Energy Policy 50 (2012) 62–71

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Trends in income and price elasticities of transport demand (1850–2010)

Roger Fouquet [a,b,*]

[a] Basque Centre for Climate Change (BC3), Alameda Urquijo 4-4, 48008 Bilbao, Spain
[b] IKERBASQUE, Basque Foundation for Science, Alameda Urquijo 36-5, 48011 Bilbao, Spain

ARTICLE INFO

Article history:
Received 5 December 2011
Accepted 1 March 2012
Available online 22 March 2012

Keywords:
Income and price elasticities of demand for transport
Energy transitions
Rebound effects

ABSTRACT

The purpose of this paper is to estimate trends in income and price elasticities and to offer insights for the future growth in transport use, with particular emphasis on the impact of energy and technological transitions. The results indicate that income and price elasticities of passenger transport demand in the United Kingdom were very large (3.1 and −1.5, respectively) in the mid-nineteenth century, and declined since then. In 2010, long run income and price elasticity of aggregate land transport demand were estimated to be 0.8 and −0.6. These trends suggest that future elasticities related to transport demand in developed economies may decline very gradually and, in developing economies, where elasticities are often larger, they will probably decline more rapidly as the economies develop. Because of the declining trends in elasticities, future energy and technological transitions are not likely to generate the growth rates in energy consumption that occurred following transitions in the nineteenth century. Nevertheless, energy and technological transitions, such as the car and the airplane, appear to have delayed and probably will delay declining trends in income and price elasticity of aggregate transport demand.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Travel over the last two hundred years has been revolutionised by a series of technological innovations. The shift from horse-drawn transport to railways to cars has radically changed people's lives. Alongside these shifts in modes of transport were energy transitions, from horse-power to coal to petroleum. Radical changes in the technology and energy sources suggest upheavals in transport behavioural patterns. This would imply difficulties in understanding and anticipating the impact of any future technological and energy transitions, such as a possible switch to electric vehicles.

One particularly interesting observation is that energy transitions are characterised by major increases in energy consumption (Grübler et al., 1999; Grübler, 2004). If this was true for future transitions, it would have major implications for long run demand for energy and carbon dioxide emissions. A transition to, for instance, electric vehicles might, therefore, produce major increases in electricity demand (beyond the expected substitution from petroleum), and may lead to large emissions if it was generated from fossil fuels.

While past energy and technological transitions have been disruptive, consumers before and after were still demanding transport services. The same should apply to future transitions. In other words, focussing on the long run aggregate demand for transport services might offer a way to identify stable patterns of behaviour in periods of transitions. In addition, estimating the long run demand for transport, and how it has evolved, might bring some light onto whether future energy transitions will be similar to past ones.

Few studies have investigated the long run evolution in the demand for transport or other energy services. Fouquet (2008 p. 265) proposed that the nineteenth century in the United Kingdom was a period of both energy transitions and of very high income and price elasticities, especially related to lighting and passenger transportation. However, at the time, no econometric analysis was performed to test these propositions.

Small and van Dender (2007) looked at transport demand in the US between 1960 and 2004, and suggested that price elasticity was lower between 2000 and 2004 than from 1960 to 2000. Goodwin et al. (2004) surveyed the literature on transport demand elasticities and tentatively concluded that income elasticities may have declined over the last forty years. Fouquet and Pearson (2012) offered estimates of trends in the demand for energy services, focussing on lighting, for a longer period (between 1750 and 2008), which is probably more relevant for studying energy transitions. This study found that income and price elasticities increased dramatically (to 3.5 and −1.7,

* Correspondence address: Basque Centre for Climate Change (BC3), Alameda Urquijo 4-4, 48008 Bilbao, Spain. Tel.: +34 944014690; fax: +34 944054787.
E-mail address: roger.fouquet@bc3research.org

0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2012.03.001

respectively) between the 1840s and the 1890s and fell rapidly in the twentieth century.

Using the same approach, this paper estimates the trends in income and real price elasticities of demand for passenger transport. An understanding of trends in transport demand elasticities in the United Kingdom will also be valuable for anticipating future transport use, energy demand and carbon dioxide emissions in this economy and others with similar levels of economic development and characteristics related to transport. For instance, if price elasticities for transport demand are low and falling, then high taxes on (or prices of) carbon are likely to have little effect on overall transport use. However, they may significantly encourage the use of low carbon technologies, energy sources and behaviour. Furthermore, this historical perspective, looking at the United Kingdom at different phases of economic development, may also be of relevance for understanding future trends in transport demand in developing economies.

Section 2 briefly reviews the literature on the demand for passenger transport. Section 3 outlines, the data sources for this study. Then, Section 4 presents and discusses the trends in transport prices and consumption, as well as income. In Section 5, the estimated trends in the price and income elasticities of demand for transport are presented. The final section draws tentative conclusions about the variations in elasticities over time, and examines their implications for our understanding of energy transitions, long run energy consumption and climate policy.

2. Demand for transport services

The demand for passenger transport services reflects individuals' willingness to pay for travelling from one place to another. Before the nineteenth century, as well as having very limited incomes, people had lifestyles that required little transport. Work was in or near the home. People socialised with their family and neighbours. Yet, historically and across cultures people's travel distances have been bound by their monetary and time budgets (Schäfer, 2000). Greater income allowed individuals to spend more money on travel. Similarly, new technologies and cheaper travel created an opportunity for the location of work and lifestyles to change (Grübler et al., 1999; Bannister, 2011). Although some evidence supports a constant relationship between income and travel demand (Schäfer and Victor, 2000), this crucial issue in future energy use and carbon dioxide emissions deserves a deeper look.

Consumer responsiveness to changes in prices and income has depended on a number of factors. Income elasticities tend to reflect whether consumers perceived a particular good as a "luxury" or as a necessity. For so-called "luxury" goods and services, consumption increased more than proportionally as income rose (i.e., high income elasticity). Normal goods and services (or necessities) were likely to have low elasticities (i.e., less than 1). In some cases, they were seen as inferior goods and services, and consumption declined with greater income. The traditional view is that, at low levels of economic development, most goods and services have been luxuries relative to basic foods. So, as incomes rose, except for basic foods, consumption for all goods and services increased more than proportionally. As income increased further, saturation effects implied that consumption and expenditure of many previously "luxury" goods and services grew less than income (Moneta and Chai, 2010).

Evidence suggests that expenditure categories mostly associated with services have tended to experience relatively lower levels of saturation. This is partly explained by the introduction of higher quality services delaying the saturation effect. Consistent with this, there is some, but limited, evidence of saturation for travel services (Moneta and Chai, 2010). In other words, as an economy develops and incomes rise, income elasticities associated with travel service demand might be expected to fall, but not necessarily to zero.

Price elasticity can be broken-down into the income and substitution effects. The income effect depends on the proportion of the individual's budget spent on the service and whether the individual tends to spend a greater proportion of the budget on the service as income rises. The substitution effect indicates the tendency to switch towards the cheaper good or service. The more substitutes available for a particular service the greater will be the substitution effect.

When considering the aggregated market for passenger transport services, it is difficult to identify clear substitutes. One could argue that communication, such as postal services, the telegraph, the telephone and emails, has offered a partial substitute, by being able to transmit messages from one person to another without needing people to travel. Thus, cheaper, faster and better communication over the last two hundred years may have reduced the need for certain types of travel (Selvanathan and Selvanathan, 1994). At the same time, they (and especially other forms of communication, such as newspapers, radio, television and the internet) have probably increased people's desire to travel more generally (Salomon, 1985). Even today, with emails, there still appears to be a relationship between distance and the mode of communication used – for interactions with people living less than 5 km, people still often engage in face-to-face communication; for regional interactions, the phone is used mostly; and for greater distances, the internet is the predominant choice (Mok et al., 2010).

