and other literature. The authors conclude that although efficiency improvements are partially offset by increases in consumption, they will result in an overall reduction in the consumption of energy.

Much of (this) earlier empirical work have been criticized for various reasons, Binswanger (2001) highlights two:
The rebound effect has not been observed directly, it is derived from other sources.
The energy price elasticities are treated as being constant, as they not usually are. (They can be expected to change as prices change).

Binswanger (2001) argues that it is not just with energy we will find a rebound effect, but also with respect to time. In the household production of services, both energy and time are relevant inputs. An important aspect of technological progress for households is, according to Binswanger (2001) not just energy saving, but even time-saving devices. These time-saving devices may not just use more energy (faster transport modes often require more energy), but have an effect on time parallel to that we have described for energy: time-saving appliances used in the production of a service will also increase the demand for that service. This "rebound effect with respect to time" may result in the following paradox:

households do not save any time at all, although they have invested in time-saving appliances. An example of the time-use paradox is that the introduction of washing machines not resulted in a decrease in the time spent on the washing of textiles (Klepp 2003).

In many ways the debate concerning the existence and size of the rebound effect presuppose or contain the debate on technology's role and ability in solving environmental problems. To those who argue that the rebound effect is small or non-existent, the following claim from the well-known book *Factor Four. Doubling Wealth, Halving Resource Use*, sounds familiar: "Or to put it another way, it means we can accomplish everything we do today as well as now, or better, with only one-quarter of the energy and materials we presently use" (Weizsäcker et al., 1997). Some claim that in this line of thinking energy efficiency programs are the ulitimate "free lunch" for politicians, not only enabelling them to meet environmental targets but also to do that in a costless or even profitable way without politically unpopular measures (Brookes, 2000).

So far, it is the economical understanding of the rebound effect that has been presented, and it seems quite clear that the term rebound effect is very much confined to the economical sphere. Several others, non-economist, discuss the same feature, of how eco-efficiency is offset by growth in consumption, without using or referring this term (McDonough and Braungart, 1998; Náray-Szabó, 2000; Uiterkamp, 2000). In his article Uiterkamp (2000), a professor of the Environmental Sciences, refer to the phenomenon: "This seems to be a common finding: technological improvements are offset by volume effects resulting from behavioural, social or demographic factors".

In an extensive review of the literature on energy consumption in the years preceding 1997, Aune (1998), a sociologist, makes no reference to the rebound effect. This might be explained by the fact that she was looking for literature on energy consumption, rather than energy conservation. But again it looks like the rebound explanation is confined to the economists' sphere.

An example concerning home insulation is described in a Danish textbook for engineers (Meyer et al., 1994). In the period 1972 to 1992 the energy used for space heating in Denmark fell with more than 30%. The authors claim that this was a result of a targeted policy including energy taxes and subsidies. It resulted in better insulation and other technical measures in addition to a more careful usage of heating (ibid; 24). But it turns out that *per square meter living area* the reduction was actually more than *50%* (ibid; 93). The reason for the discrepancy is (of course) an increase in the number of square meter living area per person in the same periode, from approx. 180 m^2 to 250m^2 (ibid;76). The text does not problematise this growth in "consumption of housing", but prescribe instead better insulation of old constructions and improved new constructions.

It seems likely that growth in consumption can occur without being a response to a change in the effective price of a consumer good or service. In line with this thinking it is suggested that energy efficiency measures can be offset by growth in consumption through other mechanisms than a pure price mechanism. An example would be how the growth in the number of households we witness especially in the Western world (Liu et al., 2003), at least partly offset eco-efficiency measures on household goods and home insulation.

So, although several researchers from different disciplines have looked into energy consumption and energy efficiency, it seems that it is only the economists themselves that have embraced the rebound effect explanation. To test the concept we now turn to car fuel use in Norway.

Empirical data

We will here present results concerning the car. First we will observe how the aggregated consumption of car fuels in Norway has increased since 1985. Then we will discuss the reasons behind this. As illustrations to this discussion we will use data both on 4 car makers' total model ranges, and follow one specific car model from 1974.

