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Rebound

Unintended consequences from **transport policies** and **technology innovations**

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- Young asian woman working from home
- Petrol pump showing the 4 main international currencies

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The Challenge

The UN conference in Copenhagen in December 2009 aimed to decide what the global targets and action will be after 2012 when the Kyoto targets expire. In the Copenhagen Accord, the majority of countries agreed to work towards the objective of limiting warming to below 2º Celsius on the basis of equity of each country and in the context of sustainable development. The UK Government set itself the target to in the Climate Change Act to reduce carbon emissions by 80% by 2050 compared to 1990 levels. Failure to mitigate climate change will result in severe consequences. The Stern Report suggests that unabated climate change could cost the world at least 5% of GDP each year and that if more dramatic predictions come to pass, the cost could be more than 20% of GDP.

Yet, transport accounts for about 20% of global manmade carbon dioxide emissions and 24% of emissions in the United Kingdom and is the only sector where emissions are still rising. And for good reason: transport not only underpins our daily lives, but is often referred to as the prerequisite for economic growth. The Eddington Transport Study highlighted that transport systems have played a pivotal role for economic growth in many economies. The performance of such transport systems can boost or hinder growth of GDP. The Eddington Transport Study estimated that eliminating existing congestion on the road network would be worth some £7-8 billion of GDP per annum and the CBI suggests the figure is closer to £12 billion. The costs of congestion are notoriously difficult to quantify, but the effect on the economy is huge.

The challenge therefore is to reduce carbon emissions from transport without impeding the economy. That means we need to rely more on innovation and the use of technology to manage existing transport networks better. New innovations however also do not come without their own pitfalls.

Rebound effects

As the world becomes more and more complex, decisions have far reaching consequences which sometimes cannot be foreseen when the original assessment was made. Rebound effects are the difference between the original engineering estimate and the real energy savings after implementing new technologies and policies. The theory is based on the economic model of supply and demand. If supply is increased, prices drop and demand rises. This rebound effect can be defined as the part of the initially expected energy savings that is lost because of the energy-economy-environment interaction. As a result, the engineering approach can over-estimate the net-benefits from improvements in energy efficiency.

The rebound effect of road transport policy can manifest themselves in either an increase in the number of vehicles, an increase in fuel consumption through increased use of other technical innovations, heavier vehicles and/or an increase in vehicle miles travelled. The easiest way to measure the rebound effect is from the vehicle-miles travelled (VMT). For example, as it costs less to drive one mile when vehicles are more energy efficient, many drivers respond by driving further. The rebound effect is the VMT increases after fuel efficiency improvements have been made. A number of studies have estimated that the direct rebound effect from fuel efficient vehicles is a loss of 10% to 30% off the original expected saving. Some of the energy efficiency improvements in vehicle technology are absorbed by innovations that lead to a more comfortable driving experience and safety features. Those devices increase the weight and direct energy use of cars on the market. The Golf LS for example as built in 1975 weighed 780kg, whilst the Golf Edition built in 2003 already weighed 1174kg.

Fuel efficient vehicles make driving cheaper, allowing the driver of those cars to perhaps use the savings towards a holiday abroad or imported goods. This mechanism is known as indirect rebound effect. The indirect rebound effect is more difficult to measure. One research group however suggests that energy efficiency improvements in transport lead to a combined direct and indirect rebound effect of 120%. In other words, after reducing carbon emissions in one sector, people spend 20% more energy than before. Another indication for this indirect rebound effect is the fact that the top 20% of British households spend almost nine times as much on transport costs as the bottom 20%.

In addition, the reduction of fuel price elasticity means that today we are more reliant on road transport than ever before. Price elasticity of demand reflects the quantity demanded of a good or service depending on the price. The demand for a product is inelastic if consumers will pay almost any price for the product. Demand for a product is elastic if consumers will only pay a certain price, or a narrow range of prices, for the product. For example, with more transport options or less need to travel, the price elasticity of fuel is elastic as people are not prepared to pay higher prices. As society becomes more dependant upon the car and the need to travel has increased, so fuel prices become inelastic and people are forced to accept higher prices.

To achieve a reduction in carbon emissions, efforts have to be made to ensure that carbon emissions are not just moved from one sector to another. One study for example suggested that the net energy benefit from telecommuting (or home homeworking) in the US was 0.4% in the best case scenario. Most of the energy use is moved to heating or cooling houses and lighting and teleworkers tend to travel further for social reasons. Buying goods online has been found to provide carbon savings, but only if the conditions are right. A study found that environmental savings can be achieved if online shopping replaces 3.5 traditional shopping trips, if 25 orders are delivered at the same time or if travel distance is longer than 50km.

It is not all bad news however. The huge potential that technology development offers can only be compounded with the growth in smarter devices, especially in personal and on-vehicle kit. Intelligent transport systems (ITS) will prove invaluable in reducing carbon emissions from transport. ITS can be used to increase the understanding of travel patterns. Smart ticketing allows accurate estimates of travel times, interchanges, and end-to-end journeys. It can therefore be used to improve existing transport links for certain routes and times, which will make public transport more attractive to passengers. Road user charging is an invaluable tool to manage travel demand and shift travel patterns. Examples of congestion charging schemes in Stockholm, London and Singapore have successfully demonstrated the technology and environmental benefits.

Changes in land use can impact on travel behaviour. By reducing the need to travel, a large number of rebound effects can be avoided. So called “compact” or “polycentric” cities mean that average journey distances, trip frequencies, traffic volumes, energy consumption and/or transport emissions can be reduced.