It is important to distinguish between the overall market elasticity of demand for transport and the demand facing individual modes of transport. Here, the focus is on the overall demand to identify a continuous demand for travel over different modes, technologies and energy sources. Most studies, however, focus on a particular mode of transport, rather than aggregate demand. An early survey of the literature offers an insight into some of the elasticities that might be expected by modes of transport (Oum et al., 1990, see also Oum et al., 1992). For rail travel, it identifies a wide range of price elasticities between -0.11 and -1.80. The variation is explained in great part by the purpose and type of rail travel. Average peak intra-city travel was -0.15 – that is, a 10% rise (or fall) in prices only reduced (or increased) consumption 1.5%. Whereas urban off-peak rail price elasticity was -1. Inter-city business travel was -0.8, and average leisure rail travel was estimated to be -1.4. For off-peak car travel, price elasticities ranged from -0.06 to -0.88 and, for peak journeys, estimates were between -0.12 and -0.49. Peak bus demand was inelastic (i.e., 0), while off-peak demand ranged from -1.08 to -1.54. Out of interest, the authors also found that the price elasticity of demand for air travel ranged from -0.08 to -4.51, indicating, in some cases, great sensitivity to prices for this more "luxury" form of transport. However, this study was unable to distinguish between short run and long run estimates. Also, these estimates are for developed economies, while the current paper is interested in demand at different phases of economic development.

More recently, Goodwin et al. (2004) surveyed the literature associated with car travel. In addition to providing a valuable range of estimates, they were interested in changes in elasticities. Although their results depend on the assumptions made about a traveller's utility function, their theoretical expectations (presented in Hanly et al., 2002) were that price elasticities increased when (fuel) prices were high and fell with lower prices, and that price elasticities fell with income (and, thus, over time). One might also expect a decline in price elasticities because, for certain journeys, transport and leisure are consumed jointly and the travel costs becomes a declining share of the total costs. However, they found no clear support for these expectations. On the other hand, they proposed that, because of saturation effects, income elasticities might be expected to fall, and tentatively concluded that income elasticities did fall.

Price elasticity is also of great interest to energy economists because of possible rebound effects (Howarth, 1997; Greening et al., 2000; Sorrell, 2007). Jevons (1865) introduced the concept of the rebound effect, arguing that improvements in energy efficiency were likely to lead to greater energy consumption (not less). Ayres (2005) proposed that rebound effects for "macro" innovations (i.e., radical innovations, like the steam engine) might generate large rebound effects and increases in energy consumption; and 'micro' innovations that improve the efficiency of existing technologies result in smaller rebound effects. Fouquet (2008, p. 277) proposed a few historical cases in the United Kingdom (particularly, freight transport between 1715 and the 1930s, passenger transport from the 1840s to the 1920s, and lighting during the nineteenth century – the latter confirmed in Fouquet and Pearson (2012)) where the rebound effects were very high – partially supporting Jevons' (1865) hypothesis.

In this light, Small and van Dender (2007) examined the price elasticity of demand for car transport. They looked at transport demand in the US between 1960 and 2004, and found that price elasticities were lower between 2000 and 2004 than from 1960 to 2000. They suggest that the rebound effect fell from 2.1% to 0.57% for a 10% efficiency improvement. Thus, for this limited sample, efficiency improvements generated only minor increases in car travel and considerable reductions in energy use. Hughes et al. (2006) also find that the price elasticity of gasoline demand has declined through time, but that, at any particular time, higher incomes groups have higher price elasticities than lower income groups. The very limited evidence on trends in income and price elasticity of demand for transport demand, and related rebound effects, invites a more detailed time series study. The rest of this paper seeks to provide more evidence.

3. Data sources and creation

To study the relationship between passenger transport use, income and prices, it is necessary to gather statistical information on travel and the prices of travelling or energy sources associated with the different modes. This section offers a summary of the sources and methods used to produce annual estimates of prices (or costs) and use of horse drawn transport (1850–1924), railways (1850–2010), buses (1904–2010) and cars (1904–2010) in Great Britain and then, from the 1920s, the United Kingdom – more detail can be found in Fouquet (2008).

For horse-drawn transport, Chartres and Turnbull (1983, p. 71) presented estimates of passenger miles per week for a number of years between 1715 and 1840. Thompson (1976) offered detailed estimates of the number of horses associated with different activities (stagecoaches, carriage, riding, as well as farm and trade), during the nineteenth and early twentieth century, and particularly from 1851. These can be linked to the 1840 estimate by Chartres and Turnbull (1983, p. 71) to estimate the average number of passenger kilometres per horse used. With this average, the number of horses used for transport can be used for calculating the millions or billions of passenger-kilometres (bpk) from 1851 to 1924. While this was a rough estimate, in the second half of the nineteenth century, horse transport was dwarfed by railways use.

For prices, Jackman (1960) collected considerable information on the cost of stage coach travel in the eighteenth and nineteenth centuries. When these were divided by the distance for particular stage coach journeys, they produced estimates of the price per passenger-kilometre. From estimates of several of the main journeys in England, an average price was estimated.

For railway use, Hawke (1970, p. 47) offered data on millions of passenger miles and millions of journeys travelled between 1840 and 1870. Mitchell (1988, p. 545) also presented data on millions of journeys travelled annually from 1842 until 1913. Thus, to calculate passenger-kilometres after 1870, it was necessary to have estimates of the distance travelled during an average journey. Munby (1978, pp. 106–7) gave estimates of billions of passenger-kilometres and the average length of train journeys between 1920 and 1970. So, the gap was only between 1870 and 1920. Surprisingly, the calculation of the average length of a railway journey in 1870 (from Hawke, 1970) and in 1920 (from Munby, 1978) are virtually identical, and the distance travelled on the average railway journey was assumed to have remained nearly constant over those fifty years. Mitchell's (1988) passenger journey data was multiplied by the average length of journeys to estimate passenger transport in billions of passenger-kilometres (bpk) between 1870 and 1913. To complement Munby (1978), from 1938 to 2010, DoT (2002) and DfT (2011) presented direct estimates of passenger-km.

These can then also be used to estimate the price of railway passenger services. Mitchell (1988, p. 545) has railway passenger receipts (in £m) between 1843 and 1980. These figures can be divided by estimates of total passenger-km travelled (discussed above) to suggest the cost per passenger-km of using railways up to 1913. Munby (1978, pp. 113–114) has direct estimates of the price (in old pence per km) from 1920 to 1970. Between 1970 and 1980, receipts were again divided by passenger-km. DoT (2002) and DfT (2011) had estimates of the price between 1991 and 2010. An inability to find values during the 1980s led to interpolation.

For twentieth century road travel, DoT (2002) and DfT (2010) presented data on passenger travel (e.g., buses, cars, motorcycles, etc.) between 1952 and 2010. Before the early 1950s, data needed to be pulled together. Mitchell (1988, pp. 557–558) had information on the number of cars and other vehicles between 1904 and 1980. Car passenger travel per vehicle was calculated for 1952 – 16,000 km per car per year. Before these years, assumptions were made about the trend in average travel per vehicle: for cars, an annual 2% decrease in the average travel per car ratio each year before 1952 – based on the idea that there were fewer roads and people travelled less per year than they did in the 1950s. This assumed trend in average distance per vehicle (back to the beginning of the century) was multiplied by Mitchell's (1988, pp. 557–558) numbers of vehicles to produce an estimate of the bpk back to 1904. Given that the number of buses was also available, a similar method was used to quantify bpk used related to public transport vehicles (Fouquet, 2008).

