Symposium:
Transportation and the Environment

What Long-Term Road Transport Future? Trends and Policy Options

Stef Proost* and Kurt Van Dender†

Introduction

Transport is closely linked to economic activity. Some modes of transport provide inputs to production through the provision of commuting and business trips and by moving goods between producers and consumers. The cost of freight transport has decreased by a factor of 10 over the last hundred years (Glaeser and Kohlhase 2004), which has facilitated a more freight-intensive organization of production. Income growth stimulates the demand for individual mobility and, together with the decrease in prices of car and air transport, has generated a strong increase in the demand for transport by households in advanced economies to support a wide range of activities, including commuting, education, recreation, use of services, shopping, and tourism. Public policy has largely accommodated—and sometimes inadvertently stimulated—these developments through spatial planning policies and infrastructure capacity decisions. Thus, economic development in advanced economies has gone hand in hand with rapidly growing transport volumes. This connection between economic activity and transport, and the resulting trend toward rapidly increasing transport volumes, is facing growing criticism from environmental policymakers. Current transport patterns are widely seen as "unsustainable" (EEA 2002; CEC 2001), especially as emerging economies (e.g., China, India, Brazil) evolve toward the levels of economic welfare and transport activity in currently advanced economies.

Economists generally define sustainability in a narrow way (Arrow et al. 2004), focusing on guaranteeing the consumption possibilities of future generations. Transport is clearly relevant to this narrow sustainability problem, as transport activities contribute to the long-term

*Center for Economic Studies, Catholic University of Leuven, Naamse straat 69, 3000 Leuven, Belgium; e-mail: stef.proost@econ.kuleuven.be.

†Joint Transport Research Centre of the International Transport Forum and the OECD, 2–4 Rue Louis David, 75116 Paris, France; e-mail: kurt.vandender@oecd.org.

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problem of climate change and jeopardize the long-term availability of oil resources. However, the transport sector also causes flow-type externalities that threaten our current way of life. If urbanization continues and economic activity is concentrated in ever larger metropolitan areas, congestion levels could become intolerable. In addition, levels of noise and pollution remain problematic despite advanced emissions control technology. There is evidence to suggest that these flow externalities are quantitatively at least as important as the transport sector's climate and energy resource impacts (see, e.g., Small and Van Dender 2007b; Proost et al. 2009).

What makes transport activities different from, say, house or factory heating, two activities that also emit greenhouse gases (GHGs)? First, in most transport activities, users compete for the use of common transport infrastructure, which causes congestion. This congestion has a negative feedback on the volume of demand. The effect of congestion on the volume of transport demand and the policies to address congestion are relatively well understood by economists (see, e.g., Small and Verhoef 2007). The second difference between transport and other activities that emit GHGs is that transport is ultimately the movement of persons or goods over space—between houses, shops, factories, etc. Thus, in the simplest of terms, we could conceivably minimize transport activities by having a very large number of small towns that are self-sufficient. However, this would come at an economic cost, in terms of both productivity (scale, diversity, specialization, etc.) and other externalities (noise, air pollution, and odor from nearby production facilities, etc.). Our knowledge of the long-term interactions among economic development, spatial distribution of economic activities, and transport costs is still very partial at best.[1] The causality often runs both ways, and multiple equilibria can exist. Economists do not yet have a clear understanding of these interactions, which makes policy advice difficult.

This article is the first of three articles in a symposium on Transportation and the Environment that examines the findings from the theoretical and empirical economics literature concerning two major transport problems: congestion and environmental impacts. This article reviews long-term trends and broad policy issues and options related to the road transport sector and its congestion and environmental impacts, particularly climate change. Taking this broad view can help establish policy priorities. We focus on the role that modal choice, technology, and spatial structure policies can play in addressing the problems related to road network congestion and GHG emissions. Addressing the different external costs of transport also requires well-targeted policies, including congestion pricing, fuel taxes, and fuel economy regulations. Anas and Lindsey (2011) discuss the potential role and effects of congestion pricing in addressing congestion and pollution externalities in urban areas. Anderson et al. (2011) analyze the impacts and efficiency of automobile fuel efficiency standards and compare them to alternative policy measures such as fuel taxes and "feebate" systems.

The remainder of this article is organized as follows. The first section describes the different types of externalities that occur in the transport sector. The next section briefly reviews long-term projections of the global demand for transport and its implications, concluding that there is little hope for controlling transport externalities through reductions in global transport volumes and that problems related to road network congestion and GHG emissions are

[1]See Fujita and Thisse (2002) for a discussion of regional location and Glaeser (2008) for a discussion of urban location.

likely to become more pressing in the future than they are now. In the following three sections, we examine three policy levers for addressing these problems: stimulating shifts in modal choice, boosting low-carbon technology adoption, and regulating land use. The final section summarizes our main findings and concludes.

Main Types of Transport Externalities

Transport activities have a number of external costs, that is, costs that are not considered by users when they decide if, where, how, and when to travel. The level of these externalities depends on many factors. For road transport, the key determinants include traffic volumes, mode choice, fuel type, fuel efficiency, driver behavior, and the location and time of day of travel.

Table 1 summarizes the five main road transport externalities and their causes. The focus of the discussion here is on the first two externalities: congestion and climate change. We do not discuss conventional air pollution, noise, and traffic accidents in detail because addressing these externalities requires very specific policy interventions that are unlikely to have major impacts on the fundamental features of our transport systems. Conventional air pollution and noise occur at the local level and can be contained to a substantial degree by fairly inexpensive technical solutions. For example, between 2000 and 2020, the use of catalytic converters, particulate traps, and cleaner fuels is expected to reduce conventional air pollution in the European Union (EU) due to road transport by 70–95 percent (Transport Mobility Leuven 2007).[2] Noise problems can be addressed to a large extent through the use of better vehicles, public abatement (noise screens), and protective measures (noise insulation). Accident externalities are complex and heavily dependent on the coordination of human behavior. However, well-enforced traffic regulations as well as improved car and road technologies have greatly reduced the average accident rate in most of the advanced economies.