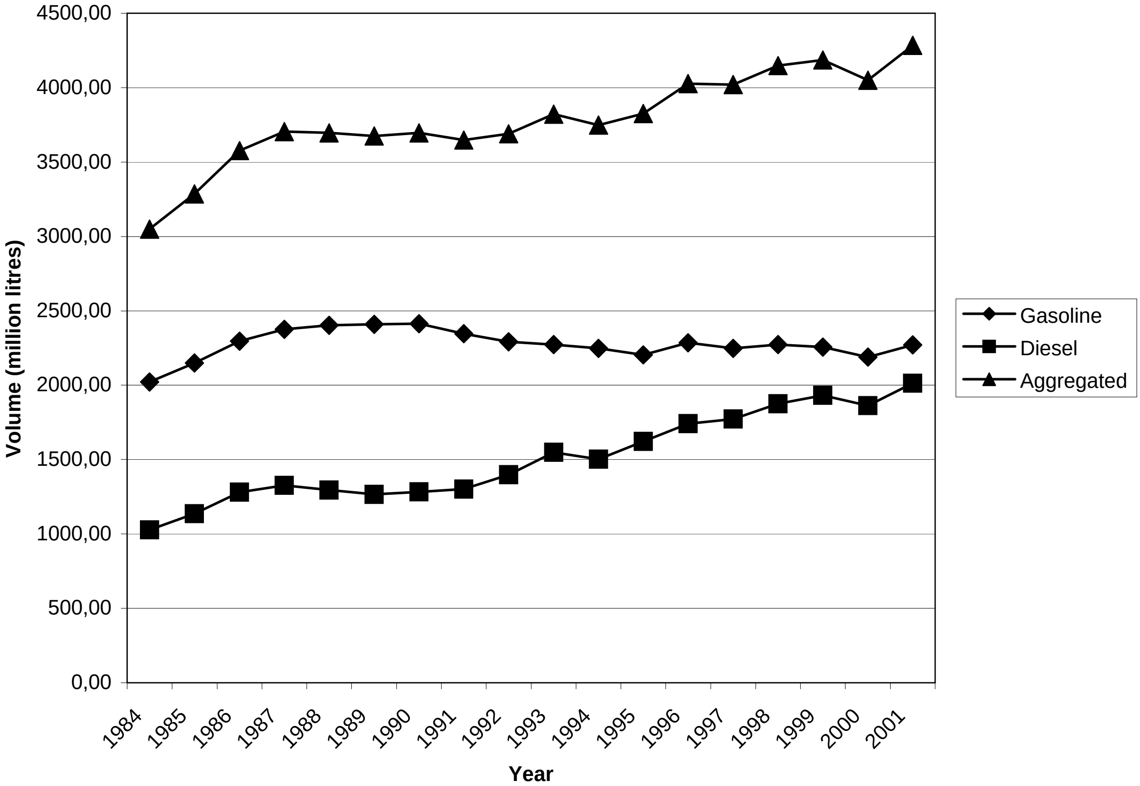
Increased fuel use is usually seen as resulting from more cars and more passenger kilometers (Greene et al., 1999; Greening et al., 2000; Binswanger, 2001; EEA, 2001). In this paper we look into other contributing factors. Some of these are also mentioned by other authors, in an *en passant* fashion. Greening et al. (2000) note that consumers' (economic) valuation may involve other caracteristics than the efficiency of fuel use in the case of personal automotive transportation. Consumers also value comfort and performance characteristics, in addition to mobility. This is what they call trade-off between attributes.

In a footnote to their paper *Fuel Economy Rebound Effect for U.S. Household Vehicles*, Greene et al. (1999) explain their focus on "realized efficiency improvements". Trade-off between potential increases in fuel economy and other desirable attributes, they mention increased acceleration and weight, are excluded in their analysis. In that line of thinking this paper can be said to look into <u>unrealized</u> efficiency improvements.

Norway is an affluent European country, with a high degree of car ownership and car use. Often claimed to be caused by (too) high prices on new cars, the average age of cars in Norway is quite high. With its complicated geography and low population density, the car is considered necessary in many parts of the country.