Passenger road transport "prices" are more complex in the second-half of the twentieth century. Rather than identifying the cost of buying a train or bus ticket, as more travellers used their own cars, a number of different expenditures were involved. At least three costs can be identified: the fuel costs, all marginal costs and annualised total costs. Table 1 shows the breakdown of the annual cost of car travel between 1971 and 2008. Fuel costs accounted for between 28% and 40% of the total annual expenses. Few of the other expenses listed are obvious marginal costs – tyre consumption also depends on distance travelled. So, fuel costs were presented as the price (or main private marginal cost) of passenger transport.

The price of driving a car one kilometre was estimated by dividing passenger fuel expenditure (in million tonnes of oil equivalent (mtoe)) by distance travelled (in bpk). Until the

Table 1
Shares of motoring costs for average households, 1971–2008.
Source: based on data from DfT (2010) and ONS (2002).

	1971 (%)	1981 (%)	1991 (%)	1996 (%)	2001 (%)	2006 (%)	2008 (%)
Purchase, tax & insurance	53.3	55.0	60.1	53.3	52.2	44.9	39.9
Spares, repairs & servicing	14.5	15.3	12.5	14.1	14.2	15.4	16.3
Petrol, diesel & engine oils	27.9	33.3	24.7	28.5	30.0	34.9	39.7
Other motoring costs	4.3	2.7	2.5	4.1	3.6	4.6	4.0

1930s, motor spirit (i.e., gasoline) was the main petroleum product for road vehicles. Then, diesel (that is, “derv”) began to be used by goods vehicles and buses. Cars used exclusively motor spirit until the 1980s, when diesel started to take a small market share. Thus, it was necessary to identify the share of motor spirit and diesel consumed for passenger services.

The Ministry of Power (MoP, 1961) indicated the share of motor spirit used by both passenger and freight transport between 1938 and 1960. The share of motor spirit used by commercial vehicles fell from 42% to 19% in that period – it was assumed that the share of buses was around 10% of commercial vehicles in 1938 and 5% by 1960, reflecting the relative decline of public transport. These shares enabled motor spirit consumption (DTI, 1997,2001,2007,2011 and back copies; MoP, 1961 and King, 1952 p. 551) to be estimated for passenger travel.

DTI (1997,2001,2007) presented the amount of diesel used by passenger travel back to 1995; in 2000, it was equivalent to 18% of the total consumption of diesel. Miller (1993) indicated the share of diesel vehicles in the passenger vehicle stock into the early 1990s, providing a basis for calculating the small amount of diesel consumed. An interpolation connected 1991 and 1995. The rest of road transport diesel (also found in DTI, 2007; MoP, 1961 and King, 1952, p. 551) was assumed to be for freight. Thus, consumption of motor spirit and derv for passenger road transport were estimated between 1910 and 2000.

DTI (2011, 1997, 2001) presented the price of motor spirit and diesel back to 1954. The Institute of Petroleum (1994) had data on the price of motor spirit from 1902 to 1953. The prices were multiplied to the consumption estimates to calculate the fuel expenditure of passenger road transport. Dividing fuel expenditure by distance enabled an estimate of fuel costs of road transport services in pence per passenger-km. All prices for transport service were converted into real terms using the data available in Allen (2007).

4. Trends in transport prices and use

Passenger transport in Britain experienced a series of revolutions that radically altered the ability to travel. First, from the mid-seventeenth century, the introduction of turnpikes, managed roads that travellers paid to use, enabled an improved road network. Then, from the 1770s, stage coach journeys became better managed and faster – by 1830, average trips took one-fifth of the time they took in the 1770s (Bagwell, 1974). Between 1775 and 1815, passenger travel increased from 0.05 billion passenger-km (bpk) to 3 bpk – a 60-fold increase in 50 years (Chartres and Turnbull, 1983).

Then, harnessing the power of steam by heating fuels revolutionised the economy and society. It, first, provided stationary power to remove water from coal mines and to spin cotton, then, as directed power, enabled transport along railways (and for ships). The introduction of steam engines to rail in the first half of the nineteenth century meant that coal rather than horses could power the carriage of people and goods. In Britain, coal was cheap (see Fig. 1) and entrepreneurs were willing to build railways that would eventually form a vast network – increasing 16-fold in the 1830s, and then another four times in the 1840s, it expanded from around 150 km in 1830 to nearly 10,000 km in 1850 and then to 30,000 km by 1900 (Mitchell, 1988, p. 541).

For the wealthy and middle classes, the railway was a superior way to travel medium and longer distances. In addition to the relative improvement in comfort, per passenger-km, in the 1830s and early 1840s, stage-coach travel cost more than 70 pence (2000 prices) and the railways around 30 pence (Fouquet, 2008 p. 163). It appears, however, that coach companies, fearing competition from railways and having invested in equipment and horses, drove up their prices in the 1820s (Hart, 1960). Inevitably, this strategy accelerated the transition to railways. This meant that the average price of transport fell greatly during the 1830s and 1840s (see Fig. 2). Railway use increased nearly fivefold in the 1840s to 1.5 bpk (see Fig. 3). For shorter distances, including to the railway station, horses were still needed. So, transport more generally increased to an estimated 5 bpk in 1850.

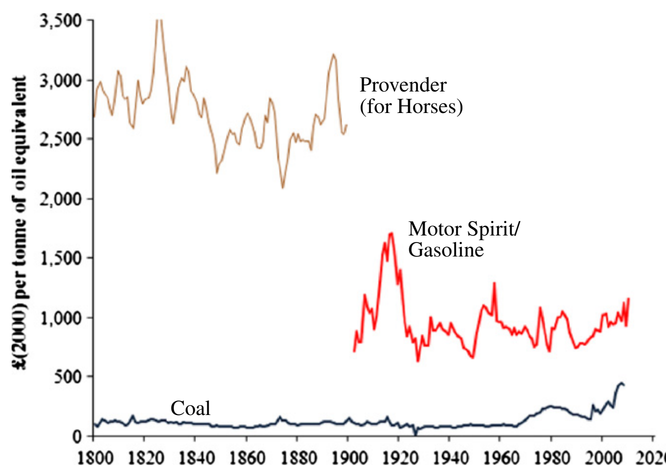

Fig. 1. Trends in the prices of energy sources for transport, 1800–2010. *Source*: Fouquet (2011).

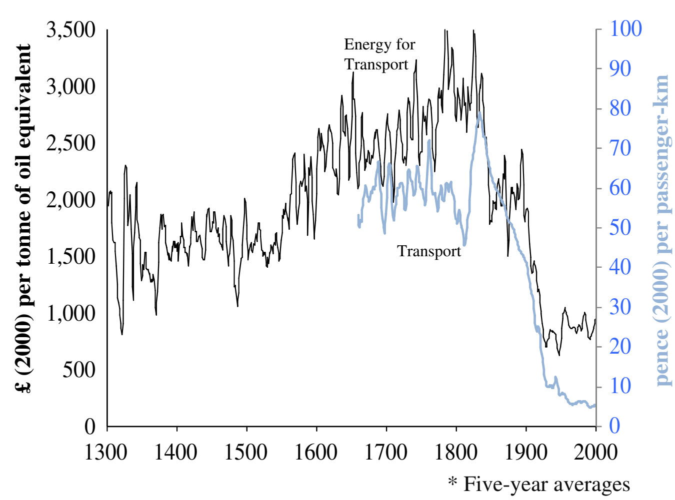

Fig. 2. Trends in the prices of energy for transport and of transport*, 1300–2000. *Source*: Fouquet (2011).