Congestion and climate change externalities both depend on the volume of transport, but otherwise they are very different from each other. As mentioned above, with congestion there is a negative feedback loop (i.e., more congestion leads to higher time costs of travel, and higher costs discourage demand). Congestion is generated by volumes of traffic that are too highly concentrated in time and space. If spreading demand over time and space were easy, then there would be no congestion problem, as there would be ample capacity to handle volumes. This suggests that policies to spread demand may be as effective as those aimed at reducing overall demand. In the case of climate change, what matters is both transport volumes and the carbon intensity of travel. The distribution of demand over time and space has no impact on GHG emissions, except to the extent that congestion levels affect fuel consumption. It follows that policies that reduce transport volumes may address both congestion and climate change costs. Anas and Lindsey (2011)

[2]This is not to say that all the problems of conventional air pollution can be addressed through these measures. For example, particulate emissions are very costly in terms of human health, and control technologies remain expensive. Strategies to promote use of diesel fuels, favored in some countries for reasons of fuel economy and GHG emissions, carry a cost in terms of particulate emissions or the control of them. Furthermore, as cheap technological fixes are gradually exhausted, policies that target a smaller number of gross polluters (shipping, diesel trains) offer pollution reductions at lower costs (IIASA 2007).

Table 1 The five main road transport externalities and policy measures to address them

	Source	Nature of costs	Orders of magnitude of costs[a] (cents/mile, 2005 prices)	Public abatement and supply-type policies	Policies affecting demand and vehicle characteristics
Congestion	Volume of use approaches or exceeds design capacity per unit of time	Mainly time and schedule delay costs	4.2–35.7	Network capacity	Congestion charges, fuel taxes, access restrictions, land-use regulation, quantity controls
Climate change	Greenhouse gas emissions from fossil fuel use	Wide-ranging and uncertain adverse impacts from climate change	0.3–3.7		Fuel efficiency standards, CO_2 or fuel taxes, cap and trade
Traffic safety	High traffic density and heterogeneity in vehicle weight and speed, increase average accident risk	Mainly health and loss of life; material damage	1.1–10.5	Adaptation of road infrastructure, emergency services, mandatory insurance	Traffic rules and procedures, risk-dependent insurance premiums
Air pollution	Fuel combustion and exhaust	Mainly health, loss of life, and environmental degradation	1.1–14.8		Standards (vehicle equipment, fuel quality), access charges
Noise	Engines and movement	Health, discomfort	0.1–9.5	Sound barriers, silent road surfacing, curfews	Standards, curfews, tradable permits

[a]Minimum and maximum values taken from Small and Van Dender (2007b, table 1).

find that in the few cities where congestion pricing has been implemented, both transport volumes within charging zones and CO_2 emissions decreased by some 10–20 percent. However, if congestion pricing mainly redistributes demand over time and space, this policy may have little impact on GHG emissions. Thus, policies that attempt to address congestion and climate change simultaneously may be effective for one problem but not for the other.

Transport Demand: Long-term Projections and Implications

This section explores how global transport volumes (measured in passenger-kilometers [km] and ton-km for freight) are likely to evolve in the long term under a business-as-usual scenario and examines their likely impacts on GHG emissions and levels of congestion.

Long-Term Trends in Transport Volumes

Various institutions publish global projections for transport demand, generally with a 2030 or 2050 time horizon (see, e.g., Exxon Mobil 2009; International Energy Agency [IEA] 2009; ITF 2009). These projections are based on partial models of the transport sector that focus more on the likely development of demand than on supply and price formation. Oil and fuel price developments, for example, are usually exogenous to the model and thus independent of how demand changes. Based on estimated S-shaped ownership dispersion patterns[3] and assumptions about the evolution of usage, the demand for private transport in these transport models is driven mainly by income growth. Given that supply is often implicitly supposed to be perfectly or at least highly elastic, these projections can be seen as sketching "where demand would like to go."

While there are differences among these projections, they agree on certain key expectations. Global transport volumes will grow very rapidly, but growth rates differ between modes and across regions, as indicated by the following orders of magnitude (taken from IEA 2009; ITF 2010c). Road use by light-duty vehicles (measured in vehicle-km) is expected to be 2.5 times as high in 2050 as it was in 2000, while road use for freight could grow by a factor of five during the same time frame. Air transport services (measured in passenger-km) are expected to grow fivefold as well. Growth will be particularly fast outside the Organization for Economic Cooperation and Development (OECD), notably in emerging economies, including China. As a result, whereas in 2005 traffic activity (passenger-km and ton-km) in OECD countries was at about the same level as in non-OECD countries, in 2050 non-OECD traffic activity is expected to be 2.5 times as high as OECD traffic activity (see IEA 2009, figure 1.9). The main driver of growth outside the OECD is in the passenger-km segment. In emerging economies, rapid income growth, and in some cases also population growth, translates into very rapid growth of car ownership levels. Ownership levels reach about 350 cars per 1,000 inhabitants in Russia and Latin America, for example, and about 250 cars per 1,000

[3]Automobile ownership as a function of income often follows a Gompertz function: slow growth at low income levels, then a takeoff level followed by rapid growth, and after an inflection point, lower growth levels until one approaches a saturation point.

inhabitants in China, India, and Southeast Asia (IEA 2009, p. 60). In the OECD, lower income and population growth and already high ownership levels are expected to translate into slower growth of vehicle stocks.

Puentes and Tomer (2008) find that car travel in the United States, measured in vehicle-km, stopped growing in recent years and argue that this is the result of not only higher fuel prices but also saturation of demand (i.e., even with higher incomes or lower prices the demand for transport would no longer increase). Crozet (2009) draws a similar conclusion for France but notes that slower or zero growth in car transport volumes does not mean that overall transportation demand has stopped increasing. Instead, he shows that faster modes of transport, such as high-speed rail (HSR) and air transport, continue to grow as incomes rise because they allow consumers to squeeze more, and more spatially dispersed, activities into the time budget. Although the jury is still out on whether car travel has actually stopped growing in advanced economies, and, if it has, whether this is because of saturation of demand for travel, higher fuel prices, or some combination of these factors, it is likely that car travel volumes will grow slowly or not at all in advanced economies and grow rapidly in emerging economies. The overall conclusion of the projections is that there will be considerable growth in global car transport volumes, especially outside the OECD. Within the OECD, particularly strong growth is foreseen for faster modes (air and HSR). Freight transport is expected to grow more strongly than passenger transport.