Recommendations

1. The carbon reduction targets are challenging and policy makers have to make bold decisions to reduce the CO_2 emissions and energy use from transport. Those reductions will have to be implemented through a mix of behavioural changes and technical innovations.
2. Most decisions result in some unintended consequences or lead to rebound effects. Studies have shown that there are benefits to new technologies. In order to maximise the benefits, the implementation of those technologies has to be reviewed on a case to case basis. Policy makers have to be careful not to generalise. E-commerce for example has got great benefits in some scenarios and little to none in others.
3. Policy makers must not get overwhelmed by their task and use the rebound effect as an excuse to do nothing. There is a cost attached to doing nothing (as impressively demonstrated by the Stern review) and is not an option.
4. Whole life cycle analysis has to be performed. Policy makers have to be careful that emissions are not simply moved from one sector to another. Countries also have to account for the emissions from the manufacturing of goods - even if those have been produced abroad.
5. Policy makers have to account for rebound effects when implementing CO_2 emission targets.
6. Carbon pricing needs to be considered as a means to mitigate the indirect rebound effect. The devil lies in the detail and a fair system needs to be devised which accommodates for people on low incomes, areas with little or no public transport, minority groups and other issues.
7. Research is needed in greater detail about rebound effects. The more accurate our knowledge is on the unintended consequences, the better we can account for them. It will also allow policy makes to pick scenarios that minimise rebound effects. This is particularly important for large-scale projects such as high speed rail or electrifying road transport.

Introduction

Transport now accounts for about 20% of global man-made carbon dioxide emissions and 24% of emissions in the United Kingdom. The UK Government has committed itself in the Climate Change Bill to an 80% reduction of green house gas emissions by 2050. This includes all sectors, and requires urgent and substantial progress in the promotion of sustainable transport.

According to UK energy sector indicators 2009, the total industrial energy consumption has fallen by 51% since 1970. However, transport has been the biggest single energy user in the UK in the past 21 years, accounting for 38% of final energy use in 2008. While the energy consumption of industry has decreased steadily over the years, the energy consumption of transport has increased and is now the largest user of energy.

Transport however not only underpins our daily lives, but is often referred to as the prerequisite for economic growth. The Eddington Transport Study (2006) highlighted that transport systems have played a pivotal role for economic growth in many economies. The performance of such transport systems can boast or hinder growth of gross domestic product (GDP).

A number of policies have been implemented with the aim to reduce the carbon emissions from transport. However, research has shown that there are unintended consequences from some of the measures taken. This report explores the impact of policies and technical innovations on the carbon footprint energy consumption.

The size of the rebound effect needs be considered when making policy decisions. If the rebound effect is large from a technology, then interventions such as pricing strategies become more effective compared to technology standards. How those pricing strategies could influence consumer behaviour can be seen when studying the effects of high fuel prices in 2008 and 2009.

Definition of unintended consequences and rebound effects

The world has become more and more complex and decisions have far reaching consequences which sometimes cannot be foreseen when an assessment is originally made. Every action has got more than one effect, some of which will be unforeseen or unintended.

Rebound effects are the difference between the original engineering estimate and the real energy savings after implementing new technologies sand policies. This rebound effect can be defined as the part of the initially expected energy savings that is lost because of the energy-economy-environment interaction. As a result, the engineering approach tends to over-estimate the net-benefits from improvements in energy efficiency (Musters, 1995).

The rebound effect is not new. In the mid 1800s Jevons argued that the economy of coal use would lead to its extensive consumption. If the quantity of coal used in a blast-furnace for instance are diminished in comparison with the yield, the profits of the trade will increase and new capital will be attracted, more producers will set up, the price of pig-iron will fall and the demand for it will increase.

The idea of rebound effects was first related to energy efficiencies by Khazzoom (1980) and Brookes (1990) and is often referred to as the Khazzoom-Brookes postulate[1] (Saunders, 1992). It states that "with fixed real energy prices, energy efficiency gains will increase energy consumption above what it would be without these gains." In other words, improved energy efficiency will lead to higher over-all energy consumption. Economists usually distinguish between a direct and indirect rebound effect.

The direct rebound effect can be broken down into the

- *Output effect:* Energy efficiency improvements during the manufacture of a commodity reduce the cost of production. It is therefore possible to produce more of a product when keeping the energy use constant. This increase in supply leads to a decrease in price and should stimulate demand. As a consequence all inputs (i.e. materials, water, labour, energy) are increased. (Greening *et al.*, 2000 and UKERC 2007)
- *Substitution effect:* If the energy price drops, then manufacturers can use the cheaper energy service to substitute for capital, labour and other materials whilst maintaining a constant production level.
- *Income effect:* Energy improvements for the consumer mean that they increase their real income, which allows them to increase consumption of goods and services.

The indirect rebound effect can be broken down into the

- *Secondary fuel use effect:* It results from increases in demand for other goods and services. Consumers will not increase their consumption of a service indefinitely. Constraints on time, changes in fashion or boredom limit the use of any one commodity and they use the saved money for other services and goods. Consumers for example may use the cost savings from energy efficiency improvements in their car to purchase other goods and services which themselves require energy to provide. Cost savings made during the every-day commute may be put towards an overseas holiday.

