Invention and Transfer of Environmental Technologies

Chapter 3

Innovation in Electric and Hybrid Vehicle Technologies: The Role of Prices, Standards and R&D

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Policy instruments are often introduced in combination, sometimes with different but related environmental objectives. In this chapter, the relative importance of fleet-level fuel-efficiency standards, after-tax fuel prices, and public support for R&D is examined using data on patenting activity in alternative-fuelled vehicles. It is found that relatively minor changes in a performance standard or automotive fuel prices would yield effects that are equivalent to a much greater proportional increase in public R&D budgets. However, there are significant differences between types of technologies – electric and hybrid vehicles. Our results suggest that appropriate sequencing of policy measures is important.

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Introduction

Faced with continuing local and regional air quality problems, greenhouse-gas reduction objectives, and energy security issues, many OECD governments have put in place policies with the objective to stimulate the development of alternative fuel vehicle technologies. Often this is accompanied by measures that aid specifically the diffusion of such innovations. While rather recent, these policies form a continuation of previous efforts to improve vehicle fuel efficiency which, depending on changes in crude oil prices and restrictions on oil supply, have been more or less high on the agenda of policy makers. They also follow on from previous regulatory efforts which have sought to reduce local and regional air pollution emissions from mobile sources (*e.g.* lead, sulphur compounds, carbon monoxide, nitrogen oxides, volatile hydrocarbons, particulate matter). This report examines the effect of the various policy and market factors on technological innovation with respect to alternative fuel vehicle technologies.

Technology overview

Fuel efficiency of motor vehicles became a heightened concern for policymakers, manufacturers and consumers in the 1970s in the aftermath of the oil price shocks. While early efforts concentrated mostly on re-designing the conventional internal combustion engine (improved engine design), at a later stage these measures were complemented with efforts to improve other, non-engine, characteristics of a vehicle which affect fuel consumption (improved vehicle design). However, further fuel efficiency improvements were necessarily deemed to be increasingly incremental.

More recently, innovations of a more radical nature have made it possible to develop vehicles relying on entirely new types of propulsion, and hence fuel, with a range of hybrid vehicles combining elements of the conventional and alternative technologies. These developments can bring about increased fuel efficiency, and reduce both greenhouse gas emissions and local and regional air pollution emissions. Governments have adapted their policies to support the development (and adoption) of such alternative-fuelled vehicles. However, they also represent a new challenge for policy makers who need to be wary of the possible negative environmental impacts of production and consumption associated with new vehicle types.

Previous efforts to improve motor vehicle fuel efficiency

Technologies to improve characteristics of a conventional engine (improved engine design)

Prior to the 1970s vehicle fuel efficiency was primarily affected by changes to carburettor settings. Following the oil price shocks in 1973 and 1979, and the introduction of the US Corporate Average Fuel Economy (US CAFE) standards in 1978, engineering of gasoline cars switched from carburettors to electronically-controlled fuel injection which allowed greater refinement in fuel mixture control. However, the introduction of catalytic converters led to an increase in fuel consumption due to: *a)* the switch from the common lean setting to a (less lean) setting for optimal catalytic reactivity; and *b)* the increase in exhaust backpressure due to the catalyst.

In the 1990s, concerns over global warming and the perception of a looming regulatory response may have contributed to designing further engineering refinements, including the introduction of direct injection in diesel engines which was previously only available for heavy-duty applications. Most fuel economy improvements of gasoline engines involved optimising engine efficiency, such as improvements in basic engine design through the use of low friction materials and optimised geometry of the combustion chamber, intake manifolds, and outlet canals (OECD, 2004).

In late 1990s and 2000s, improvements in diesel engines were achieved through introduction of electronically-controlled fuel injection, such as common rail and unit injectors that allow flexible injection timing and rate shaping, but also enable much higher pressures. In gasoline cars improvements were achieved through better partial-load efficiency of the engine, through introduction of variable valve actuation, direct injection, or integrated starter alternator enabling start-stop driving mode (OECD, 2004).

In sum, measures which are primarily designed to improve fuel efficiency are listed below (see Annex B of the volume for the patent search strategy):

- Air-to-fuel ratio devices.
- Electronic fuel injection and engine management systems (on-board diagnostics, sensors).
- Ignition timing, variable valve timing, variable compression ratio, combustion chamber geometry.
- Engine performance during cold start, accelerating, decelerating idling, and cruising.
- Combustion air and fuel conditioning.

Measures to address local air pollutant emissions (emissions control technologies)

When considering motor vehicle fuel efficiency it is important to also take account of measures aimed at reducing local air pollutant emissions, such as carbon monoxide (CO), nitrogen oxides (NO_X), volatile hydrocarbon compounds (HCs) and particulate matter (PM). These measures include post-combustion (after-treatment) devices, engine design measures, and changes in fuel characteristics. Measures which are primarily designed to reduce local air pollutant emissions are listed below (see Appendix A2 for further details and the corresponding patent search strategy):

- Positive crankcase ventilation.
- Air injection.
- Exhaust gas recirculation.
- Thermal reactor.
- Catalytic converters, HC adsorbers, NO_X adsorbers, de-NO_X systems, diesel oxidation catalysts.
- Particle filters.
- Fuel characteristics that improve combustion (oxygen-containing additives).

Some of these measures may interfere with efforts to improve engine fuel efficiency. In many cases efforts to increase fuel efficiency (and reduce CO_2 emissions) will reduce emissions of local air pollutants such as CO, NO_X and HCs. However, in other cases measures introduced to meet one policy objective may have negative impacts on the achievement of another objective – for example, oxygen-containing additives in fuel may reduce emissions of local air pollutants but increase fuel consumption; similarly, installation of catalytic converters in gasoline cars may reduce emissions of local air pollutants but increase fuel consumption; on the other hand, introduction of direct injection in diesel engines improves fuel economy but can have negative impacts on emissions of NO_X and PM; and finally, installation of diesel particle filters may reduce PM but increase NO_X emissions. Therefore, policy makers have at times faced the need to consider the various engineering and environmental trade-offs in setting their policy objectives.

However, the primary focus of this report is on the AFV technologies, and trade-offs between local air pollutants emissions and fuel economy are of less interest in the case of AFV technologies. For these reasons, this report does not devote more space to this issue (see, for example, Haščič *et al.* (2010) for analysis of effects of environmental policies on emissions control innovations; Vollebergh (2010) provides additional discussion of conventional fuel efficiency measures and the trade-offs involved). Nevertheless, even in the AFV field some engineering-environment trade-offs will necessarily arise (see Section 2.2 for a brief discussion).

Technologies to improve vehicle characteristics (improved vehicle design)

It is expected that further reductions in fuel consumption of the conventional internal-combustion engine will be achieved through lowering vehicle weight, rolling resistance, and other factors (not related to engine design) with an important effect on vehicle fuel consumption. Clearly, improved vehicle design will increase fuel efficiency of any vehicle, including those using AFV technologies. To summarise, these measures typically address the following issues (see Appendix A3 for further details and the corresponding patent search strategy):

- Inertia during acceleration or deceleration.
- Friction of moving and rotating components.
- Air resistance (improved aerodynamic design).
- Rolling resistance.
- Energy requirements of operating electric components of a vehicle (lighting, air-conditioning and heating system, other auxiliary electric systems and accessories).
- Light-weighting of complementary equipment (passive safety, noise insulation).
- Fuel-saving driver-support devices or devices that improve driving style (speed control, eco-driving).
- Non-combustion emissions (vapour recovery systems, improved fuel tanks).

Alternative fuel vehicle technologies

A variety of fuels have been proposed as alternatives to conventional purely petroleum-based blends, including:

1. *Liquid hydrocarbon fuels* such as methanol, ethanol (bio-ethanol), bio-diesel, and their blends with conventional fuels (E85, M85) – using such fuels requires development of dual-fuel (flexible-fuel or flex-fuel) vehicles capable of running on conventional gasoline

(or diesel) as well as an alternative fuel, or a blend thereof. While each of these alternative fuels have their pros and cons, they typically require only minor technical modifications to the vehicle. Rather than being a technological problem, the major obstacle to their wide-spread use seems to be the lock-in of the fuel distribution system, price competitiveness relative to conventional (gasoline/diesel) fuels as well as safety (*e.g.* methanol) and environmental and health concerns.[1]

There a number of other alternative fuels that may imply using new types of propulsion. However, the primary obstacle to their wider use has been the lack of appropriate storage systems. These fuels include:

1. *Gaseous hydrocarbon fuels* such as compressed natural gas (or CNG, mostly methane) and liquefied petroleum gas (or LPG, mostly propane) – this requires development of on-board pressurised storage systems.
2. *Hydrogen* – requires development of on-board storage systems (*e.g.* pressure vessels, in metal hydrides, in active graphite, or in nanofibres of graphite) or reforming and conditioning systems for production of hydrogen from hydrocarbon fuels (if fuel other than hydrogen is used) (*e.g.* steam reforming, shift reaction, partial oxidation).
3. *Electric energy* – requires development of on-board storage systems, that is, secondary cells (rechargeable batteries) such as the lead-acid, lithium-ion, nickel-cadmium, or nickel-metal-hydride batteries.

The alternative propulsion systems that have been developed include: *a)* hydrocarbon- or hydrogen-fuelled internal combustion engine; *b)* electric engine; and *c)* hybrid systems. Table 3.1 gives a schematic representation of the various fuel and propulsion alternatives for vehicles.

Table 3.1. **Alternative systems of vehicle propulsion and fuel supply**

			Type of propulsion		
			Internal combustion engine	Hybrid system	Electric engine
Type of fuel	Liquid	Hydrocarbons	Conventional gasoline/ diesel vehicle	Hybrid electric vehicle	Fuel-cell electric vehicle
	Gaseous	Hydrocarbons	LNG/LPG vehicle		
		Hydrogen	Hydrogen vehicle		
	Grid electricity (external supply)		–	Plug-in hybrid vehicle	Pure electric vehicle

In an *internal combustion engine* the chemical energy of fuel (hydrocarbon blends or hydrogen) is transformed into mechanical energy through thermal expansion (fuel combustion). Alternative fuels with the potential to reduce CO_2 emissions include those with lower carbon content and higher hydrogen content than conventional gasoline or diesel (*e.g.* hydrogen, methanol, natural gas, or bio-diesel).

A *fuel-cell electric vehicle* combines a hydrogen-fuelled cell with an electric engine. The chemical energy of fuel is first converted into electric energy, and subsequently transformed into mechanical energy using an electric motor. A fuel cell is a device which transforms chemical energy of fuel (hydrogen) into electric energy without combustion (hence unlike internal combustion engines, fuel cells convert chemical energy into electrically energy directly) (OECD, 2004). A number of different fuel cell types have been developed (are under development), each with its characteristic electrode materials, electrolytes and membranes.[2] Hydrocarbon-based fuels can, in principle be used as well in fuel cell vehicles, however these need to be first converted into hydrogen fuels, and thus require also on-board reforming and conditioning systems. Advantages of fuel cells include their high conversion efficiency and zero (if hydrogen used as fuel) or very low pollutant emissions (if carbonaceous fuels used) (OECD, 2004).

In the case of a *pure electric vehicle* (also called, battery electric vehicle) electric energy is drawn directly from a storage medium (a battery).[3] The advantages of a vehicle equipped with an electric engine include regeneration of deceleration energy (*e.g.* regenerative braking), automatic engine shutdown (start-stop mode), and optimisation of engine drive conditions, all of which yield improved fuel efficiency and significantly better performance in terms of exhaust emissions. Moreover, no CO_2 is emitted in the case of hydrogen cells. The disadvantages include heavier weight and more complex engineering due to the additional motor and battery, as well as higher manufacturing costs (OECD, 2004).

At present electric vehicles are rarely commercialised in their pure form and are typically manufactured by combining elements of the conventional and alternative propulsion systems, as hybrid vehicles. A *hybrid electric vehicle* is equipped with: *i)* a primary power source (*e.g.* a conventional hydrocarbon- or hydrogen-fuelled internal combustion engine, or alternatives such as fuel cells) in order to power the electric generator; *ii)* a power storage unit (*e.g.* battery, flywheel, or ultra-capacitor); and *iii)* a drive unit (*i.e.* an electric engine). Combination of two propulsion systems allows a hybrid vehicle to achieve greater fuel economy. This is due to improved conversion efficiency since as much as 41-66% of energy consumed is used for propulsion, at zero (with hydrogen used as fuel) or very low (with hydrocarbon fuels) exhaust emissions (OECD, 2004). Table 3.2 provides a break-down of the various sources of fuel efficiency improvements of AFVs compared to conventional technologies.[4]

Table 3.2. **Breakdown of energy utilisation (%) by vehicle type**

Energy consumption	Conventional mid-size gasoline vehicle		Hybrid electric vehicle		Fuel-cell electric vehicle		Pure electric vehicle	
	Urban	Highway	Urban	Highway	Urban	Highway	Urban	Highway
A. Drivetrain losses	**76**	**68**	**68**	**65**	**71**	**67**	**51**	**40**
Thermodynamic losses[1]	60	60	51	56	31	27	18	13
Engine losses[2]	12	3	11	3	28	29	6	4
Transmission losses	4	5	6	6	12	11	27	23
B. Used for components	**13**	**12**	**19**	**11**	**16**	**12**	**27**	**22**
Auxiliaries	2	1	3	1	3	1	4	2
Accessories	1	1	1	1	1	1	2	2
Air conditioning	10	10	15	11	12	10	21	18
C. Used for propulsion	**11**	**20**	**13**	**22**	**13**	**21**	**22**	**38**
Air resistance	2	11	2	12	3	11	4	21
Roll resistance	4	7	5	8	5	8	8	13
Kinetic losses/braking	5	2	6	2	5	2	10	4
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
C/(A + C) =	0.13	0.23	0.16	0.25	0.15	0.24	0.30	0.49

1. Battery losses in the case of full electric vehicle; Reformer losses in the case of fuel cell electric vehicle.
2. Fuel cell losses in the case of fuel cell electric vehicles.
Source: Adapted from OECD (2004: pp. 121, 139, 148, 149).

Potential negative environmental implications of AFVs

The fuel efficiency benefits associated with more widespread adoption of AFVs will likely result in reduced in-use CO_2 emissions as well as reduced emissions of local air pollutants (*e.g.* CO, HC, NO_X, PM). However, depending upon the means by which the alternative fuels (electricity, hydrogen, or biofuels) are generated, there may be negative environmental consequences. For instance, spent nuclear waste can be a significant environmental concern.[5] In addition, the manufacture and disposal of batteries needs to be undertaken with care to avoid negative environmental impacts (see Maclean and Lave, 2003. The IEA Implementing Agreement on Hybrid and Electric Vehicles examines such issues *www.ieahev.org/hybrid.html*).

Invention in AFV technologies: Evidence from patent data

As a measure of innovation in AFV (and other) vehicle technologies, patent counts have been developed. Patents are a set of exclusionary rights (territorial) granted by a state to a patentee for a fixed period of time (usually 20 years) in exchange for the disclosure of the details of a given invention. Patents are granted by national patent offices on invention (devices, processes) that are judged to be new (not known before the application of the patent), involving a non-obvious inventive step and that are considered useful or industrially applicable. The use of patent data as proxy for innovation has a long history in the field of innovation economics. Griliches (1990) argues that patents are imperfect but useful indicators of inventive activity. Their main limitation is linked to the facts that not all innovations are patented, not all patented innovations have the same economic value and that propensity to patent may vary across countries and technological fields.