Expected GHG Emissions

GHG emissions from transport depend on transport volumes and on the carbon intensity of the various technologies used. Transport was responsible for about 13 percent of world GHG emissions in 2004 and accounted for 23 percent of global and 30 percent of OECD GHG emissions from fuel combustion in 2005 (ITF 2009).[4]

Although better fuel economy offsets part of the growth in transport demand, the result is that, under a business-as-usual scenario, world transport emissions of CO_2 are expected to more than double by 2050 (ITF 2008; IEA 2009). While the share of OECD countries in total transport emissions of CO_2 is estimated to be about 60 percent in 2010, it is projected to decline to 45 percent in 2030 and 35 percent in 2050 (ITF 2008). Light-duty vehicles' share of total CO_2 emissions is expected to decline from 42 percent in 2010 to 36 percent in 2030 and stay there through 2050. The share of aviation in total CO_2 emissions is projected to grow from 15 percent in 2010 to 22 percent in 2030 through 2050; emissions from aviation are expected to be three times as large in 2050 as they were in 2010.

This projected growth in CO_2 emissions from the transport sector is clearly not compatible with ambitious climate change mitigation objectives. Moreover, the underlying growth in transport volumes poses additional challenges regarding other transport externalities, including noise, traffic safety, conventional air pollution, and congestion. The continuing global trend toward urbanization and the particularly fast growth in the number of megacities[5] further highlight the need to address the local pollution and congestion

[4]In a later section, we discuss how low-carbon technologies in a number of key market segments could evolve in the long term.

[5]In 2008, about half of the global population lived in cities; in 2050, city dwellers are expected to comprise about 70 percent of the (bigger) total (United Nations 2008).

problems that arise from transport activities. Furthermore, there is concern regarding the availability and the security of resources to fuel all these transport activities (cf., e.g., Aleklett 2007). Even if the projected growth in transport volumes is slowed down by higher energy prices, we will argue below that policy interventions will be needed to control the main transport externalities.

Stimulating Shifts in Transport Modes

This section discusses the use of policies that affect modal choice for passenger and freight transport as a means to address the congestion and climate change externalities of road transport.

Modal Choice for Passenger Transport

There are three main drivers of modal choice for passengers (De Jong and van de Riet 2008): income levels, relative user costs (including time costs), and public policy.[6] As discussed in the previous section, higher incomes lead to increased demand for transport services, in particular car ownership and use. Higher incomes also tend to imply higher opportunity costs of time. This means an increased preference for faster modes of transport (which allow passengers to cover large distances in a short time), starting with car transport and then HSR and air transport. Relative user costs of air and HSR have also decreased over time due to increased competition and economies of scale. Finally, public policy affects modal choice as it is mostly governments that invest in rail and airport infrastructure. It is typical for scheduled services like bus, rail, and air connections to be characterized by economies of density and economies of scale (although scale economies for bus operations are exhausted in even medium-sized cities). It is very costly to construct a railway track, but once in place, the variable cost of a train is low and roughly constant (as long as the network is not congested). In addition, with more users, the occupancy rates increase. This means that more vehicles need to be deployed, which increases the frequency of public transport services and reduces waiting times at stops (Mohring 1972).

Passengers' choices concerning their modes of transport have implications for many transport externalities. For example, a car with one passenger has an external congestion cost per passenger that is about ten times as high as a bus with twenty-five passengers because a bus has the same congestion effects as 1.5–3 cars (Al-Kaisy, Hall, and Reisman 2002). Assuming sufficiently high occupancy rates, a bus also uses less fuel and has lower accident costs per passenger. The air pollution cost per passenger of rail transport depends on the occupancy rate and on the type and amount of fuel used. With a high occupancy rate, rail has almost no external costs except for the congestion costs among the rail passengers and rail freight and the external noise costs. This suggests that the external costs of transport can be mitigated by favoring bus and especially rail transport, a strategy that has gained wide support in policy circles, most notably in the EU.

[6]As discussed below, population density also affects passenger modal choice. High population densities are necessary for rail, light rail, and metro solutions to become economically attractive.

The present market shares of different modes of passenger transport differ greatly across countries. For example, in China and India, private passenger cars had a market share (in terms of passenger-km) of less than 20 percent in 2005 (IEA 2009). Minibuses, buses, rail, and air accounted for the remainder of the market. In contrast, in OECD Europe, private passenger cars account for 65 percent of total passenger transport volume, and bus/rail and air each account for about 15 percent of the total. In North America, cars account for approximately 80 percent, bus and rail 5 percent, and air transport 15 percent of the passenger transport market (IEA 2009).

Policies Concerning Urban Transport

Although urban transport accounts for a small share of overall passenger transport (about 20 percent), congestion and air pollution problems are more acute in urban areas than elsewhere. Urban transport also relies on more modes of transport than transport in nonurban areas.[7] Urban transport modal shares vary greatly across countries. One of the most striking differences is the small share of private motor vehicle trips in European and Asian cities compared to many North American cities. For example, private motor vehicle trips account for 20 percent of all trips in Hong Kong, 30 percent of all trips in Amsterdam, 45 percent of all trips in Berlin, 50 percent of all trips in Rome, 90 percent of all trips in Calgary, and 95 percent of all trips in Houston (IEA 2009, p. 206, using data from the UITP Millennium Cities Database).

Investment in urban public transport and even its operating costs are generally subsidized.[8] The main justifications for these subsidies are the economies of scale and the fact that the external congestion and air pollution costs of car use in urban areas are not reflected in user prices. The optimization of public transport fares suggests that there should be high subsidy rates when the external costs of car use are not reflected in car use costs (see, e.g., Proost and Van Dender 2008; Parry and Small 2009). However, high subsidies do not guarantee a high-performing urban public transit system. Experience with public transport subsidies has been mixed, resulting in a fierce debate among economists concerning their effectiveness. For example, Winston and Maheshri (2007) find that the U.S. public rail systems are heavily subsidized but not welfare improving, with the exception of the Bay Area Rapid Transit system in San Francisco. In many countries, light rail systems have been absorbing a disproportionately large share of public transport investments but without solid economic justification (see, e.g., Pickrell 1992).