- *Embodied energy:* The equipment used to improve energy efficiency requires energy to manufacture and install. Electric vehicles for example may be more fuel efficient, but the manufacture of batteries in itself is energy-intensive. This embodied energy consumption will offset some of the energy savings achieved.
- *Transformational effect:* Innovations such as cars, refrigerators and mobile phones have lead to intrinsic changes in the societal behaviour (UKERC, 2007 and Throne-Holst, 2003).

Fuel efficient vehicles

The rebound effect for road transport manifests itself in either an increase in the number of vehicles, an increase in fuel consumption through increased use of other technical innovations and/or an increase in vehicle miles travelled. The easiest way to measure the rebound effect is from the vehicle-miles travelled (VMT). It costs less to drive one mile when vehicles are more energy efficient. If there is no rebound effect, then the VMT should remain constant. The rebound effect is the VMT increases after fuel efficiency improvements have been made. A number of studies have estimated the rebound effect from fuel efficiency improvements in cars.

Reference	Size of rebound effect	Methodology
Blair *et al.* (1984)	Rebound effect: 21%	Data series for Florida between 1967 and 1976
Leung and Vesenka (1987)	Rebound effect: 25%	Annual data from Hawaii between 1967 and 1980
Mayo and Mathis (1988)	Rebound effect: 22%	U.S. time series between 1958 and 1984
Gately (1990)	Rebound effect: 9%	U.S. time series between 1966 and 1988
Greene (1992)	Rebound effect of 5-19% with a best estimate of 12.7%	U.S. time series between 1957 and 1989
Jones (1993)	Short-run rebound effect: 13% Long-run rebound effect: 31%	Re-evaluation of Greene's data
Walls *et al.* (1993) as quoted by Greening *et al.* (2000)	Rebound effect: 51% One car household: 29% Two car household: 41% Three and more cars household: 78%	1990 Nationwide Personal Transportation Survey
Schimek (1996)	Short-run rebound effect: 7% Long-run rebound effect: 29%	
Haughton and Sarkar (1996)	Short-run rebound effect: 16% Long-run rebound effect: 22%	Cross-sectional time series data for 50 U.S. States and the District of Columbia between 1970 and 1991
Puller and Greening (1997) (quoted by Greening *et al.* 2000)	Rebound effect: 49%	Multiple years of consumer expenditure survey
Greene (1997)	Short-run rebound effect: 10% Long-run rebound effect: 20%	
Goldberg (1998)	Rebound effect: 20%	Based on the Consumer Expenditure Survey between 1984 and 1990
Greene, Kahn and Gibson (1999)	Rebound effect: 23% 17% for households with three vehicles and 28% for households with one vehicle	Based on the Residential Transportation Energy Consumption Survey between 1979 and 1994
Pickrell and Schimek (1999)	Rebound effect: 4%	Based on 1995 cross-sectional data from the National Personal Transportation Survey
Greening, Greene and Difiglio (2000)	Short-run rebound effect: 10% Long-run rebound effect: 20-30%	Summary of 22 studies
Greene and Schafer (2003)	A 10% increase in fuel efficiency leads to a 1-2% rebound effect	
West (2004)	Rebound effect: 87%	Based on 1997 Consumer expenditure survey
Kenneth Small and Kurt Van Dender (2005)	Short-run rebound effect: 4.7% Long-run rebound effect: 22.0%	U.S. State data between 1966 and 2001

Figure 1: Summary of studies on the rebound effect from energy efficiency improvements in cars.

Studies that did not include vehicle age as an explanatory variable tend to give higher estimates of the rebound effect. Walls et al. (1993) for example demonstrated that rebound effects could be 29% for single-vehicle households, 41% for two-vehicle households and 78% for three-and-more vehicle households and Puller and Greening (1997) estimated the rebound effect to be 49%. When vehicle age is included in the estimates of the rebound effect, then they are between 10% and 30%.

Throne-Holst (2003) argued that it is not sufficient to focus on price mechanisms. Some of the energy efficiency improvements in vehicle technology are absorbed by innovations that lead to a more comfortable driving experience and safety features. Those devices increase the weight and direct energy use of cars on the market. Kopperud (2002) summarised the data for comparable Volkswagen Golf models between the years 1975 and 2003.

	Fuel consumption (L/100 km)	**Weight (kg)**
Golf LS (1975)	7.0	780
Golf Edition (2003)	6.6	1174

Figure 2: A comparison of the fuel consumption and weight of a Golf LS and Golf Edition. Table amended from Throne-Holst (2003) who quotes Kopperud (2002)

Ruzzenenti and Basosi (2008) found that in light and heavy duty trucks the power increased and the fuel economy decreased between 1978 and 2005. They believed that if efficiency is pursued in times of low energy prices, then the energy enhancements are likely to be converted into power increases. In the ideal case energy losses in form of heat are reduced and thus lead to an increase in energy efficiency.

	Fuel consumption (L/100 km)	**Engine power (HP)**
Light duty truck, Fiat-Iveco (Model Alfa Romeo 35AR8, 1978)	11.00	72
Light duty truck, Fiat-Iveco (Model Iveco daily 35s12, 2005)	7.73	116
Heavy duty truck, Fiat-Iveco (Model 220 F 35, 1978)	39.00	350
Heavy duty truck, Fiat-Iveco (Model Stralis at 440S43, 2005)	24.73	430

Figure 3: Comparison of the fuel consumption and engine power of light duty trucks and heavy duty trucks. Table amended from Ruzzenenti and Basosi (2008).

