ANALYSIS OF AUTO INDUSTRY AND CONSUMER RESPONSE TO REGULATIONS AND TECHNOLOGICAL CHANGE, AND CUSTOMIZATION OF CONSUMER RESPONSE MODELS IN SUPPORT OF AB 1493 RULEMAKING

CASE STUDY OF LIGHT-DUTY VEHICLES IN EUROPE

UCD-ITS-RR-04-14

June 2004

by

Belinda Chen
Institute of Transportation Studies
University of California, Davis 95616, USA
Ph (530) 754-5829
Fax (530) 752-6572
bschen@ucdavis.edu

and

Dan Sperling
Department of Civil and Environmental Engineering
and
Institute of Transportation Studies
University of California, Davis 95616, USA
Ph (530) 752-7434
Fax (530) 752-7872
dsperling@ucdavis.edu

Institute of Transportation Studies
One Shields Avenue
University of California
Davis, California 95616
Tel: 530-752-0247 Fax: 530-752-6572
http://www.its.ucdavis.edu/
email: itspublications@ucdavis.edu

FINAL REPORT

Contract 02-310
Project No. 008545

Analysis of Auto Industry and Consumer Response to Regulations and Technological Change, and Customization of Consumer Response Models in Support of AB 1493 Rulemaking –

Case Study of Light-Duty Diesel Vehicles in Europe

Belinda Chen
bschen@ucdavis.edu

Daniel Sperling

Prepared for the California Air Resources Board and
the California Environmental Protection Agency

Prepared by:
Institute of Transportation Studies
University of California, Davis
One Shields Avenue
Davis, CA 95616

June 2004

DISCLAIMER

The statements and conclusions in this Report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

ACKNOWLEDGEMENTS

This Report was submitted in fulfillment of Contract 02-310, *Analysis of Auto Industry and Consumer Response to Regulations and Technological Change, and Customization of Consumer Response Models in Support of AB 1493 Rulemaking*, by the Institute of Transportation Studies at the University of California, Davis (ITS-Davis) under the sponsorship of the California Air Resources Board. Work was completed as of June 1, 2004.

TABLE OF CONTENTS

ABSTRACT v
EXECUTIVE SUMMARY vi
1. INTRODUCTION 1
2. MANUFACTURERS' PERSPECTIVE ON LIGHT-DUTY DIESEL VEHICLES 2
Diesel vehicles as a CO_2 reduction strategy 2
Automaker R&D 4
European emission standards 4
Vehicle Costs and Pricing 5
3. CONSUMERS' PERSPECTIVE ON LIGHT-DUTY DIESEL VEHICLES 7
Diesel vehicle characteristics 7
Potential economic incentives 9
Other potential consumer considerations 13
4. EXPLAINING THE DIFFERENCES IN LIGHT-DUTY DIESEL VEHICLE SALES 13
5. SUMMARY AND CONCLUSIONS 17
REFERENCES 18

ABSTRACT

Diesel vehicle sales in the European Union have increased from 23% of all light duty vehicles sold in 1994 to 41% in 2002. This rapid increase in market penetration is due to four related factors: a voluntary agreement by European automobile manufacturers in 1998 to reduce CO_2 emissions from new light duty vehicles by 25% from 1995 levels by 2008; significant advances in diesel technology; preferential fuel and vehicle pricing in most European countries; and preferential European Union regulation of diesel emissions. However, the growth in sales is not uniform throughout Europe, largely due to differences in fuel and vehicle pricing.

EXECUTIVE SUMMARY

Diesel vehicles are steadily increasing their share of the European light duty automotive market. Sales of diesels in the European Union have nearly doubled between 1994 and 2002, from 23 percent to 41 percent. Four factors explain this growth: improved diesel technology, fuel and vehicle taxation policy that favors diesels, air pollutant emission policies that favor diesel, and a voluntary agreement by automakers to reduce carbon dioxide (CO_2) emissions per vehicle kilometer by 25 percent between 1995 and 2008.

The voluntary agreement is key. It provides the overarching policy framework for industry, national governments, and local governments to support diesel engines (and other technologies that emit less CO_2). The automotive industry is focusing on diesel engines as the best way to achieve the CO_2 reduction goal, and a variety of measures have been put in place to support this strategy. Diesel engines are indeed a credible strategy to reduce CO_2 emissions. The mix of new light-duty diesel vehicles in 2002 for the entire European Union consumed about 20 percent less fuel and emitted roughly one-tenth fewer CO_2 emissions per kilometer than average new gasoline vehicles.

Improvements in diesel technology have been important to the upsurge in diesel sales. European automakers have invested heavily in advancing diesel technologies. These improvements have changed the common perception of diesels as heavy, noisy, and polluting, enhancing their appeal to a broader range of consumers—not only those looking for sizeable fuel savings. Those improvements continue. Diesel vehicles are now roughly equivalent in performance to gasoline vehicles, though consumers pay a premium for the additional fuel savings.

The surge in diesel vehicles sales has been facilitated by European emission standards that, unlike the United States, allow diesel engines to emit more particulate matter and nitrogen oxides than gasoline engines. Emission improvements have been dramatic, but still lag gasoline technology, especially for nitrogen oxides.

Diesel vehicle market shares are not uniform across Europe, however. Differences are largely explained by differing taxation policy – mostly related to fuels and vehicles. In some countries, diesel fuel is priced as much as 40% less than gasoline fuel, which can lead to substantial savings in fuel expenditures when combined with the improved fuel economy of diesel vehicles. In other countries, registration and annual ownership taxes are structured specifically to encourage purchasing low CO_2-emission vehicles. Together, favorable vehicle and fuel taxation policies have clearly played a central role in expanding light duty diesel vehicle sales in Europe.

1. INTRODUCTION

The European Union (EU) signed the Kyoto Protocol in 1997 pledging to reduce its emissions of greenhouse gases 8 percent below 1990 levels by 2008-2012. [1] Carbon dioxide (CO_2) is the most prevalent of greenhouse gases, and combustion of fossil fuels is the principal source of anthropogenic CO_2 emissions. The transportation sector accounts for 28 percent of total CO_2 emissions in Europe, with roughly 12 percent of the total produced by passenger vehicles. [2] To comply with the pending Kyoto Treaty and to pursue an overall goal of reducing greenhouse gases, the European Council and Parliament—the EU's legislative bodies—established a goal of reducing CO_2 emissions from new passenger vehicles to below 120g CO_2/km by 2005, or 2010 at the latest. It was stated that most of these reductions would be achieved through technological measures taken by industry with the remainder through consumer demand measures such as education and fiscal incentives that would encourage the purchase of more efficient vehicles.

The regulatory body of the EU, the European Commission, began negotiating with automakers in the mid 1990s to reduce CO_2 emissions from passenger vehicles. In 1998, the European Automobile Manufacturers Association (ACEA) voluntarily agreed with the European Commission to reduce average CO_2 emissions from new vehicles below 140g CO_2/km by 2008 (equivalent to about 41 miles per gallon of gasoline), representing a 25% reduction from 1995 levels. The agreement applies only to M_1 category vehicles, defined as vehicles used for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat. Members of ACEA include BMW, Daimler Chrysler, Fiat, Ford of Europe, General Motors Europe, Porsche, PSA Peugeot Citroen, Renault, Scania, Volkswagen, and Volvo. In addition, ACEA committed to an interim target of 165-170g CO_2/km for 2003, when it would also evaluate the potential of achieving an industry average of 120g CO_2/km by 2012. The voluntary agreement indicated that by the year 2000 some individual vehicle models would be introduced that emit less than 120g CO_2/km. Should the industry achieve its target reductions, the voluntary commitment is estimated to account for over 15% of the EU's total reductions required by the Kyoto Protocol. [1]

ACEA's voluntary commitment is based on several important conditions. The first assumption is that clean fuels (less than 50 ppm sulfur content) will be widely available by 2005 to enable the application of catalysts and particulate filters whose effectiveness is highly sensitive to sulfur levels. Second, non-ACEA automotive companies would be required to make equivalent commitments to reduce CO_2. In 2000, the Japanese and Korean Automobile Manufacturers Associations, comprised of all companies headquartered in those countries, agreed to similar objectives, thereby resulting in all major international automakers agreeing to the same voluntary standards. Thirdly, the commitment was adopted with the condition that failure to make sufficient progress towards achieving this goal would result in legislative action in 2008. Lastly, the Commission would not hinder the diffusion of CO_2 efficient technologies by such measures as tightened vehicle emission standards.