Duranton and Turner (2010) found evidence in U.S. cities for the fundamental law of road congestion (i.e., that transport volumes increase proportionally to highway capacity, so that building extra capacity does not reduce congestion levels). They found that between 1983 and 2003 individual as well as commercial traffic increased with the stock of roads in a city and that cities with less congestion attracted people. This implies that an increase in the volume of urban road transport is partly generated by new road capacity. This also suggests that public policy matters. Duranton and Turner (2010) also examined the full effect of a small increase in highway capacity and found that in the absence of congestion pricing, the costs of the investment in increased capacity were generally somewhat higher than the benefits. This does not imply that

[7]For these reasons, we discuss urban and nonurban transport separately.
[8]The exceptions include minibuses in developing countries.

there are no beneficial road investment projects but rather that these projects need to be subjected to a rigorous economic analysis. Finally, Duranton and Turner (2010) found that in the United States, the provision of public transport had no impact on volumes of car transport. Thus, it appears that public transport provision was not effective in reducing road congestion.

Policies Concerning Nonurban Transport

While for short and medium distance passenger transport, the main competing modes are car, bus, and rail, for long distances (i.e., beyond 300 km), HSR and air are the most important modes of transport. HSR displays strong economies of scale and thus requires high volumes of use to be justified economically. While HSR requires very large up front investments, it has low variable costs. Thus, an efficient HSR system will require high public investment subsidies, fares that more or less cover the marginal operating costs and a large market. De Rus and Nash (2007) and ITF (2010a) estimate that under the most favorable circumstances (i.e., low construction cost and distance of 500 km), a minimum of six to nine million passengers are needed in the first year to justify a HSR project. When the up front investment costs are mainly paid by public funds, the door is wide open for political lobbying. In the EU, China, and Japan, governments have opted for a highly subsidized network of HSR. An HSR system has yet to be built in the United States. Although the current U.S. administration favors some HSR projects, only limited funding has been made available to date.

Air transport, the main alternative for long distance trips, is less fuel efficient per passenger-km than rail and also generates more external noise costs (Maibach et al. 2007). In a study of all the main HSR projects in the EU, Adler, Pels, and Nash (2010) find that some HSR projects are economically justified when prices reflect marginal costs (rather than average costs). They also find that the environmental disadvantages of air transport as such are not sufficient to justify investing in HSR. The environmental appeal of HSR is further reduced when emissions during the construction phase of HSR are taken into account. Moreover, if environmental and energy concerns dominate, then policymakers may prefer the more energy-efficient conventional rail to the high-speed option.

In summary, existing economic analyses of HSR and conventional rail infrastructure projects cast doubt on the wisdom of using modal shifts in passenger transport to address environmental and congestion issues. Rail and bus have a role to play in some markets, in particular where densities of demand are very high. But an across-the-board pursuit of a modal shift toward rail and bus may be a costly policy mistake. The rationale for investing in HSR and bus lies mainly in the spatial density of demand rather than in its environmental performance.

There has been a striking difference between the passenger transport policy options (and hence the shares of road, rail, and air) adopted in the United States versus those in the EU and Asia. This is partly a reflection of their different economic geography (i.e., distances) and spatial development (i.e., densities), which affects the economic justification for various passenger transport options.

Modal Choice for Freight Transport

Until a hundred years ago, the location of economic activities and cities was directly determined by transport costs, which were driven by access to railroads, ports, and inland waterways. Since then, the road network has expanded dramatically and freight costs have declined sharply. This has resulted in the relocation of economic activity and a shift toward road freight transport at the expense of rail and inland waterways.

Road (and air) freight can be up to ten times less fuel efficient than rail freight and a hundred times or more less fuel efficient than waterborne freight. So why have the shares of rail and inland waterway shipping declined over time relative to road freight? The reasons include changes in the nature of the goods moved and the rising importance of speed and flexibility. Institutional factors have also been important. For example, moving a freight train through different EU countries traditionally required a change in both locomotive and driver in each country. In the United States, in contrast, there is often one company that organizes freight from coast to coast. This is one of the reasons for the higher modal share of freight rail in the United States compared to Europe.

One of the EU's main policy objectives over the last fifteen years has been to discourage the strong growth in road freight that accompanied the European integration process. In fact, the European Commission's (EC) policy paper (2001) stated that the EU's transportation policy objective was to approximately double the market share of both passenger and freight rail traffic, which had fallen to 6 and 8 percent, respectively, in 1998. Achieving this policy objective required the harmonization of rail procedures to allow the use of the same equipment and a single driver in different countries. It also gave rise to a massive European subsidy program for rail investments.[9]

However, Proost et al. (2010) show that objectives concerning modal shares are not ideal for selecting investments. In a benefit–cost analysis of twenty-two of the EU's thirty priority (mainly rail and inland waterways) projects (valued at a few hundred billion Euros), Proost et al. (2010) find that only twelve of the twenty-two projects pass the benefit–cost test using a social discount rate of 5 percent. The analysis also indicates that only a minority of the selected projects has any real *European* value added in the sense of local investments benefiting other countries, suggesting that the case for using EU funds to subsidize these projects is weak overall. Finally, Proost et al. (2010) find that the EU's thirty priority projects are not systematically located in the poorer regions of the EU, making it difficult to defend the funding of these projects purely on equity grounds.

The finding that transport investments have not been efficient is not an exception. Knight (2004) analyzed the decision-making process in the United States concerning funding for the Interstate Highway Fund in the 1990s. The assumption was that elected representatives would try to favor their own constituencies, resulting in an oversupply of federally funded public works projects. Knight's findings suggest that for every dollar invested from the highway fund, an additional dollar was wasted, leading to the funding of a substantial number of inefficient transport projects.

Overall, there are reasons to subsidize particular rail and inland waterway projects. Economies of scale in rail and inland waterways require large investments and large public subsidies to operate the infrastructure at their social marginal cost. However, the large public investment requirements have often resulted in "pork barrel" politics and projects that were not always justified in welfare terms, as illustrated by the U.S. highway fund and EU experiences. To reduce the risk that public funds will be used wastefully, it is important to evaluate the costs and benefits of each investment project separately rather than focusing on

[9]It is worth noting that countries that have joined the EU more recently are steering their investments more toward the improvement of road networks than toward rail (ITF 2010b). Clearly, this trend will not help the EU attain the desired modal shift.

modal shifts at the strategic policy level. This approach is preferable because it recognizes that different modes of transport are efficient in different circumstances and it avoids establishing a bias toward particular transport modes through the adoption of artificial intermediate policy objectives such as modal choice and greenhouse emissions limits for the transport sector.