Finally, the European Environment Agency (2009) concludes that although the energy efficiency of passenger and freight road transport has been improved, gains have been far outpaced by increasing transport demand.

Fuel prices

The Congressional Budget Office (CBO) reviewed in their 2008 study the effects of petrol prices on driving behaviour and vehicle markets. Between 2003 and 2007 the average retail price for one gallon of petrol in the United States almost doubled. A 10% increase in the retail price of petrol lead to a reduced consumption of about 0.6% in the short run. Those changes are likely to come from changes in behaviour such as

- Driving more slowly: The CBO report shows that a 50 cents increase in fuel prices lead to a reduction of the average speeds on uncongested urban freeways by nearly 0.75 miles per hour.
- Accelerating and breaking more slowly.
- Undertaking fewer journeys.
- Switching to alternative modes of transport: The CBO report showed that where a modal shift from road traffic to rail was possible, the average traffic on freeways declined by about 0.7%.
- Car pooling.
- Driving in easier traffic conditions.

A 10% sustained increase in fuel prices can lead to a reduction in fuel consumption of about 4% in the long-run. Responses in the long-run include short-term behavioural changes in addition to measures like:

- Buying more fuel efficient vehicles: The share of light trucks on the U.S. market declined from about 55% in 2004 to 52% in 2006.
- Moving closer to the workplace.

Those findings were mirrored in a study by the Department for Transport (2002). They found that an increase of fuel prices by 10%, resulted in a decrease in traffic volume of about 1% within one year, building up to a reduction of about 3% in the longer run. Furthermore, the fuel consumption was reduced by 2.5% within one year, and 6% in the longer run. The total number of vehicles was found to go down by less than 1% in the short run and 2.5% in the longer run.

Price elasticity - How much are drivers prepared to pay for petrol

Price elasticity of demand reflects the quantity demanded of a good or service depending on the price. The demand for a product is inelastic if consumers will pay almost any price for the product. Demand for a product is elastic if consumers will only pay a certain price, or a narrow range of prices, for the product. The short-run price elasticity is a measure of the change in driving behaviour as a result of change in petrol prices. Those responses include a reduction in the amount people drive and eco-driving. Drivers for example tend to accelerate slower and drive at reduced speed.

Small and Van Dender (2007) estimated, as shown in Fig 4, that the short-run elasticities of miles driven and fuel consumption with respect to fuel price declined over the past decades. Those results were echoed by Hughes *et al.* (2006) who found that the short-run price elasticity of U.S. petrol demand is significantly more inelastic between 2001 and 2006 than it was between 1975 and 1980.

	1966-2001	1997-2001
Short-run elasticity of vehicle miles travelled with respect to fuel cost	-0.0452	-0.0216
Short-run elasticity of fuel consumption with respect to fuel price	-0.0873	-0.0657

Figure 4: Comparison of the short-run elasticity due to high fuel prices. Table amended from Small and Van Dender (2007).

Reasons for this decrease in the short-run elasticity might include:

- *Land-use:* Increases in suburban developments have led to larger distances between travel destinations. This means that people are more dependent on cars as their daily transport means and cannot easily change to other modes of transport such as walking, cycling or public transport.
- *Increased income:* As incomes rise, a greater number of trips are discretionary which might make them also less sensitive to price increases. People on lower incomes reduce their travel to a minimum and have little room to change their behaviour in light of high petrol prices.
- *Fuel efficiency:* Since the vehicle fleet has become more fuel efficient, a decrease in distance travelled leads to a lower reduction in fuel consumption than in the 1980s.

Travel time budget and travel time use

Lyons and Urry (2005) summarise personal travel across Great Britain. They illustrate that between 1952 and 1999 the distance travelled increased from 218 billion passenger kilometres to 728 billion passenger kilometres. Between 1972 and 2000 the average annual distance travelled per person increased by 53%, while the average number of trips increased only by 8% and the time spent making these trips increased only by 2%. They argue that this has been achieved by increasing journey speeds. Those figures have given rise to the idea of a constant travel time budget. Schafer (1998) summarised this notion by claiming that people spend about the same time travelling per day. If transport becomes faster, people travel further.

The theory about time budgets is however much disputed. Höjer and Mattsson (2000) for example warn that this idea is too simplistic. They caution that there is a danger of generalising. Londoners for example spend 30% more time travelling than those living in Scotland. Mokhtarian and Salomon (2001) argue that people try to actively decrease travel time if it exceeds their desired optimum, but seek to increase travel time if it falls short of their ideal amount. This is because travel time is not necessarily viewed as negative. Lyons and Urry (2005) summarise how travel time can be used to for activities including:

- Sleeping/snoozing
- Reading for leisure
- Working
- Talking to other passengers
- Window gazing/people watching
- Playing games
- Listening to music/radio
- Phone calls
- Eating/drinking.

Mokhtarian and Salomon (2001) note that travel time is often perceived as ‘anti-activity time’ which helps commuters to relax, reflect on the day or to mentally shift from work to leisure or vice versa. They also stress that people take pleasure from their journey such as enjoying the sensation of speed or marvelling at scenic routes. All those factors encourage longer travel times.

The Travel time budget hypothesis however is widely disputed. Kitamura *et al.* (1997) for example summarised two studies by Fujii *et al.* (1997) which studied the effect of a 10 min reduction in commuting time. The model indicated that as a result commuters sent about 1.88 min longer on out-of-home activities and 7.11 min more on in-home activities. The average travel time increased by only 0.36 min.