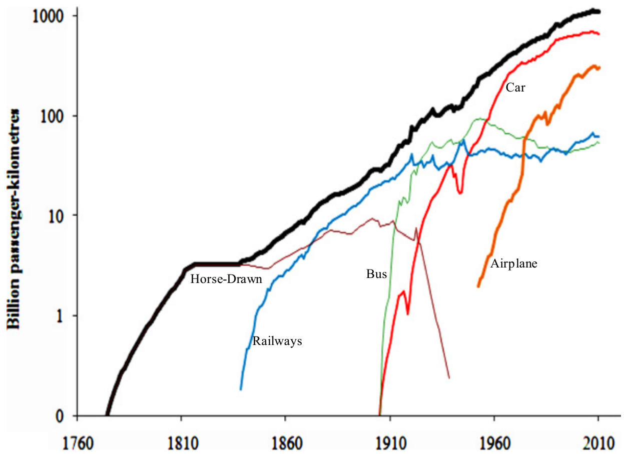

Fig. 3. Consumption of passenger transport, 1750–2010.

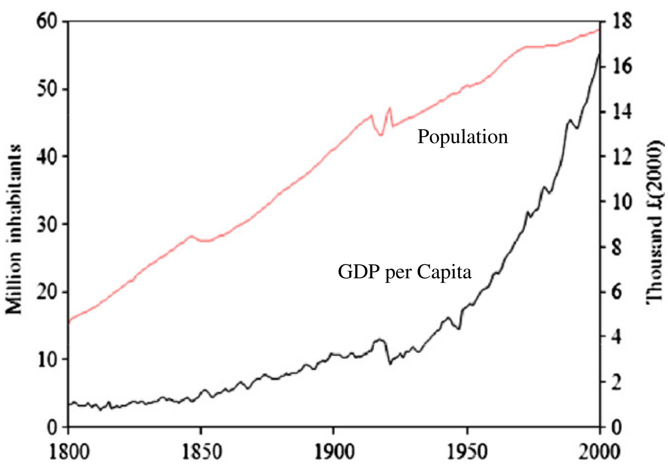

Fig. 4. GDP per capita and population, 1700–2000.
Source: ONS (2002), Mitchell (1988), Broadberry et al. (2009).

A number of factors were driving the consumption in transport services in the second half of the nineteenth century. Income levels increased substantially – more than doubling in the second-half of the nineteenth century (see Fig. 4). More efficient steam engines in the 1860s and 1870s helped. In 1840, one tonne of coal could achieve 1700 passenger-km; by 1870, it could move more than 3000 passenger-km; and 3400 passenger-km in 1900 (Fouquet, 2008 pp.165–166). Although important, fuel costs were a relatively small share of the price of transport – falling from over four pence to under two pence per passenger-km, which amounted to about one-tenth of the price (see Fig. 2). Better management enabled travel prices to fall. For instance, by 1842, the railway network had become commercially integrated, allowing customers to buy one ticket for connecting journeys. Also, speed of travel increased and comfort improved (Leunig, 2006).

Furthermore, in the latter part of the nineteenth century, owners began to appreciate, with governmental pressure, that third-class customers were a large potential market. Selling cheap tickets allowed a large proportion of the population, whose only other option was walking (or possibly riding on a slow wagon), to travel more and save time, opening-up many opportunities (Leunig, 2006, p. 651). The railways, which started as an improvement on the stagecoach for the wealthy, became a new service for the masses, transforming the nature of mobility and society. Consequently, passenger transport increased from 5 bpk in 1850 to nearly 30 bpk in 1900 – with railways providing 63% of the services (see Fig. 3).

Interestingly, since the distance travelled during the average train journey appears to have remained constant between 1870 and 1920 (see Section 3), the growth may have been associated only with an increase in the number of journeys travelled. Alternatively, there may have been far more shorter (e.g., intra-urban) and longer (e.g., inter-city) journeys, and they happened to have cancelled each other out, leaving the average distance of a journey unchanged.

The next transition was the result of the introduction and development of the internal combustion engine. Despite the greater cost per unit of energy (see Fig. 2), petroleum derivatives, such as gasoline or motor spirit and diesel or derv, became the dominant energy sources for the internal combustion engine, and eventually transportation.

For the middle and lower classes, the bus offered a cheap and more flexible public transport service than horses for shorter journeys, and improved connections between train stations (Bagwell, 1974, p. 224). Despite competition from the incumbent tramways in many of the larger cities, their use increased spectacularly in the first-quarter of the twentieth century. Between 1903 and 1913, there was a 270-fold increase in motor-buses used in London (Munby, 1978, p. 562). By 1930, there were more than 50,000 buses on British roads, providing an estimated 50 bpk. This increased in 1950 to just under 80,000 buses, providing nearly 90 bpk by 1950 (Mitchell, 1988, p. 557–558; DfT, 2010).

Meanwhile, the car started as a toy for the rich. The number of private motor cars owned in Britain grew rapidly from 8000 in 1904 (the first year for which data exists) to 132,000 in 1914 – a 16-fold rise in ten years (Mitchell, 1988, p. 557). Then, after the First World War, and with the rising per capita income levels (see Fig. 4) and falling car prices (the average price of a car fell from about £(2000) 25,000 in 1910 to £(2000)10,000 by the early 1930s (Foreman-Peck, 1981, pp. 264–265)), middle class car use grew. By 1924, 0.5 million cars were being driven and, in 1938, 2 million cars (Mitchell, 1988). Car travel increased from 0.55 bpk in 1910 to 2.5 bpk in 1920 to 15 bpk in 1930 to 32 bpk in 1939 – dropping substantially during the Second World War (see Fig. 3).

Interestingly, between 1924 and 1938, motor spirit consumption increased from 1.6 to 4.4 million tonnes. This implied that, by the end of this period, each car consumed 2300 l per year, which was a 50% decline on use 14 years earlier (BPP, 1926; King, 1952). This indicated that, in the 1920s and 1930s, fuel efficiency and average travel habits changed greatly.

Several factors were driving-up the demand for and use of car travel. From the 1920s until the early 1970s, motor spirit prices remained relatively stable, averaging about £(2000) 0.65 per litre. Despite the Oil Shocks, average oil prices stayed within the £(2000) 0.50–0.80 per litre range (or £(2000) 700–11,000 per tonne shown in Fig. 1) in the second half of the twentieth century (Fouquet, 2008, p. 177). Second, fuel efficiency (measured as the passenger-km per tonne of oil used) improved 86% in the third quarter of the twentieth century. By 1990, fuel efficiency improved another 15%. However, it fell 4% over the next decade – most probably reflecting the fashion for bigger and more powerful vehicles. Finally, per capita income increased 76% between 1950 and 1975, and 75% between 1975 and 2000 (see Fig. 4).

Despite rising incomes, bus use fell 32% from 1950 to 1975, and 25% from 1975 to 2000. Similarly, passenger rail travel use remained stable in the third-quarter of the twentieth century, and then rose 30% in the final quarter. In the meantime, car ownership soared from 2.2 million in 1950 to 14 million in 1975 (Mitchell, 1988, p. 557–558) to 23 million in 2000. Car travel rose at a similar rate – from 50 bpk in 1950 to 330 bpk in 1975 (i.e., nearly a sevenfold increase) to 640 bpk in 2000 (i.e., nearly a doubling) (see Fig. 3).

This suggests that travel behaviour changed considerably during this time. In addition to declining motoring costs and rising income, the nature of transport was radically transformed by the introduction and expansion of cars. For instance, cars allowed freedom to determine the destination, flexibility about the route taken and privacy (and exclusivity) during the journey. The car began as a source of status and leisure, and still in the 1930s, three in every four cars bought were for leisure (O'Connell, 1998, p. 77). The growing use of cars created a cultural re-alignment in which people expected to (and were expected to) travel by car. Cities and related activities (whether associated with work, shopping or leisure) increasingly became built around accessibility by car (O'Connell, 1998). Thus, harder to measure social and cultural forces also propelled the demand for car use.

An average car in 1950 was responsible for 15,000 passenger-km. This increased 35% to 21,000 passenger-km in 1975 and then another 30% to almost 28,000 passenger-km in 2000. Thus, in the second-half of the twentieth century, mobility increased considerably and all the growth in passenger transport was in the use of private cars rather than buses or railways.