A voluntary agreement is a unique approach to regulating emissions, and contrasts with the policy approaches used in the United States (and Japan). In the US, the federal government imposes mandatory performance standards for fuel economy and air

pollutant emissions, a more adversarial and legalistic approach. The then-president of ACEA, Bernd Pischetrider, Chairman and CEO of BMW, stated at the time of the agreement that "the voluntary approach will provide much greater flexibility. In particular, one of the main objectives of ACEA's collective commitment is to preserve the rich diversity of product offering within Europe's car manufacturers for the benefit of our customers and the entire EU economy." [3 1998] By establishing an industry-wide standard, the agreement acknowledges that reductions are less costly for some manufacturers than others and that emission levels vary widely among different vehicle types. Thus, individual manufacturers are not bound to meeting specific targets. Additionally, because improved fuel economy implies a tradeoff with other attributes such as vehicle size or horsepower, an individual manufacturer may be reluctant to introduce a new technology for fear of losing market share to competitors who have not made a similar tradeoff. However, a voluntary agreement applicable to all manufacturers may minimize such risks if the entire industry is working collectively towards the target reductions. [4]

By 2002, CO_2 emissions of new vehicles sold in Europe had fallen to 166g CO_2/km, meeting the interim target ahead of schedule. [5] However, manufacturers are resisting recent discussions with the European Commission to establish a new reduction target of 120g CO_2/km for 2012. [6] Automakers contend that the cost of achieving such large reductions in CO_2 would be far more than consumers are willing to pay. In a study commissioned by ACEA, Arthur D. Little management consulting company found that the cost of meeting the new target would amount to $61 billion each year for the industry or about $4,900 per vehicle, mostly from changes in the powertrain. [7] To date, ACEA will only publicly commit to the original target of 140g CO_2/km by 2008. [6] Meanwhile, the European Commission seems intent on reducing emissions to the 120g CO_2/km level between 2005 and 2010.

2. MANUFACTURERS' PERSPECTIVE ON LIGHT-DUTY DIESEL VEHICLES

Diesel vehicles as a CO_2 reduction strategy

Light-duty diesel vehicles are considered one of the major technologies for achieving short-term reductions. Although diesel fuel is roughly 15% more carbon-intensive than gasoline per volume, the higher fuel efficiency of diesel vehicles results in fewer carbon emissions per mile. [8] The difference in efficiency stems from the fact that diesel fuel contains about 11% more energy per volume than gasoline and that diesel engines are able to operate at higher compression, allowing for a more efficient combustion process. [9] In almost all countries, the difference between diesel and gasoline fuel consumption has been increasing since 1995, with the average diesel vehicle widening its fuel economy advantage. By 2002, diesels in the EU averaged 20% lower fuel consumption per kilometer than gasoline vehicles. Fuel consumption of gasoline vehicles has not remained stagnant, though, with gasoline consumption also falling each year in every country. Figure 2.1 compares the average fuel consumption of new diesel and gasoline vehicles sold in the EU and its member countries. However, these averages reflect sales volumes of models. Comparing equivalent versions of gasoline and diesel vehicles reveals diesels consuming about one-quarter less fuel per

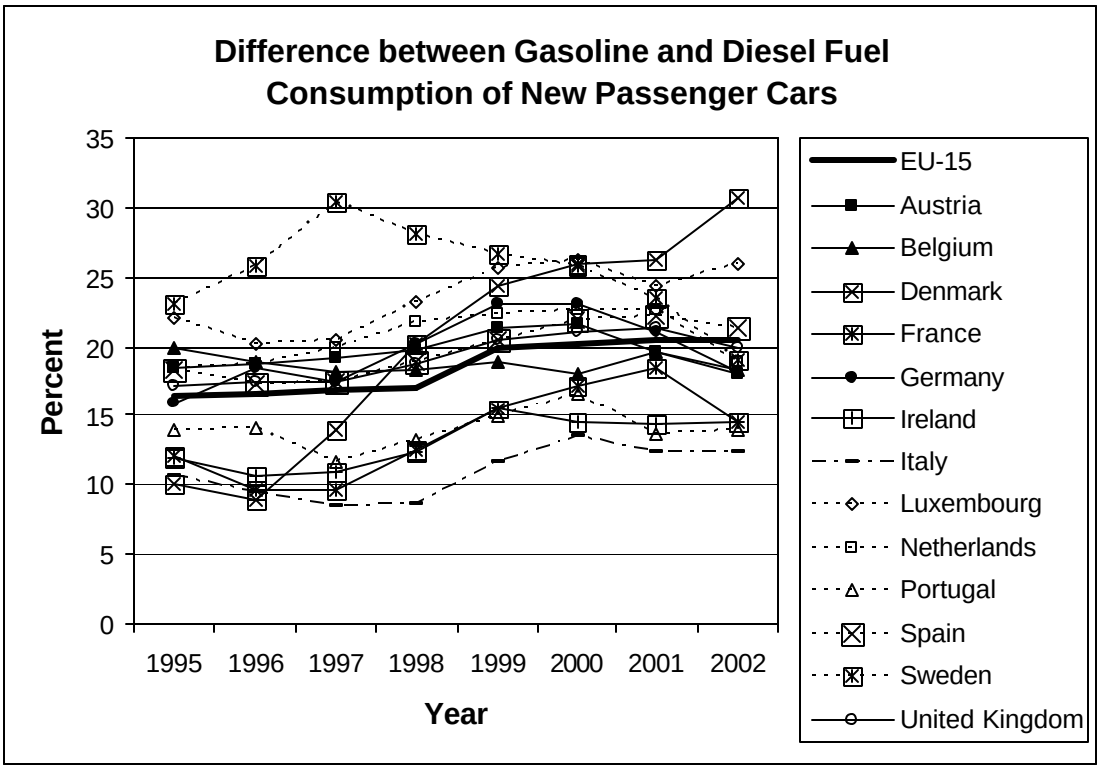

Figure 2.1 DIFFERENCE IN FUEL CONSUMPTION OF NEW PASSENGER CARS

Percent difference in diesel vehicle fuel consumption from gasoline consumption, e.g. in the EU the average new diesel vehicle consumed 16-21% less fuel than the average new gasoline vehicle.

(Sources: Monitoring of ACEA's Commitment on CO_2 Emissions Reduction from Passenger Cars 1995-2002, Joint Report of the European Automobile Manufacturers Association and the Commission Services)

kilometer. [10] The fact that this difference is not reflected in most countries—fuel consumption differs by 25% or more in only three countries—indicates that diesel sales are weighted towards larger higher-consuming vehicle models.

In 2002, gasoline vehicles sold in Europe emitted an average of 172g CO_2/km, while new diesel vehicles emitted nearly 10% less (155g CO_2/km), with some recent models emitting as low as 108g CO_2/km[1]. [12] The difference in CO_2 emissions from diesels are not nearly as great as the reduction in fuel consumption, reflecting the higher carbon content of diesel fuel compared to gasoline. As with fuel consumption, CO_2 emissions are weighted by sales. Thus, additional emissions reductions could be achieved by promoting the sale of more efficient vehicles—both gasoline and diesel. However, even a complete shift to diesel vehicles assuming current technologies and sales mix would only provide 40% of the necessary reductions to meet the commitment's targets. Also, some of these reductions would be offset by the increased energy required to produce low-sulfur diesel fuel required to comply with stricter emission standards. [13]

While a shift to diesel vehicles was never envisioned to be the sole strategy for achieving emissions reductions, they have played an important role in the industry's progress to date. Roughly 90% of diesel vehicles sold in 2001 emitted less than 180

[1] Citroën launched their 1.4 C2 in September 2003 claiming 108g CO2/km and a fuel economy of up to 70 mpg. [11. *UK: Small diesel car sales up 25%*, in *Just-Auto.com Daily News Alert*, D. Leggett, Editor. 2003, Just-Auto.com. p. Source: just-auto.com editorial team.]

gCO_2/km (over one-third of sales already meeting the 140 gCO_2/km goal) compared to only about 65% of gasoline vehicles falling into that category (less than 15% meeting the commitment target). [14] Nearly 20% (7.9g CO_2/km) of the 25% reductions called for in the voluntary agreement is expected to be achieved through widespread diffusion of diesels. [8] However, the reductions from diesels result not only from the change in fuel type but also from greater efficiency improvements of diesel technology compared to gasoline vehicles. [15]

Automaker R&D

European automakers are currently devoting half of their research and development expenditures to CO_2 efficient technologies. [16] The European Council for Automotive Research and Development, EUCAR, is a strategic cooperation of European automakers for technological innovation. In 1998, EUCAR launched 'CO2perate' specifically to research CO_2 emissions reductions technologies within the constraints of safety, affordability, and consumer acceptance. The program is funded through 2004 at 300 million EUR, with funding split mostly between the EU and the industry. [17] Research is directed toward powertrain development of traditional combustion engines and hybrid electric and fuel cell vehicles, light weight materials, and improved efficiency of electronics and vehicle control systems. The EUDIESEL project, a joint venture of automakers, suppliers, and universities, aims to develop a direct injection diesel passenger car with improved air pollutant emissions, while still maintaining the fuel economy of most diesels. Such vehicles would combine high-pressure fuel injection, electronic valve control, and homogeneous charge compression ignition to reduce NO_x and particulates.

These internally and cooperatively funded R&D investments have proven successful as manufacturers have been able to develop and introduce new and improved technologies on a large scale, producing early emissions reductions beyond their expectations. [15] The use of diesel engines and fuels is playing a key role, but automakers are also developing and introducing a variety of other efficiency-improving technologies, including turbochargers, high pressure direct injection systems for gasoline as well as diesel engines, new transmission systems, starter-alternators, electric steering, and improved air-conditioners. [16] ACEA expects that direct injection engines, for both gasoline and diesel engines, will comprise 90% of the new vehicle market by 2008. [18] The European manufacturers have less experience with hybrid drivetrains than the Japanese, and have chosen to focus on diesels to achieve CO_2 reductions. However, EUCAR's Surplus Value Hybrid (SUVA) program hoped to have a marketable hybrid available in 2004, though they have yet to announce any significant progress towards this goal to date.