High speed rail

Public transport is promoted as a low carbon technology because of its low space demand and high energy efficiency per passenger kilometre. A growing number of countries see high speed rail as a way to encourage modal shift. However, high speed rail systems are not compatible with existing rail infrastructure and rely on new build rail networks. Spielmann *et al.* (2007) evaluated the environmental rebound effect of high speed rail in Switzerland. They compared the environmental impact of a transport network without high-speed rail with the environmental impact of the transport network with high-speed rail for different scenarios. Their life cycle assessment included operation, energy supply, vehicle supply and infrastructure supply. The group assumed that people always spend the same amount of time travelling. A constant travel time budget means that if travel speed increases, the time saved will be used to travel further and more. Based on those assumptions Spielmann *et al.* (2007) found that the implementation of a high speed rail system leads to a higher environmental impact than for scenarios without high speed rail. However, as described above, the theory of travel time budgets is highly disputed.

Baum-Snow and Kahn (2000) evaluated the effects of new expanded urban rail transit services in five major U.S. cities. They found that the new rail transit has a small impact on usage and housing values. According to them a decrease in transit distance from 3km to 1km away could lead to a rent increase of $19 per month and housing values by $4972.

The siting of railway terminals and parkways can impact on the shape of a city and bring economic prosperity to the area. Modelling existing traffic flows suggests that railway terminals should be located in city centres. Siting railway terminals away from the city centre can however stimulate economic growth and rejuvenate the area. Bristol Parkway for example stimulated growth of a commercial centre around this station. In Germany, medium sized cities are connected to high speed rail terminals by public transport links in the next large city. The example of Kassel shows how the city growth towards the parkway and a new commercial centre was created and the prosperity growth back into the back streets and into the commercial shopping area.

Telecommuting

Working from home is often quoted as one way to reduce the environmental impact. Telecommuting has been found to reduce the overall vehicle use by 50-70% Matthews and Williams, 2005). It allows the reduction of company office space and cuts done on the daily commute, which also has got a positive impact on congestion. It does however require energy to heat or cool the home office. It may also lead to people moving further from the workplace, which could stretch urban cities further apart (this is often referred to as sprawl). Aebischer and Huser (2000) reported that there would be a 30% increase in household energy use if one person in a household was working from home. It was also found that the number of non-commuting trips increases slightly with telecommuting (Mokhtarian, 1998).

Mokhtarian (1997) estimated that 1-2% of vehicle travel could be reduced by telecommuting, and that long-term benefits might be even smaller because of urban sprawl. In 2000 Mokhtarian reported that when taking all rebound effects into account, a net reduction in vehicle miles travelled might be as low as 0.6% or even less. Matthews and Williams (2005) found that for current estimated telecommuting populations and practices in the United States and Japan result in only 0.01–0.4% national energy savings in the United States and 0.03–0.36% national energy savings in Japan. Even if 50% of information workers adopted telecommuting, 4 days per week, the potential energy savings are estimated to be only about 1%. Roth *et al.* (2008) estimated that 4 million telecommuters in the U.S. who work from home one or more days per week reduce the primary energy consumption by about 0.13 - 0.18% and the net CO_2 emissions by 0.16%-0.23%. Reduced travel accounted for most of the reduction in the calculation and reduced floor space also made a large contribution. In addition to that, about 0.8% of light-duty vehicle fuel consumption could be saved. However, the group warns that early adoptors tend to have longer than average commutes, which might reduce the effect of telecommuting if it was used more. On the other hand, companies might be able to further reduce their floor space, which would make telecommuting more beneficial.

Rebound effects from telecommuting can include:

- *Urban sprawl:* employees who use telecommuting may move further from their workplace because they commute on fewer days.
- *Additional trips:* telecommuters often have to make additional trips for shopping or to run errands which they would have

otherwise done during the commute.

- *Change in vehicle use:* the vehicle might be used by other household members when it would have otherwise been used for the commute.
- *Additional heating:* Telecommuters often use energy to heat or cool their homes and to power electronic equipment.
- *Extended network of friends:* People might use the telecommunications equipment to stay in touch more with friends and family in further parts of the country. This then could lead to further travel when those people want to meet up.

E-commerce

E-commerce is an area where ICT could have a significant impact on the environmental footprint by optimising transport logistics, reducing overproduction and warehouse space. Just-in-time delivery was found to reduce the material inventory by 28% (Romm *et al.*, 1999). Downey (2000) reported that U.S. companies were able to significantly cut logistics expenditure by introducing ICT in their purchasing system. Other studies however show that those savings depend on parameters such as load rate of vehicles, delivery distance and population density. Online-shopping also changes the structure of delivering freight towards smaller units, which increases packaging.

Plepys (2002) demonstrated that environmental savings can be achieved if online shopping replaces 3.5 traditional shopping trips, if 25 orders are delivered at the same time or if travel distance is longer than 50 km. Matthew and Hendrickson (2001) demonstrated that roughly the same amount of energy is used to distribute 1 million dollars worth of bestseller books in U.S. metropolitan areas by traditional retails (28-33 TJ of energy) as by online shopping (30 TJ of energy). A similar study in Japan concluded that traditional retail has a lower environmental impact in dense urban areas (Williams and Tagami, 2001).