To summarise the long run trends in land transport, the estimated average price of passenger transport services fell from £(2000)0.63 per passenger-km in 1850 to £(2000)0.39 in 1900 to £(2000)0.08 in 1950 to £(2000)0.05 in 2000 – a 12-fold decline in 150 years. Income per capita increased from £(2000)1500 per year in 1850 to £(2000)3200 in 1900 to £(2000)5200 in 1950 to £(2000)17,000 in 2000 – nearly a 12-fold rise in 150 years. Land passenger transport consumption soared from less than 4.5 bpk in 1850 to 27 bpk in 1900 to 186 bpk in 1950 to nearly 740 bpk in 2000 – a 165-fold rise in 150 years. If income and price were both unit elastic in relation to transport demand for these 150 years, consumption would have increased 144-fold. Thus, the evidence suggests the demand for land transport was either elastic for the last 150 years or very elastic during certain periods.

Yet, the introduction of air travel has increased total passenger transport even more rapidly over the last 60 years. In 1950, airplanes provided 2 bpk. By 1975, this had increased to 62 bpk, and up to 260 bpk in 2000, reaching 305 bpk in 2010. So, at present, air travel provides almost half the number of passenger kilometres that cars do – airplanes are responsible for 28% of all passenger transport and cars for 61%. Recent total[1] (i.e., land and air) use increased more – from 192 bpk in 1950 to 1012 bpk in 2000, and 1095 bpk in 2010. Thus, total passenger transport increased 220-fold in 150 years, indicating even higher income and/or price elasticities.

5. Income and price elasticities, and rebound effects

This section presents some estimates of the influence of income and prices on transport use, and their trends over the last 150 years. Following the same approach as Fouquet and Pearson (2012), a vector error correcting model was used to provide an econometric analysis of the data and the trends, and estimate the cointegrated relationship between travel, income and transport prices. The emphasis should not be on the methods used, which are open to criticism and other scholars might improve upon,[2] but the trends.

Given the trended nature of the data (see Figs. 2–4) and the tendency for long run transport use (or energy related to transport), GDP and travel costs to be cointegrated (Bentzen, 1994; Fouquet et al., 1997; Ramanathan, 1999), the possibility of using vector error-correcting models (VECM) was explored. From a statistical perspective, such models were appropriate.

First, for the long run trends in transport consumption, GDP per capita and the price of transport, non-stationarity could not be rejected. In addition to the standard tests for unit roots, an augmented Dickey–Fuller test where the time series is transformed via a generalised least squares (GLS) regression was used to improve the power of the test (Elliott, Rothenberg and Stock, 1996). Here, for up to 15 lags, and incorporating the assumption of a time trend, the tau-statistics could not reject at the 10% confidence level. Thus, unit roots (i.e., non-stationarity) were likely.

Second, the causal relationship between transport consumption and per capita GDP was examined. The results suggest unidirectional causality from per capita GDP to transport use. As expected, GDP per capita was not influenced by either transport use or prices, as transport has been only a small component of economic activity (generally less than 8% of GDP). Although still significant, as will be shown by certain elasticity estimates, the causality test indicated that prices were less of a powerful explanatory variable of transport consumption. The results indicate that, in the second-half of the nineteenth century, consumption may have also influenced prices – perhaps reflecting the importance of economies of scale in driving down early railway costs. While this raised a simultaneity problem, for this exercise, it was assumed that causality was unidirectional from prices to consumption for the whole period.

Third, tests rejected the null hypothesis of no cointegrating equations for the relationship between transport consumption, GDP per capita and the price of transport – for the whole period between 1850 and 2010 (see below). Having selected the appropriate number of lags from a series of different tests (Nielsen, 2001), tests for the existence of cointegrating equations were performed and, when the null hypothesis of no relationship was rejected, almost always one cointegrated relationship could not be rejected (based on methods developed in Johansen, 1988, 1995).

These VECM were, therefore, used to estimate the evolution of income and price elasticities. The approach was to estimate elasticities for fifty year periods moving through time. For example, the income and price elasticities were estimated for the period 1850–1899, then 1851–1900, and so on until 1961–2010. Then, the elasticity for any particular year would be the moving average (i.e., the average of all elasticities estimated where that year was included). For example, for the moving average around the year 1950, fifty income elasticity estimates were produced (for the periods 1900–1950, 1901–1951, and so on until 1950–2000) and the average of all these estimates was equal to 0.91. Estimated in the same way, the average price elasticity around 1950 was -0.72.

Inevitably, for some periods, the results were either not as expected or the possibility of no cointegrated relationship could not be rejected. In particular, the period broadly between 1850 and 1869 produced unexpected price elasticities and the absence

[1] Sea passenger transport was excluded because the author has only managed to find data from 1950, despite its historical role in international transport. In 1950, there were 6.4 bpk by sea, implying that it provided less than 4% of total passenger travel at the time. Its role fell further, providing less than 3 bpk at the beginning of the twenty-first century (DfT, 2011).

[2] The author would like to thank Bill Nordhaus, David Stern, Lester Hunt and Lutz Killian for their comments on this avenue of research. Lutz Killian questioned whether long run elasticities can be estimated with time series, rather than with panel data (see Kilian and Murphy, 2010). The other three scholars encouraged this line of research, although offered caution about the methods. Naturally, the author of this paper is solely responsible for the choices made and the limitations of the methods used.

of cointegrating relationships could not be rejected. Most of the price elasticities were positive and large. In the absence of a satisfactory explanation, these estimates were excluded from the calculation of the average estimates. Consequently, for the years 1850–1869 less than five estimates for price elasticity were available and no average was calculated. Nevertheless, the majority of estimates produced standard signs and sizes – income elasticity estimates were used for 97% of the moving averages over the 160 years and, between 1870 and 2010, price elasticity estimates for 93% of the moving averages.

Fig. 5 presents the trends. It shows the clear the decline (in absolute terms) of both income and price elasticities. In the third quarter of the nineteenth century, they were at their highest, falling in several waves, the first, in the final quarter of the century, then, in the early 1900s, and, finally, from the 1920s until the end of the century, a gradual decline for land transport.

It is worth noting first, however, that consumption associated with horse-drawn carriage in the late eighteenth and early nineteenth centuries had increased 60-fold in fifty years (Chartres and Turnbull, 1983). In the last quarter of the eighteenth century, average income grew 30%, travel prices fell around 25% and journey speeds increased up to 80%. Thus, although there is a lack of annual data, it indicates spectacular sensitivity to changes in availability, prices, quality of service and income levels. So, we can conclude that income (and other variable) elasticities were very high, especially in the late 1700s.

In the 1850s, income elasticity was also very high – a 10% increase in income led to a 31% increase in travel (see Table 2). The creation and expansion of the railway network allowed the upper and growing middle classes to travel more. This expansion coincided with the rise in average income levels during the mid-nineteenth century. Transport services were a key household expenditure. During the second-half of the nineteenth century, expenditure as a proportion of GDP increased from 6% to 7% (Fouquet, 2008, p. 271). At the time, households were spending three times more on travelling than on heating their homes and six times more than on lighting their homes.