European emission standards

European automakers' strategy to pursue light-duty diesel vehicles was enabled by favorable emission standards. Unlike the United States where light duty gasoline and diesel vehicles must comply with the same air pollution regulations, diesels in Europe are subject to different standards than gasoline vehicles. Current and future emission standards in Europe are detailed in Table 2.1. Under the conditions of the industry's agreement, these standards are not likely to be further tightened before 2008. In an

uncontrolled state, diesel engines emit less carbon monoxide and hydrocarbons than gasoline engines, but more nitrogen oxides and particulate matter. Dramatic progress has been made in the past few years in reducing particulate emissions from diesel engines, and future diesel engines are expected to have particulate emissions comparable to those of gasoline engines. However, current Euro 3 standards for particulate matter emissions from diesel vehicles are more than eight times higher than US Tier 2 standards on a per-kilometer basis, and also less stringent in that they apply only for 80,000 kilometers, versus 193,080 kilometers for US standards.[2] This discrepancy is reduced somewhat by Euro 4 standards that take effect in 2005, but even then the standards will still be about four times higher for diesel vehicles than US Tier 2 standards – and for only 100,000 km.[3]

Reduction of nitrogen oxide emissions from diesel engines has proven far more difficult and costly. Current EU standards allow diesel cars to emit roughly three times more oxides of nitrogen than gasoline engines, and upcoming Euro 4 standards are almost six times less stringent for diesel vehicles than US Tier 2. For gasoline vehicles, European standards are about two times less stringent than US standards. In this case of NOx emissions, diesel's preferential treatment is critical. If diesel vehicles were required to meet the same low level of NOx emissions as gasoline cars, the additional cost would be substantial. [19]

Table 2.1 EUROPEAN VEHICLE EMISSION STANDARDS (GRAMS PER KILOMETER)

		Carbon Monoxide		Hydrocarbons		Oxides of Nitrogen		Particulates
		Diesel	Gasoline	Diesel[1]	Gasoline	Diesel	Gasoline	Diesel
Euro 3[2] (2000)	PC	0.64	2.3	0.06	0.20	0.50	0.15	0.05
	LT[4]	0.64-0.95	2.3-5.22	0.06-0.08	0.20-0.29	0.50-0.78	0.15-0.21	0.05-0.1
Euro 4[3] (2005)	PC	0.50	1.0	0.05	0.10	0.25	0.08	0.025
	LT[4]	0.50-0.74	1.0-2.27	0.05-0.07	0.10-0.16	0.25-0.39	0.08-0.11	0.03-0.06

[1] Hydrocarbon limits for diesels calculated by subtracting NOx limit from combined hydrocarbon and oxides of nitrogen limit; no standards exist only for hydrocarbons.
[2] Euro3 standards apply for a useful life of 80,000 km
[3] Euro4 standards apply for a useful life of 100,000km
[4] Light truck values represent the range for Classes I, II, and III (Reference Mass RW<1305kg, 1305kg<RW<1760kg, RW>1760kg)
(Source: [1])

Vehicle Costs and Pricing

Although diesel vehicles do indeed emit less CO_2, automakers presumably would not pursue diesels as a CO_2 reduction strategy without a sound business case—particularly since at present the agreement is voluntary and each manufacturer is free to develop a range of technological options. One may therefore conclude that the recent success of diesels is in part due to their profitability and not just their CO_2 savings. Diesel sales have been so strong that recently demand has been exceeding supply. Both Renault and PSA/Peugeot-Citroen attributed lost sales in 2001 to a lack of diesel engines. Managing director of Automobiles Citroen said, "We could have made more sales if our

[2] Note that the US and EU use different test cycles to obtain vehicle emissions levels.
[3] US Tier 2 and California LEV2 standards no longer are uniform numbers but include a range of emission level "bins" that vehicles can be certified at, but each automaker must still meet average standards for its fleet.

diesel engine production had been up to it." In fact, Renault halted assembly at two plants in 2002 due to the shortage of diesel engines rather than accumulate gasoline vehicles. [20]

Diesel vehicles do have higher production costs than their gasoline counterparts. Diesel vehicles must be built to withstand a higher compression ratio which adds to both vehicle weight and material costs. Most diesel vehicles are also equipped with turbochargers, sophisticated direct-injection systems, and emissions control equipment such as particulate traps and regenerative filters that may not be installed in gasoline vehicles. Major automotive suppliers such as Bosch, Siemens, and Delphi have been competing to supply diesel engine components to the expanding diesel car market. [21]

A direct comparison between diesel and gasoline vehicles is not straightforward. But in a sample of 41 pairs of diesel and gasoline vehicles, Verboven found the average wholesale replacement cost of a diesel engine to be $586 more than a gasoline engine. Meanwhile, the difference in vehicle prices averaged $1567. [22] Based on this observation and the results of a consumer demand model, Verboven estimates that only 10-25% of the price premium for diesel vehicles can be attributed to their higher production costs. [22] The remainder of the difference is due to firms discriminating between consumers traveling high and low-mileage, essentially charging more to consumers valuing fuel economy. The amount of the premium depends on fuel costs, which in turn vary by country. Table 2.2 details the variation in vehicle prices in the fifteen EU countries for a single popular-selling model. (Note that this table is only intended as an illustrative example of price variations and may not represent all vehicles on the market.) In almost all cases, diesel vehicles are priced 800-6040 EUR higher than gasoline vehicles of equivalent performance (as measured by horsepower), suggesting that the additional costs are passed on to consumers, often with significant profit to the automaker.

Table 2.2 PRICE OF PEUGEOT 307, GASOLINE AND DIESEL MODELS, TAXES INCLUDED

Vehicle Price w/tax (EURO)	2.0 HDi (90 bhp) Diesel	1.6 (110 bhp) Gasoline	Price Difference for Diesels
Austria	19,900	19,000	+900
Belgium	18,760	17,460	+1,300
Denmark	33,266	29,091	+4,175
Germany	16,350	15,550	+800
Greece	NA	16,950	NA
Finland	25,100	21,600	+3,500
France	18,450	16,800	+1,650
Ireland	25,655	22,205	+3,450
Italy	18,650	17,150	+1,500
Luxembourg	17,829	16,594	+1,235
Netherlands	23,710	19,900	+3,810
Portugal	29,015	22,975	+6,040
Spain	18,600	17,090	+1,510
Sweden	16,771	16,771	0
United Kingdom	20,320	19,034	+1,286

EUROS, MODEL YEAR 2003. (Source: www.peugeot.com)

3. CONSUMERS' PERSPECTIVE ON LIGHT-DUTY DIESEL VEHICLES

As essentially the same models of diesel vehicles are offered throughout all the European markets, the variability in diesel sales between countries is best explained by differing consumer preferences and economic incentives. [23] The rise in diesel popularity can be attributed to a number of complementary factors. Much of the recent surge in diesel sales is due to technological advances that have improved vehicle performance. These improvements have changed the common perception of diesels as heavy, noisy, and polluting vehicles while maintaining their fuel economy advantages, making them appealing to a broader range of consumers—not only those looking for sizeable fuel savings such as taxis. [10] At the same time, the price of diesel fuel continues to be about 20% less expensive than gasoline (see Figure 3.1) and the taxation policies in a number of countries favored diesel vehicle purchases. However, the differences in these factors in each country have contributed to the varying growth in diesel vehicle sales.