Biofuel production

The environmental impact of biofuels is still heavily debated. A number of reports have been commissioned to evaluate the net energy balance of biofuel production using different feedstocks and different production processes (Defra, 2008; Gallagher, 2008). Biofuels are said to have lower emissions than fossil fuels and to be carbon-neutral if the carbon they emit to the atmosphere when burned is offset by the carbon that plants absorb from the atmosphere while they are grown (Royal Society 2008). However, factors such as land-use change, feedstocks and technology used to convert organic materials into biofuels have an impact on the life cycle analysis (Phalan 2009). The replacement of carbon-rich landcovers such as savannas, forests and peat lands are likely to increase the impact of biofuels on climate change. The pay-back times for biofuels grown in those areas can be very long as shown in table 5. It can be seen that it will take decades before the CO_2 emissions released during the land conversion are offset.

Feedstock	**Land use**			
	Degraded farmland	**Grassland**	**Woody Savannah**	**Forest**
Cassava	0	22	82	213
Castor	0	192	707	1845
Coconut	0	0	120	489
Groundnut	0	75	275	717
Maize	0	58	213	557
Oil Palm	0	0	15	71
Rice	0	35	130	340
Soy	0	169	624	1628
Sugarcane	0	9	36	98
Wheat	0	80	296	771

Figure 5: Carbon payback times in years for crop-based biofuels produced from different land-uses in the Southeast Asian humid tropics. Table is an extract from Gibbs et al. (2008).

Where land is scarce, biofuel crops will add to the pressure to convert landcovers into arable land either directly or indirectly by displacing other crops. Some studies have suggested that agricultural production biofuel crops do not directly increase the amount of land used for agricultural purposes, but has caused deforestation for other crops (Casson, 2003 and Smeets *et al.* 2006).

Biofuels were estimated to contribute significantly to the spike in food prices in 2008. Higher food prices then lead to a continued malnutrition of the poorest members of society (Mitchell, 2008).

Depending on the type of feedstock used for biofuel production and on the area where it is grown, additional irrigation will be needed. This can cause saliniation and put additional pressure on this scarce resource. In addition, sediment from soil erosion, fertiliser and pesticide run-off and wastes from feedstock production can further contaminate fresh water supplies (Phalan, 2009). Finally, ethanol production processing demands currently more water per unit of biofuel produced than petroleum refining (Crutzen *et al.*, 2008).

Electric vehicles and hybrid vehicles

De Haan *et al.* (2007) investigated whether people would upgrade small or already fuel efficient cars to hybrid vehicles and if households would tend to increase the number of vehicles owned when purchasing a hybrid vehicle. They concluded that hybrid buyers on average do not switch from small, already fuel efficient cars to new hybrid vehicles. They found that hybrid-vehicle buyers were twice as likely as buyers of normal cars to increase the number of cars in their household. On the other hand, normal car buyers were twice as likely as Prius buyers to be first time car buyers. They argue that this finding might be due to the long waiting times for hybrid vehicles, which might have caused a pre-selection of buyers from multi-car households.

Electric vehicles can reduce the CO_2 emissions from transport. However, that largely depends on the electricity mix. Grid powered electric vehicles will only be zero carbon if they draw their electricity from carbon free sources. Before around 2020 this can only be from renewables or nuclear as carbon capture and storage will not be deployed at scale before this time.
In 2007, the domestic electricity demand was about 115 TWh in the UK. Of this demand, 5% was met by renewables and 19% by nuclear power. The summer minimum demand in 2007/2008 was at about 23 GW, which already exceeds the capacity for low carbon electricity sources of about 18 GW. Given that night time minimum system demands exceed nuclear and renewable capacity in general it is difficult to see how increases in night time electricity demand from vehicle charging will have a positive impact in the short term. If the number of electric vehicles rapidly increases in the short-term, then they will be largely charged by electricity generated by coal fire power stations.

Induced travel and generated traffic

Roads traffic levels tend to grow to a point where congestion starts to act as a deterrent for further traffic expansion. If road capacity is increased to overcome the congestion in that area, the number of trips also increases until congestion in again acts as a limiting factor. This is called generated traffic resulting from a variety of sources (Lee):

- Diverted traffic from other routes.
- Rescheduled traffic from different times.
- Shifts from other modes of transport.
- Changes in occupancy.
- Additional vehicle trips.

Induced travel is an increase in total vehicle mileage due to improvements to roads resulting from an increase in vehicle trip frequency and distance, but excludes travel shifted from other times and routes (Litman, 2010b). Goodwin (1996) demonstrated that a 20% decrease in travel time can lead too an average of 10% increase in traffic in the short-term and a 20% increase in traffic in the long-term. As a result, the economic benefits of transport projects can be overestimated if induced traffic is not accounted for (SANCTRA,1994).

Choices on transport modes

Rossiter and Dresner (1991) found that after regulations came into place which mandated the purchase of seats for infants during air travel rather than allowing children to travel for free on a parent’s lap led to a net increase in fatalities. Families switched to other modes of transport to save money, which meant that more travellers were killed on highways than infant lives saved on airplanes due to the use of safety seats.

Waters and Yu (2003) found that the introduction of the Canadian air transport security charge led to a diversion of about 253,000 air trips to car trips, which increased the number of fatalities and injuries on motorways. Similarly, Rossiter and Dresner (2004) found that increases in the passenger waiting time and cost for air travel after changes to the safety procedures following the September 11th terrorist acts lead to an increase in fatalities due to traffic diversions.