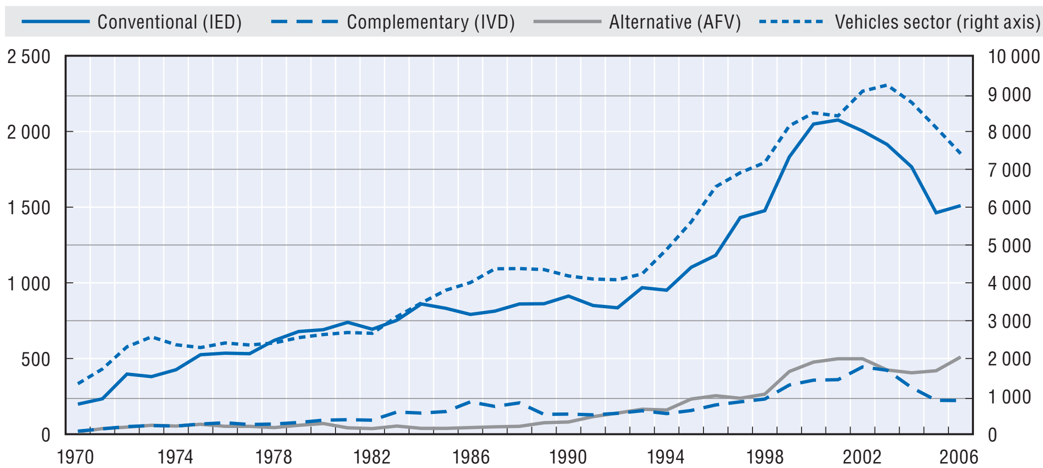
To identify the patents that are relevant for AFV and other technologies, we proceed as follows: First, we review the engineering and trade literature to identify relevant technologies. Subsequently, through a keyword search, we carefully review a number of patents abstracts in the selected technologies. As a result, we are able to identify International Patent Classification (IPC) codes used for filing patents of the selected technologies. Next, we use the individual IPC codes to examine a sample of patent documents in order to verify their "cleanliness". We only retain those IPC codes where conclude that they are not contaminated by many irrelevant patents (see Appendix A4 for a detailed description of the final patent search strategy). Finally, we use the selected IPC codes to extract patent data from the *PATSTAT Database* (EPO, 2009). This includes patents filed at more than 80 application authorities (including national patent offices but also regional patent offices such as the EPO) between the 1960 and 2007.

As the next step, we use the extracted patent data to construct a count of "claimed priorities" (CPs) which are defined as patent applications which have been filed at an additional office to the "priority" office. These patents represent the most valuable inventions in our sample because their patentee requested protection in more than one market. Previous research has shown that the number of additional patent applications (other than the priority application) is a good indicator of patent value (see Guellec and van Pottelsberghe, 2000; Harhoff *et al.*, 2003). The derivation of CPs based on an economic threshold criterion was advocated already by Faust (1990).

Figure 3.1 shows patenting in technologies that target fuel efficiency through *conventional* measures (improved engine design – IED), through *complementary* measures (improved vehicle design – IVD), such as improved air and rolling resistance, and through

Figure 3.1. **Patenting in alternative *versus* conventional fuel-efficiency technologies**

Number of patent applications (claimed priorities, worldwide)

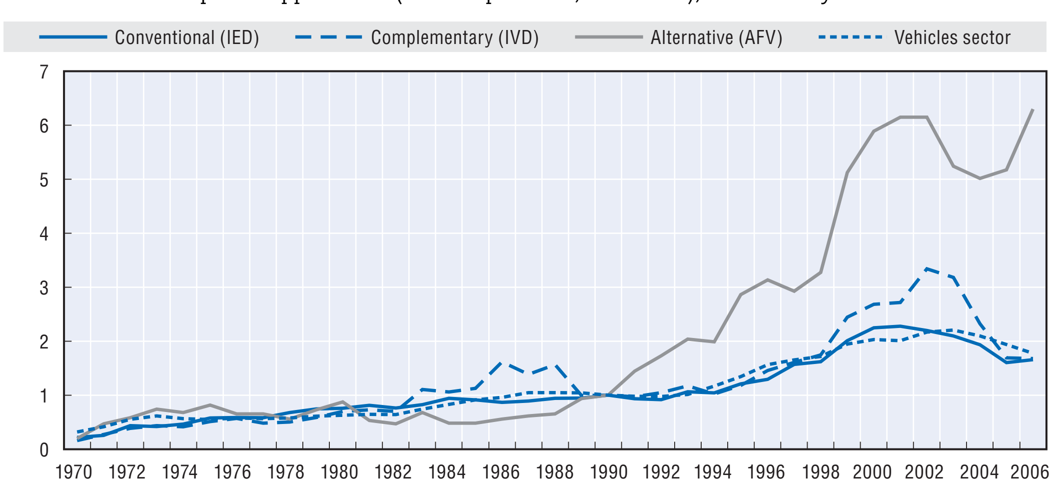


developing an *alternative* fuel vehicle (AFV). In addition, patenting for the entire motor *vehicle sector* is shown (displayed on the right axis). The data indicate that AFV patenting represents a relatively small portion (5-7%) of patenting in the vehicles sector. This is comparable with "complementary" (IVD) measures but is 3-4 times less than patenting in "conventional" (IED) technologies.

Despite the relatively small proportion, there has been a very strong growth in AFV patenting since the early 1990s. This is seen more clearly in Figure 3.2 where the data is indexed on a single year (1990). This contrasts with "conventional" technologies whose growth rate has more-or-less mirrored that in the sector overall. There was a stronger than average growth in "complementary" technologies in the 1980s, and then again during 1999-2004.

Figure 3.2. **Growth of patenting in alternative *versus* conventional fuel-efficiency technologies**

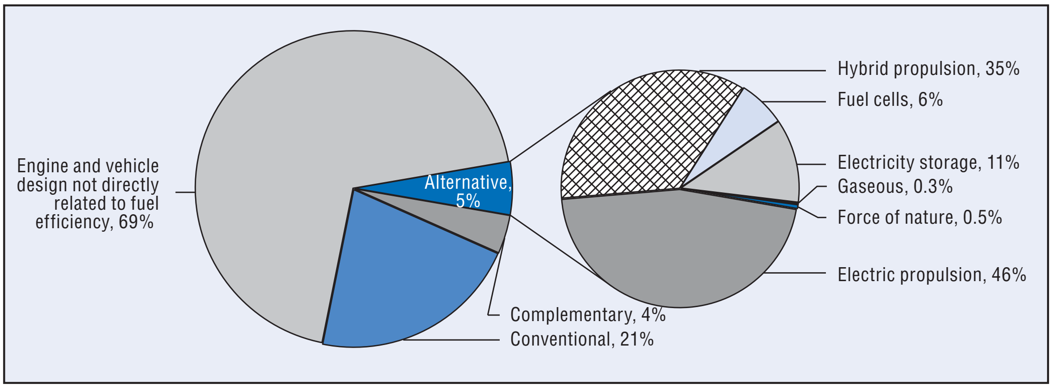
Number of patent applications (claimed priorities, worldwide), indexed on year 1990 = 1.0



At a more disaggregated level (Figure 3.3), most of AFV patenting can be categorised as relating to electric and hybrid propulsion, with patenting related to fuel cell applications and electricity storage being much less important. Finally, patenting in gaseous/hydrogen systems and propulsion via force of nature (solar/wind) is insignificant.

Figure 3.3. **Patenting in alternative fuel vehicle technologies**

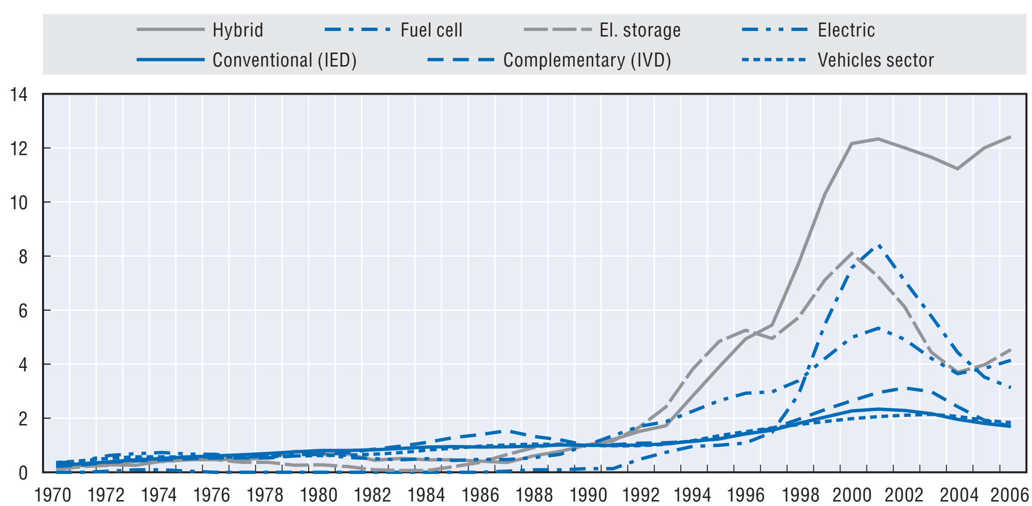
Number of patent applications (claimed priorities, worldwide)



In terms of growth rates (Figure 3.4), the fastest growth occurred in hybrid propulsion, especially between 1994 and 2000, with growth in storage, fuel cell applications, and electric propulsion being less pronounced.

Figure 3.4. **Growth of patenting in alternative fuel vehicle technologies**

Number of patent applications (claimed priorities, worldwide), 3-year moving average, indexed on year 1990



Note: Data for fuel-cell vehicle indexed on year 1995 because the base in 1990 is zero.

Next we examine the origin of AFV inventions by categorising patents by the country of residence of the inventor. Japan is by far the biggest inventor country in the field, followed by Germany and the United States (Figure 3.5).

The dominant position of Japanese inventors is also evident from the growth rates they achieved. Throughout the 1990s Japanese inventors recorded the fastest growth in

Figure 3.5. **Patenting in alternative fuel vehicle technologies, by inventor country**

Number of patent applications (claimed priorities, worldwide)

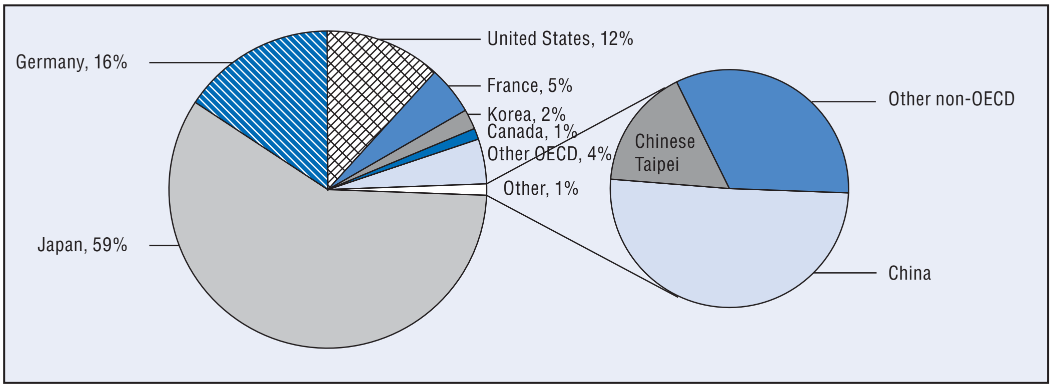
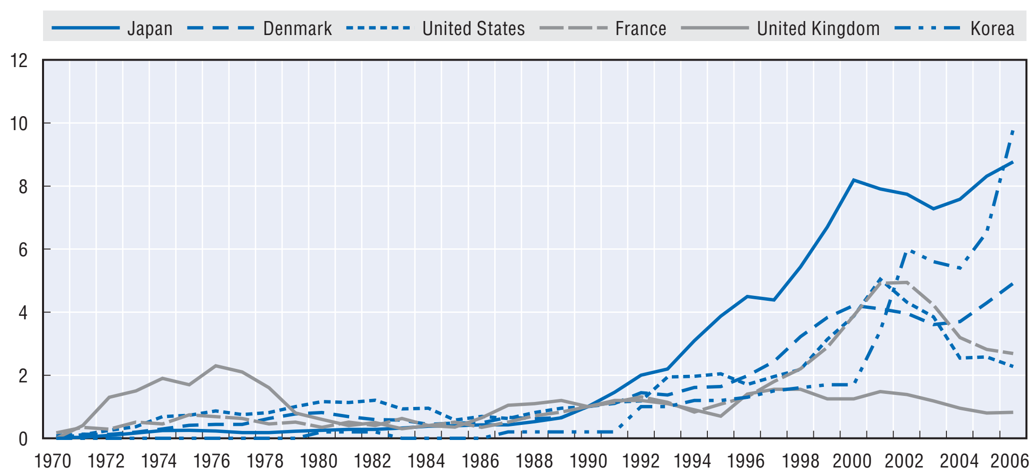


Figure 3.6. **Growth of patenting in alternative fuel vehicle technologies, by inventor country**

Number of patent applications (claimed priorities, worldwide), 3-year moving average, indexed on year 1990



Note: Data for Korea is indexed on year 1992 because the base in 1990 is zero.

patenting from among the major inventor countries. In the late 1990s, other countries started to challenge Japan's position, including Germany, France, and the US. Starting in 2001, Korean inventive activity showed unmatched growth rates.

Data for all inventor countries, disaggregated by technology (AFV, IED, IVD and the vehicles sector overall) are summarised in Table 3.3. Interestingly, countries such as China (CN) and Chinese Taipei (TW) have higher counts for "alternative" than for "conventional" technologies. Moreover, China has the highest share of alternative technologies on total sectoral patenting (Figure 3.7).

Within the AFV field, countries may specialise in specific technological areas (Figure 3.8). For example, in Korea and Canada most of their AFV patenting (> 90%) was in electric propulsion in 1990s, while both countries have become more "diversified" in the 2000s. To a lesser extent this is also true of the US, JP, DE, and FR. Conversely, Sweden had a rather diversified invention portfolio in the 1990s and became more specialised in the 2000s (in hybrid propulsion).

Table 3.3. **Inventing countries for alternative fuel vehicle technologies**

Number of patent applications (claimed priorities, worldwide), 1970-2006

	Alternative fuel vehicle (AFV) technologies							Conventional (IED)	Complementary (IVD)	Vehicles sector overall
	ELE	HYB	STO	FCL	GAS	NAT	Total			
JP	2 540	1 585	748	218	18	10	3 192	15 906	2 093	50 644
DE	648	436	131	97	6	7	990	10 137	1 557	42 970
US	628	271	139	51	8	18	844	4 181	939	23 844
FR	183	138	35	16	2	1	299	1 358	460	14 723
GB	103	42	16	2	2	2	134	1 046	238	5 913
IT	54	33	9	0	1	2	89	623	164	4 309
KR	60	27	25	6	3	3	86	208	53	2 227
CA	52	16	10	8	0	2	68	184	52	2 018
CH	44	21	6	3	0	0	52	158	28	1 361
SE	21	30	11	0	0	0	51	361	119	3 250
AT	25	8	4	1	0	0	32	398	26	1 392
NL	13	15	4	0	1	2	26	93	22	1 684
CN	12	5	4	0	0	2	21	16	7	271
TW	12	10	4	0	0	1	18	14	33	567
ES	8	10	3	0	0	1	17	58	22	990
FI	7	2	3	1	0	0	11	72	15	722
IL[1]	7	2	3	0	0	1	11	11	6	257
AU	6	2	0	1	0	0	7	97	17	546
CZ	3	6	0	1	0	0	7	13	4	148
BE	6	2	0	0	0	0	7	53	14	944
DK	2	3	1	0	0	0	5	67	5	407
BR	2	3	0	1	0	0	4	27	11	162
HU	2	1	1	1	0	0	3	15	8	200
IN	3	0	0	0	0	0	3	14	2	46
TR	2	1	0	0	0	0	2	18	0	22
PL	1	0	0	0	0	0	1	17	1	79
RU	0	0	0	0	0	1	1	17	11	128
LU	0	1	0	0	0	0	1	33	4	224

Note: Countries with at least 10 patents (CPs) in any of the major categories are included in the table.

1. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Figure 3.7. **Transition towards AFV technologies**

Ratio of AFV on total sectoral patenting, 1990-99 compared to 2000-07

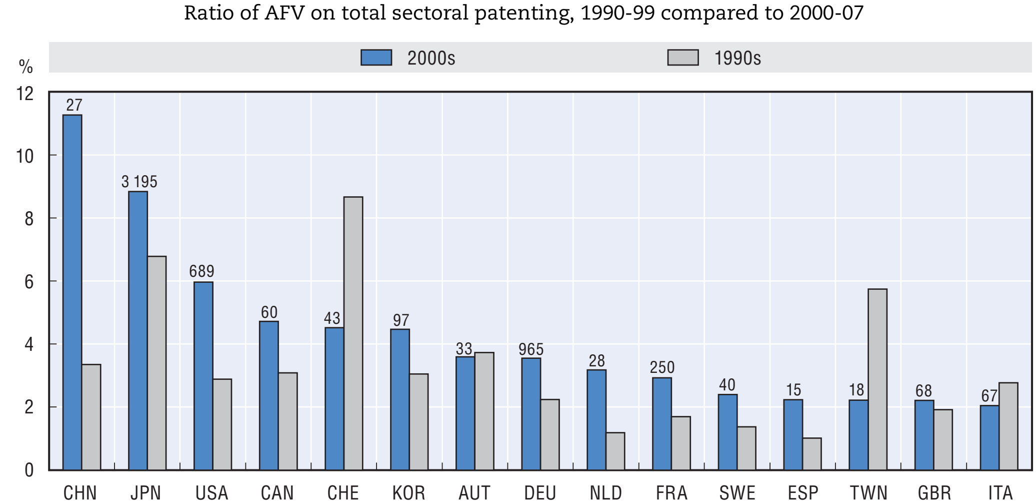
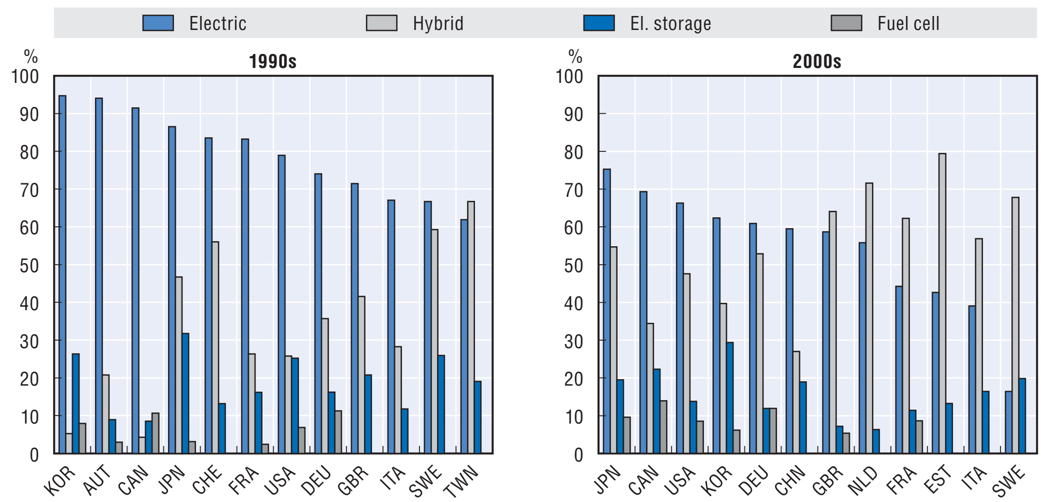


Figure 3.8. **Specialisation *versus* diversification**

Share within AFV Technologies



Note: Countries with at least 10 AFV patents (CPs) are included.

The car sector is a highly concentrated industry and of multi-national character, with research and development facilities frequently located in countries different from those of manufacturing facilities or those where they are legally domiciled. Therefore, rather than speaking of inventors, it may be useful to categorise the data by patentee (patent applicant or patent owner).

Table 3.4 gives lists the top forty patentees in each of the three fields examined. Three Japanese firms clearly dominate AFV patenting, followed by the US, Korean, and European patentees. Two main types of companies/groups can be distinguished – car manufacturers and equipment suppliers. Overall, 50% of inventions in AFV is due to 13 patentees (most of them car manufacturers). In the area of "complementary" vehicle design (IVD), there is less concentration, with 20 patentees (mostly equipment suppliers) responsible for 50% of patents. Conversely, in "conventional" (IED) there are only 10 patentees (mostly car manufacturers) responsible for half of the total count.

Table 3.4. **Top forty patentees for motor vehicle technologies: 1998-2007**

% share of patent applications within a field, based on claimed priorities, worldwide

Alternative (AFV)	%	Complementary (IVD)	%	Conventional (IED)	%
Toyota	12.05	Michelin	6.55	Bosch	18.96
Honda	7.40	Bosch	6.26	Siemens	5.92
Nissan	4.94	Continental	3.36	Toyota	5.54
Ford	3.79	Daimler/Chrysler	3.30	Denso	3.77
Hyundai	3.52	Toyota	2.90	Ford	3.40
Bosch	3.05	LUK	2.89	Hyundai	2.98
General Motors	2.98	Nissan	2.75	Honda	2.94
Renault	2.50	Siemens	2.62	Daimler/Chrysler	2.42
Daimler/Chrysler	2.28	Hyundai	2.11	Renault	2.29
Hitachi	1.98	ZF Group	1.82	Mitsubishi	2.17
Aisin	1.83	Denso	1.77	Nissan	2.13
ZF Group	1.74	Volkswagen	1.76	Delphi	2.11
Peugeot Citroën	1.61	BMW	1.73	Volkswagen	1.75
Siemens	1.25	Gertrag Ford	1.68	Hitachi	1.64

Table 3.4. **Top forty patentees for motor vehicle technologies: 1998-2007** *(cont.)*

% share of patent applications within a field, based on claimed priorities, worldwide

Alternative (AFV)	%	Complementary (IVD)	%	Conventional (IED)	%
Mitsubishi	1.09	Bridgestone/Firest.	1.65	Caterpillar	1.60
LUK	1.06	Honda	1.58	General Motors	1.35
Denso	1.02	Renault	1.46	Continental	1.24
Volkswagen	0.97	Goodyear	1.38	Peugeot Citroën	1.20
BMW	0.90	Eaton	1.27	BMW	0.81
SUZUKI	0.69	Pacific Industrial	1.21	Magneti Marelli	0.72
YAMAHA	0.69	General Motors	1.20	Yamaha	0.67
General Electric	0.55	Pirelli	1.16	Fiat	0.65
Lockheed Martin	0.55	Peugeot Citroën	1.12	Isuzu	0.60
Sanyo	0.50	Porsche	1.06	Detroit Diesel	0.57
Visteon	0.48	Sumitomo	1.03	Visteon	0.54
Valeo	0.40	Volvo	1.01	Volvo	0.52
Volvo	0.39	Hitachi	0.95	INTL Engine IP	0.52
Continental	0.38	Lear	0.78	Mazda	0.51
BAE Systems	0.38	Yokohama Rubber	0.66	Audi	0.46
Kia	0.36	Audi	0.58	Eaton	0.45
Eaton	0.36	Deere	0.57	Behr	0.41
Matsushita	0.36	Schrader	0.56	Keihin	0.37
Jungheinrich	0.34	Fuji	0.52	AVL	0.37
Porsche	0.34	Dana	0.51	Scania	0.36
Linde	0.33	Scania	0.46	Kia	0.35
Delphi	0.32	Visteon	0.45	Honeywell	0.31
Ballard	0.32	Kia	0.43	Pierburg	0.31
Bombardier	0.31	Mitsubishi	0.42	FEV	0.29
Michelin	0.31	Mannesmann	0.41	General Electric	0.27
Deere	0.29	Aisin	0.38	Valeo	0.24
Total (n = 25 444)	**100**	**Total (n = 15 061)**	**100**	**Total (n = 62 321)**	**100**

Note: Patentee names have been partially cleaned (name-matching).

Inside the AFV field, a small number of patentees dominate all the four major areas – electric, hybrid, electricity storage, and fuel cells. Toyota is a clear leader in the electric and hybrid field, with other Japanese and Korean firms also active. The patentees for inventions related to gaseous fuel/hydrogen systems are more mixed, coming from a wide variety of fields. This is also true of the patentees in the area denominated as "powered by force of nature". However, the latter area shows a very low degree of concentration, while the gaseous fuel/hydrogen area is very concentrated. It must be borne in mind that the counts are much lower in these two areas.

Table 3.5. **Major patentees for alternative fuel vehicle technologies: 1998-2007**

% share of patent applications (claimed priorities, worldwide) within the field, top forty applicants

Electric propulsion	%	Electricity storage	%	Hybrid propulsion	%
Toyota	11.77	Toyota	10.89	Toyota	13.17
Honda	7.57	Honda	6.91	Honda	7.57
Nissan	4.75	Hyundai	4.56	Nissan	5.59
Hyundai	3.41	Nissan	4.03	Ford	5.24
Gertrag Ford	3.27	Bosch	3.23	Bosch	4.14
General Motors	2.95	Ford	3.05	Hyundai	3.57
Bosch	2.39	Daimler/Chrysler	2.78	General Motors	3.14
Daimler/Chrysler	2.21	Denso	2.30	ZF Group	2.86
Hitachi	2.18	General Motors	2.14	Peugeot Citroën	2.71

Table 3.5. **Major patentees for alternative fuel vehicle technologies: 1998-2007** *(cont.)*

% share of patent applications (claimed priorities, worldwide) within the field, top forty applicants

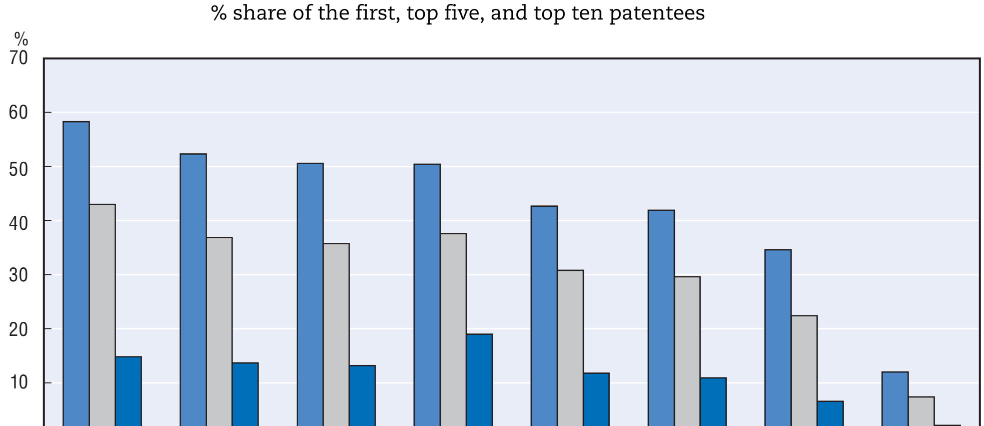
Electric propulsion	%	Electricity storage	%	Hybrid propulsion	%
Renault	2.15	Hitachi	1.99	Aisin	2.61
Aisin	1.80	Renault	1.91	Renault	2.42
Siemens	1.73	Kia	1.60	Hitachi	2.13
ZF Group	1.54	Sanyo	1.52	Luk	2.03
Mitsubishi	1.23	Matsushita	1.29	Daimler Chryler	1.96
Peugeot Citroën	1.01	Volkswagen	1.26	Volkswagen	1.45
Total (n = 11 621)	**100**	**Total (n = 3 135)**	**100**	**Total (n = 8 583)**	**100**
Fuel-cell vehicle	%	Gaseous fuel/hydrogen systems	%	Powered by force of nature (sun, wind)	%
Toyota	14.81	Exxon Mobil	13.68	Ford	2.09
Honda	8.40	BG Group (British Gas)	11.49	Honda	1.32
Renault	8.33	John Hopkins University	4.21	Outfitter Energy	1.32
Nissan	6.38	Ford	3.79	Webasto	1.32
General Motors	5.04	Xu Defang	3.68	Power Light	1.32
Daimler/Chrysler	4.48	BMW	3.33	Gericke de Vega, Dora Angelica	1.10
Siemens	3.47	Bosch	3.16	Nissan	0.88
Hyundai	2.98	Fiat	3.16	Bosch	0.88
Ballard	2.21	Toyota	2.89	ELK Premium Building Products	0.88
Bosch	2.19	Hyundai	2.89	Zhang Junjie	0.88
Delphi	1.98	Texaco Ovonic Hydrogen Systems	2.28	Toyota	0.77
Peugeot Citroën	1.75	Kia	1.84	Shanghai Jiaotong University	0.66
Farnow	1.61			Canon	0.66
Ford	1.53				
Emitec	1.51				
Total (n = 1 461)	**100**	**Total (n = 190)**	**100**	**Total (n = 454)**	**100**

Note: Patentee names have been partially cleaned (name-matching).

Figure 3.9 summarises the information concerning the degree of "concentration" of patentees in the different fields, including those which relate to the use of conventional fuels.

Figure 3.9. **Concentration in the market for AFV inventions: 1998-2007**

% share of the first, top five, and top ten patentees



	Fuel-cell vehicle	Gaseous/ hydrogen	Hybrid propulsion	Conventional (IED)	Electric propulsion	Electricity storage	Complementary (IVD)	Force of nature
% top ten	58%	52%	51%	50%	43%	42%	35%	12%
% top five	43%	37%	36%	38%	31%	30%	22%	7%
% top one	15%	14%	13%	19%	12%	11%	7%	2%

Government policies aimed at AFV technologies: An overview

There are a large number of market failures and barriers that affect markets for AFVs, including:

- Environmental externalities (local/regional, GHGs).
- Knowledge spillovers related to innovation in general.
- Network effects and monopoly conditions (infrastructure).
- Consumption externalities (slow "uptake" of innovations).
- Capital market failures (limited financing for high-risk investment).
- Market power within the manufacturing sector.

Governments employ a broad range of policies aimed at addressing these failures and barriers, including the following policy instrument types:

- Direct R&D support (public funding, fiscal incentives, prises).
- Performance standards (portfolio obligations).
- Pricing (fuel taxes, vehicle tax differentiation).
- Information-based measures (labels).
- Demonstration projects, public procurement.
- Investment in infrastructure.
- Anti-trust laws to ensure non-collusive behavior related to innovation.

In this report we focus specifically on those policies and measures that have the potential to spur innovation in motor vehicle technologies, and particularly those which are likely to encourage innovation in AFVs.

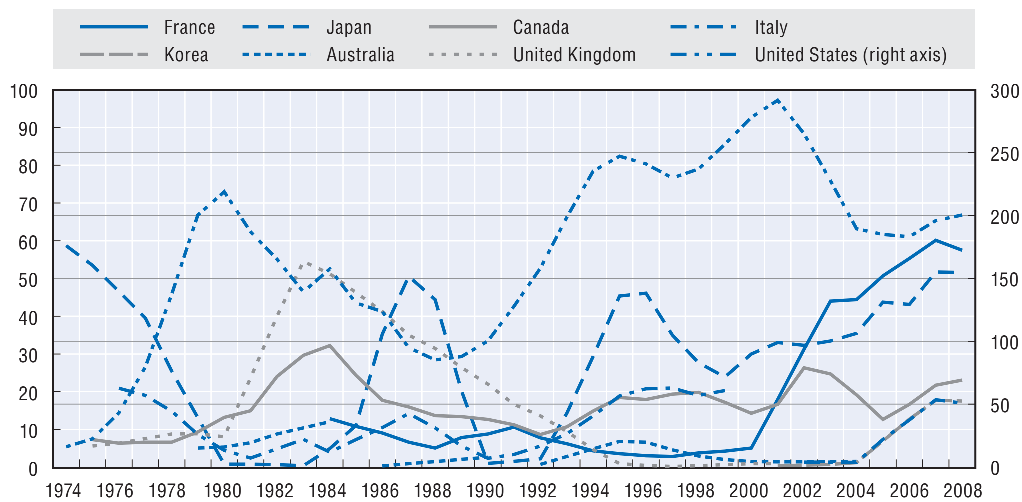
Direct support for R&D

One of the most common ways of encouraging inventive activity is direct financial support for research and development using public sector budgets – *i.e.* grants or tax credits. Dedicated schemes of R&D subsidies for the development of alternative vehicle technologies have been put in place in a number of OECD countries. Some of the recent initiatives include: Japan's 2009 *Programme of Innovation for Green Economy and Society* which promotes development of high-efficient and low-cost solar batteries, low-cost and easy-to-use electric cars, as well as hydrogen production from non-fossil fuels;[6] the United States' 2007 *Energy Independence and Security Act* which includes provisions for the funding of research into hydrogen technologies (IEA, 2009a); the United Kingdom's 2007 *Low Carbon Transport Innovation Strategy* which provides government funding aimed at accelerating the development and market penetration of new lower carbon technologies (IEA, 2009a) (see also *www.dft.gov.uk/pgr/scienceresearch/technology/lctis/lowcarbontis*); and Canada's *Programme of Energy Research and Development* which supports early-stage and applied energy R&D aimed at clean transportation systems, including hydrogen and fuel cells, plug-in hybrid electric vehicles, advanced fuels and emissions reduction (see also *www2.nrcan.gc.ca/ES/OERD/english/View.asp?x=1317*).