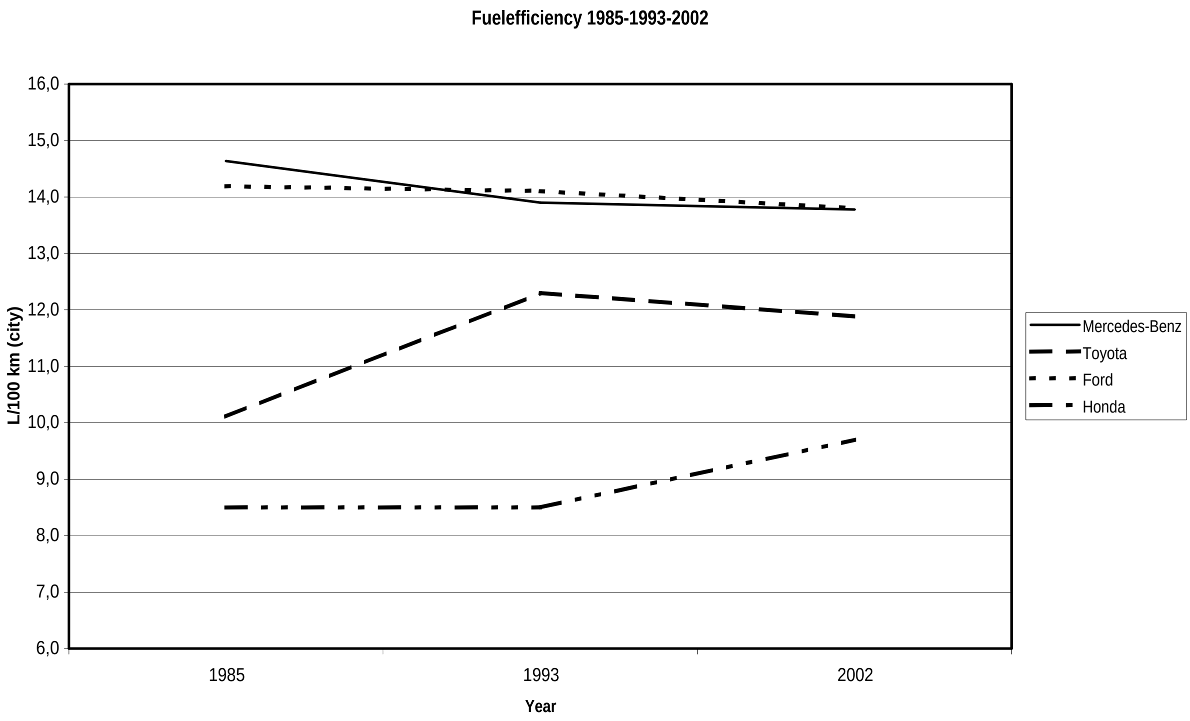
If we look at the total auto fuel consumption for Norway, we will find it has grown with more than 30% from 1984 to 2001, from three thousand to more than four thousand million litres.

The development in fuel consumption in Norway, 1984-2001 (Source:Statistics Norway).



Many would expect more noteable effects of technological innovations aimed at reducing consumption of fussil fuels. To investigate this further, we used American data on fueleconomy (US DoE & EPA, 2002). We looked into the average fuel efficiency of the model range of 4 carmakers over three years: 1985 – 1992 – 2002. We did not take marketshares of the different models into account, but made only a straight (rough) average. We excluded the models that run on fuel other than gasoline, like diesel, electrisity, E85 (a mixture of 85% ethanol and 15% gasoline) and others.

The car makers were chosen to reflect the span of the car market, with regard both to price and the geographical aspects. The following were chosen: The European maker Mercedes Benz, the American maker Ford, the Japanese maker Toyota and the Japanese maker Honda. We found interesting trends.



Surprisingly, even when considering the reservations we have taken, the amount of gasoline required per 100 km driven, has decreased only moderately for the European/American producers (-3-6%). For Japanese cars the picture is quite different, as there is a significant increase (+14-18%). The Japense entered the American car market with mainly small cars, and have since then expanded into other size classes. This probably explain a significant part of the increase.