Boosting Adoption of Low-Carbon Vehicle Technologies

Cars and trucks account for the majority of GHG emissions from the transport sector.[10] In the short term, the focus for decreasing GHG emissions from the transport sector should be on the improvement of conventional vehicle engine technologies (see Anderson et al. 2011). In the longer term, new vehicle technologies that use other fuels may be able to reduce GHG emissions and help reduce oil dependence and/or oil depletion. This section addresses three questions concerning these new vehicle technologies. First, how costly and environmentally efficient are they? Second, what is the willingness of consumers to adopt them? And third, do car manufacturers have sufficient incentives to develop these new technologies?

New Car Technologies

We focus here on vehicle technologies that, according to the IEA (2009), could play a role in reducing GHG emissions in the 2020–2040 time period (see Table 2). We start with the characteristics of new cars in the United States and the EU in 2010. As shown in Table 2, using GHG emissions per vehicle mile in the OECD as a baseline (index 100), there is a difference of 25 percent between U.S. and EU GHG emissions from new cars (index 115 versus 90). Several factors are responsible for this difference, but the dominant factor is the difference in gasoline and other car-related taxes. In the United States, the tax on gasoline is estimated to be 17 percent of the resource cost, while in EU countries it can be 160 percent or more.[11] This implies an effective CO_2 tax (called a gasoline tax) of \$47/ton of CO_2 in the United States and €365/ton of CO_2 in the EU (using 3.17 tons of CO_2/ton of gasoline). In some EU countries, diesel cars have a market share of over 50 percent. While these vehicles are more fuel efficient, they also emit more conventional pollutants, mainly highly damaging particulates (Maibach et al. 2007).

Table 2 also presents characteristics of new car technologies that could play a role in the 2020–2040 period. While it is not yet clear what type of cars will be used, the data in Table 2 suggest that it is likely that improved conventional cars will still dominate the market. If the EU and Japan continue to impose high taxes on gasoline and diesel, and if more stringent emissions standards are implemented in an increasing number of countries, it is estimated

[10]According to the IEA (2009), light-duty vehicles and freight trucks account for about two-thirds of the global tank-to-wheel emissions of CO_2 from transport in the 2000–2010 period.

[11]The data for the United States and EU (here represented by France, which takes an average position in the EU) are for March 2010 and are from Energy Prices and Taxes, IEA (2010). We express taxes as a percent, but part of the tax is fixed. We do not judge whether the tax in France is too high or too low, as the tax also serves as a second-best instrument to address other externalities. See Parry and Small (2005) for an assessment of the gasoline tax in the United States and the United Kingdom.

Table 2 Characteristics of new car technologies in OECD countries

Technology	GHG emissions index (well to wheel) per unit distance, OECD 2010 = 100	Major consumer disadvantages and costs	Other externalities
OECD 2010			
OECD	100		
Gasoline (United States)	115		
Gasoline (EU)	90		
Diesel (EU)	80		More conventional air pollutants
OECD 2020–2040			
Gasoline	80–45	Extra cost of 0–$2,000/vehicle	
Diesel	80–45	Extra cost of 0–$2,000/vehicle	More conventional air pollutants
Hybrid gasoline	60–34	Extra cost of $2,000–$4,000/vehicle	
Hybrid diesel	50–34	Extra cost of $2,000–$4,000/vehicle	More conventional air pollutants
Plug-in hybrid	30–19 Lower bound requires CCS or renewables	Extra cost of $7,500/vehicle	Less conventional emissions in urban areas
Electric car	45–14 Lower bound requires CCS or renewables	Smaller range, slower and more frequent refueling + extra cost of $10,000–$20,000/ vehicle and requires adaptation of electricity distribution	Less conventional emissions in urban areas
Compressed natural gas, hydrogen, biofuels	With current technologies not certain that there is a decrease in GHG emissions	Requires new distribution network extra vehicle adaptation costs and smaller trunk space	

Source: adapted from IEA (2009).
Note: CCS = carbon capture and storage.

that new conventional gasoline and diesel cars in 2020–2040 may emit per mile only 50 percent as much GHGs as new cars in 2010 but at an additional cost of up to $2,000/vehicle. Achieving this lower emissions level will require a combination of engine improvements, weight reduction, better aerodynamics, and reduced rolling resistance. Some design choices imply reducing other desirable vehicle attributes, including size, comfort, and possibly (and more controversially) safety. If current tax and regulatory incentives are not continued, emissions reductions for conventional cars in 2020–2040 may be limited to 20 percent (IEA 2009).

The next type of cars that may be used, after improved conventional cars, are hybrid cars. While these vehicles are already on the market, they can be made more efficient. Hybrids can offer an extra 20-percent reduction in GHG emissions compared to improved gasoline and diesel cars, at an additional cost per vehicle of $2,000–$4,000. Although hybrids are more expensive, they have the advantage of being able to bridge the gap with electric cars.

The intermediate technology is the plug-in hybrid, which has a larger battery than other hybrids. Plug-in hybrids take power from the grid but can still rely on a small combustion engine for longer trips. The GHG reduction potential of plug-in hybrids and electric vehicles ultimately depends on the emissions associated with the production of electricity. If electricity production is mainly coal based (as is expected to be the case in the United States, China, and India), effective carbon capture and storage technologies, which store the GHG emissions of a power plant, are needed before electric vehicles can deliver the additional savings in GHG emissions relative to improved conventional vehicles. Even in cases where the base load on the electrical grid is produced in a low-carbon manner (i.e., nuclear or wind), the marginal load can be considerably more carbon intensive. Moreover, transitioning to broader low-carbon loads takes time. Plug-in hybrid and pure electric cars come at an extra cost of $7,500 to more than $10,000/vehicle. These vehicles also have a more limited range and less trunk space. While improvements will be made, it is not clear whether electric cars will become very close substitutes for conventional cars. They may be sufficiently appealing for some market segments (e.g., multiple-vehicle households in advanced economies), but it appears unlikely that they will dominate the market overall for the period up to 2040. Thus, although electric vehicles may be part of the solution for decarbonizing transport, they are not a panacea.