Data on R&D expenditures related to alternative motor vehicle technologies is rare. However, some data is available on government R&D spending directed at improving energy efficiency in transportation. While the budget allocations have varied over time, in the recent years there seems to have been a general increase in many countries. For example, spending has risen substantially in France, Korea, and Finland, and to a lesser extent in Japan, Canada, Italy and Sweden. On the other hand, spending has been decreasing in the UK, the Netherlands, Australia and Turkey. Figure 3.10 shows the series for selected countries. Perhaps the most surprising feature of the data is the high degree of volatility reported.

Figure 3.10. **Energy technology RD&D public budgets towards improving energy efficiency in transportation**

Million USD in 2008 prices and PPP, three-year moving average



Note: Data for Germany are not available.

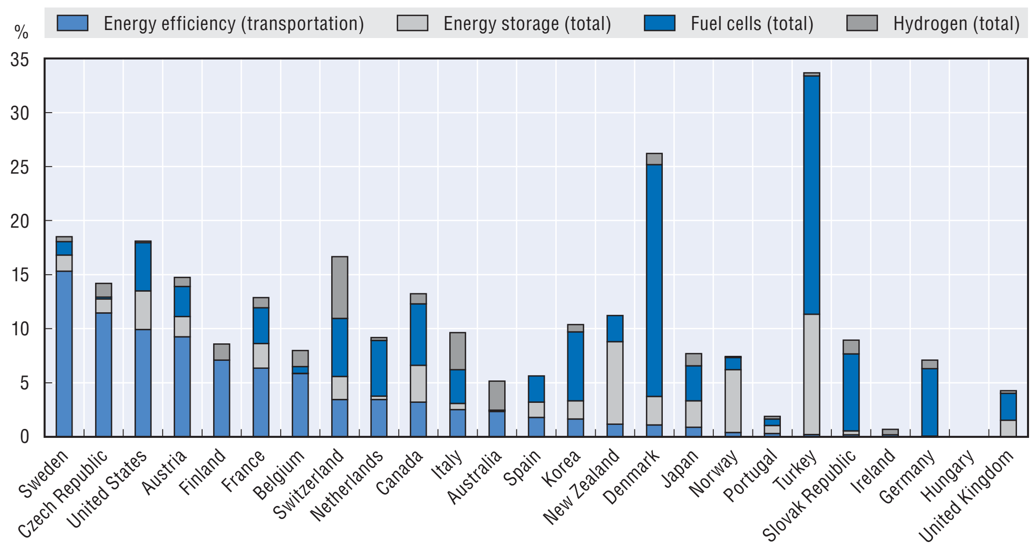
Source: OECD.Stat (*www.oecd.org/statistics*), *Energy Technology R&D Budgets*.

While there are large differences across countries in the size of energy R&D budgets (in absolute terms and as percentage of GDP), there are also differences in the priorities being funded. Figure 3.11 gives the proportion of total energy R&D directed at selected objectives of relevance to AFV development. For example, the greatest share of energy budgets is devoted to improving transportation energy efficiency in Sweden and the Czech Republic. The share of energy storage is highest in Switzerland and Italy, fuel cells in Turkey and Denmark, and hydrogen-related research in Turkey, New Zealand and Norway.

Recently, another means of directly encouraging R&D has been (re)discovered by OECD governments – inducement prises (see *www.ieahev.org/hybrid.html* for some examples). For instance, the United States' *H–Prise* is a competitive programme that awards cash prises to advance R&D, demonstration, and commercial application of hydrogen energy technologies (IEA, 2009a). Another example is the *EcoCAR Challenge* presented below. Newell and Wilson (2005) suggest that technology inducement prises could be a useful complement to standard R&D grants, and point out that there could even be conceptual advantages associated with (well-designed) inducement prises. These include, for example, rewarding output, risk borne by researchers, lower barriers to entry, and generally lower cost to government than direct contracts. On the other hand, Newell and Wilson point out that duplication of effort and up-front liquidity constraints are some of the potential disadvantages of inducement prises.

Figure 3.11. **Public R&D funding for specific energy technology areas: 2004-08**

As % share of total energy technology R&D public budgets



Source: OECD.Stat (*www.oecd.org/statistics*), *Energy Technology R&D Budgets*, 2010.

Box 3.1. **The EcoCAR challenge in the United States**

The EcoCAR Challenge is a three-year competition that builds on the 19-year history of the US Department of Energy advanced vehicle technology competitions by giving engineering students the chance to design and build advanced vehicles, with the goal of minimising the environmental impact of personal transportation. The technologies explored in EcoCAR are identical to those being investigated by the automotive industry, such as full electric, hybrid, plug-in hybrid, and fuel cell hybrid vehicles. The only fuels approved for use in EcoCAR are E10 ethanol, E85 ethanol, B20 biodiesel, compressed gaseous hydrogen, and the energy carrier electricity. By the end of the competition, the sponsors expect fully developed vehicles equivalent to prototypes ready for a production decision. Teams will receive USD 10 000 in seed money in Year One, a wide range of power-train components, a vehicle donated by GM, and technical and mentoring support from the competition sponsors. EcoCAR teams will also have a GM mentor knowledgeable in technologies relevant to the team assigned to assist them during the competition. Participating schools will be required to match cash seed money donations from EcoCAR sponsors and to provide class credit for students participating in the competition (IEA, 2009a) (see also *www.ecocarchallenge.org*).

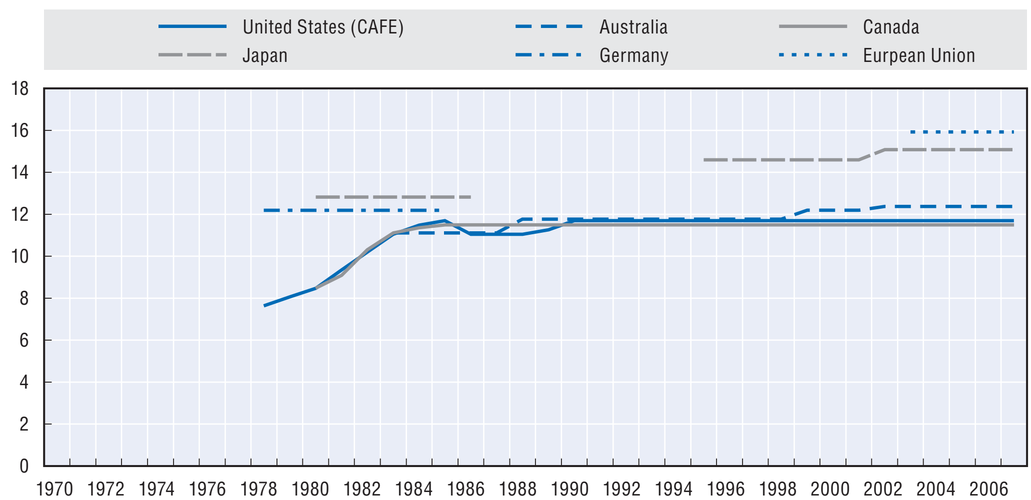
Performance standards and portfolio obligations

Vehicle performance standards typically set minimum limits on fuel efficiency, and more recently, maximum limits on CO_2 emissions. If a standard requires limits that are not possible to be met using current technology, the potential of the performance standard to spur innovation will be greatest (technology-forcing).

Mandatory fuel efficiency standards are rare. Until very recently, the only such example was the United States' Corporate Average Fuel Economy (CAFE) set of standards, enacted in 1975 and first applicable to 1978 models. After an initial increase in stringency, the gradual tightening was temporarily relaxed after 1984 when it began to be really binding. After many years when the US car fuel economy standard was unchanged and the truck fuel economy standard was rising only slightly, in April 2010 the US Environmental Protection Agency and the US Department of Transportation announced a joint rulemaking to establish the first-ever US emission standards for greenhouse gases (GHG) and the biggest increase in CAFE standards in 30 years. By 2016, new light-duty vehicles (cars and light trucks averaged together) are projected to meet GHG and fuel economy standards of approximately 35 miles per gallon or about 6.7 litres per 100 kilometres (that is, 15 km per litre). This value represents a 23% reduction in GHG levels relative to new 2011 vehicles (USEPA/NHTSA, 2010). Following the adoption of the US CAFE standards in 1975, Australia and Canada adopted similar standards but only on a voluntary basis.

Figure 3.12. **Mandatory (US) and voluntary (other countries) fuel efficiency standards for passenger cars**

In kilometres per litre of fuel



Source: Data courtesy of Herman Vollebergh.

Even prior to these developments, voluntary fuel efficiency schemes were introduced around the oil crises of the 1970s in several OECD countries like Germany and Japan (OECD/IEA, 1984). In the mid-1990s, efficiency requirements for passenger cars were included in Japan's Top Runner Programme, at significantly more stringent levels than those above. As is the case for other product categories, the Programme requires that the currently most efficient technology becomes industry standard (average performance level) by a target date. In 2005, the Government of Japan drafted new fuel efficiency standards with the target year set at 2015 for passenger vehicles. Manufacturers and importers will need to achieve the average fuel efficiency levels, calculated as the harmonised weighted average of the fuel efficiency levels by the number of shipped vehicles. The standards are expected to result in a 23.5% improvement in the fuel efficiency of passenger vehicles by 2015, compared to 2004 levels. (OECD/IEA, 2009a) (see also *www.eccj.or.jp/top_runner/index.html*).

In 1990, the State of California (US) introduced the "Zero Emission Vehicle" (ZEV) regulation as part of its broader Low Emission Vehicle Programme. The direct objective of the regulation was development of zero-emission vehicle technologies that could be mass-produced and be affordable in the market as soon as possible. While the regulation set certain minimum technical requirements that were intended to make the vehicle attractive to the US consumers,[7] it left the choice of technology to meet the requirements with the manufacturers (technology neutrality). The ZEV regulation was clearly technology forcing because no technologies capable of meeting the ZEV requirement were available at the time. While the original objectives have not been met as rapidly as initially intended, and the regulation has been amended several times to allow for certain flexibility in meeting the mandate, the goal towards commercialisation of ZEVs has been maintained. Indeed, there is evidence suggesting that the ZEV mandate played a major role in inducing the development of electric, and related, vehicle technologies.[8] (See Box 3.2 for further discussion).

Box 3.2. **The Zero Emission Vehicle (ZEV) regulation in California**

In 1990 the California Air Resources Board (CARB), a State agency responsible for ambient air quality oversight, adopted a plan to reduce vehicle emissions to zero and introduced the Zero Emission Vehicle (ZEV) regulation. Initially, the ZEV required that by 1998, 2% of the vehicles that large manufacturers produced for sale in California had to be ZEVs, increasing to 5% in 2001 and 10% in 2003. Manufacturers failing to meet the requirement could be fined up to 5,000 USD for each violation.

In 1996, the ZEV mandate allowed partial ZEV (PZEV) credits for "extremely" clean vehicles that were not pure ZEVs to meet the ZEV mandate during the initial period (1998-2003), but left in place the underlying goal of 10% ZEVs in 2003.

In 2001-03, in the face of cost, lead-time, and technical challenges, CARB amended the mandate in order to better align the regulation with the status of technology development: by 2003, only 2% of the cars would have to be pure ZEVs (that is, battery or fuel cell EVs), 6% could be PZEVs (that is, very low emitting conventional gasoline vehicles), and the remaining 2% could be met using advanced-technology PZEVs (that is, hybrid EVs, natural gas vehicles). In fact, it was the progress achieved in development of battery technology that (unexpectedly) benefited the development of hybrid cars (Calef and Goble, 2007).

In the 2009 review (*www.arb.ca.gov/msprog/zevprog/2009zevreview/2009zevreview.htm*) of the ZEV it was suggested that given the successful commercialisation of PZEVs[*] the CARB may consider removing the option to use PZEVs and AT-PZEVs to meet the ZEV mandate. Instead, it was proposed that efforts now concentrate on helping to move the pre-commercial pure ZEV technologies (battery EVs, fuel-cell EVs, plug-in hybrid EVs, and hydrogen internal combustion engine vehicles) from demonstration to commercialisation in 2015. In addition, complementary policies to develop the supporting infrastructure (electricity and hydrogen fuelling stations) are under consideration (CARB, 2009a).

In the late-2009 revision of the ZEV regulation, the option to use PZEVs has been retained but the overall standards have been increased – 11% for the 2009-11 model years, 12% for 2012-14, 14% for 2015-17 and 16% for 2018 and beyond. For the 2009-11 model years the minimum requirements are 2.5% ZEVs (or credits generated by ZEV vehicles), another 2.5% can be met with AT PZEVs (or corresponding credits), and the remainder of the manufacturer's ZEV requirement may be met using PZEVs. The proportion of the overall ZEV mandate that must be met by AFVs (that is, ZEVs or ATPZEVs) will increase over time eventually reaching 10% by 2018 (CARB, 2009b).

* Indeed, the PZEVs are considered as a collateral outcome of the ZEV regulation. In total, over one million PZEVs and 250 000 AT PZEVs have been delivered for sale in California as a result of the ZEV regulation, *www.arb.ca.gov/msprog/zevprog/2009zevreview/zevwhitepaper.pdf*.

Source: For further details see CARB (2009) at *www.arb.ca.gov/msprog/zevprog/background.htm*.

In Europe, voluntary agreements on fuel efficiency targets were first introduced in Germany, but other countries had comparable agreements, like Italy and Sweden (OECD/IEA, 1984). In 1998 the EU negotiated voluntary commitments with the industry. Failure to meet these targets led the EU to adopt a mandatory set of emission limits in 2009 (see Box 3.3 for further details).

Box 3.3. **Carbon dioxide emission limits in the European Union**[1]

Carbon dioxide emission targets for new passenger cars were first set in 1998/99 through voluntary agreements between the European Commission and the automotive industry. These agreements targeted fleet-average CO_2 emissions of 140 g/km by 2008/09. Initially, significant CO_2 emission reductions were achieved but after 2004 the targets were no longer met.[2] In response to the failure of the voluntary targets to achieve further reductions, the Commission developed a *mandatory* CO_2 emission reduction programme for passenger cars and light commercial vehicles in 2009.[3]

The new CO_2 standards are legally-binding and apply as of 2012. In the case of passenger cars, a fleet-average CO_2 emission target of 130 g/km is to be reached by each vehicle manufacturer by 2015. Further emission reduction of 10 g/km is to be achieved by measures, such as more efficient air-conditioning systems or tyres, and the use of biofuels. The new regulation makes these objectives binding for the average fleet of a given car manufacturer in successive stages: In 2012, 65% of their car fleet must meet the target, in 2013 75% and in 2014 80% and 100% from 2015. The regulation also defines a long-term target of 95 g CO_2/km to be reached from 2020, with the modalities for reaching this objective to be reviewed by the Commission by 2013.

Manufacturers who miss their average CO_2 targets are subject to *penalties*. Between 2012 and 2018, the penalties are EUR 5 per vehicle for the first g/km of CO_2; EUR 15 for the second gram; EUR 25 for the third gram. For emissions of more than 3 grams over the limit, EUR 95 is charged per newly registered vehicle. From 2019, the penalty will be EUR 95 per new car for every gram above the target.

In the initial period, certain types of vehicles receive additional incentives. For example, vehicles emitting less than 50 g CO_2/km receive *super-credits*. Each such vehicle is counted as 3.5 cars in 2012 and 2013, as 2.5 cars in 2014, 1.5 cars in 2015, and as 1 car from 2016. CO_2 emissions of vehicles capable of running on a mixture of gasoline with 85% ethanol (E85) are reduced by 5% until the end of 2015. This reduction applies only where at least 30% of the filling stations in a member state provide E85.[4]

The Programme also allows for certain *flexibilities* for manufacturers, including: *a)* several manufacturers may form a pool to jointly meet their CO_2 emission targets (pooling); *b)* manufacturers may apply for credits for innovative CO_2 reducing technologies which are not accounted for in the current test cycle (*e.g.* energy efficient lights), with the total contribution of such "eco-innovation" credits limited to 7 g CO_2/km in each manufacturers average specific target; and finally; and *c)* low-volume manufacturers (fewer than 10 000 new cars registered per year) may, under certain conditions, apply for a derogation from the specific emission targets.

1. Based on *www.dieselnet.com/standards/eu/ghg.php* and *http://ec.europa.eu/transport*.
2. According to one study (T&E, 2006) only three out of 20 car brands (Fiat, Citroën and Renault) were in 2005 on track to meet the 140 g/km commitment. Several manufacturers of large cars (BMW, Volvo, Audi) trail far behind, with brands such as Mazda, Suzuki and Nissan being the worst performers.
3. Regulations 443/2009/EC and COM(2009)593.
4. These provisions have been criticised by some environmental groups (see *e.g.* CE Delft, 2010).