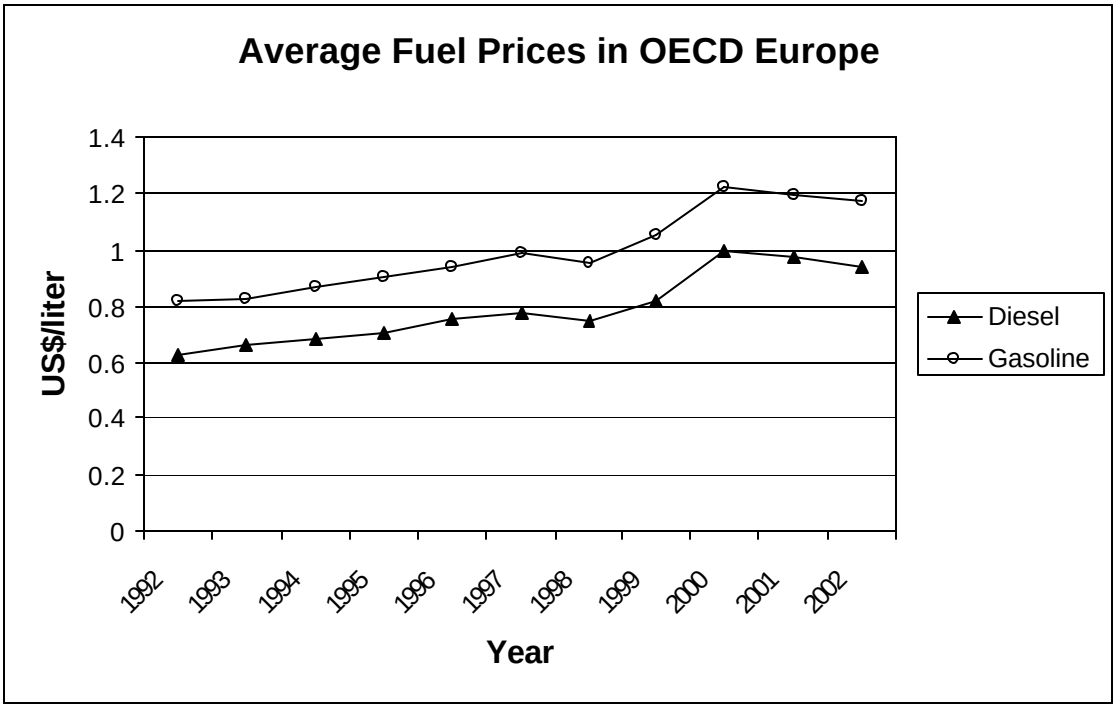

Figure 3.1 COMPARISON OF FUEL PRICES IN OECD EUROPE

Diesel prices are for non-commercial use, gasoline prices are for unleaded (95 RON). Prices are in constant dollars using purchasing power parities.
(Sources: IEA Energy Prices and Taxes 1999: 3rd-4th Quarter and 2003: 2nd Quarter)

Diesel vehicle characteristics

Overall growth in diesel sales is arguably product driven. For the consumer, diesels have provided improved performance without sacrificing fuel savings. While the industry's CO_2 agreement may have motivated manufacturers to invest more heavily in diesel technology, consumer appeal would have been limited without vehicle improvements that made diesel performance comparable to that of gasoline vehicles.

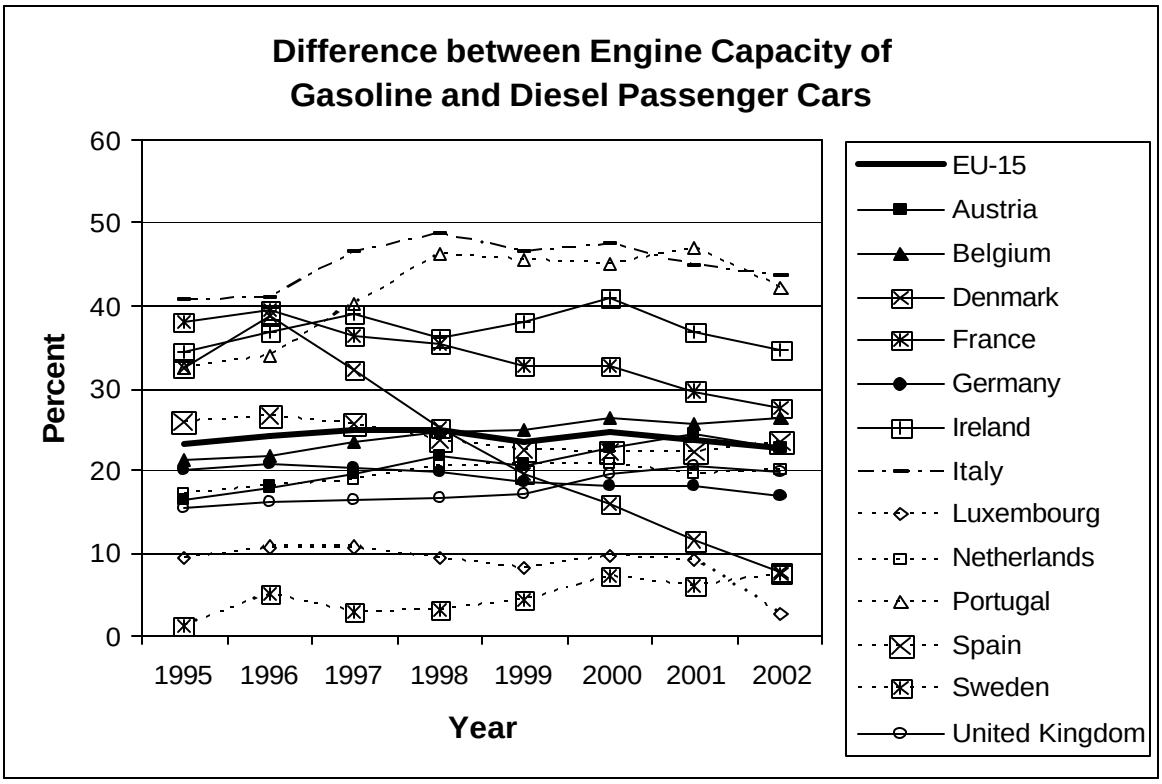

Figure 3.2 TRENDS IN ENGINE SIZE DIFFERENCES FOR NEW DIESEL AND GASOLINE CARS
(Sources: Monitoring of ACEA's Commitment on CO_2 Emissions Reduction from Passenger Cars 1995-2002, Joint Report of the European Automobile Manufacturers Association and the Commission Services)

Diesel engines are generally more durable than gasoline ones but also more expensive, larger, and heavier. The added weight results from the fact that a larger sized engine is required to obtain the same performance as a gasoline engine. [10] Though compression ignition engines used in diesel vehicles produce greater torque, they produce lower power for the same engine size. Thus, as shown in Figure 3.2, the engine size of the average diesel vehicle sold is always larger than for the average gasoline vehicle, though this difference varies by country. [15] The wide range is likely due to the sales-weighting, with consumer in some countries favoring the larger, more powerful diesels. However, engine sizes of each type have remained remarkably stable over time within each country. From 1995 to 2001 gasoline engines in Europe grew by only 1.3% and diesels by 1.6%. [15]

Meanwhile, both vehicle weight and power have been increasing steadily. Such trends suggest that vehicles have become more fuel efficient—in part through design improvements in air drag and rolling resistance—but not all of the efficiency gains have translated into fuel savings. [24] The improved efficiency can instead be used to increase the size or performance of a vehicle with no changes to fuel consumption. Diesel vehicle weight has increased 100-200 kg more than the weight of gasoline vehicles since 1995. However, vehicle weight of both fuel types have almost all been increasing since 1995 despite the decrease in fuel consumption and CO_2 emissions. Overall, between 1995 and 2001, diesel vehicles increased in weight by almost 10%. [15] This increase in vehicle weight not only accounts for larger engines but also larger vehicle sizes. Similarly,

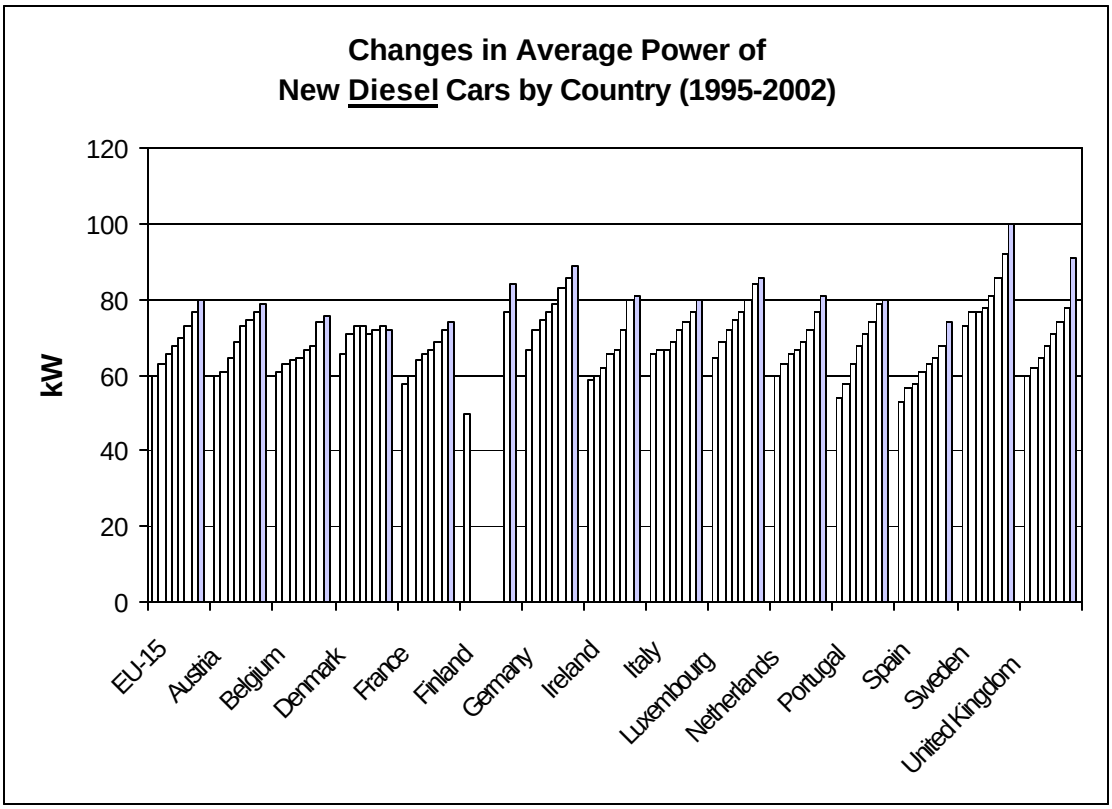

Figure 3.3 TRENDS IN AVERAGE POWER OF NEW DIESEL CARS
(Sources: Monitoring of ACEA's Commitment on CO_2 Emissions Reduction from Passenger Cars 1995-2002, Joint Report of the European Automobile Manufacturers Association and the Commission Services)

average power of new diesel vehicles grew by almost 30% between 1995 and 2001, with averages fairly similar between countries. (See Figure 3.3) [15] At the same time, power of the average gasoline vehicle sold has remained relatively constant over time. For diesels, the increased power presumably broadens the vehicle's market, appealing to both luxury markets and small economy vehicle segments. The increase in size and power results from both the introduction of new models as well as incremental increases among existing models as manufacturers continue to distinguish their products from competitors by offering additional power, space, and amenities for the same price. [24] Such improvements in vehicle characteristics have made diesel vehicles more comparable to their gasoline equivalents with the additional benefit of improved fuel economy. However, whether consumer demand or manufacturer marketing is responsible for these trends is unclear.