Low-GHG Fuels

In addition to turning to more efficient conventional cars and electric cars, a third technological option for reducing GHG emissions in the road transport sector is to use low-carbon fuels (e.g., biodiesel, ethanol, compressed natural gas). These fuels can be used in conventional engines but require an additional distribution infrastructure. Furthermore, when the whole fuel cycle is taken into account, several of these fuels deliver no or only small GHG emissions reductions, and there are concerns about their effects on nonfuel markets such as food (Hahn and Cecot 2009). Following the initial enthusiasm for biofuels, there has been increased awareness of their limitations, and research into better-performing biofuels continues. As with electric vehicles, it appears that biofuels can play a role in reducing road (or air) transport emissions of GHGs but setting quantity targets for their deployment risks obtaining few real reductions at a high cost per unit (IEA 2009). The other alternative fuel—hydrogen—delivers GHG emissions savings only if it is made with low-carbon electricity. Moreover, vehicle and distribution costs are high. Thus, we see little potential for this technology over the next two or three decades.

Consumer Attitudes

The attitudes of consumers toward new car technologies, and their willingness to adopt them, has been studied extensively since the 1990s (see Brownstone, Bunch, and Train 2000), especially in light of the state of California's plan to stimulate the development and adoption of low- and zero-emission vehicles. Most nonstandard technologies offer a shorter driving range (pure electric vehicles), smaller trunk space (natural gas, electric vehicles), smaller size (very fuel-efficient vehicles), and lower speed and acceleration than conventional technologies. Consumers' purchase decisions are based on a subjective assessment of these and other vehicle characteristics, given expected patterns of use and energy prices. Revealed and stated preference techniques can be used to estimate how consumers value the various vehicle attributes (see, e.g., Brownstone, Bunch, and Train 2000), and the values can then be integrated into a more correct comparison of alternative technologies.[12]

The results of such analyses of consumer behavior indicate that with a sufficient price discount, some consumers are willing to accept the discomfort of certain new technologies (see, e.g., Brownstone, Bunch, and Train 2000). To summarize, the evidence again suggests that there is a market for alternative technologies but that one should not expect conventional technologies to be swept away as long as the alternatives cannot compete on key attributes, including purchase price and expected user costs.

Government Policies and Incentives

What will drive future government policies in the car sector, and will there be sufficient incentives to develop and adopt new vehicle technologies? Governments are usually driven by four types of concern when they choose car sector policies: climate change, the tax base, the security of oil supply, and profits and employment in the domestic car industry. With respect to climate change, the probability that a general and strong global climate agreement will be signed and implemented appears to be small because climate change is a pure public "bad" and abatement benefits are uncertain and achievable only in the very long run. As long as alternative car technologies remain expensive, it seems rather unlikely that there will be widespread adoption of the least carbon-intensive technologies simply because the threat of climate change cannot be translated into a credible policy commitment to both cooperate in the research and development (R&D) phase and stimulate such widespread adoption (Barrett 2006). However, for a big country that wants to implement a climate policy in a non-cooperative world, developing low-GHG car technologies and transferring them to the rest of the world could be an important element of its strategy (see Barla and Proost 2008). In fact, in the past, Europe and Japan have developed more fuel-efficient cars that could be used in the United States, China, India, and other countries.[13] More research is needed (e.g., along the lines of Ulph and Ulph 2007) on the relationship between national fuel efficiency policies and strategic trade policies.

Another reason why the adoption of technologies that use alternative fuels is likely to be limited is that in many countries with high gasoline taxes, alternative fuels such as electricity, natural gas, and biodiesel are subject to much lower excise duties than traditional fuels. This strong tax incentive is unsustainable because if there is a large shift toward lower-taxed fuels, tax authorities will see their revenue base eroded. Of course, removing the tax incentive would make alternative fuels less attractive. While the political tension between environmental and public finance concerns shifts over time, the latter ultimately tend to weigh more heavily on government decisions. In addition, it is expected—or hoped—that sooner or later countries will move away from an energy-based taxation system for road transport and toward one

[12]Such techniques can be used for any new type of vehicle technology.

[13]Whether Europe and Japan will be able to maintain leadership in producing fuel-efficient cars is not clear. China invests in battery research and acquires technological knowledge through direct purchases from foreign producers. More generally, Chinese R&D expenditures are growing very fast, with its share in global R&D increasing from around 2 percent in 1996 to around 10 percent in 2007 (OECD 2010).

based on distance, time of day, and place (see, e.g., NTPP 2009; Anas and Lindsey 2011).[14] The price increases necessary to contain other externalities will keep traffic from growing too strongly, but abandoning fuel or energy as the main tax base means that the transition to more fuel-efficient cars will be based more on technologies that are already available because the new taxation regime would have a lower implicit incentive for reducing GHG emissions (see Proost et al. 2009).

In principle, higher oil prices and concerns about oil supply security offer an additional incentive to reduce oil consumption in the road sector. As long as this reduction takes the form of more fuel-efficient vehicles, the oil security concern and the climate concern work in the same direction in motivating policy. However, if the oil import concern implies the use of more nonconventional fuel, the two concerns can have opposing impacts, as the production of some nonconventional fuel generates much higher CO_2 emissions.

Concerning the domestic car industry, governments appear to pay attention to the competitive position of their national car industries when they decide on fuel efficiency policies. However, we know of no systematic documentation of such behavior.

Regulating Land Use to Reduce Transport Volumes

The spatial distribution of economic activities is clearly an important determinant of transport patterns and volumes. Passenger transport flows are dependent on the locations of residences, workplaces, schools, recreation facilities, shops, etc. Freight transport flows depend on the organization of production and the location of input and output markets. However, the connection between spatial structure and transport also flows in the other direction, with transport costs being an important determinant of the location of economic activity. This section reviews key insights from the new economic geography (NEG) and then discusses theoretical and applied work on the connections between urban sprawl, transport volumes, and land-use policies. It is especially important to consider the connections between transport and spatial structure in policy debates about reducing GHG emissions because transport activity is a direct source of GHG emissions and urban density affects energy use for heating and cooling via the size and type of dwellings.