In 2003 a voluntary target was put in place by the Australian automotive industry. Development of similar standards is currently underway in Canada (see also *www.ec.gc.ca/default.asp?lang=En&n=714D9AAE-1&news=29FDD9F6-489A-4C5C-9115-193686D1C2B5*). In the United States, following the "endangerment finding" (USEPA 2009), introduction of national regulatory standards for GHG emissions has been under consideration. Such standards could include GHG emission standards for new motor vehicles and new motor vehicle engines.[9]

Pricing policies

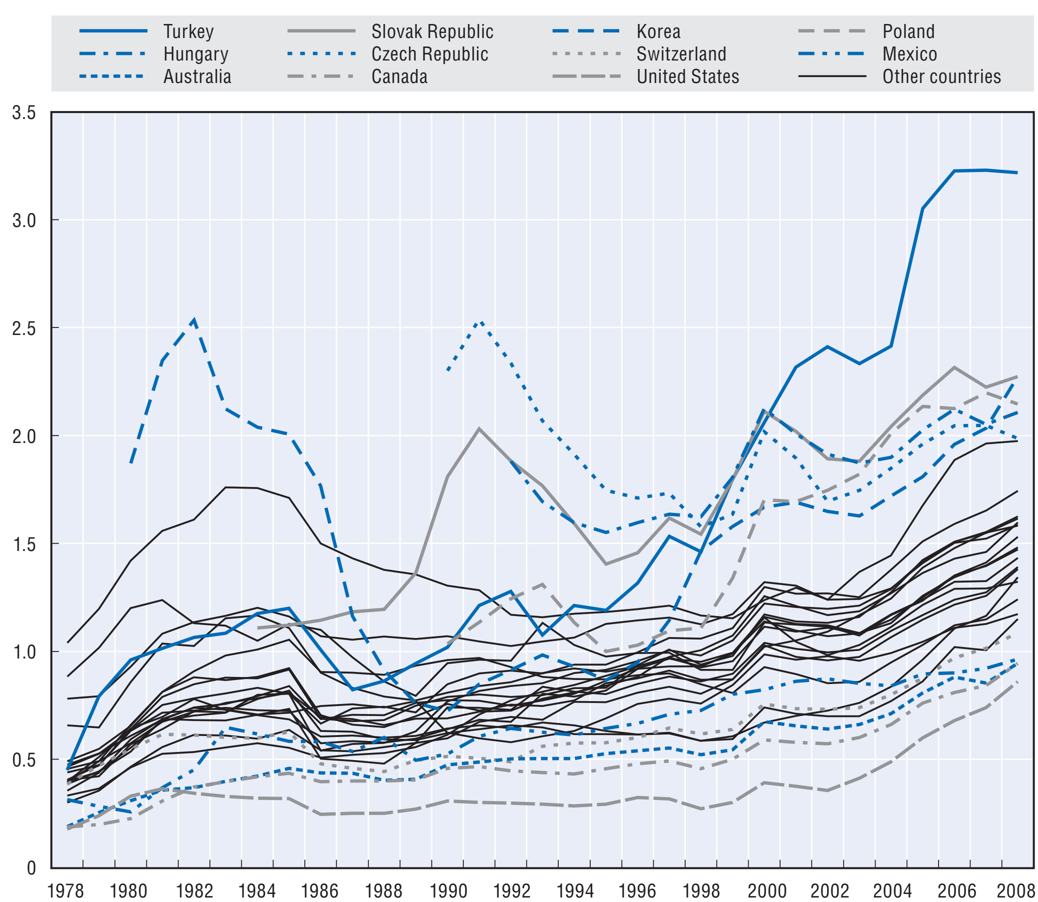
In this section policies and measures are discussed that aim at changing the relative prices of inputs (fuel taxes, CO_2 taxes, and taxes on energy carriers in general) and prices of outputs. Output taxes may be distinguished by their point of incidence – whether they impose a tax on the purchase (vehicle purchase taxes, tax credits, or subsidies), ownership (annual motor vehicle tax), or usage of a vehicle (kilometre tax, road usage taxes, pay-as-you-drive schemes, road pricing). In addition, emission trading schemes can be envisaged for large transport operators. All of these policies will – whether directly or indirectly – encourage the use of (and thus innovation in) AFVs.

Automotive fuel taxes

A comparison of automotive fuel prices gives an indication of pricing policy in OECD countries since the after-tax price of fuels reflects the effects of the imposition of excise taxes, value-added taxes, as well as various forms of price regulations. Gasoline prices (in PPP terms) have increased 2- to 5-fold in most OECD countries between 1978 and 2008. In Turkey prices have risen as much as a 7-fold (Figure 3.13).

Figure 3.13. **Gasoline prices in OECD countries**

End-use after-tax prices for households, in USD per litre using 2008 prices and PPP



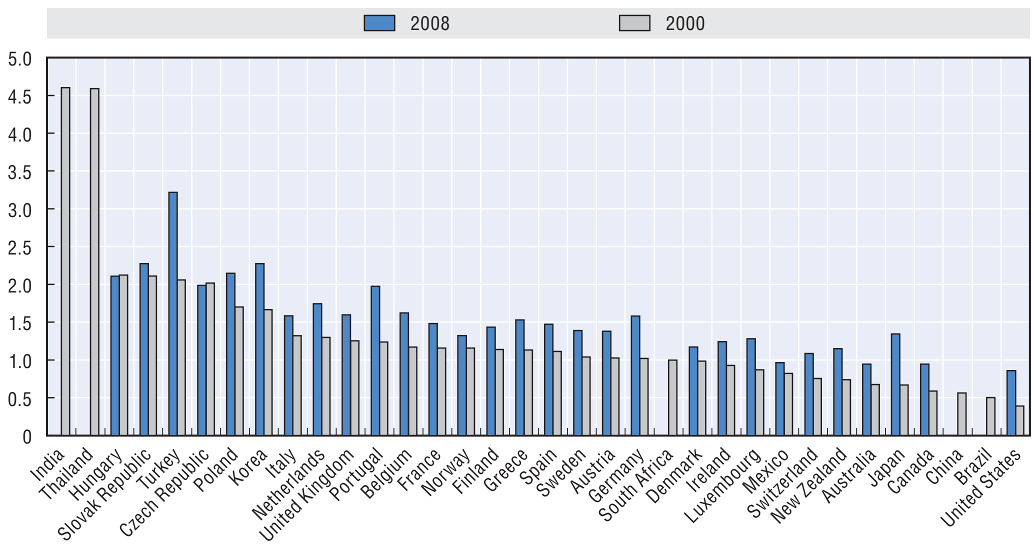
Note: Prices displayed represent the lowest-cost envelope of the fuel price range in a country; most of the time, this corresponds to premium leaded gasoline (prior to mid-1980s) and premium unleaded gasoline (95 RON) in Europe and regular unleaded gasoline outside of Europe.

Source: OECD.Stat, *Energy End-Use Prices* (3Q 2009)

Some data is also available for non-OECD countries (Figure 3.14). In 2000, consumers in India and Thailand paid by far the highest prices (on the PPP basis), followed by those in Hungary and the Slovak Republic. The lowest price levels (on the PPP basis) were observed in the US, Brazil, China, and Canada. During the period from 2000 to 2008, prices have generally risen (except for Hungary and the Czech Republic), with the highest absolute increases recorded in Turkey, Portugal and Japan, and highest percentage increases in USA, Japan, Portugal and Canada.

Figure 3.14. **After-tax gasoline prices**

End-use after-tax prices for households, in USD per litre using 2008 prices and PPP



Note: China 1998, Brazil 1994.

Source: OECD.Stat, *Energy End-Use Prices* (3Q 2009)

Similar developments have been observed for automotive diesel prices (Figure 3.15). During the period from 2000 to 2008, diesel prices have risen in all countries for which data is available, with the highest absolute increases recorded in Korea and Turkey and highest percentage increases in Korea, USA, and Japan (Figure 3.16).

In addition to explicit taxes on fuel inputs, some countries tax fuel through inclusion of transport emissions in their ETS schemes (see Box 3.4 for the example of New Zealand).

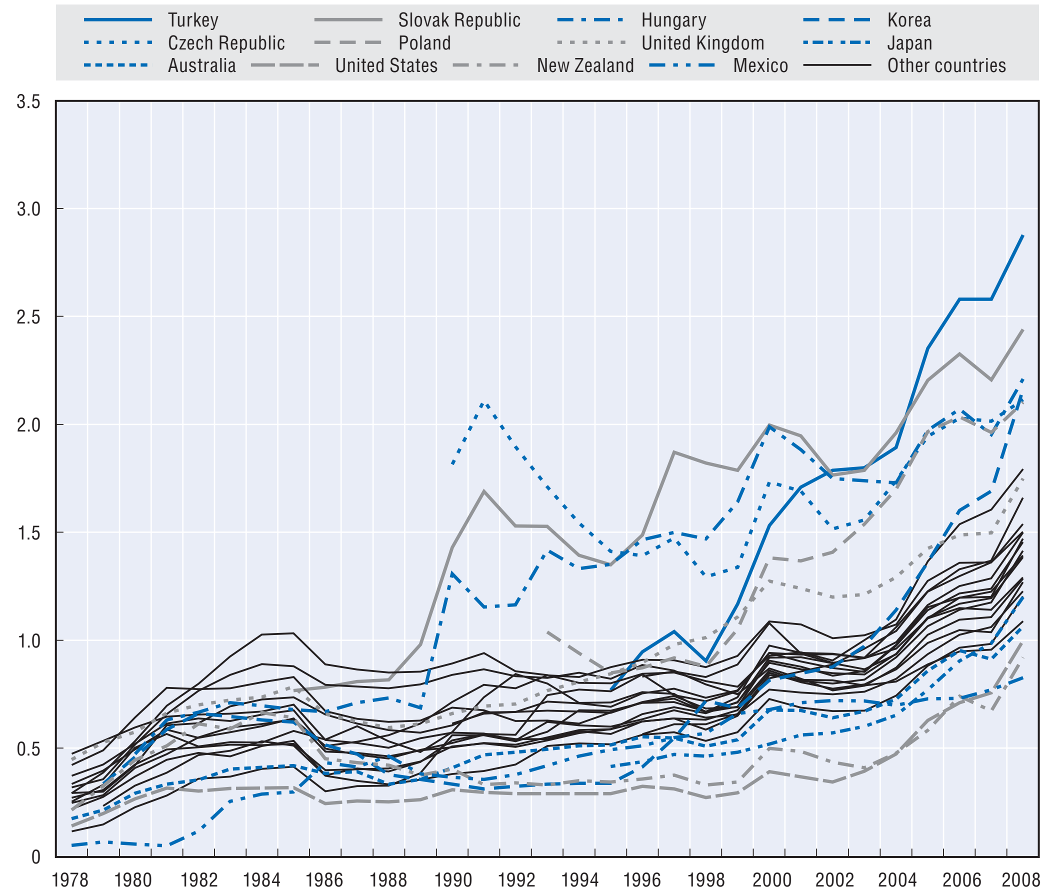
Vehicle purchase taxes and tax credits

A number of OECD governments have included fiscal incentives for the purchase of lower-emission vehicles in their vehicle purchase tax schemes. For example, in the framework of its "Environment Programme" (*Grenelle de l'environnement*), France introduced a "bonus – malus" scheme[10] that subsidises the purchase price of low-emission cars (ranging from EUR 5 000 for 0-60 g CO_2/km to EUR 100 for 111-120 g CO_2/km, based on the 2011-12 rates) while it imposes a tax on the price of the more polluting ones (ranging from EUR 200 for 151-155 g CO_2/km to EUR 2 600 for 240 g CO_2/km and over, based on the 2011-12 rates) (*www.legrenelle-environnement.fr/spip.php?rubrique195*). The scheme is intended to be broadly revenue-neutral.

In Japan, the *Scheme to Develop and Disseminate Low-Carbon Technologies* provides subsidies and tax breaks on the purchase of fuel-efficient vehicles.[11] In addition, Japan's

Figure 3.15. **After-tax automotive diesel prices**

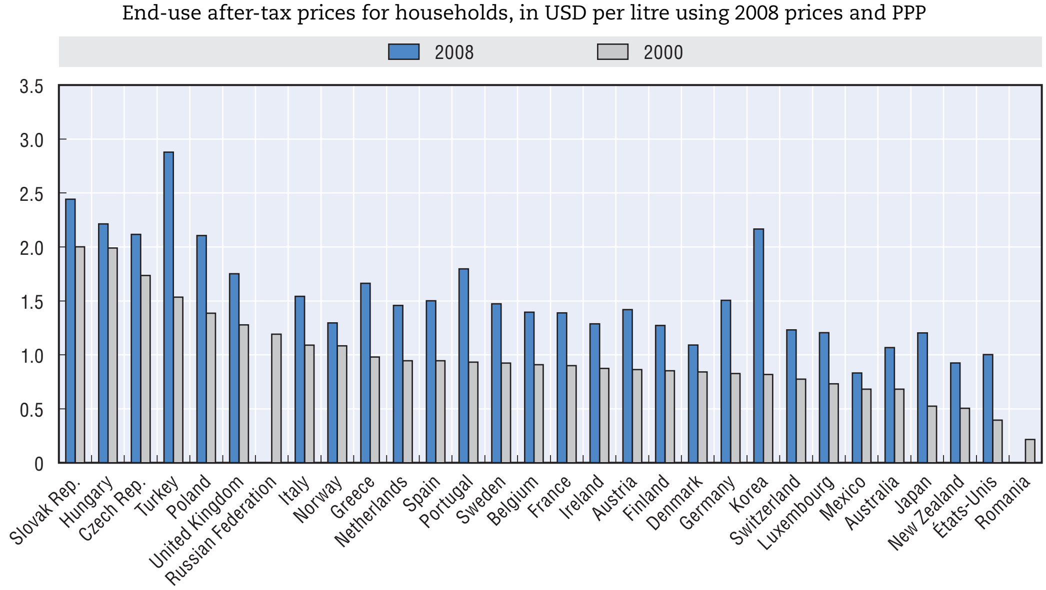
End-use after-tax prices for households, in USD per litre using 2008 prices and PPP



Source: OECD.Stat, *Energy End-Use Prices* (3Q 2009).

Figure 3.16. **After-tax automotive diesel prices**

End-use after-tax prices for households, in USD per litre using 2008 prices and PPP



Source: OECD.Stat, *Energy End-Use Prices* (3Q 2009).

Box 3.4. Transport emissions in New Zealand's ETS scheme[1]

As of November 2009 the New Zealand government has all but passed new legislation which will underpin the operation of a comprehensive emissions trading scheme (ETS) covering all sectors of the economy. Individual sectors are being phased in gradually between 2008 and 2013.[2] The transport sector, considered as one part of the "liquid fossil fuels" sector, will enter the NZ ETS on 1 July 2010. During a transition phase (until December 2012) ETS obligations will be implemented progressively requiring ETS participants to surrender only one unit for every two tonnes of CO_2-eq. emitted, and providing a NZD 25 fixed price option.

The ETS covers liquid fossil fuels used in New Zealand (incl. petrol, diesel, aviation gasoline, jet kerosene, light fuel oil, and heavy fuel oil). Biofuels are not included. The scheme applies to liquid fossil fuels as far up the supply chain as possible – in other words, when refined oil products leave the refinery or are imported. Consequently, it is the fuel suppliers who take fuel from the refinery or who import it who will be required to participate in the scheme. Individual vehicle users are not participants in the ETS.

1. Based on IEA (2009a) and *www.climatechange.govt.nz/emissions-trading-scheme/index.html*.
2. Personal communication, The Delegation of New Zealand to the OECD, Meeting of the WPNEP, November 2008.

Programme of Innovation for Green Economy and Society provides tax incentives for the development and diffusion of next-generation vehicles.[12]

In the United States, the *Energy Policy Act* of 2005 provides a tax credit for buyers of dedicated alternative fuel vehicles up to a maximum value of USD 4 000. The fuel cell vehicle tax credit is available up to a maximum of USD 8 000, the hybrid vehicle tax credit is up to USD 3 400.[13] More recently, the 2009 *American Recovery and Reinvestment Act* provides for approximately USD 30 billion in the form of tax-based incentives to support clean energy research, development, and deployment. In addition, a plug-in hybrid electric vehicle consumer tax credit (up to USD 7 500) is available (IEA, 2009a).