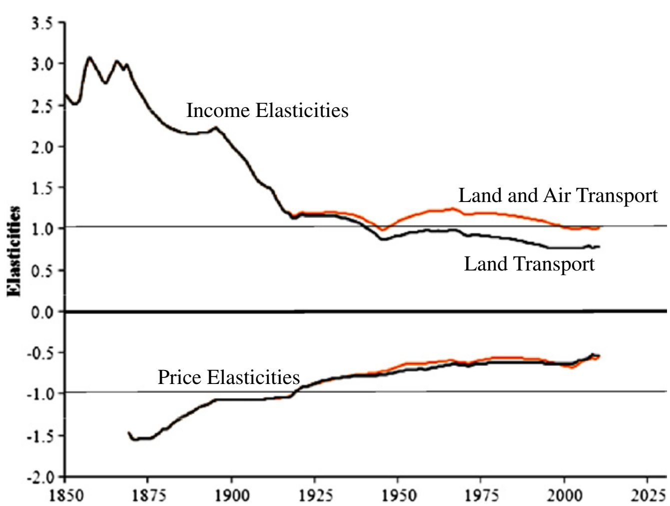

Fig. 5. Income and price elasticities for passenger transport demand, 1850–2010. *Source*: see text.

The growth in average income throughout the nineteenth century, as well as the decline in prices, made railways accessible not only to upper and middle classes, but also working classes. Fouquet and Pearson (2012), commenting about lighting demand, proposed that below certain levels of accessibility, the energy service only provides a basic level of service. However, beyond a threshold, the service can help to meet many other demands – in relation to work and to leisure, thus, transforming lives.

For instance, the expansion of the railways coincided with increased urbanisation. As populations moved to urban centres from the beginning of the nineteenth century, they were closer to transport nodes, thus, more able to take advantage of transport services. Later, in the second-half of the nineteenth century, the expansion of suburbia was driven by the growth in suburban railway services. From the 1840s, upper and upper-middle class households had sought to move away from the crime, sewage and smoke, and the expansion of urban railway networks enabled them to move to the suburbs (Luckin, 2000). The introduction of the Cheap Trains Act of 1883 and a rapid expansion of suburban housing in the 1890s offered an opportunity for lower-middle class families to live in the suburbs and commute into the city (Jackson, 2003; Burnett, 1986). The urbanised area of London increased fivefold between 1841 and 1901 (Demographia, 2011). Thus, transport changed people's lifestyles, which, in turn, required higher levels of transport services to be sustained.

While transport services were still a "luxury", by the early 1900s, income elasticity of transport demand fell dramatically. It fell from an average of 2.2 in the 1890s to 1.2 in the 1920s (see Table 2). Surprisingly, the development of the internal combustion engine and the growth of bus and car use did not stop the decline in income elasticity. After the Second World War, land transport became a "necessity", as it was an essential part of everyday life.

It is surprising that the introduction of cars, allowing for personal freedom of travel and privacy, did not raise income elasticity. Nevertheless, without the introduction of cars, income elasticity of travel demand would probably have fallen further, implying a substantially less mobile economy and society. In other words, the technological and energy transition associated with the internal combustion engine and particularly the car, which offered a different travelling experience, probably slowed the decline in income elasticities.

This hypothesis (that energy and technological transitions can delay the decline in income elasticities) is supported for air travel. When the same regressions were run using total (land and air) passenger transport, income elasticity stayed around 1.2 between the 1920s and 1980s (see Table 2 and Fig. 5). Neverthe-

Table 2
Decade averages of income and price elasticity of land and total passenger transport demand, 1850–2010.
Source: see text.

Decade	Income elasticity	Price elasticity	Decade	Income elasticity	Price elasticity	Decade	Income elasticity	Price elasticity
1850	3.1	–	1910	1.3	−1.0	1970	0.8, 1.2*	−0.7
1860	2.9	−1.5	1920	1.2	−0.9	1980	0.8, 1.2*	−0.7
1870	2.5	−1.5	1930	1.1, 1.2*	−0.8	1990	0.7, 1.1*	−0.7
1880	2.2	−1.3	1940	0.9, 1.0*	−0.8	2000	0.7, 1.0*	−0.6
1890	2.2	−1.1	1950	0.9, 1.2*	−0.7	2010	0.8, 1.0*	−0.6
1900	1.8	−1.1	1960	0.9, 1.2*	−0.7			

Note (*): first value is for land transport; second value is for total (land and air) transport.

less, looking in a little more details indicates that income elasticities for total passenger transport started to decline from the mid-1960s, but only reached unity at the beginning of the twenty-first century. For land passenger transport, an income elasticity of 1 was reached in the 1940s. Thus, it appears that the introduction of air travel delayed the decline in passenger transport income elasticity by roughly 60 years.

Interestingly, air travel had far less influence over price elasticities. It very slightly reduced consumer sensitivity to prices. This may be because consumers are more driven by their rising incomes. More probably, however, it simply reflects the price variable used. This was an average of land passenger transport, and does not incorporate the declining price of air travel between 1950 and 2010, for which data was not found.

Returning to the long run trends, the general decline in land transport price elasticities was more gradual than for income (see Table 2). In the 1870s, price elasticity was -1.5, implying that a 10% decrease in transport prices would lead to a 15% rise in passenger travel (during the 1850s and 1860s, only a few of the price elasticity estimates were significant). This fell close to -1 by 1890, falling to -0.9 during the 1920s and to -0.7 for most of the second-half of the twentieth century. Between 2000 and 2010, price elasticity stood at -0.6. This indicates that, over the last 60 years (and throughout the major shift to cars, the dependence on oil for transport and the Oil Shocks), a surprisingly stable relationship has existed between transport (and indirectly petrol) prices and consumption.

Separating price elasticity into its two components can help a little to understand the decline. The income effects appear to have fallen – travel expenditure relative to GDP fell from more than 8% in the 1920s down to 2% at the end of the twentieth century (Fouquet, 2008, p. 271). So, changes in prices would have had a much greater effect on consumer purchasing power at the beginning of the twentieth century than at the beginning of the twenty-first century. Given the difficulty of identifying clear substitutes for transportation, it is hard to assess whether the substitution effect changed over the last 150 years. It is possible that communication technologies could have acted as a substitute for certain transport needs. However, the telephone, for instance, was very slow to diffuse in the United Kingdom – although introduced in 1881, only 21% of households had telephones by 1965; this increased to 77% in 1983 (Bowden and Offer, 1994, p. 744). One might propose that, during the twentieth century, while income effects were falling, the substitution potential was increasing. Thus, the considerable changes in income effects and possibly substitution effects over the last 80 years may have cancelled each other out (to a certain extent), implying that there was only a modest decline in price elasticities.

Transport demand price elasticities are also of interest for identifying possible rebound effects. Energy efficiency improvements associated with cars effectively reduced the marginal cost of travel. Although this was not very relevant for the nineteenth century, since the fuel costs were a small proportion of the price of rail transport, it has been more important in the second-half of the twentieth century or the twenty-first century. The study suggests that, despite the Oil Shocks and major changes in car technology, consumers today may still be increasing their travel by 6% for a 10% increase in fuel efficiency, implying only a 4% energy saving. That is, this study proposes that there is a substantial rebound effect associated with aggregate transport demand.

This is considerably larger than other studies, such as Small and van Dender (2007). One explanation is that, in fact, the rebound effect will be smaller than 6%, because fuel costs (if one of the main marginal costs) tend to be less than one-third (although 40% in 2008) of the total annual expenditure on cars (see Table 1). So, the rebound effect may be considerably lower – that is, closer to 2%, implying a 8% energy saving. Another possible explanation is that studies that focus only on car travel will tend to ignore the effects between modes of transport – such as cheaper costs of running a car encourage rail users to travel more by car.

6. Conclusion

This paper sought to estimate the trends in real income and price elasticities of demand for aggregate transport. Focussing on the experience in the United Kngdom, it tried to identify the influences of the increase in per capita income (12-fold between 1850 and 2000) and of the decline in the real price of transport (12-fold between 1850 and 2000) on the rapid rise in aggregate passenger land transport consumption (165-fold over 150 years). Using standard econometric techniques and modelling of long run economic behaviour, a series of income and price elasticities were estimated. For each year, a moving average estimate was calculated, thus, providing a time series of the income and price elasticities from the middle of the nineteenth century to the beginning of the twenty-first century.