Transport and Agglomeration

Through its focus on the location decisions of firms, workers, and consumers, the NEG provides a helpful macroscopic (yet microeconomic) framework for examining the evolution of the spatial distribution of economic activity.[15] At its core, the NEG identifies a tradeoff for location choices between transport costs and scale economies. The latter can be internal to firms, favoring concentration of production in fewer plants, or it can be external, favoring the agglomeration (or concentration) of economic activity in fewer locations (cities). The external benefits of agglomeration derive from the lower transport costs of intermediate inputs,

[14]While many see such a change as desirable and perhaps inevitable in the long run, the transition poses major political challenges, as witnessed by the recent failure in the Netherlands to implement distance-based charging when the initial political agreement crumbled under the pressure of public opinion.
[15]We do not describe the main insights of this work here. For a summary, see Fujita and Thisse (2002).

labor market pooling, and exchange of ideas. Hence, the concentration of economic activity in cities boosts productivity.

However, the decision to locate in a city also depends on intra-urban transport costs that are often ignored in the NEG. Within a city, congestion of fixed factors (e.g., land, infrastructure) puts a brake on agglomeration through high property prices that result at least partly from long travel times on transport networks. Transport costs between cities or markets matter as well. When such costs are high, the tendency to concentrate production is weaker because getting goods to faraway markets costs more. Therefore, the historical decline in transport costs has been an important impetus for continued concentration of economic activity.

Agglomeration economies have received attention recently in the context of the appraisal of intra-regional transport investment (e.g., Venables 2007). If there are external agglomeration economies and if transport infrastructure contributes to their exploitation, then there are benefits to transport investments over and above those included in standard project appraisal (which focuses on the effects on transport users). Eddington (2006), for example, argues that agglomeration economies ought to be taken into account on the basis of empirical evidence because doing so increases the returns to transport investment on average and differentiates between projects on the basis of where they improve transport conditions. Ellison, Glaeser, and Kerr (2010) find that for the U.S. manufacturing sector, the sharing of goods (interindustry deliveries), labor market pooling, and the transfer of ideas all contribute more or less equally to explaining agglomeration but that interindustry linkages are somewhat more important. It is, however, not clear how strong the empirical case for accounting for agglomeration economies is at this stage (see Graham and Van Dender 2009).

The NEG approach differs from the "fixed location" view that is common in transport economics: NEG treats location of activities as endogenous, while most of transport economics takes location of economic activities as given. This implies that decisions about which transport networks to develop have a direct and long-lasting impact on where economic activity will take place and how efficient it will be. Ideally, these location effects should be taken into account in appraisal. However, it appears that current state-of-the-art research in this area does not yet allow for the construction of models that provide concrete, project-specific policy guidance.

Passenger Transport and Urban Sprawl

Whereas transport economics usually takes the locations of households and firms as given, urban economics focuses on the tradeoffs between transport and property or rental costs in location decisions (see, e.g., Glaeser 2008). A stylized fact in this context is that many households prefer living in relatively low-density urbanized environments and that employers choose to locate out of city centers in response to high central city prices. Where legislation and other framework conditions allow it (or favor it[16]), the result is urban development with fairly low densities and decentralized distribution of employment. This pattern is particularly prevalent in—but not unique to—the postwar United States and is often referred to as urban sprawl. Sprawl has a negative connotation, as it is associated with a range of

[16]For example, minimum parking requirements are often thought to stimulate sprawl and car-oriented transport choices.

Table 3 Annualized individual travel behavior by residential density, United States, 1995

Residential density (housing units/square mile)	Person trips	Person miles	Share of vehicle trips (% total)	Share of vehicle miles (% total)
0–99	1,521	16,973	62	63
100–499	1,604	15,092	64	63
500–1,499	1,601	14,366	58	63
1,500–2,999	1,588	12,923	62	62
3,000+	1,532	10,304	56	50
Mean	1,568	14,064	61	60

Source: Ross and Dunning (1997, table 36).

problems. For example, decentralization and low densities are thought to generate lifestyles that induce excessive car travel and energy consumption.

Residential Density and Travel Behavior

Travel survey data indeed suggest a strong dependence of distances traveled on residential density (a common but imperfect indicator for sprawl). Table 3 shows the relationship between residential density and travel behavior for the United States in 1995 and indicates that density has very little impact on the number of trips but a large impact on the average annual distance traveled, with households in the least dense areas traveling 20 percent more than the average household and households in the most dense areas traveling 25 percent less. At first glance, then, sprawl (lower-density development) would seem to inflate travel distances by increasing average trip lengths. Higher-density development is associated not only with lower average travel distances but also with reduced reliance on cars (i.e., fewer car trips). The evidence in Table 3 appears to suggest that this effect is most pronounced at very high densities.[17] Trip distances offer one possible explanation for this phenomenon, as nonmotorized modes of transport become feasible when trips are very short. Alternative explanations include greater access to public transit and different transport demand patterns for households that choose to reside where densities are high (see below).

Recent econometric work has tried to sort out the cause and effect between residential density and travel behavior in order to assess the potential for using anti-sprawl policies to contain vehicle-miles traveled. Before considering the empirical evidence, however, we examine the extent to which the phenomenon of urban sprawl justifies land-use policy.

Market Failures and Policy Approaches

Basic microeconomics suggests that urban sprawl is a policy issue because market failures render market outcomes inefficient. Some important market failures associated with urban development are that markets do not account for the benefits of open space and that they contain no mechanism for charging developers for infrastructure. Furthermore, the external costs of traffic congestion and energy consumption are not accounted for without policy.

[17]Published travel survey data for the Netherlands for 2008 confirm that the share of car distance in total distance drops sharply only at very high levels of density: The average share is 82 percent, and it drops to 61 percent at density levels of more than 25,000 addresses per square mile (MVW 2009, table 9).

Microeconomics further suggests that well-targeted policies are required in order to control these externalities. Ideally, external congestion costs, and possibly local air pollution costs, are reflected in congestion charges. GHG emissions are closely linked to fuel consumption and hence are best dealt with through fuel taxes. Private development choices can be guided through property and development taxes.