Annual motor vehicle ownership taxes

Many OECD countries have in the past imposed taxes on vehicle ownership with the tax rate determined on the basis of vehicle weight and engine size. More recently, the basis of vehicle tax is now based on CO_2 emissions (for example, this is the case of Germany[14] and Italy[15]). Such moves to link car taxes wholly or in part to the CO_2 emissions from new cars are being encouraged by the European Commission also in other EU member states. For example, the United Kingdom has already responded to this request from the European Commission by linking the vehicle holder's tax (road tax) and the addition to taxable income for private use of a company car to the CO_2 emissions. In doing so, the UK intends to help ensure that 10% of all new cars sold in the UK in 2012 will produce CO_2 emissions of 100 g/km or less (IEA, 2009a). In addition, the UK has reformed its annual vehicle tax by incorporating incentives favouring low-CO_2 vehicles (see Box 3.5).

Kilometre (road usage) taxes

The primary objective of road pricing policies, in addition to raising funds for road maintenance, is to encourage a modal shift away from personal transport. Hence, while road pricing may impact the overall volume of traffic, it is unlikely to provide incentives for

Box 3.5. Vehicle excise duty in the United Kingdom*

All cars in the UK are subject to an annual tax called the Vehicle Excise Duty (VED). While in the past the same flat rate applied for all cars, starting in 2001 the VED was reformed to incentivise fuel-efficient and low-carbon vehicles. Under the new scheme, newly registered cars were placed into VED rate bands according to their CO_2 emissions. Within each band, alternatively fuelled cars, including hybrid vehicles, benefit from a discount. The excise scheme is designed to be revenue-neutral.

In 2006, the tax rate for the lowest emission cars (band A: 0-100 g/km) was reduced to zero, while tax rate for the most polluting cars (band G: 226 g/km and higher) was increased to GBP 300 from 2007 and to GBP 400 from 2008.

In 2009, a major overhaul of the VED system took effect, expanding to 13 bands differentiated according to CO_2 emissions. The new system increases the number of bands for the more polluting vehicles and sets lower tax rates for alternative fuel cars.

Vehicle tax rates (2010/11) for cars registered on or after 1 March 2001

Band	CO_2 (g/km)	Standard rate	Alternative fuel rate
A	Up to 100	£0	£0
B	101-110	£20	£10
C	111-120	£30	£20
D	121-130	£90	£80
E	131-140	£110	£100
F	141-150	£125	£115
G	151-165	£155	£145
H	166-175	£180	£170
I	176-185	£200	£190
J	186-200	£235	£225
K	201-225	£245	£235
L	226-255	£425	£415
M	Over 255	£435	£425

The new system provides also additional incentives for purchasing low-emission cars. Tax rates for new cars when they are first registered ("first-year rates") are now set such that the difference between the least and the most polluting vehicles is accentuated. This is intended to send a stronger signal to the buyer about the environmental implications of their car purchase.

Vehicle tax rates (2010/11) for new cars

Band	CO_2 (g/km)	First-year standard rate	First-year alternative fuel rate
A	Up to 100	£0	£0
B	101-110	£0	£0
C	111-120	£0	£0
D	121-130	£0	£0
E	131-140	£110	£100
F	141-150	£125	£115
G	151-165	£155	£145
H	166-175	£250	£240
I	176-185	£300	£290
J	186-200	£425	£415
K	201-225	£550	£540
L	226-255	£750	£740
M	Over 255	£950	£940

* Based on IEA (2009a) and *www.direct.gov.uk/en/Motoring/OwningAVehicle/HowToTaxYourVehicle/DG_172916*.

reducing per-unit fuel consumption and CO_2 emissions. However, these schemes can be modified in order to provide such incentives. For example, an interesting and innovative policy is to be implemented in the Netherlands. It will impose a tax on road usage (kilometres driven annually) applying a differentiated tax rate which varies by the type of vehicle reflecting its CO_2 emissions. Such policy thus combines elements of a pure kilometre tax and a pure CO_2 emissions tax. (See Box 3.6 for more details.)

Box 3.6. **Road usage tax in the Netherlands***

Faced with increases in road traffic, congestion, and the associated environmental problems, the Dutch government (after consultation with automotive and industry associations, trade unions, and environmental organisations) introduced a tax per kilometre to be charged for vehicles on Dutch roads, differentiated by time, place and other environmental factors. The pricing system will rely on satellite technology to operate. After an initial trial period, the system is scheduled to be operational in 2011 (freight transport) and 2012 (personal transport) (IEA, 2009a).

With the introduction of the kilometre tax, the former fixed car taxes (annual motor vehicle tax and vehicle purchase tax) are being abolished. Consequently, the tax burden will shift from car ownership to car usage. Under the new scheme, motorists will thus only pay for the kilometres actually driven. A base rate per kilometre driven in the Netherlands will apply. The base rate will be differentiated on the basis of vehicle's CO_2 emissions. In addition, a per-kilometre surcharge may apply for driving particularly busy routes during rush hours. This is intended to both reduce CO_2 emissions and reduce traffic (especially during peak hours). It is expected that reducing the number of cars on the road during peak commute by 10% will eliminate traffic jams. The policy is intended to be revenue-neutral.

* Based on *www.verkeerenwaterstaat.nl/english/topics/mobility_and_accessibility/road_pricing/index.aspx*.

Information-based measures

The presence of information asymmetries between buyers and sellers leads to inefficient market outcomes because buyers are unable to purchase goods with the bundle of attributes that correspond to their preferences. In addition to such market imperfections, certain types of goods may not be offered in the market at all (incomplete markets).

In the markets for new cars, both types of market failures may be present. Lacking or unclear information about vehicle characteristics may discourage consumers from purchasing a fuel-efficient or a low-CO_2 vehicle. To mitigate such situations, many OECD governments have introduced policies that allow consumers make informed choices (*e.g.* product labelling) and that influence consumers to purchase more fuel-efficient products (*e.g.* green vehicle guides, free advice to consumers). In addition, such measures may help mitigate the problem of incomplete markets because they allow other policies to be "tied" with these information measures (for example, providing a price bonus/subsidy for the purchase of a vehicle with a low-CO_2 label).

Product labelling

In Australia, fuel consumption labelling (litres per 100 km) has been mandatory since 2001. It applies to new passenger vehicles, four-wheel drive and light commercial vehicles sold in the domestic market. Since 2004 the label must also carry a CO_2 emissions (g/km) figure. The scheme now applies to all vehicles up to 3.5 tonnes of gross vehicle mass (incl. some larger off-road vehicles) (IEA, 2009a) (see also *www.environment.gov.au/settlements/transport/fuelguide/label.html*).

In New Zealand, fuel economy labels must be displayed on new and used (manufactured after 2000 for which data is available) passenger cars at the point of sale. The fuel economy information is expressed in three different ways: *i)* fuel economy cost per year; *ii)* fuel economy rating out of six stars; and *iii)* fuel consumption in litres per 100 km (IEA, 2009a) (see also *www.rightcar.govt.nz* and *www.fuelsaver.govt.nz*).

In Japan, a fuel efficiency labelling system was introduced in 2004 to promote public awareness of vehicles that achieved the Top Runner fuel efficiency standards. The labelling discloses fuel economy performance with an identifiable sticker, indicating either the status of "fully compliant" or "plus 5%", "plus 10%" or "plus 20% higher fuel efficiency compared to the standard" (IEA, 2009a) (for further details see *www.eccj.or.jp/summary/local0703/eng/02_04_06.html*).

Similar schemes have been introduced also in other countries, including the US where every new passenger car and light truck sold in the domestic market is required to have a fuel economy window sticker label, listing the fuel economy estimates (city and highway) (IEA, 2009a). Mandatory fuel economy and CO_2 emissions labelling scheme has also been put in place in the EU. As of 2008, fuel efficiency and CO_2 emissions labelling of new vehicles is mandatory also in Korea[16] and Turkey (see also *www.sanayi.gov.tr*) (IEA, 2009b).

Consumer education

To further help consumers choose fuel-efficient and lower-CO_2 vehicles, many governments have issued consumer guides and set up programmes that offer free advice to households and businesses on how to improve their fuel economy and CO_2 emission performance. For example, consumer guides have been published in the United States (see Box 3.7) and Australia (see *www.greenvehicleguide.gov.au* and *www.environment.gov.au/*

Box 3.7. **Fuel economy guide and green vehicle guide in the United States***

The joint US Department of Energy and the US Environmental Protection Agency programme has been in place since 2000, producing a yearly Fuel Economy Guide, and maintaining a website that provides information on fuel efficiency for new vehicles (*www.fueleconomy.gov*) The Fuel Economy Guide provides consumers with detailed information about fuel consumption, carbon footprint, and air pollution score for the newest model year vehicles, as well as information about hybrids, alternative fuel vehicles, electric vehicles, and fuel cell vehicles. A list of fuel economy leaders, ranking the top model year performers, is also included.

The Green Vehicles Guide is designed to provide consumers with fuel economy and emission information for all cars and light trucks sold in the United States. Consumers can use the Green Vehicle Guide to find the cleanest, most fuel-efficient vehicle that meets their needs. Each vehicle is given an Air Pollution Score and Greenhouse Gas score on a scale of 0-10, with 10 being the best. Users can compare individual vehicles or vehicle types in terms of fuel efficiency and emissions. It provides information about the fuel economy, air pollution emissions, and greenhouse gas emissions for specific models and configurations of vehicles.

* Based on (IEA, 2009a). For details see *www.fueleconomy.gov/feg* and *www.epa.gov/greenvehicles*.

settlements/transport/fuelguide/index.html), and in Canada free advice is provided to households (see also *www.ecoaction.gc.ca/ecoenergy-ecoenergie/personalvehicles-vehiculespersonnels-eng.cfm*) and businesses (see Box 3.8 for details). In addition, some countries have been actively promoting changes in driving habits that contribute to increased fuel efficiency, so-called "eco-driving" (*e.g.* Japan, Canada, Finland, and the Netherlands) (see also *www.ecodriving.org*, *www.hetnieuwerijden.nl*, *www.asiaeec-col.eccj.or.jp/eng/e3105promo_ecod.html*, *www.ecoaction.gc.ca/ecoenergy-ecoenergie/personalvehicles-vehiculespersonnels-eng.cfm*).

Box 3.8. **Advice for the freight sector in Canada**

The commercial highway freight sector is responsible for about 10% of Canada's greenhouse gas emissions. The "ecoENERGY for Fleets" programme introduces fleet operators to energy efficient practices that can reduce fuel consumption and emissions. Free practical advice is offered on how energy-efficient vehicles and business practices can reduce fleet operating costs, improve productivity and increase competitiveness. The Programme helps to ensure fleet vehicle owners and managers are aware of the fuel efficiency benefits of new and developing technologies. It is expected that more than 200 000 professional drivers – of heavy trucks, buses, construction and other vehicles – will receive training in energy efficient vehicle operating techniques over the four years of the programme (IEA, 2009a) (see also *www.ecoaction.gc.ca/ECOENERGY-ECOENERGIE/fleets-parcsvehicules-eng.cfm*).

Demonstration and deployment programmes

Public procurement can be an effective means of encouraging innovation with respect to AFV vehicles. Since there are important positive externalities and economies of scale associated with the fuelling infrastructure, "take off" in the market may be dependent upon a significant purchaser taking the lead (network effects). Moreover, there may be important demonstration effects (demand-side information externalities). Faced with co-existence of the network and demonstration effects, public programmes to purchase a fleet of AFVs can provide a spur to adoption by private buyers, thus inducing innovation (see OECD, 2003 for a discussion of the types of goods for which public procurement is likely to be an effective means of inducing innovation). Several examples of such programmes are reviewed next.

Following the introduction of the ZEV regulation in California in 1990, the French government initiated a national programme to develop and deploy electric vehicles in 1992. As part of the programme domestic car manufacturers pledged to develop electric vehicles and the national electric utility set out to build the appropriate charging infrastructure. The formal agreement signed in 1995 aimed at 100 000 electric vehicles on France's roads by 1999 and 5% of newly registered vehicles being electric. In addition, it set a target of 10% of public sector vehicle fleets to be electric. One year later the target was increased to 20% for government agency fleets of at least 20 vehicles. The procurement programme was complemented with several rental programmes intended to familiarise the public with AFVs as well as to foster behavioural changes of car users (car-sharing). Despite these efforts, by the end of 2002, about 7 500 electric vehicles were on France's roads (over 90% in fleets of municipalities and public utilities) – much less than the initial objective of 100 000, but still more than any other industrialised country at the time (there were about 3 500 electric vehicles in the rest of Europe) (Calef and Goble, 2007) (see also Richard, 1992 and Groupe Interministériel Véhicules Électriques, 1995).

In 1993, Sweden decided to launch its own "Electric and Hybrid Vehicle" RD&D programme. In addition to technology development, it also included test-driving of vehicles for private and commercial purposes, and experimenting with infrastructure for recharge, battery exchange, and servicing. The goal was to evaluate the possibility to introduce AFVs to the Swedish market on a larger scale. In the course of the programme, the number of electric and hybrid vehicles used in the country went up from zero in 1993 to 650 in 2000 (KFB, 2000).

In 1995, Japan initiated a procurement programme aiming to replace 10% of vehicles in public fleets with AFVs by 2000 (battery, hybrid, and fuel cell electric vehicles, CNG and LPG vehicles, and methanol-fuelled vehicles qualified). In 2001, the goal was extended for all vehicles used by government with AFV by 2004. According to Åhman (2006), this first procurement programme did not meet the target as only a few AFVs were in use in 2000, mostly due to public budget constraints. The procurement programme complemented a number of promotional, leasing, and purchasing incentive programmes in operation since 1976. For example, the 1996 "Purchasing Incentive Programme" subsidised 50% of the incremental purchasing price of a battery-powered electric vehicle (BPEV). Initially only a small number of BPEVs were put in use (655 BPEVs between 1977 and 1996, mostly re-converted conventional vehicles) but starting 1997 the numbers began to rise faster following an expansion of government policies which now covered also hybrid vehicles. As Åhman (2006) points out, this helped Japan to become the first country to have a hybrid electric model on the passenger car market. In 2001, there were over 50 000 hybrid electric vehicles in use in Japan. As a next stage, by 2010 about 50 000 fuel cell electric vehicles should be introduced in fleets of public utilities and industry (Åhman, 2006).

More recently, other OECD countries have launched new or extended the existing public procurement programmes in order to accelerate market introduction of AFVs technologies. These include, for example, the United Kingdom (for example, see the "Low Carbon Vehicle Procurement Program" at *www.dft.gov.uk/pgr/scienceresearch/technology/lowcarbonvehicleprocurementprog*), United States (for example, see the Clean Cities Programme of 1993 at *www1.eere.energy.gov/cleancities*), Japan (for example, see the Green Procurement Law of 2000 at *www.env.go.jp/en/laws/policy/green* and the Plan to Control GHG Emissions at *www.env.go.jp/earth/action*), Australia (New South Wales) and Korea. For recent reviews of worldwide initiatives to increase "uptake" of AFVs see IEA (2009c) and SEI (2008).

Measures improving co-ordination

Demand-side infrastructure development

Markets for alternative fuel vehicles suffer from significant network externalities (re-fuelling infrastructure). Addressing these market failures is critical to achieving diffusion or "uptake" of the innovation. Besides achieving environmental objectives, a broad diffusion will create market demand which itself will provide continuing incentives for further product innovations (and thus allowing government to withdraw from supporting R&D).

For example, the United States' *American Recovery and Reinvestment Act* of 2009 provides an "alternative refuelling property credit" – a tax credit to businesses (*e.g.* fuel distribution stations) that install alternative fuel pumps, such E85 fuel, electricity, hydrogen, and natural gas (IEA, 2009a).