Carbon lock-in

Unruh (2000) argues in his paper that industrial economies have become locked into using fossil-fuel based processes and transport systems. This is particularly true for vehicle technology. Familiar characteristics of fossil-fuelled vehicles contribute to the slow transition combined a long vehicle lifetime of cars. Davis and Diegel (2002) (as quoted by Tukker *et al.*, 2006) found that the median lifetime of vehicles has increased. A car that was built in 1966 had an average lifetime of 11 years. Cars built in 1990 are on average 15 years on the road. This means that it would take about 20 years to translate technology changes fully into the vehicle fleet. Carbon lock-in is positively encouraged through

- Technology: dominant design, standard technology architecture and components, compatibility.
- Organisational: routines, training, customer-supplier relations.
- Industrial: industry standards, technological inter-relations, co-specialised assets.
- Social: system socialisation, adaptation of preferences and expectations.
- Institutional: Government policy intervention, legal frameworks.
- Financial: upfront investment needed for change.

Another aspect of lock-in of behaviour is the 'Free-rider' syndrome as described by Hallsworth *et al.* (1995). As long as other drivers are not changing their behaviour to a more sustainable way, most drivers continue to look after their own interest. This has been demonstrated by Cross and Guyer (1980). They commented on the voluntary 55mph speed limit in the USA which preceded mandatory restrictions. The vast majority of co-operative drivers travelling at 55mph increased their speed after having been overtaken by drivers who did not adhere to the speed limit.

Life cycle analysis

Spielmann et al. (2006) evaluated the environmental impact of prolonged use of passenger cars. Legal limits on the exhaust emissions in new cars for example mean that new cars tend to be less polluting than older cars. The life cycle analysis included the exhaust and abrasion emissions, the supply chain of fuels, manufacture, maintenance and disposal of the vehicles. They found that 85% of CO_2 emissions occur in the vehicle use phase and 75% of NO_x. They found that a 15 year lifetime of vehicles is environmentally favourable over a 12 year lifetime. However, large uncertainties made it impossible to make any general recommendations.

Anecdotal evidence

So far, this report has shown that common wisdom can be misleading. The following section summarises a number of unintended consequences of transport policy and transport innovations which have been reported either in the media or in discussions with the Transport Sector Panel. There is little or no scientific evidence for those accounts and research is needed to establish if those rebound effects are real and how large they are.

- **Amalgamation of local services:** Policies such as the closure of post offices and the proposal of super clinics have a great effect on transport needs. As a result, people have to travel further to gain access to previously local services.
- **Toughening of CRB checks:** Criminal Record Bureau (CRB) checks mean that an individual who has "contact with children or vulnerable adults and is of a specified nature (e.g. teaching, training, care, supervision, advice, medical treatment or in certain circumstances transport) on a frequent, intensive and/or overnight basis" has to undergo a CRB check[2]. Anecdotal accounts show that some parents consider stopping existing car pools for their school run, which would lead to an increase in traffic.
- **Noise regulations impact on CO_2 emissions of planes:** London Heathrow has got some of the world's most stringent noise regulations. It is set within an urban setting. Technology used to meet those requirements in the Airbus A380 leads to an increase in fuel consumption by roughly 2% compared to the fuel consumption if it did not have to meet those regulations[3].
- **CO_2 standards for buses:** It has been claimed that new diesel vehicles which meet the latest standards for exhaust emissions are less fuel efficient than the older vehicles they replace. While Euro IV engines have an improved fuel economy compared to Euro III engines, they are still higher than those of Euro I and Euro II engines. Most diesel engines are optimised to have low CO_2 emissions at high speeds. Buses however operate at an average speed of 20mph, which means that emissions are about twice as high at operating conditions than under ideal conditions.
- **Journey times for railways:** Anecdotal evidence suggests that some trains take longer for the same routes than a decade ago. Not all routes have seen journey times lengthen. Indeed, on many routes journey times are now faster than they have ever been. In order to maintain even intervals on the fast tracks for the increased services to Manchester and Birmingham as well as service to Liverpool and to Preston and Carlisle, many stops on fast trains have been withdrawn such as Watford Junction. Passengers from there must leave earlier and change en route; their journey times have increased although the trains on which they ultimately travel are faster.
  Many train journeys now take longer because of the need for longer dwell times at stations to allow the larger numbers of passengers travelling to board and alight. Limited door spaces at many stations means stops, which previously took only 30 seconds, may now require a minute or more. If that is multiplied along the length of the line, the additional minutes soon mount up and a longer journey time is inevitable. However, steps are being taken to address this, especially in urban areas, by longer trains or more frequent services, though that is a longer-term solution.
  There are more trains on the network now and they experience more red signals. Journey times are actually longer as the line speeds on some lines have dropped.
- **The Passenger's Charter:** Introduced in 1992, for the first time paid compensation to passengers delayed on trains. As the time penalty was triggered by delay, at the outset 60 minutes or more, there was a temptation to pad the timetable with what

became called “Charter minutes” between the last calling point and the terminus of the train to reduce as far as possible the likelihood of late arrival. Trains often arrived extremely early as result. This practice was quickly pounced upon and prevented from reoccurring. Train operating companies however are still known to hedge their performance risk by adding padding in the journey time to ensure that their ‘right time’ arrivals work.