Potential economic incentives

According to a 1999 survey of motorists in Britain, France, Germany, Italy, the Netherlands, and Spain, 49% of respondents ranked fuel costs as one of their top three concerns regarding road transportation (28% of total respondents ranking fuel costs as their top concern), compared to only 15% for the effect of cars on the environment (3% ranking as their top concern). [25] Thus, the growth in diesel sales from the consumer's perspective seems to relate more to their private costs of vehicle ownership than to the

social costs of CO_2 emissions. Diesel vehicles have the potential to offer substantial savings to their owners.

FUEL PRICES. Referring again to Figure 3.1, there is a substantial difference in fuel prices that would favor the sale of diesel vehicles in Europe. The difference between diesel and gasoline fuel prices is largely due to the differences in fuel taxes. With the exception of the United Kingdom where the difference has been slowly eliminated since 1995, diesel is taxed between 13-45% lower than gasoline. (See Figure 3.4) Countries with higher fuel taxes tend to have no or low registration tax, thus using the fuel tax to compensate for the lost revenue. [2] As a result of these fuel tax policies, diesel vehicle owners stand to save significantly in fuel expenditures, especially drivers with high annual driving distances. Consumer choice models typically base fuel type choices on mileage heterogeneity because they assume that consumers have a different willingness to pay for fuel savings. [22] Results of a nested logit model on three groups of vehicles of varying fuel efficiencies indicate that vehicle demand is elastic with respect to operating costs, which mostly consist of fuel costs. [26] Thus, a rational consumer would choose to purchase a diesel when the higher fixed initial costs of the vehicle can be offset by the lower operating costs in the long run.

Returning to the prior illustrative example of the Peugeot 307 shows the potential benefit of diesel vehicles to consumers between countries (See Table 3.1). Assuming that the diesel and equivalent gasoline versions were driven the same distances per year in a

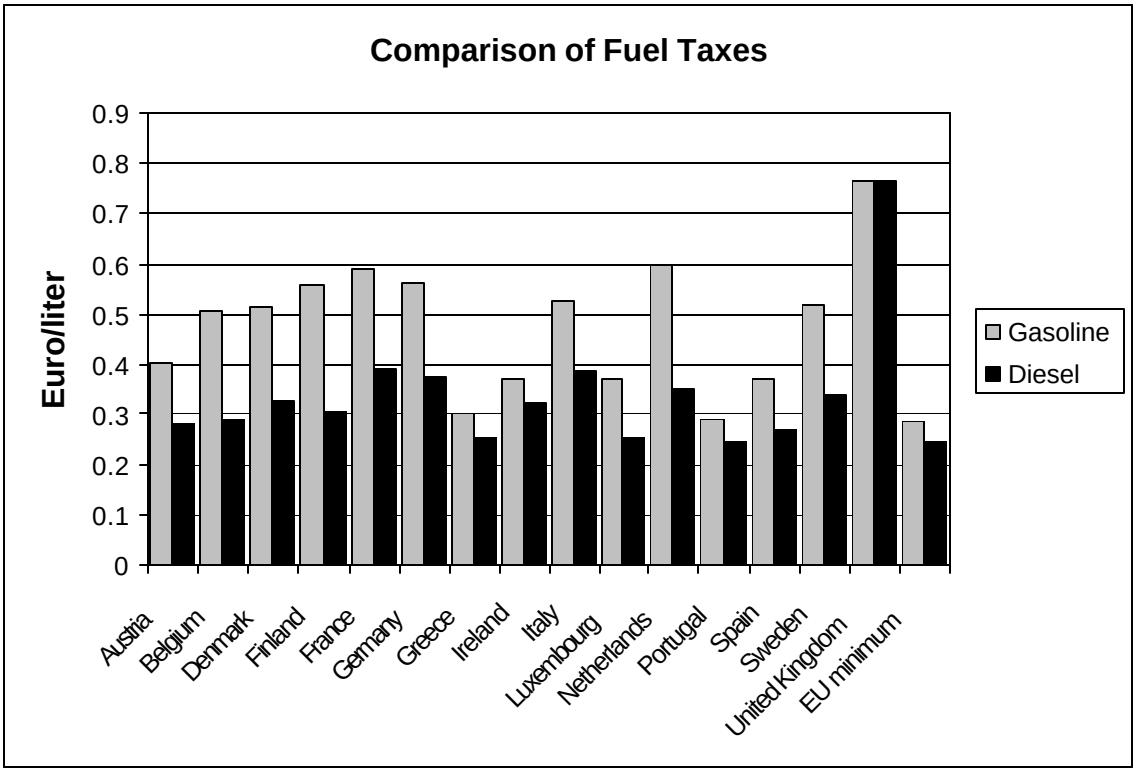

Figure 3.4 COMPARISON OF DIESEL AND GASOLINE FUEL TAXES (2000) (Sources: [27])

Table 3.1 COMPARISON OF CONSUMER BENEFITS FOR PEUGEOT 307, GASOLINE AND DIESEL MODELS

Country	(A) Price Difference for Diesels	(B) Diesel Fuel Savings (US$/yr)	(C) Payback Period (yrs)	(D) Passenger-Miles per capita (yr)	(E) Diesel Savings (miles)
Austria	+900	218	4.1	5308	4340
Belgium	+1,300	293	4.4	6520	5280
Denmark	+4,175	264	15.8	6790	4651
Germany	+800	172	4.7	6823	4132
Greece	NA	208	NA	7634	4433
Finland	+3,500	216	16.2	5320	4166
France	+1,650	123	13.4	4781	2377
Ireland	+3,450	213	16.2	5628	3660
Italy	+1,500	199	7.5	7147	4605
Luxembourg	+1,235	384	3.2	7281	7153
Netherlands	+3,810	181	21.0	5884	3744
Portugal	+6,040	203	29.8	5387	4494
Spain	+1,510	200	7.5	4722	3665
Sweden	0	236	0	6498	4223
United Kingdom	+1,286	162	7.9	6473	1923

given country (Table 3.1, Column D[4]), the diesel version could save consumers between $123 to $384 per year in fuel expenditures based on the vehicle's fuel economy and the country's fuel prices (Table 3.1, Column B). Using the simple formula of dividing the incremental price of the diesel (Table 3.1, Column A) by the annual fuel savings yields the payback period for the consumer's initial investment for improved fuel economy. Note that more sophisticated payback periods typically involve discounting and other considerations, however based on the work of Kurani and Turrentine (2004, see their report as part of this contract) most consumers do not consider these factors in this much depth, if at all. Column C of Table 3.1 shows that the payback period ranges from 0 to almost 30 years. Countries with shorter payback periods tend to have a greater market share of diesel vehicles. Given that consumers may be thinking more about their annual mileage than the payback period, Column E converts the fuel savings from dollars into miles. Thus, for the same annual fuel expenditure of the gasoline vehicle, in many cases the diesel version could be driven nearly twice as much.

In reality, though, owners of diesel vehicles may not actually be spending less on fuel. Schipper et al. found that despite the improved fuel economy of diesel vehicles, they do not necessarily result in net fuel or CO_2 savings *per vehicle* given that they are driven longer distances. [10] In Italy, the Netherlands, and the United Kingdom, annual fuel expenditures were higher for diesel vehicles than gasoline vehicles and about equal

[4] Note that these are passenger-miles per capita and not per vehicle. However, this example is only intended to show the variation between countries and the potential benefit to consumers. The variation in passenger-miles between countries can be due to multiple factors such as vehicle ownership levels, urban form and density, and availability of public transit. (Source: Passenger-miles per capita for 2001. ENERGY & TRANSPORT IN FIGURES, Statistical Pocket Book 2003. European Commission)

for both fuel types in France (based on 1995 fuel prices). On average, gasoline vehicles are driven substantially less than their diesel counterparts. [22] In a sample of five European countries, average annual distances per diesel vehicle in 1995 ranged from 42 to 113 percent greater than the average for gasoline vehicles. However, the extent to which this difference can be attributed to a rebound effect is unclear. Empirical evidence presented by Hivert (1994, as cited in [10]) indicates that some rebounding occurs: drivers switching from gasoline to diesel vehicles increased their travel by 3500 km while drivers switching in the other direction decreased their travel by 6000km.[5] The rebound effect does not account for the entire difference in mileage, though. Self-selection likely accounts for a large portion of this difference as those drivers who anticipate driving greater annual distances will consider the operating costs of their vehicle purchase more carefully. A portion of these purchases may in fact be as company cars that are intended for high-mileage driving. Another confounder influencing the difference in annual vehicle kilometers traveled is that mileage will be redistributed with a household fleet to favor the more fuel economic vehicle. Diesels may also be favored because on average diesel vehicles are newer than gasoline vehicles; overall, newer vehicles tend to be driven more than older ones.