Another example is the German *National Development Plan for Electric Mobility (2010-20)* which, in addition to supporting R&D in batteries and electric car designs, targets developing the necessary infrastructure for a large-scale introduction of battery-powered vehicles in Germany. This includes the use of renewable energy and intelligent charging of batteries to stabilise power grid and integrate fluctuating renewable energies. Another important goal is to achieve international standardisation (technical norms) of charging infrastructure and associated vehicle components with the aim of reducing the overall infrastructure investment cost and increasing consumption spillovers. The Plan's stated goal is to have 1 million electric vehicles on German roads by 2020, and 5 million by 2030.[17]

An ambitious technology diffusion project has been adopted in Portugal. The 2009 *National Programme for Electric Mobility* aims at creating a nation-wide infrastructure that would allow a large-scale diffusion of electric vehicles. The goal is to develop a fully integrated and totally interoperable system, allowing any individual the access to any provider of electricity in any charging point exploited by any service operator. The goal is to ensure transparency in the market and thus low entry barriers and competition along the value chain. The Portuguese electric mobility network is projected to comprise 1 300 slow-charge and 50 fast-charge points, installed across the country over the next two years. Another objective of the plan is to achieve integration of the system with increasing renewable electricity production.[18]

In sum, national governments are currently taking steps that will shape the future electric vehicle market. As much as each of these steps is an important individual contribution to achieving wide market diffusion, co-ordination between national governments is desirable – notably to achieve a certain degree of interoperability of the national systems. For example, this can be achieved through harmonisation of technical norms (*e.g.* charging infrastructure). However, it is important that standardisation is not done too hastily and that the benefits of standardisation are weighted against its costs (*e.g.* reduced competition, risk of technology lock-in).

Supply-side innovation platforms and industrial networks

In addition to network externalities affecting the demand side, markets for innovation frequently suffer co-ordination problems resulting in high transaction costs. A *National Platform on Electric Mobility* envisaged in the above-mentioned German *National Development Plan for Electric Mobility* is an example of a measure intended to reduce these costs.

In the UK, the "Low Carbon Vehicles Innovation Platform" has been set up under the umbrella of the "Technology Strategy Board" which plays a leadership role in providing greater co-ordination of various government agencies and research institutions with the aim of stimulating business R&D and innovation, in particular through co-ordination of support for RD&D, combined with better co-ordination of policy and regulation, linked through to public procurement opportunities (IEA, 2009a) (see also *www.innovateuk.org* and *www.innovateuk.org/ourstrategy/innovationplatforms/lowcarbonvehicles.ashx*).

Measures taken in some non-OECD countries

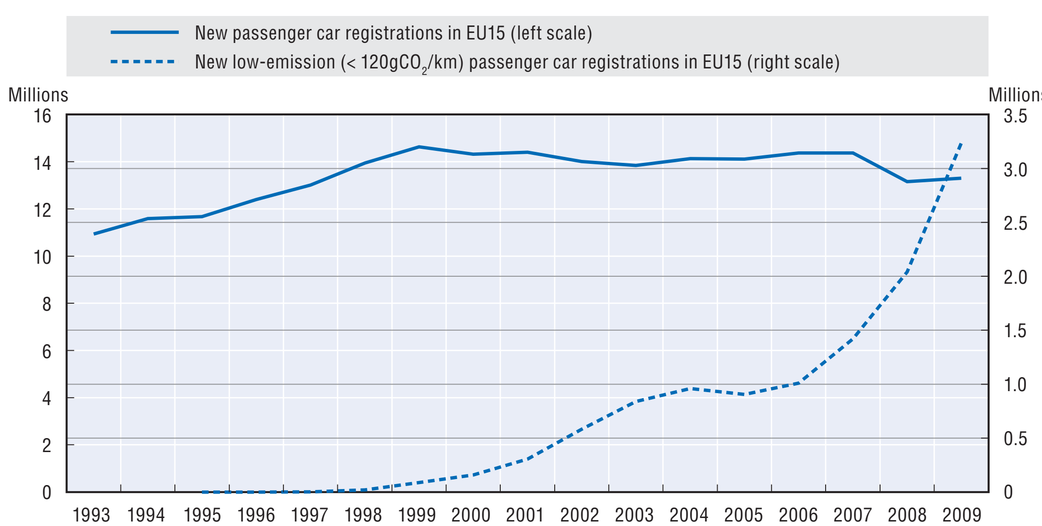
In China, vehicle excise tax rates, fuel efficiency standards, and differentiated VAT rates are applied. Excise tax rates for vehicles have been proportional to engine size since 1994. As of 2006, the range of tax rates was broadened accentuating the differences between cars with small and large engines. Mandatory fuel efficiency standards for passenger cars, established in 2004, classify vehicles into 16 categories based on vehicle weight. Different standard apply to vehicles with manual and automatic transmission. The standard values are maximum allowable limits for each vehicle type, not the limits for the fleet average of the categories. Differentiated value added tax rates are applied to purchase of vehicles – 3% VAT for less than 1.5 litres of cylinder volume and 20% VAT for 4 litres and above (IEA, 2009a).

In many other non-OECD countries policies have been put in place to improve fuel efficiency of conventional vehicles [*e.g.* in India (*www.dhi.nic.in/autopolicy.htm*) and South Africa (*www.polity.org.za/pdf/notice3324.pdf*)]. Moreover, several non-OECD countries appear to place a strong emphasis on steering their car markets towards ethanol and other biofuels as well as on increasing their domestic biofuels supply. Policies aimed at developing the markets for electric and hybrid vehicles seem to be of lesser importance or are lacking. This is in clear contrast with many OECD countries and may be linked to the status of technological development as well as natural resource factors. Biofuels policies, have been put in place for example in Brazil (biodiesel R&D, mandatory ethanol and biodiesel blending content) (*www.iea.org/textbase/pm/?mode=cc&id=4109&action=detail*, *www.iea.org/textbase/pm/?mode=weo&id=3437&action=detail*; see also *www.mme.gov.br/site/home.do* and *www.anp.gov.br*), India (ethanol production subsidies, mandatory blending) (*www.iea.org/textbase/pm/?mode=cc&id=3840&action=detail*; *planningcommission.nic.in/reports/genrep/cmtt_bio.pdf*), South Africa (biofuels strategy) (*www.dme.gov.za*), and China (pilot cities for using ethanol fuel) (*www.china5e.com/laws/index2.htm?id=200503220009*).

Adoption of AFV technologies

There is clear evidence that adoption of fuel-efficient lower-CO_2 vehicles (including those using conventional engines) has intensified and market shares have increased substantially in recent years (Figures 3.17 and 3.18). For example, in the course of three years the sales of lower-emission cars (less than 120g CO_2/km) in the European Union (EU15) have increased from 9% in 2006 to 25% in 2009.

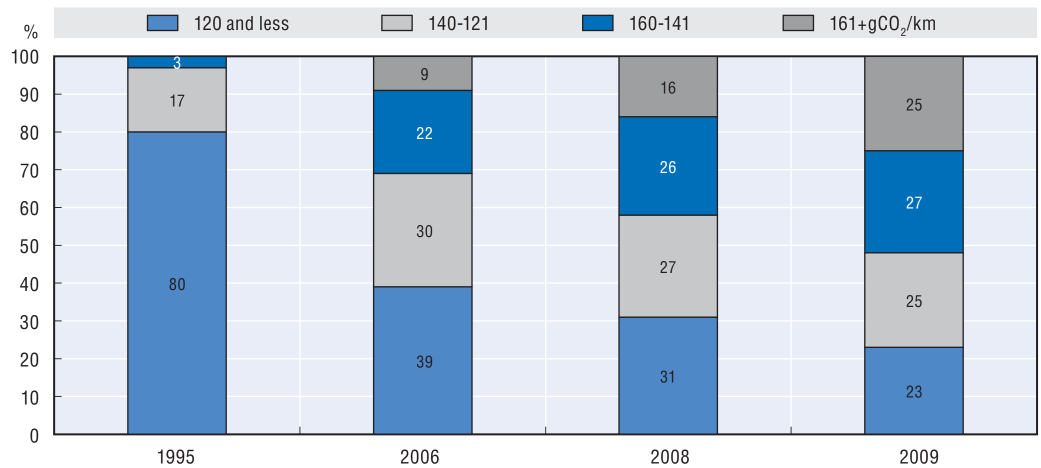
Figure 3.17. **Adoption of fuel-efficient vehicle technologies**



Source: ACEA (2010).

Figure 3.18. **Adoption of fuel-efficient vehicle technologies**

New passenger cars sold in the European Union (EU15) classified by CO_2 emissions (g CO_2/km)

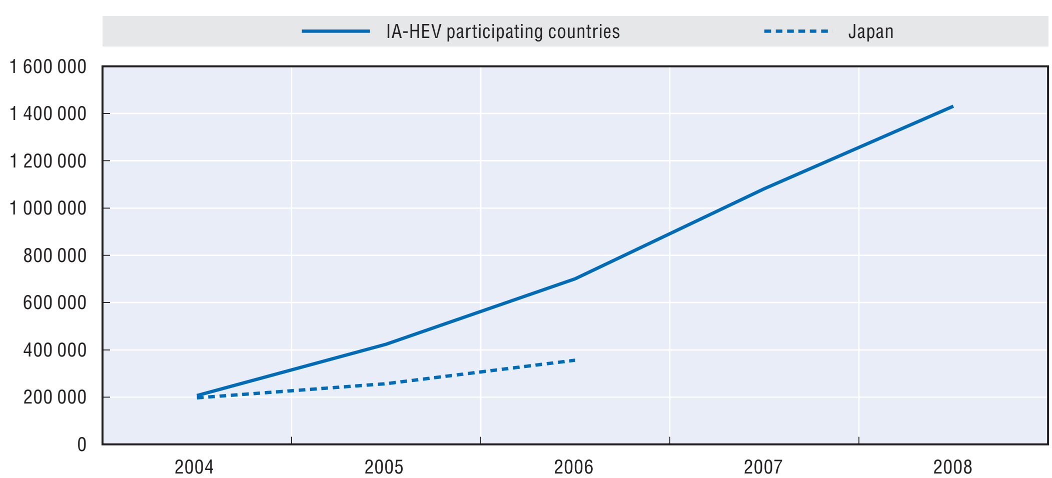


Source: ACEA (2010).

When it comes to alternative fuel vehicles, the limited evidence available suggests that while the sales of AFVs (mostly hybrid vehicles) have been growing rapidly (Figure 3.19), their market share remains rather low (*e.g.* 2.8% in the US, *www.electricdrive.org/index.php?ht=d/Articles/cat_id/5514/pid/2549*).

Figure 3.19. **Adoption of hybrid electric vehicles in selected countries**

Size of vehicle fleet



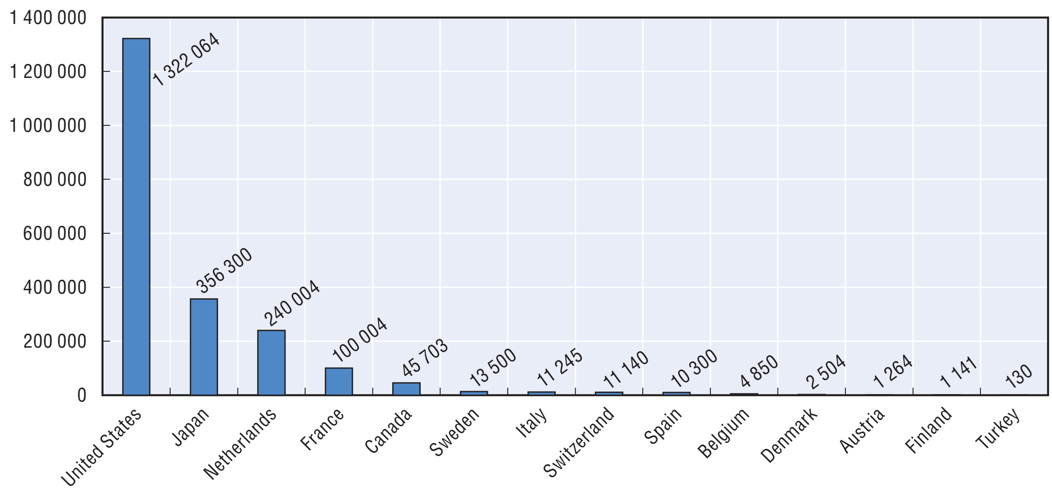
Note: Countries participating in the IA-HEV include: Austria, Belgium, Canada, Denmark, Finland, France, Italy, the Netherlands, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

Source: IEA's Implementing Agreement on HEVs (*www.ieahev.org/evs_hevs_count.html*).

According to the IEA's Outlook for Hybrid and Electric Vehicles, the United States, Japan, and the Netherlands have currently the greatest fleets of hybrid electric vehicles (Figure 3.20). The IEA expects that the growth in the share of hybrid cars worldwide is expected to continue and reach 2.2 million units by 2012, but remain below 10% of new car sales in 2015 (partly due to production restrictions, *e.g.* batteries). The share of electric cars is expected to be well below the share of hybrid cars in 2015 (IEA, 2009b).

Figure 3.20. **Adoption of hybrid electric vehicles in selected countries**

Stock of vehicles in 2008 or the latest available year



Note: Data for Japan and France for 2006; Sweden, Austria and Turkey for 2007.

Source: IEA's Implementing Agreement on HEVs (*www.ieahev.org/evs_hevs_count.html*).

Innovation effects of government policies: Empirical evidence based on patent data

In this section we provide preliminary evidence on the effects of policy measures (such as those discussed in Chapter 4) on inventive activity. While it is impossible to develop comparable data across all policy types, countries, and years we focus on the effects of pricing policies, standards and public R&D expenditures. However, a more informal comparison of some measures introduced in individual countries with innovation rates is possible.

As noted above, patent counts have been developed for AFVs based on extractions from the *PATSTAT Database* (EPO, 2009). We constructed a panel of 17 countries[19] and 25 years (1983-2007), however due to many missing observations for the R&D variable (Germany in particular) only 337 observations are retained for regression estimation. The dependent variable is constructed as the share of AFV patenting on sectoral patenting. This approach is suitable because: *i)* the denominator is well-defined in this case (unlike in some previous studies[20]); and *ii)* AFV patenting represents only a relatively small share of the sector overall. We verify that the estimation panel is non-stationary. We then estimate a fixed-effects panel data OLS with heteroskedasticity-robust standard errors.

We test several policy hypotheses. We regress the share of AFV on sectoral patenting on explanatory variables which include public R&D expenditures on fuel efficiency improvements in transportation (in millions USD using 2008 prices and PPP, obtained from the IEA's *Energy Technology R&D Budgets Database*). We also include after-tax gasoline and diesel prices (in USD per litre using 2008 prices and PPP, obtained from the IEA's *Energy End-Use Prices Database*). In both cases the expected sign is positive. Our third policy hypothesis is about the effect of the Zero Emission Vehicle (ZEV) regulation adopted in 1990 in California (USA) which targeted specifically the development and commercialisation of an electric vehicle.[21] This hypothesis is tested by controlling for the effect of the other vehicle fuel efficiency standards in place.

The ZEV standard mandates the percentage of manufacturers' future sales that must be ZEV-qualified vehicles. Over time, several amendments of the initial ZEV standard were adopted. Given this, a continuous variable is constructed as the upper "envelope" of the discounted (at 10%) stream of ZEV mandates applicable for a given year.[22] As such, the variable represents the "implicit" stringency of the series of ZEV mandates over time. And finally, the model also includes variables representing the various fuel efficiency standards (mandatory and voluntary standards, measured in km/l, lagged three years). The descriptive statistics for the panel dataset are provided in Table 3.6.

Table 3.6. **Descriptive statistics for the panel dataset**

Variable	Unit	N	Mean	Std. dev.	Min.	Max.
Share of electric vehicle patents on sectoral patenting	Count of claimed priorities	337	0.0186	0.0304	0	0.2553
Share of hybrid vehicle patents on sectoral patenting	Count of claimed priorities	337	0.0118	0.0266	0	0.25
Public R&D spending on energy efficiency in transport	mln USD 2008 PPP	337	23.12	51.46	0. 05	305.53
Gasoline price	USD per litre 2008 PPP	337	0.7964	0.2776	0.245	1.59
US-ZEV standard	Stringency index	337	3.27	2.29	0	7.51
US-CAFE standard	Km per litre	337	11.28	0.80	8.47	11.70
JP-CAFE standard	Km per litre	337	8.96	6.72	0	15.08

Note: Panel of 17 countries and 25 years (1983-2007).

The regression results (reported in Table 3.7) provide strong evidence of a positive and statistically significant effect of R&D spending on inventive activity both in the electric and hybrid technologies (given that our R&D variable is rather generic – it does not distinguish between spending on electric *versus* hybrid technologies – it not surprising that results do not vary much across the models estimated). We also find that fuel prices have a positive and significant effect on inventive activity in hybrid propulsion but no such evidence has been found for electric propulsion. Finally, we find that the ZEV standard has had a positive and statistically significant effect on inventive activity in electric propulsion, while the effect on hybrid inventions is insignificant. These results suggest that targeted R&D will encourage invention in both types of technologies. However, while fuel pricing is more likely to have an effect on technologies that are closer to the market (hybrids), technology standards appear to be necessary in order to incentivise invention in technologies further from the market, or more "radical" technologies (electric).