There are two problems with this approach to addressing the market failures associated with urban sprawl. First, a wide range of instruments (e.g., zoning policies, property and transport taxes) affect location decisions and transport costs. Thus, it is not clear ex ante in which direction urban development is distorted, although the dominant view is that zoning policies and the underpricing of transport lead to densities that are too low (National Research Council [NRC] 2009). Second, if one also considers the development of new cities, the optimal equilibrium concerning urban development may well contain more cities, more cities with attached subcenters (polycentricity), and more sprawl (see Anas and Pines 2010). This issue is important to consider in light of the growth and problems of megacities in newly developing countries, which will see exponential growth in car ownership.

A particularly popular policy approach is to rely on command-and-control regulations that directly regulate land use by stipulating what kind of development is allowed where (e.g., zoning policies that stipulate maximum building heights or minimum parking space requirements). When they are enforceable, such instruments are certainly effective. That is, they produce tangible results. However, they are not necessarily cost effective (i.e., the results may be obtained at too high a cost) or efficient (i.e., the results do not necessarily coincide with what an efficient market would produce). Hence, such direct regulations are justified only when there are severe restrictions on better-targeted instruments.

Empirical Evidence

Recent empirical studies have investigated whether the strong link between residential density and travel distance (see Table 3) is a *causal* connection.[18] Analyses using disaggregated data show that this causal link exists but that it is not as strong as it appears at first sight (Bento et al. 2005; Brownstone and Golob 2009). The reason is that households choose particular locations on the basis of their preferences (captured through observed and nonobserved characteristics), and those preferences, along with density, explain transport choices. This means that no major reductions in transport volumes or energy consumption should be expected from land-use planning unless truly drastic changes in land-use occur. Brownstone and Golob (2009) find that in California, a change in residential density of 1,000 housing units per square mile (40 percent of the sample mean) leads to 1,171 fewer miles driven (an average reduction of 4.7 percent) and 64.7 less gallons of gasoline consumed per year (an average reduction of 5.5 percent). About two-thirds of the reduction in gasoline consumption is due to less driving, and one-third is due to the fact that households in more densely populated areas tend to own more fuel-efficient vehicles. While changing driving and energy consumption levels by about 5 percent is not negligible, changing population density by 40 percent is likely to be infeasible in all but a limited number of circumstances. In fact, Brownstone and Golob (2009) find that only about 6.6 percent of 456 U.S. cities increased population density by more than 40 percent

[18] For a detailed review, see NRC (2009).

between 1950 and 1990 (and those that did tended to experience declining living conditions), while in the median city, population density actually declined by 36 percent. A special report by the NRC (2009) concludes that anti-sprawl policies have limited potential but that this limited potential should nevertheless be exploited by removing excessive constraints on development and—ultimately—consumer choice.[19]

A potential lesson for newly (re-)developing cities is that rapid declines in residential density along the U.S. model ought to be avoided if energy use is to be contained. However, such policies can be costly in terms of welfare and are likely justified only when the shadow price of carbon is high (i.e., when the expected costs of climate change are at the high end of the range found in the literature). Even with stringent decarbonization targets, there are less costly policies than those that focus on discouraging driving solely for the sake of saving energy (Van Dender 2009). In addition, reducing urban sprawl can produce unexpected results concerning the connection between urban spatial structure and travel needs, as the latter depend on other factors besides residential density. For example, a monocentric city (i.e., one with a well-defined single center, such as Paris), in which all travel is directed to the city center, likely has longer average commutes than a polycentric city of the same residential density. Gaigné, Riou, and Thisse (2010) point out that under many circumstances polycentricity may be a better way to contain travel demand and energy consumption than striving for a more compact city, especially because making one city more compact may well mean that another becomes more sprawled. Glaeser and Kahn (2010) also discuss this general equilibrium view, which emphasizes that it is the overall outcome that matters, not just what happens in one city. Adopting such a global view would generally lead one to favor the use of carbon taxes over local policies as a means to address emissions of GHGs.

Conclusions

Long-term global projections indicate that road transport demand will continue to expand in the future, especially in emerging economies, which will soon account for more than half of the world's car and truck use. This article has examined three policy levers to address the growing GHG emissions and congestion externalities associated with these trends.

We find that in some cases policies that affect modal choice can reduce environmental impacts, but whether they are attractive from a broader economic point of view is far from obvious. In theory, a modal shift from road and air to rail and inland waterways offers great potential for reducing congestion and GHGs. However, experience in the EU suggests that the vigorous pursuit of such a modal shift is justified only when the spatial density of demand is sufficiently high. In general, we find that the better environmental and congestion performance of rail and water transport relative to road and air transport does not provide sufficient justification for massive investments in these modes.

Over the last twenty years, improvements in vehicle technology have reduced conventional air pollution significantly. Reducing GHG emissions through the improvement of conventional vehicle technologies is possible, and at a relatively low cost. However, the adoption of alternative vehicle technologies and low-carbon fuels is likely to be limited for the period up to 2040.

[19]The counterfactual scenarios in the report have been criticized as being too pessimistic; see, e.g., Ewing, Nelson, and Bartholomew (2009) and Calthorpe Associates (2010).

Concerning transport and the spatial distribution of activities, policymakers have been tempted to use land-use planning to increase residential densities and limit commuting distances. We find that although spatial structure affects transport demand, it has limited potential as a policy lever. Moreover, our limited understanding of the interactions among location choices, residential densities, and travel behavior heightens the risk that well-intentioned land-use policies will trigger unintended—and undesirable—consequences.

In conclusion, our review of global road transport trends and the policy options and challenges related to congestion and climate change suggests that containing overall transport volumes will be very difficult and that it is justified in only some cases rather than as a general strategy. Reducing the transport sector's carbon footprint will, to a large extent, be a technological challenge. Here, progress is being made, and fuel economy can be improved at moderate costs. However, whether such improvements will actually materialize depends on governments maintaining a strong policy commitment to the goal of decarbonization. Moreover, it remains to be seen whether reducing carbon emissions from the transport sector is the cheapest way to attain global decarbonization targets. It is therefore important to adopt a broad intersectoral approach to the design of least-cost carbon-abatement strategies. Narrow approaches risk producing ineffective and expensive recommendations.

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