VEHICLE TAXES. In addition to the standard value added tax (15-25%) required in all EU countries, new car buyers in ten of the member countries are also subjected to a one-time registration tax at the time of purchase. Those countries without registration taxes generally have large vehicle car industries. These tax rates are widely varied between countries, ranging from as little as 267 EUR in Italy to as much as 15659 EUR in Denmark. [2] In seven of the ten countries, the rate is based upon the sale price, in some cases further differentiated by engine size, fuel type, or fuel consumption; two countries base the tax solely on engine displacement and the final country has a flat tax. Manufacturers thus tend to price vehicles lower in high-tax countries so that the consumer's final cost of purchasing a new car is relatively uniform across countries. However, diesels will still generally be more expensive than their gasoline counterparts, in part because they are subjected to higher taxes either explicitly based on fuel type or indirectly based on vehicle attributes. The higher registration taxes for diesel vehicles have been included in the price difference and payback period calculation, which contributes to some of the variation between countries.

Vehicle owners are also responsible for annual circulation (ownership) taxes. In general, countries with high registration taxes tend to have relatively lower circulation taxes. With the exception of France where taxes are determined regionally, all Member States impose a national circulation tax. Annual taxes range from 14 EUR for small vehicles in Portugal to 2,272 EUR for gas guzzlers in Denmark. [27] Average annual taxes are typically concentrated within the 100-500 EUR span. [2] Similar to registration taxes, the ownership tax bases vary from engine size, power, and weight to fuel consumption or CO_2 emissions. In almost all countries, though, diesel vehicle owners pay higher circulation taxes to compensate for the reduced fuel tax revenue. For diesels, the higher circulation taxes could feasibly eliminate their annual fuel savings.

These additional costs play an important role in a consumer's purchasing decision in that consumers consider the entire cost of vehicle ownership to which vehicle taxes

[5] A more thorough analysis on the rebound effect is underway by researchers at UC Irvine and therefore will not be discussed here further.

may contribute significantly. [22] Recently, tax incentives have been created for low CO_2-emission vehicles in some countries. Beginning in 2001, ownership taxes in the United Kingdom became based on CO_2 emissions, with vehicles emitting less than 150 g CO_2/km charged paying more than one-third less the tax (159 EUR) than those vehicles emitting more then 185g CO_2/km (246 EUR). [27] Though diesel vehicles are taxed an additional 15 EUR, this taxation policy would still moderately favor diesel sales. In Germany, circulation tax exemptions are offered for vehicles meeting low air quality and CO_2 emission targets. Similarly, Austria bases its registration tax based on fuel consumption, exempting the most efficient vehicles from the tax. In Denmark, registration taxes will be reduced by between one-sixth and two-thirds depending on the vehicle's fuel consumption. However, diesel vehicles are subject to a slightly more stringent standard than gasoline vehicles for the same tax reduction. [27]

Other potential consumer considerations

A host of other factors maybe also be influencing consumers during their vehicle purchase decision. From the supply perspective, the proliferation of models available as diesels would broaden their appeal to prospective buyers. Markets dominated by manufacturers more aggressively pursuing diesels would thus be expected to exhibit larger growth in diesel sales. Consumers in different regions of Europe may also have different requirements for their vehicles. For instance, mountainous areas might favor diesels for their increased torque at lower speeds while colder climates might discourage them due to slower start times in cold weather. At an even smaller scale, residents in congested urban areas often prefer diesel vehicles given their improved fuel economy and lower operating costs. [26] Cultural and educational differences may impact the extent to which consumers view global climate change, oil dependency and air pollution as problems. In addition, vehicle demand would be influenced by population demographics. [24] Income in particular would affect both the type of vehicle purchased and the intensity with which it is driven. Vehicle usage, an important criterion in consumer choice models, is also impacted by road investments, urban density/decentralization, and the quality of public transit.

4. EXPLAINING THE DIFFERENCES IN LIGHT-DUTY DIESEL VEHICLE SALES

Overall, sales of diesel vehicles in the EU have roughly doubled between 1994 and 2002, with much of the growth occurring in the latter years. (See Figure 4.1) In 2003, Italy joined France, Spain, Austria, Belgium and Luxembourg to become the sixth European country where diesel vehicles outsold gasoline models. For Europe overall, diesel sales reached a new record in 2003 capturing 44% of the new car market. [28] In contrast, diesel sales in the United States peaked in 1981 at 5.1 percent and have not exceeded 1 percent since 1985. [29] With the exception of England, diesel penetration continues to increase in all major markets. [30] However, the sales volume of diesel vehicles has not been uniform across European countries. (See Figure 4.2)

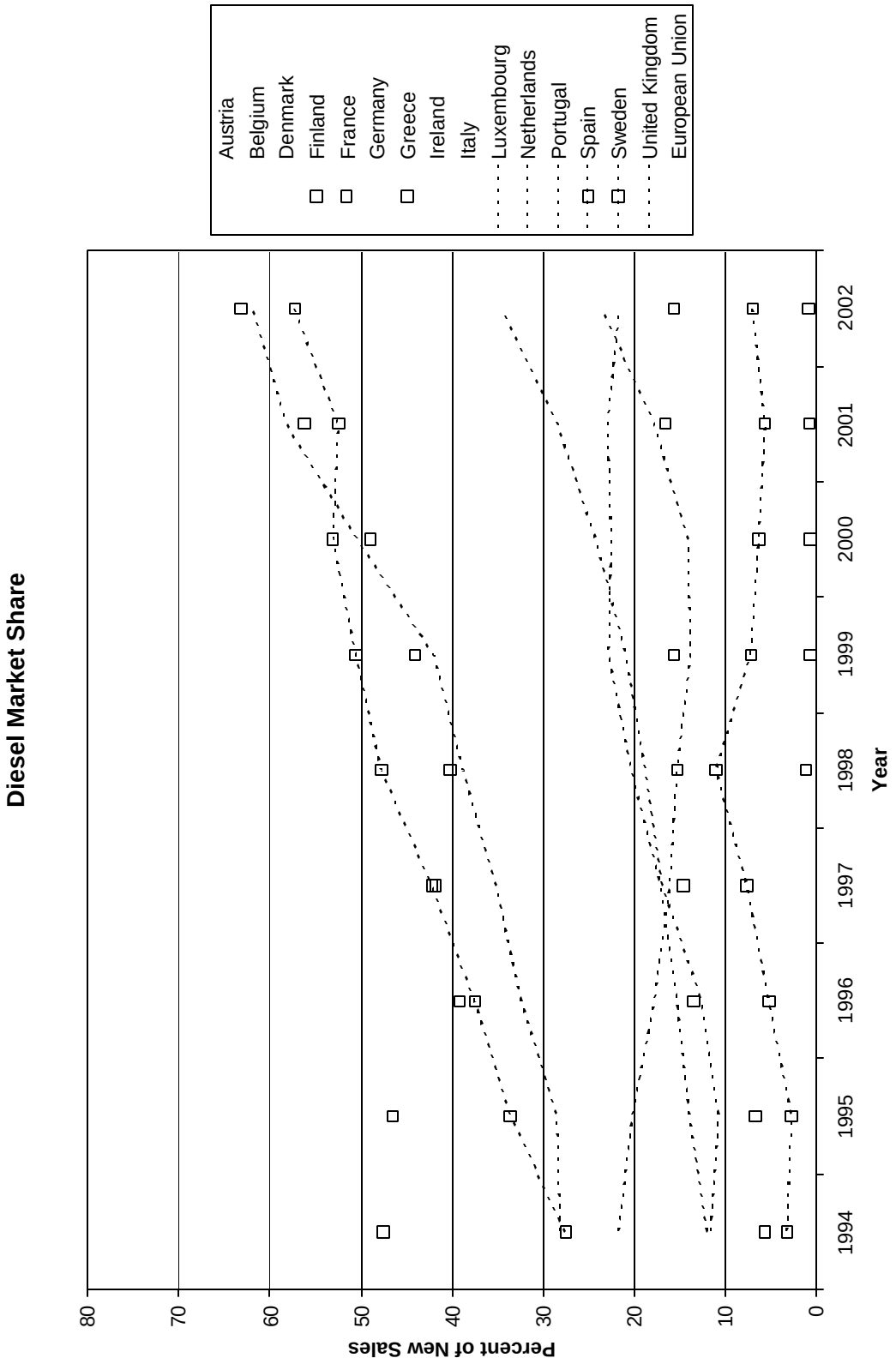

Figure 4.1 DIESEL SHARE OF NEW VEHICLE SALES (Source: ACEA)