Table 3.7. **Regression estimates of the effect of standards, R&D, and prices on AFV inventive activity**

Dependent variable: Share of AFV on sectoral patenting	Electric		Hybrid	
	(1)	(2)	(3)	(4)
Specific public R&D expenditures	5.75e-05*	6.46e-05**	9.63e-05***	9.63e-05***
Gasoline price	0.0004	0.0058	0.0272*	0.0272*
US-ZEV standard	0.0029*	0.0026*	0.0005	0.0005
US-CAFE standard	0.0012	0.0011	0.0012	0.0012
JP-CAFE standard		–0.0002		–2.07e-06
Intercept	–0.0059	–0.0064	–0.0267	–0.0267
Country fixed effects	Yes	Yes	Yes	Yes
N	337	337	337	337

*** < 0.1%, ** < 1%, * < 5%. Panel of 17 countries and 25 years (1983-2007).

An alternative explanation is possible, namely that while a policy may induce advances in the development of an "electric" vehicle, they may not go far enough in order to constitute the "critical mass" of inventions necessary to producing an "electric" vehicle. However, such "partial" advances may turn out to be sufficient to produce a "hybrid" vehicle. (According to this line of thinking, hybrid vehicles would be a means for a partial cost recovery on the way to a full electric vehicle, thus allowing reducing the risk associated with such radical innovation.)[23]

No statistically significant effect is found for the US-CAFE standards. Similar results are obtained if the Canadian or the Australian standards are included instead (not reported); this not surprising given the high correlation with the US-CAFE standard. In the case of the Japanese and European standards no evidence of an effect is found. In alternative specification of the models, we also included the fuel efficiency standards one-by-one (US, JP, AU, CA, EU), and all together as one variable (assuming autarky[24]), but our findings remain unchanged. While no statistically significant effect of the CAFE standards on electric/hybrid patenting was found, these standards may have had an effect on inventive activity to improve fuel efficiency of conventional vehicles – the original target of the standards (hypothesis not tested here).

In sum, these estimates provide evidence that technology standards may have an effect on inventive activity provided they are sufficiently stringent. One could speculate that the differential effect of the standards on different technologies is due to differences in: *i)* the degree of stringency of a standard; *ii)* their mandatory or voluntary character; and *iii)* distance from the externality targeted (electric *versus* hybrid *versus* conventional).

Additional robustness checks were performed using alternative specifications of the model. The qualitative findings for standards and prices remain unchanged when the R&D variable is dropped from the model, thus allowing Germany to be included in the estimation sample because R&D data for Germany are missing. The same holds when an alternative R&D variable is included instead (we used "total energy R&D" expenditures; the estimated coefficient is insignificant, suggesting that the significant effect of the more targeted R&D variable – reported in Table 3.8 – is not a simple coincidence).

Table 3.8. **Estimated elasticity of patenting activity in electric and hybrid vehicles with respect to changes in standards, R&D and fuel prices**

	Electric		Hybrid	
	(1)	(2)	(3)	(4)
Public R&D exp.	0.0714*	0.0802**	0.1887***	0.1886***
Gasoline price	0.0158	0.2469	1.8357**	1.8325*
US-ZEV standard	0.5134*	0.4575**	0.1357	0.1365
US-CAFE standard	0.7145	0.6745	1.1040	1.1046
JP-CAFE standard		–0.1153		0.0016

Note: Based on conditional marginal effects evaluated at sample means.

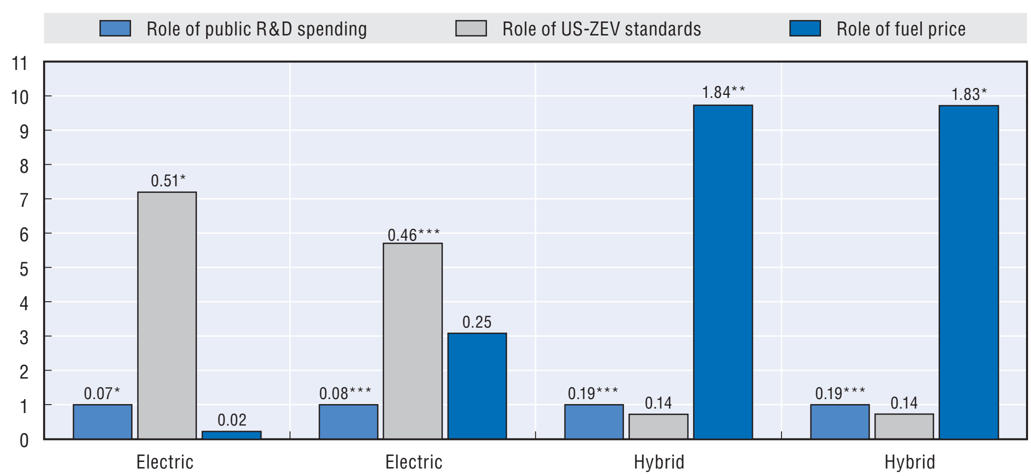
In addition, the dynamic effects have been examined more broadly. For example, lags of the US-CAFE standard ranging from 1 to 5 years yield similar results; lagging the R&D and price variables does have a cost in terms of lower significance levels of these regressors suggesting that there are short time lags between changes in these variables and invention, or that these changes are already integrated in inventors' expectations.

In order to facilitate interpretation of results (and their implications for policy design), we compute the marginal effects and elasticities corresponding to selected models reported in Table 3.8. The estimated elasticities suggest that for a 1% change in the stringency of the ZEV standard the level of inventive activity in electric propulsion will increase by about 0.5%. Similarly, for a 1% change in fuel price levels, invention in hybrid propulsion will increase by about 1.8%. However, both electric and hybrid patenting is rather inelastic with respect to public R&D expenditures because for a 1% rise in public R&D spending invention will increase only by 0.07-0.19%.

Overall, these results provide empirical evidence that the elasticity of inventive activity in electric vehicle technologies with respect to a standard is positive but relatively inelastic. Development of hybrid vehicle technologies is highly fuel price-elastic. And finally, for both types of technologies increases in public R&D budgets have positive but relatively minor effects.

To illustrate this point more clearly, in Figure 3.21 these elasticities are shown as multiples of the effect of R&D (normalised to R&D=1). This shows that the effect of fuel prices on "hybrids" patenting is 9-10 times greater than the effect of public R&D spending for an equal percentage marginal change, and that the effect of the ZEV standards on "electric" patenting is 6-7 times greater than the effect of public R&D.

Figure 3.21. **Effect of technology standards and fuel prices relative to the effect of public R&D (normalised to R&D = 1)**



Note: The histogram shows empirical elasticities, evaluated at sample means, and normalised in terms of the effect of "public R&D spending" (R&D = 1.0). Bars shown "without fill" represent estimates that are not statistically significant at the 5% level. Numbers above the bars give the actual elasticity estimates.

The implications of comparing a percentage change in R&D spending with a percentage change in stringency of a technology standard is difficult to translate directly into practical policy advice. With this in mind, we conducted calculations where rather than setting the change in policies to an equal percentage change and calculating the end results, we did the contrary – we first "fixed" the end result to be equal across the policy scenarios and then calculated the change in policies necessary to obtain this (fixed) end result. The aim is to illustrate the relative importance of the different policies in achieving a given goal. In other words, we asked the question: "What change in policies would be needed in order to obtain an equal (and infinitesimal) change in inventive activity?"

- For example, to induce a 1% increase in *electric* vehicle innovations, the alternatives are:
  - Increase the stringency of ZEV by 2% (*)[25] – that is, require a 3.33% mandate instead of 3.27% mandate, on average).
  - Increase public R&D by 14% (*) – that is, spend USD 26 mln instead of USD 23 mln per year per country, on average).
- Similarly, to induce a 1% increase in *hybrid* vehicle innovations, the alternatives are:
  - Increase fuel price by 5% (*) – that is, USD 0.84 instead of USD 0.80 per litre of gasoline, on average. However, the actual increase in fuel taxes would have to be higher, depending on the share of fuel taxes on the final price of automotive fuels. Since the tax share is approximately 50% in OECD countries, fuel taxes (value-added and excise taxes) would thus need to rise by about 10%, on average.[26]
  - Increase R&D by 53% (***) – that is, spend USD 35 mln instead of USD 23 mln per year per country, on average.

In sum, these results indicate that relatively minor changes in a technology standard or automotive fuel prices would yield effects that are equivalent to a much greater increase in public R&D budgets. However, it is important to note that the "political" feasibility of these alternatives is not equal, and may vary across countries. Therefore, while in theory two policies an equivalent level of stringency and with the same incidence (targeting the same externality) would be expected to have the same effect on innovation, the policies we observe (our empirical data) do *not* have the same level of "implicit" stringency and hence their effects are different.

Moreover, in practice policies are usually implemented as a "mix" of various policy instruments, partly a consequence of division of responsibilities between various government agencies[27] with imperfect co-ordination of policy-making (the "mixes" may be to varying degrees intended, or unintended). There may be positive or negative interaction effects between policy instruments included in a policy "mix". For instance, on the one hand public investment in R&D of frontier technologies may allow for more stringent regulation, on the other hand more stringent regulation may necessitate supporting R&D in selected technological areas in order to facilitate compliance by the private sector. (These interactions may be dynamically complicated and are not further addressed here.)

And finally, the "policy objectives" may vary across the policies examined with implications for both effectiveness and efficiency. For instance, technology standards and R&D spending place emphasis on inducing innovation. They have only indirect (and in the case of R&D, perhaps positive) effect on car ownership and car use. Conversely, fuel prices are often primarily intended to affect changes in car ownership and use, and the impacts on innovation are "incidental" (but potentially significant). Nevertheless, our results show that even slight changes in policies for which innovation effects may be secondary may stand as an attractive innovation-inducing alternative to increased public spending.

This work could be extended in several directions. For example, a case could be made to set up the estimation models in a conceptually different manner. The automotive industry is, for the most part, a highly concentrated and intensely multinational sector. Therefore, rather than examining the determinants of inventive activity (by inventor countries), it may be interesting to also examine "adoption" of inventions in different countries (patent jurisdictions). This would allow studying the effect of domestic *versus* foreign policies on international patenting more directly.

Conclusions and policy implications

There are a number of market failures and barriers which affect the markets for AFVs. These include at least the following:

- environmental externalities associated with emissions of local and regional air pollutants, as well as greenhouse gases;
- network effects and monopoly conditions associated with the infrastructure needed to fuel different vehicle types;
- consumption externalities which can result in slow take-up of "innovative" vehicles whose characteristics have not been fully demonstrated in the market; and
- capital market failures which can result in limited financing for high-risk investments (such as those associated with R&D in AFVs).

In order to overcome these market failures and barriers, government policies need to provide a whole spectrum of incentives from encouraging invention to commercialisation and diffusion. In designing such policies, several general principles should be borne in mind:

- The optimal mix of policies should address the different failures and barriers listed above – *i.e.* R&D support (upstream knowledge spillovers), prices (downstream externalities in use), labels (information failures) and procurement (network and demonstration effects).
- Policies whose environmental objectives are determined the basis of abatement costs using existing technologies are unlikely to stimulate innovation. Policies need to be sufficiently stringent to "force" technological change. This can be achieved through performance standards, awards and subsidies, and environmentally-related taxes. The latter are likely to be less demanding in terms of information requirements, but there may be political barriers to their implementation.
- Policies should create opportunity costs that provide incentives for innovators to drive emissions down to zero ("depth" of incentives). Such policies have the potential to encourage "radical" innovations, which have not been foreseen by policymakers.
- Policy flexibility is important so that a wide spectrum of technological options is examined – this applies to AFV relative to other fields as well as within the AFV field. The danger of "picking winners" (*e.g.* through public procurement, R&D support, standards) can result in early technological lock-in.
- Finally, and perhaps most importantly, continuous commitment to the policy objective is key. In order for innovators to take the necessary risks, they need a credible and predictable policy framework.

Notes

1. For example, widespread use of E85 could significantly increase local air pollution due to emissions of formaldehyde and acetaldehyde with ozone-related negative health effects (Jacobson, 2007).
2. According to Masters and Ela (2008) proton-exchange-membrane (PEM) cell, also called polymer-electrolyte membrane cell, is the most appropriate for vehicles.

3. Both, a fuel cell and a battery function on a similar principle as they convert chemical energy directly into electric energy. The difference is that batteries can be regenerated when charged, while fuel cells require re-fuelling.
4. For example, the data suggest that a conventional gasoline-fuelled engine is a rather inefficient way of converting the chemical energy stored in fuel into motion because only about 11% (urban area) to 20% (highway) of energy is actually used to move the vehicle.
5. Another example would be production of methanol from natural gas which yields no improvement in CO_2 emissions on a well-to-wheel basis (OECD, 2004).
6. Personal communication, The Delegation of Japan to the OECD, Meeting of the WPNEP, April 2009.
7. For example, it required a minimum driving distance of 100 miles on a single charge, later amended to 50 miles (Calef and Goble, 2007).
8. For example, see Calef and Goble (2007) for a discussion of ZEV's innovation effects. See also Gruenspecht (2001) and Calef and Goble (2007) (and references cited therein) for suggestions on improvement of the policy.
9. Personal communication, The Delegation of the USA to the OECD, Meeting of the WPNEP, November 2008.
10. Personal communication, The Delegation of France to the OECD, Meeting of the WPNEP, November 2008.
11. Personal communication, The Delegation of Japan to the OECD, Meeting of the WPNEP, November 2009.
12. Personal communication, The Delegation of Japan to the OECD, Meeting of the WPNEP, April 2009.
13. Personal communication, The Delegation of the United States to the OECD, Meeting of the WPNEP, April 2010.
14. Personal communication, The Delegation of Germany to the OECD, Meeting of the WPNEP, November 2008.
15. Personal communication, The Delegation of Italy to the OECD, Meeting of the WPNEP, May 2007.
16. Personal communication. The Delegation of Korea to the OECD, Meeting of the WPNEP, April 2009.
17. Personal communication, The Delegation of Germany to the OECD, Meeting of the WPNEP, November 2009. See also *www.bmu.de/english/mobility/doc/44799.php*.
18. Personal communication, The Delegation of Portugal to the OECD, Meeting of the WPNEP, April 2010. See also the "MOBI.E" pilot-project (*www.mobi-e.pt*) and the "National Energy Strategy for 2020" (*www.portugal.gov.pt/pt/GC18/Governo/Ministerios/MEI/ProgramaseDossiers/Pages/20100415_MEID_Prog_ENE2020.aspx*).
19. Including Austria, Australia, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom and the United States.
20. For example, innovations in air and water abatement as well as waste management (AWW), discussed in Chapter 2 of this book, are relevant to many "sectors". As such defining the denominator corresponding to AWW patents is complicated.
21. This assumes that California's ZEV mandates were of broad relevance for the entire United States and even internationally. For empirical evidence of such "California effect" see, for example, Perkins and Neumayer (2011).
22. Only mandates to be met with electric and hybrid vehicles were considered (pure ZEVs and ATPZEVs); proportion of the mandate allowed to be met by sales of vehicles with conventional engines, although fuel-efficient (PZEVs), were disregarded.
23. Indeed, it has been suggested that hybrid vehicles (referred to as "advanced-technology partial ZEVs" or ATPZEVs) could be considered a collateral outcome of California's ZEV regulation. According to one report, about 250 000 ATPZEVs have been delivered for sale in California as a result of the ZEV regulation (*www.arb.ca.gov/msprog/zevprog/2009zevreview/zevwhitepaper.pdf*).
24. In this latter case it is assumed that only "domestic" effects of policy are possible. This is in contrast to the former variables which are constructed assuming non-autarky – meaning that a country's policy may have an effect on activity at home as well as abroad.
25. Asterisks indicate statistical significance, with *** < 0.1%, ** < 1%, * < 5%. The numeric values used here refer to averages based on the estimation panel.

26. Among the OECD countries, the polar cases are a tax share of 67% in Germany and the UK, and 17% in the US.

27. For example, fuel taxation is typically in the domain of Ministries of Finance, while emission standards may fall under Ministries of Environment, and R&D grants may be disbursed by the Ministry of Transport.

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