The results indicate that income and price elasticities were very large (3.1 and -1.5, respectively) in the mid-nineteenth century and declined continuously since then. Land transport demand became price inelastic (i.e., less than one) in the early 1920s and income inelastic at the end of the 1930s and in the early 1940s. However, the trends in income elasticity for total passenger transport demand remained higher, around 1.2, and only fell to unity in the twenty-first century. This indicated that the introduction of air travel delayed the decline in income elasticities by sixty years.

It is worth stressing points made earlier about the study's limitations. The reliability and coverage of the data (especially for the nineteenth century) and also the validity of the econometric procedures can be questioned and criticised. Perhaps the estimates are the outcome of a flawed statistical analysis. Yet, the econometric estimates broadly match the data – that is, between 1850 and 1900, jointly income and price elasticities were greater than one and, between 1950 and 2000, for land transport, they were less than one.

Also, providing a long-run perspective on changes in transport demand elasticities, these results support theoretical and prior empirical expectations about transport demand. These expectations were, first, that saturation effects will reduce income elasticity, although more slowly than for basic goods (Hanly et al., 2002; Moneta and Chai, 2010; Goodwin et al., 2004) and, second, that price elasticities fall as prices decline and incomes rise (Hanly et al., 2002; Small and van Dender, 2007). They are also similar to the trends in elasticities for lighting demand – income and price elasticities peaked in the second-half of the nineteenth century (3.5 and -1.7, respectively) and declined during the twentieth century (Fouquet and Pearson, 2012).

As well as matching expectations and providing greater detail on trends, these results are of interest for anticipating future behaviour. The elasticity estimates, which were remarkably stable during the twentieth century, suggest that aggregate passenger land transport consumption in the United Kingdom will increase by 8% from a 10% rise in income and by 6% from a 10% decline in average transport prices in the early twenty-first century. This also gives clues to the rebound effect, which is estimated to be between 2% and 6% from a 10% fuel efficiency improvement.

Since the study offers a long run perspective, some readers may be interested in long run forecasts of trends in elasticities. It is obvious that to do so is to risk being very wrong. However, current forecasts of energy demand and carbon emissions look forward decades and centuries, and depend on some evidence about the trends in elasticities. So, despite the speculative nature of forecasting (and the slight increase in income elasticities during the first decade of the twenty-first century), the trends in this study and prior expectations suggest that income and price elasticities are likely to decline gradually.

One of the reasons for focusing on aggregate transport demand and the related elasticity trends was to identify the impact of energy transitions on energy use. Aggregate transport demand offered a stable variable through periods of dramatic change. It is important to point-out that, within this framework, energy and related technological transitions have two ways to influence aggregate transport demand (Fouquet, 2010): first, by reducing the costs or prices of transport services, which did occur in past transitions, and can be represented by a slide down the demand curve; and, second, through providing higher quality services, which also occurred, and might be reflected by a shift in the demand curve.

Here, it is proposed that the dramatic increase in energy consumption that followed the transition from stage coaches (and horse power) to railways (and coal) was due to very high income and price elasticities. Prices fell substantially generating greater transport use. Even more important seems to have been the dramatic shift in the demand curve (reflected in the high income elasticity). The transition to the internal combustion engine (and petroleum products), buses and cars, led to a large increase in energy consumption. However, income elasticities were around unity and price elasticities were less than one. In other words, the energy transition from coal to petroleum boosted energy consumption relatively less than the one from horse power to coal. Given past trends, prior expectations and the tentative forecast above, it is tempting to conclude that any future energy transition in the land transport sector will increase energy consumption relatively less than past transitions.

Having said this, the demand for transport-related energy is driven first by the demand for transport and then by the relationship between the technology for providing transport and the amount of energy required (Small and van Dender, 2007). The extent of the increase in energy consumption will depend on (i) the decline in transport prices, (ii) transport price elasticities, (iii) the change in fuel efficiency, (iv) transport income elasticity and (v) improvements in the quality of the transport service associated with the transition, which will affect the income elasticity. The latter highlights an important feature of energy transitions: by raising the quality of the service, as cars and arguably planes did, they delay the decline in elasticities. So, when comparing two scenarios of the future (one with and one without transition), unless the transition is towards a highly energy efficient technology (and this is possible), it is likely that the scenario with an energy transition will generate higher energy consumption. Whether this scenario produces more or less carbon dioxide emissions will depend on the energy source used.

Up to this point, the discussion has been about behaviour in the United Kingdom, and possibly by analogy in other developed economies. Since this study looks at trends in elasticities at different phases of economic development, it can provide some clues to trends in developing economies. Their elasticities are probably higher than in developed economies. So, as these economies develop and incomes rise, transport use is likely to rise more than proportionally, with major effects on the demand for current energy sources and on the local and global environment.

It is possible that income and price elasticities are not as high in developing economies today as in Victorian Britain – for a given level of income, transport prices are substantially lower in developing economies today than in nineteenth century England. Also, as these economies develop, their elasticities will probably also fall. Again, the introduction of new and superior quality transport services associated with a transition will probably delay or slow-down the declining trend.

This study focussed mostly on land transport. It appears that elasticity estimates for air travel in developed economies are still high. Thus, a technological and/or energy transition in air transport services may well generate high increases in transport and energy consumption in both developed and developing economies. Again, the environmental impact will depend on the energy source used after the transition.

This discussion implies that trends in energy consumption are likely to continue to grow. There may be policies and strategies that can reduce or stabilise transport demand, if that is desirable (Bannister, 2011). However, the underlying argument of this paper is that energy use is driven by the demand for mobility, and energy and technological transitions will not stop this demand or its trend. Nevertheless, this paper proposes that, although future transitions will probably not generate the dramatic increases in energy consumption experienced during transitions in the nineteenth century, they may well alter (and shift upwards) the trends in transport and related energy use, with substantial implications for carbon dioxide emissions. Especially given the relatively low price elasticity of demand for land transport in industrialised countries, the role of policies, such as carbon pricing or taxing, will be not so much to reduce demand for travel but to encourage a shift towards low carbon energy sources, technologies and possibly behaviour.

Acknowledgements

I would like to thank Bill Nordhaus, David Stern, Lester Hunt, Lutz Killian, Peter Pearson, Paul Warde and Steve Sorrell, as well as two anonymous referees, for comments related to this research line and/or this paper. Of course, the author of this paper is solely responsible for any errors.

References

Allen, R.C., 2007. Pessimism preserved: real wages in the British Industrial Revolution. Economics Series Working Papers 314. University of Oxford. Department of Economics. 〈http://www.nuffield.ox.ac.uk/General/Members/allen.aspx〉.
Ayres, R.U., 2005. Resources, scarcity, technology and growth. In: Simpson, R.D., Toman, M.A., Ayres, R.U. (Eds.), Scarcity and Growth Revisited: Natural Resources and the Environment in the New Millennium. Resources for the Future, Washington D.C.
Bagwell, P.S., 1974. The Transport Revolution from 1770. B.T. Batsford, London.
Bannister, D., 2011. The trilogy of distance, speed and time. Journal of Transport Geography 19 (4), 950–959.
Bentzen, 1994. J. Bentzen, An empirical analysis of gasoline demand in Denmark using cointegration techniques. Energy Economics 16 (2), 139–143.
Bowden, S., Offer, A., 1994. Household appliances and the use of time: the United States and Britain since the 1920s. Economic History Review 47 (4), 725–748.
BPP: British Parliamentary Papers, 1926. Coal Statistical Tables. Irish University Press, Shannon, Ireland.
Broadberry, S. Campbell, B., Klein, A., Overton, M., van Leeuwen, B., 2009. British Economic Growth, 1270-1870, Working Paper. 〈http://www2.lse.ac.uk/economicHistory/pdf/Broadberry/BritishGDPLongRun.pdf〉.
Burnett, J., 1986. A Social History of Housing 1815–1985. Methuen, London.
Chartres, J., Turnbull, G., 1983. Road transport. In: Aldcroft, D., Freeman, M. (Eds.), Transport in the Industrial Revolution. Manchester University Press, Manchester.
Demographia, 2011. London Urbanized Area: Historical Estimated Population & Density. 〈http://www.demographia.com/db-lonuza1680.htm〉.
DoT, 2002. GB Transport Statistics (GBTS). HMSO, London.
DfT, 2011. GB Transport Statistics (GBTS). HMSO, London.
DTI, 1997. Digest of United Kingdom Energy Statistics (DUKES). HMSO. London.
DTI, 2001. Digest of United Kingdom Energy Statistics (DUKES). HMSO. London.
DTI, 2007. Digest of United Kingdom Energy Statistics (DUKES). HMSO. London.
DTI – Department of Trade and Industry, 2011 and backdates. Digest of United Kingdom Energy Statistics. HMSO, London.
Elliott, G., Rothenberg, T.J., Stock, J.H., 1996. Efficient tests for an autoregressive unit root. Econometrica 64, 813–836.