- **Automated doors on trains:** Train doors now are mechanically locked whereas in the past, the passengers slammed them shut. On trains with sliding doors, it takes about 45-60 seconds from pressing the closure button and the train leaving the station. During that time it has to be confirmed that all doors are closed with station staff, the station staff gives ‘Right Away’, the Guards door is closed, a bell is rung to confirm that the doors are closed. The current safety regime demands this level of attention. Some stations however manage to run this regime within 20 seconds.
- **Stockholm congestion charge exemption:** Low-carbon vehicles were exempt from the congestion charge in Stockholm. Those were vehicles that ran on bio gas, E85, ethanol, electricity, producer gas, methane, methanol, natural gas or hydrogen. However, after a rapid hike in registrations for low-carbon vehicles, congestion increased in Stockholm. The Swedish Parliament therefore amended the rules regarding congestion tax for green cars. Low-carbon vehicles registered after 1 January 2009 cannot apply for exemption of the congestion charge any more. The exemption will however continue to apply up until 1 August 2012 for vehicles that were exempt from tax obligations prior to 1 January 2009.
- **Social inclusion:** Anecdotal accounts showed that if there are a large number of road signs in close proximity of each other, drivers tend to slow down to be able to process the information. This is particularly true for drivers with dyslexia Information on parking restrictions can be misleading and unclear and park-and-ride information is often too complex to comprehend for people with learning disabilities[4].

  Low floor buses have been designed to create better access for wheel chair users to public transport. However, there have been accounts that those buses have been more successful with baby buggies which can cause problems when wheelchair users wants to get onto those buses. Often there is not enough room for all the buggies as well. Another issue with low floor buses is that there are fewer seats at the front and the elderly passengers prefer to sit at the lower level rather than climbing than climbing a step to get to the rear area of the bus[5].
- **Car clubs:** Car clubs were initially invented to encourage people to sell their cars. The idea was that once people do not own a car, they will do short trips by public transport, walking or cycling. However, it was reported that they so far have been mostly used by people who did not own a car, and thereby contributing to an increase in car journeys.

Lessons learned

Transport is an essential part of our life. Yet, a large part of our transport needs is generated due to the design of our living spaces. People travel to get to work, bring children to school, to shop and to visit family and friends. In addition, a lot of goods and food have to be transported long distances to the shops.

Cities must provide job opportunities, housing, education, amenities and recreational facilities. In order to reduce the need for transport, those services should ideally be close together and connected through public transport links. By reducing the need to travel, a large number of rebound effects can be avoided. So called “compact” or “polycentric” cities mean that average journey distances, trip frequencies, traffic volumes, energy consumption and/or transport emissions can be reduced. However, in reality the situation is much more complex. Litman (2010a) estimated that local land use factors (neighbourhood density, mix, design, etc.) can reduce per capita vehicle travel 10-20%, while regional land use factors (location of development relative to urban areas) can reduce automobile travel 20-40% compared with overall national average values.

People have to be given the opportunity to change behaviour. The proximity to low carbon transport options such as public transport, walking and cycling influences travel patterns.

There is a need for more innovative approaches. For example, if villages are too small to make local amenities viable, then those amenities could be brought to the consumer. A case to case analysis has to be made and an effort should be made not to jump to premature conclusions. There is a way to do this more sustainably.

Pricing technologies have a role and can help people make better informed decisions.

Conclusion and recommendations

This report debates the unintended consequences of transport innovation and transport policy. The good news first: technological advances help to reduce the CO_2 emissions from transport. Fuel efficient vehicle, telecommuting, electric vehicles and other technologies will all play a role in moving countries closer to achieving their carbon reduction targets. However, technologies and policy measures often lead to rebound effects and unintended consequences. Those policies do not render policies ineffective, but reduce their benefits. It is therefore important to quantify the rebound effects of those policies in order to account for them when devising roadmaps to meet carbon reduction targets. Below are seven recommendations for policy makers:

1. The carbon reduction targets are challenging and policy makers have to make bold decisions to reduce the CO_2 emissions and energy use from transport. Those reductions will have to be implemented through a mix of behavioural changes and technical innovations.
2. Most decisions result in some unintended consequences or lead to rebound effects. Studies have shown that there are benefits to new technologies. In order to maximise the benefits, the implementation of those technologies has to be reviewed on a case to case basis. Policy makers have to be careful not to generalise. E-commerce for example has got great benefits in some scenarios and little to none in others.
3. Policy makers must not get overwhelmed by their task and use the rebound effect as an excuse to do nothing. There is a cost attached to doing nothing (as impressively demonstrated by the Stern review) and is not an option.
4. Whole life cycle analysis has to be performed. Policy makers have to be careful that emissions are not simply moved from one sector to another. Countries also have to account for the emissions from the manufacturing of goods - even if those have been produced abroad.
5. Policy makers have to account for rebound effects when implementing CO_2 emission targets.
6. Carbon pricing needs to be considered as a means to mitigate the indirect rebound effect. The devil lies in the detail and a fair system needs to be devised which accommodates for people on low incomes, areas with little or no public transport, minority groups and other issues.
7. More detailed research is needed about rebound effects. The more accurate our knowledge is on the unintended consequences, the better we can account for them. It will also allow policy makes to pick scenarios that minimise rebound effects. This is particularly important for large-scale projects such as high speed rail or electrifying road transport.

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End Notes

1	It is sometimes also called Jervon's paradox
2	CRB website http://www.crb.gov.uk
3	House of Commons Transport Select Committee (2003) Sixth Report Aviation, Volume II, Minutes from Wednesday 30 April 2003
4	Phone conversation with IET member
5	E-mail conversation with National Express

Notes

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