Some of the car models on the American market use large amounts of fuel per kilometer, and contribute significantly to the disappointing trend. They have earned themselves the label "gas guzzler". These are dominated by the light trucks, or the so-called SUVs - sport utility vehicles. Although there is no clear definition of what a SUV is, either in the industry or amongst regulators, it can at least be characterized by these five features (Bradsher, 2002):

- four-wheel drive available as standard or optional equiment
- an enclosed rear cargo area like a minivan
- high ground clearance
- pickup-truck underbody
- designed primarily for urban consumers

The SUVs or light trucks are exempted from US federal fuel economy regulations that govern most other vehicles (Bradsher, 2002).

In an overview of energy use per passenger-km for the total car fleet in European countries, for 1980-1999, (EEA, 2001) find that the energy efficinency har improved only slightly over this periode: "Technological improvements in fuel efficiency have largely been offset by traffic growth and low occupancy rates (ibid; 39)".

We also find other developments that work against the technological improvements: It is not only the SUVs that disappoint when it comes to fuel economy development. One of the worlds most sold car models is the Volkswagen Golf. It was introduced in 1974, and on the 25th of June last year (2002) it surpassed the Beetle in sales, when Golf Number 21.517.415 left the assembly line (Volkswagen 2002). Over the years the model has evolved, and reflects many of the technological changes the automobile industry has been through in this period. The Golf is a notion in itself, and a reference point for a whole class of Compact family cars.

Table 1: An overview of comparable models of the Golf 1975-2003 (Kopperud, 2002).

Model	***Year***	***Engine size (litre) / horsepower***	***Fuel consumption (l/10 km)***
Golf LS	1975	1,6 / 70	0,70
Golf CL	1985	1,6 / 75	0,78
Golf GL	1995	1,6 / 75	0,72
Golf Edition	2003	1,4 / 75	0,66

From this table we can see that the fuel consumption is reduced with less than 6% from 1975. That year Volkswagen had no 75 hp model, so if we compare the 1985 numbers with 2003, which are both 75 hp, we find a reduction of 15%. But even this number will probably disappoint many. We had expected that the engine development had revolved faster, and had achieved lager reductions. How can this be explained? One of the answers can be found in table 2, where we look at the weights of the same models as in Table 1:

Table 2: Weights of comparable models of Volkswagen Golf (Kopperud, 2002).

Model	***Year***	***Weight (kilograms)***
Golf LS	1975	780
Golf CL	1985	870
Golf GL	1995	1060
Golf Edition	2003	1174

Here we see that the weight has increased by 50% since 1974, and by 35% since 1985. This makes the weight of the car a great challenge, and according to Dresselhaus and Thomas (2001): "Further great challenges lie in making the substantial improvements in materials that are needed to increase efficiency in the generation, conversion, transmission and use of energy. For example, the most effective way to increase fuel economy in automobiles is to lower their weight, and we are starting to see more vehicle components being made of lightweight, tough and strong composite materials."

But what are the reasons for the dramatic increase in weight? During these years the demands on comfort and especially safety measures have increased significantly. Steel beams and air bags are installed to reduce damages if cars collide. Air conditioning and servo control are more typical comfort measures. These contribute both by their weight, and some also increase the direct energy demand (to run the air conditioning, for instance).

It is not obvious that the increased demands on security and comfort in cars are effects of a decrease in the effective price of auto mobility. These demands have at least a part of their explanation in a different realm of society.

Conclusion

Through their discussion and elaboration of the rebound effect, the economists have drawn attention to how growth in consumption can offset energy efficiency gains. The rebound effect is usually taken to describe a pure price mechanism to explain why energy efficiency measures often give less than expected energy savings. The question of the rebound effect, on how measures taken on the production side are countered on the consumption side is at the very core of the debate on sustainable consumption.

Here we have argued that the rebound effect mechanism is not sufficient to make clear the relationship between energy efficiency measures and succeding growth in consumption. This is probably true in many instances, and here the case of the fuel economy developments in cars have been explored in some detail. Other factors seem relevant and necessary to explain the lacking realised improvements. Contributions to a more complete understanding of how growth in consumption offset energy efficiency measures can come from ecological modernization theory, reflexive modernity and theories on everyday life and routinised consumption.

Maybe it is time to shift the focus from *resource efficiency* in a labotoratory-like setting to *efficiency of use* in an everyday life setting.

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