Foreman-Peck, J., 1981. The effect of market failure on the British motor industry before 1939. Explorations in Economic History 18 (3), 257–289.
Fouquet, R., 2008. Heat Power and Light: Revolutions in Energy Services. Edward Elgar Publications, Cheltenham and Northampton, MA, USA.
Fouquet, R., 2010. The slow search for solutions: lessons from historical energy transitions by sector and service. Energy Policy 38 (10), 6586–6596.
Fouquet, R., 2011. Divergences in long run trends in the prices of energy and energy services. Review of Environmental Economics and Policy 5 (2), 196–218.
Fouquet, R., Hawdon, D., Pearson, P.J.G., Robinson, C., Stevens., P.G., 1997. The future of UK final user energy demand. Energy Policy 25 (2), 231–240.
Fouquet, R., Pearson, P.J.G., 2012. The long run demand for lighting: elasticities and rebound effects in different phases of economic development. Economics of Energy and Environmental Policy 1 (1), 83–100.
Goodwin, P., Dargay, J., Hanly, M., 2004. Elasticities of road traffic and fuel consumption with respect to price and income: a review. Transport Reviews 24 (3), 275–292.
Greening, L.A., Greene, D.L., Difiglio, C., 2000. Energy efficiency and consumption – the rebound effect – a survey. Energy Policy 28 (6–7), 389–401.
Grübler, A., 2004. Transitions in energy use. Encyclopedia of Energy 6, 163–177.
Grübler, A., Nakicenovic, N., Victor, D.G., 1999. Dynamics of energy technologies and global change. Energy Policy 27, 247–280.
Hanly, M., Dargay, J., Goodwin, P., 2002. Review of income and price elasticities in the demand for road traffic, Report 2002/13. ESRC Transport Studies Unit, University College London. London.
Hart, H.W., 1960. Some notes on coach travel. Journal of Transport History 4 (3), 146–160.
Hawke, G.R., 1970. Railways and Economic Growth in England and Wales (1840–1870). Clarendon Press, Oxford.
Howarth, R.B., 1997. Energy efficiency and economic growth. Contemporary Economic Policy 15 (4), 1–9.
Hughes, J.P., Knittel, C.R., Sperling, D., 2006. Evidence of a shift in the short-run price elasticity of gasoline demand. NBER Working Paper No. 12530. National Bureau of Economic Research.
Institute of Petroleum, 1994. UK Petrol Prices (1902–1993). Library & Information Service. Institute of Petroleum, London.
Jackson, A.A., 2003. The London railway suburb, 1850–1914. In: Evans, A.K.B., Gough, J.V. (Eds.), The Impact of the Railway on Society in Britain: Essays in Honour of Jack Simmons. Ashgate, Adershot.
Jackman, W.T, 1960. The Development of Transportation in Modern England. Frank Cass. London.
Jevons, W.S., 1865. The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines. Macmillan, London.
Johansen, S., 1988. Statistical analysis of cointegration vectors. Journal of Economic Dynamics and Control 12, 231–254.
Johansen, S., 1995. Likelihood-Based Inference in Cointegrated Vector Autoregressive Models. Oxford University Press, Oxford.
Kilian, L., Murphy, D., 2010. The Role of Inventories and Speculative Trading in the Global Market for Crude Oil, CEPR Discussion Papers 7753.
King, A.L., 1952. Statistics relating to the petroleum industry, with particular reference to the United Kingdom. Journal of the Royal Statistical Society 115 (4), 534–565.
Leunig, T., 2006. Time is money: a re-assessment of the passenger social savings from Victorian British railways. Journal of Economic History 66 (3), 635–673.
Luckin, B., 2000. The pollution in the city. In: Daunton, M.J. (Ed.), The Cambridge Urban History of Britain: 1840–1950. Cambridge University Press, Cambridge.
Miller, K., 1993. Transport Sector Energy Model. Report for Economics and Statistics Branch. Department of Trade and Industry, London.
Mitchell, B.R., 1988. British Historical Statistics. Cambridge University Press, Cambridge.
Mok, D., Wellman, B., Carrasco, J.A., 2010. Does distance matter in the age of the internet? Urban Studies 47 (13), 2747–2784.
MOP – Ministry of Power, 1961. Statistical Digest 1960. HMSO, London.
Moneta, A., Chai, A., 2010. The evolution of Engel curves and its implications for structural change. Discussion Papers in Economics 201009. Griffith University, Department of Accounting, Finance and Economics.
Munby, D.L., 1978. In: Watson, A.H. (Ed.), Inland Transport Statistics: Great Britain, 1900–70, Vol. I. Clarendon Press, Oxford.
Nielsen, B., 2001. Order determination in general vector autoregressions. Working Paper. Department of Economics. University of Oxford and Nuffield College.
O'Connell, S., 1998. The Car in British Society: Class, Gender and Motoring. Manchester University Press, Manchester.
ONS: Office of National Statistics, 2002. Social Trends. HMSO, London.
Oum, T.H., Waters, II, W.G., Yong, J.S., 1990. A survey of recent estimates of price elasticities of demand for transport. Working Paper. Policy, Planning and Research. Infrastructure and Urban Development Department. The World Bank.
Oum, T.H., Waters II, W.G., Yong, J.S., 1992. Concepts of price elasticities of transport demand and recent empirical estimates. Journal of Transport Economics and Policy 26 (2), 139–154.
Ramanathan, 1999. R. Ramanathan, Short- and long-run elasticities of gasoline demand in India: an empirical analysis using cointegration techniques. Energy Economics 21, 321–333.
Small, K.A., van Dender, K., 2007. Fuel efficiency and motor vehicle travel: the declining rebound effect. The Energy Journal 28 (1), 25–52.
Salomon, I., 1985. Telecommunications and travel: substitutability or modified mobility? Journal of Transport Economics and Policy 19 (3), 219–235.
Schäfer, A., 2000. Regularities in travel demand: an international perspective. Journal of Transportation and Statistics 3 (3), 1–32.
Schäfer, A., Victor, D.G., 2000. Transportation Research Part A: Policy and Practice 34 (3), 171–205.
Selvanathan, E.A., Selvanathan, S., 1994. The demand for transport and communication in the United Kingdom and Australia. Transportation Research (Part B) 28 (1), 1–9.
Sorrell, S., 2007. The Rebound Effect: An Assessment of the Evidence for Economy-Wide Energy Savings from Improved Energy Efficiency. UK Energy Research Centre, London.
Thompson, F.M.L., 1976. Nineteenth century horse-sense. Economic History Review 39 (1), 60–81.