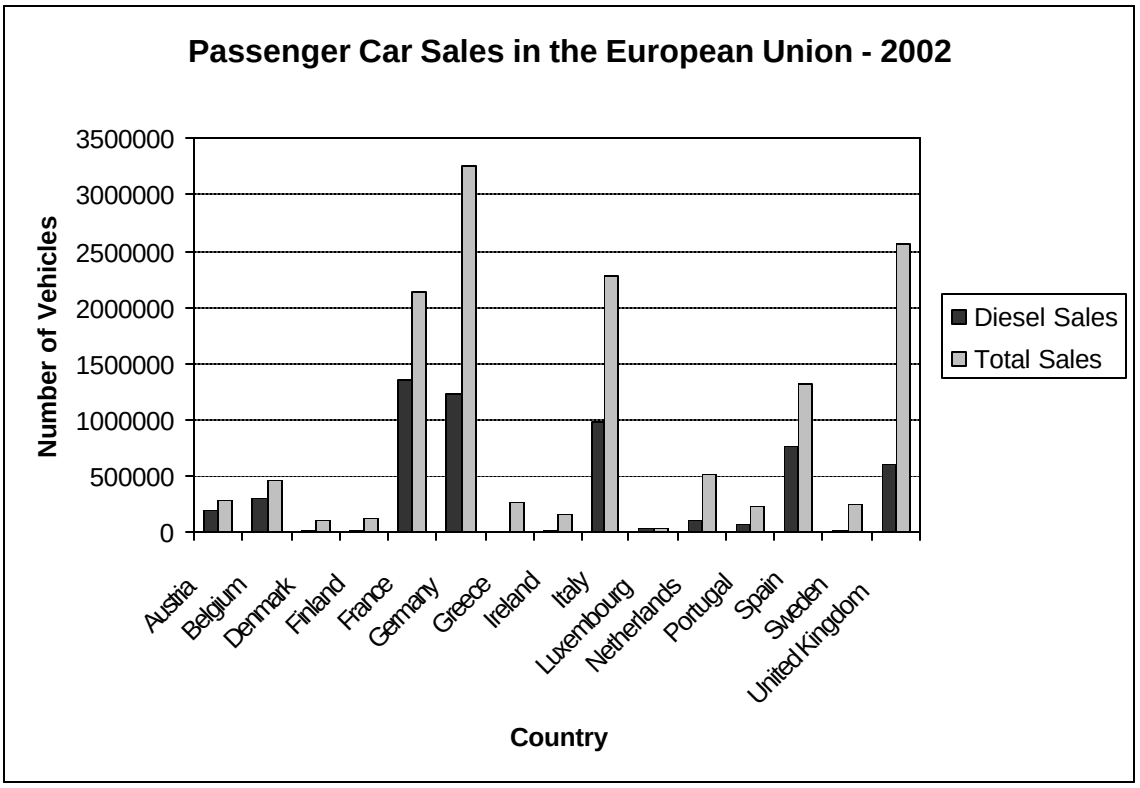

Figure 4.2 DIESEL SALES VOLUMES IN 2002 (Source: ACEA)

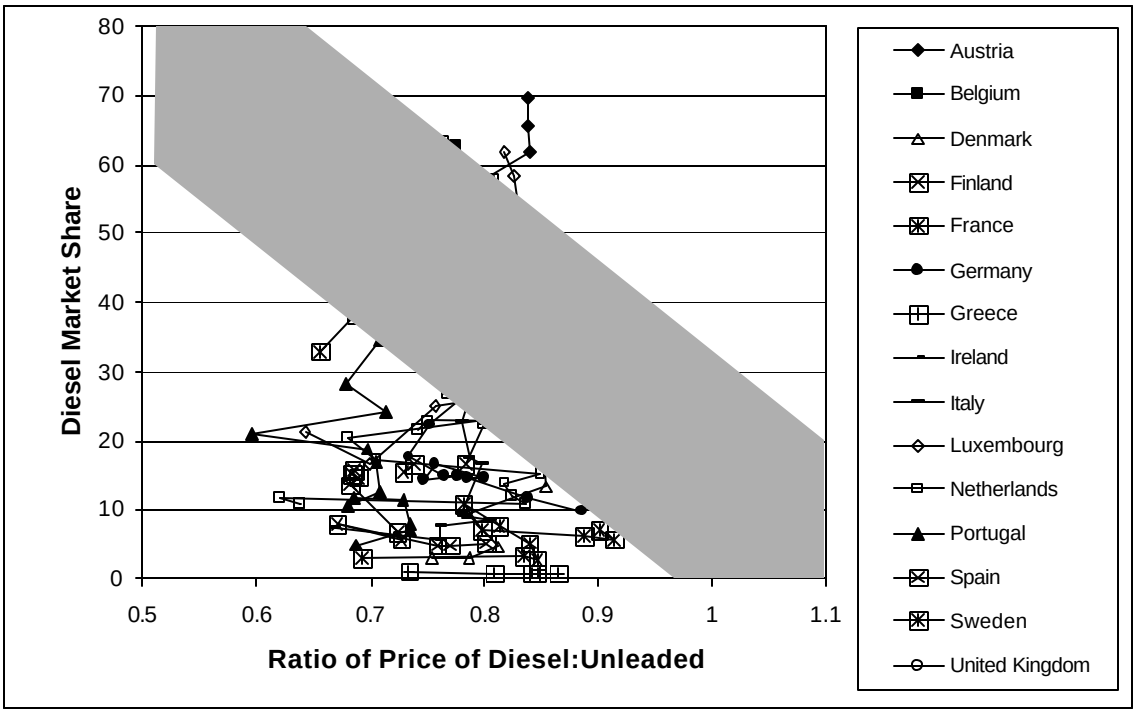

Figure 4.3 COMPARISON OF DIESEL:GASOLINE PRICE RATIO AND MARKET SHARE OF NEW DIESEL VEHICLES (1992-2002)

Diesel prices are for non-commercial use, gasoline prices are for unleaded (95 RON)
(Sources: IEA Energy Prices and Taxes 1999: 3rd-4th Quarter and 2003: 2nd Quarter)

The variability in tax levels on fuels and vehicles is the primary factor explaining the differences in diesel sales between countries. [23] For countries that have experienced the most growth, fuel prices do appear to be a motivating determinant. Lower diesel fuel prices offer the potential for substantial savings. Likewise, in some countries where diesel has a minimal price advantage, diesel vehicle sales are accordingly low. However, if diesel market share was solely explained by the fuel price advantage, the curves in Figure 4.3 would all be expected to fall within the shaded area where diesel sales are high when diesel fuel is much less expensive than gasoline and sales are low when the fuels are more evenly priced.

Clearly other forces are at work for countries where diesel fuel is priced appreciably lower than gasoline but diesel sales remain limited. The price premium for a diesel varies by country, as does the vehicle registration tax which effectively increases the purchase price of the vehicle. In some cases, the potential fuel savings may not offset the necessary initial investment of purchasing a diesel vehicle. Additionally, the annual circulation taxes may completely eliminate the fuel cost savings, which would discourage sales of diesels in certain countries. Tax policies may also work in the opposite direction, though, to provide incentives for diesel purchases in the absence of a significant fuel price advantage.

Table 4.1 COMPARISON OF DIESEL MARKET SHARE IN 2002 TO FISCAL/ECONOMIC FACTORS

	Market Share	Price Ratio	Registration tax favors:	Ownership tax favors:
Austria	69.6 (1)	0.84 (11)	Diesel	Diesel
Belgium	64.3 (2)	0.74 (4)	Gasoline	Gasoline
Denmark	20.1 (11)	0.84 (11)	Gasoline	Neutral
Finland	15.6 (13)	0.73 (2)	Gasoline	Gasoline
France	63.2 (3)	0.76 (5)	NA	NA
Germany	37.9 (7)	0.82 (9)	NA	Gasoline
Greece	0.9 (15)	0.85 (12)	Gasoline	Gasoline
Ireland	16.4 (12)	0.91 (14)	Gasoline	Gasoline
Italy	43.5 (6)	0.82 (9)	Neutral	Diesel
Luxembourg	61.9 (4)	0.82 (9)	NA	Gasoline
Netherlands	21.6 (10)	0.74 (4)	Gasoline	Gasoline
Portugal	34.6 (8)	0.71 (1)	Gasoline	Gasoline
Spain	57.3 (5)	0.80 (6)	Gasoline	Gasoline
Sweden	7.0 (14)	0.90 (13)	NA	Gasoline
United Kingdom	23.5 (9)	1.03 (15)	NA	Diesel

Ranks of Market Share and Price Ratio shown in parentheses.
(Sources: ACEA, IEA Energy Prices and Taxes 1999: 3rd-4th Quarter and 2003: 2nd Quarter, and COWI)

Table 4.1 summarizes the relationship between diesel sales in 2002 and taxation policies between countries. If market share were determined solely by the difference in price of diesel fuel and unleaded gasoline, the market share and price ratio ranks would be expected to match. In Belgium, France, Germany, Italy, and Spain low diesel fuel prices relative to gasoline prices appear to be encouraging diesel sales despite tax policies favoring gasoline vehicles. Similarly, in Denmark, Greece, Ireland, and Sweden higher

diesel fuel prices are discouraging the sale of diesels, though tax policies may be reinforcing the effect of fuel prices.

However in the remaining countries, the taxation policies are the dominating driver behind determining market share. In Austria, registration taxes are lower for more fuel economical vehicles while ownership taxes are based upon vehicle power (kW), both of which favor diesels. Thus, despite relatively more expensive diesel fuel compared to other European countries, Austria has long been the leader in diesel sales due to its favorable tax polices. Similarly, despite diesel fuel being more expensive than gasoline, diesel sales in the United Kingdom are also higher than expected as a result of a new ownership tax based on CO_2 specifically. The opposite effect is observed in Finland, the Netherlands, and Portugal where diesel market shares have been limited even though the price ratio between diesel and gasoline is relatively favorable. In Finland and the Netherlands, ownership taxes are based on weight but differentiated by the vehicle's fuel type. Thus, in the Netherlands, a diesel vehicle is taxed 283% higher than a gasoline vehicle of the same weight; in Finland diesel owners pay a weight-based tax but gasoline vehicle owners pay a flat (and generally lower) tax. Ownership taxes are also differentiated by fuel type in Portugal though based on engine capacity instead of weight. Drivers in these countries may not reach the breakeven vehicle kilometers traveled for the fuel cost savings to exceed the additional expense of owning a diesel vehicle. The higher vehicle taxes on diesels appear to be the reason Portugal has experienced only moderate growth in diesel vehicle sales despite having the most favorable fuel price ratio in the EU.

Such fiscal measures appear to have a significant influence on diesel shares, which could play an important role in achieving the European Commission's goal of reducing emissions from new vehicles to 120g CO_2/km.

5. SUMMARY AND CONCLUSIONS

Light-duty diesel vehicles in Europe have experienced tremendous popularity. Spurred by the auto industry's voluntary agreement to reduce CO_2 emissions, diesel technology has improved greatly so that new vehicles offer increased power and size while maintaining engine capacity and even improving fuel economy. Although these technological advances may improve the consumer's perception of diesels, taxation policies in the Member States vary widely and play a pivotal role in diesel sales.

In the case of Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Spain, and Sweden, favorable tax treatment of diesel fuel dominates other effects, with market shares roughly correlated to the price of diesel fuel relative to gasoline. In the remaining countries, the market share of diesels is more closely related to the amount of registration and/or ownership taxes paid on the vehicle. For example, looking at the price ratio, one would expect that Austria would have a minimal share of diesels when in fact it is the leader in diesel sales. This result can be explained by registration and ownership tax policies that strongly favor diesel vehicles. Similarly, Finland, the Netherlands, and Portugal would be expected to rank high in diesel sales without tax policies discouraging diesel vehicles. Fiscal measures, together with the voluntary CO_2 agreement between automakers and the EU, clearly play an important role in influencing consumer purchases of new vehicles in Europe – in ways that could reduce CO_2 emissions.

REFERENCES

1. *Vehicle Emissions Reductions*. 2001, European Conference of Ministers of Transport: Paris.
2. *TAXATION OF PASSENGERS CARS IN THE EUROPEAN UNION - options for action at national and Community levels*. 2002, COMMISSION OF THE EUROPEAN COMMUNITIES: Brussels, Belgium.
3. ACEA, *The European Automobile Manufacturers commit to substantial CO2 emission reductions from new Passenger Cars.* July 29, 1998. p. Press Release.
4. Fulton, L.M., *Voluntary Agreements as Drivers of Technological Change in the Transport (Light-duty Vehilce) Sector*. 2000, International Energy Agency: Paris.
5. *Implementing the Community Strategy to Reduce CO2 Emissions from Cars: Fourth annual report on the effectiveness of the strategy (Reporting year 2002)*. 2003, COMMISSION OF THE EUROPEAN COMMUNITIES: Brussels, Belgium.
6. *Belgium: EU and carmalers fail to agree on CO2 emissions objectives*, in *Just-Auto.com Daily News Alert*, D. Leggett, Editor. 2004, Just-Auto.com. p. Source: just-auto.com editorial team.
7. Krix, P., *Study: Emission targets come at high price.* Automotive News, 2003. **78**(6072): p. 18.
8. Kageson, P., *The Drive for Less Fuel: Will the motor industry be able to honour its commitment to the European Union*. 2000, European Federation for Transport and Environment: Brussels, Belgium.
9. *Demand for Diesels: The European Experience*. July 2001, Diesel Technology Forum: Frederick, MD.
10. Schipper, L., C. Marie-Lilliu, and L. Fulton, *Diesels in Europe: Analysis of Characteristics, Usage Patterns, Energy Savings and CO2 Emisssion Implications.* Journal of Transport Economics and Policy, 2002. **36**(2): p. 305-340.
11. *UK: Small diesel car sales up 25%*, in *Just-Auto.com Daily News Alert*, D. Leggett, Editor. 2003, Just-Auto.com. p. Source: just-auto.com editorial team.
12. *Monitoring of ACEA's Commitment on CO2 Emission Reduction from Passenger Cars (2002)*, in *Joint Report of the European Automobile Manufacturers Association and the Commission Services*. 2003, COMMISSION OF THE EUROPEAN COMMUNITIES: Brussels, Belgium.
13. Monahan, P. and D. Friedman, *The Diesel Dilemma: Diesel's Role in the Race for Clean Cars*. 2004, Union of Concerned Scientists: Cambridge, MA.
14. *Implementing the Community Strategy to Reduce CO2 Emissions from Cars: Third annual report on the effectiveness of the strategy (Reporting year 2001)*. 2002, COMMISSION OF THE EUROPEAN COMMUNITIES: Brussels, Belgium.
15. *Monitoring of ACEA's Commitment on CO2 Emission Reduction from Passenger Cars (2001)*, in *Joint Report of the European Automobile Manufacturers Association and the Commission Services*. 2002, COMMISSION OF THE EUROPEAN COMMUNITIES: Brussels, Belgium.

16. *UK: European motor industry struggles with demands for reduced CO2 and noxious emissions,* in *Just-Auto.com Daily News Alert*, D. Leggett, Editor. 2003, Just-Auto.com. p. Source: SupplierBusiness.com.
17. EUCAR, *CO2perate.* 1999. p. http://www.acea.be/EucarInternet/publications/CO2perate99.html.
18. Plotkin, S. *European and Japanese Initiatives to Boost Automotive Fuel Economy: What They are, Their Prospects for Success, Their Usefulness as a Guide for U.S. Action*. in *80th Annual Meeting, Transportation Research Board, January 7–11, 2001*. 2001. Washington, DC.
19. Kliesch, J. and T. Langer, *Deliberating Diesel: Environmental, Technical, and Social Factors Affecting Diesel Passenger Vehicle Prospects in the United States*. 2003, ACEEE.
20. Wright, C. and W.O. Weernink, *Europe's love of diesels is boon to suppliers.* Automotive News, 2002. **76**(5999): p. 22D.
21. Chew, E., *Direct-injection diesels are on a roll; Fuel-economy concerns create demand in Europe.* Automotive News, 1999. **74**(5849): p. 16.
22. Verboven, F., *Quality-based price discrimination and tax incidence: evidence from gasoline and diesel cars.* Rand Journal of Economics, 2002. **33**(2): p. 275-297.
23. Mayeres, I. and S. Proost, *Should diesel cars in Europe be discouraged?* Regional Science and Urban Economics, 2001. **31**(4): p. 453-470.
24. Van den Brink, R.M.M. and B. Van Wee, *Why has car-fleet specific fuel consumption not shown any decrease since 1990? Quantitative analysis of Dutch passenger car-fleet specific fuel consumption.* Transportation Research Part D-Transport and Environment, 2001. **6**(2): p. 75-93.
25. Lawson, S., A. Butler, and E. Downing, *Motorists' concern in six European countries.* Traffic Engineering and Control, 2000. **41**(1): p. 14-6.
26. McCarthy, P.S. and R.S. Tay, *New vehicle consumption and fuel efficiency: A nested logit approach.* Transportation Research Part E-Logistics and Transportation Review, 1998. **34**(1): p. 39-51.
27. COWI, *Fiscal Measures to Reduce CO2 Emissions from New Passenger Cars*. 2002, European Commission's Directorate-General for Environment.
28. *UK: Diesel car sales set new European record in 2003,* in *Just-Auto.com Daily News Alert*, D. Leggett, Editor. 2004, Just-Auto.com. p. Source: just-auto.com editorial team.
29. Hellman, K.H. and R.M. Heavenrich, Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2003. 2003, Office of Transportation and Air Quality, U.S. Environmental Protection Agency. EPA420-R-03-006.
30. Love, M., Diesel Passenger Car and Light Commercial Vehicle Markets in Western Europe. 2001, Ricardo Consulting Engineers Ltd: West Sussex, United Kingdom.