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# Fuel Prices and New Vehicle Fuel Economy in Europe

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Abstract

This paper evaluates the effect of fuel prices on new vehicle fuel economy in the eight largest European markets. The analysis spans the years 2002–2007 and uses detailed vehicle registration and specification data to control for policies, consumer preferences, and other potentially confounding factors. Fuel prices have a statistically significant effect on new vehicle fuel economy in Europe, but this estimated effect is much smaller than that for the United States. Within Europe, fuel economy responds more in the United Kingdom and France than in the other large markets. Overall, substantial changes in fuel prices would have relatively small effects on the average fuel economy of new vehicles sold in Europe. We find no evidence that diesel fuel prices have a large effect on the market share of diesel vehicles.

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## 1. Introduction

Amid growing environmental and energy security concerns in Europe, an improved understanding of the relationship between new vehicle fuel economy, fuel prices, and fuel taxes would inform several economic and policy questions. First, little empirical evidence supports (a) an effect of fuel taxes on carbon dioxide ($CO_2$) emissions or oil imports or (b) an effect of recently proposed fuel tax reforms on the new vehicle market. For several decades, fuel taxes in Europe have been set at high levels to encourage consumers to drive less and purchase vehicles with high fuel economy. It is widely believed that high fuel taxes, compared to those in the United States for example, contribute significantly to the high fuel economy of new vehicles in Europe, and thereby reduce $CO_2$ emissions and oil imports. Fuel taxes vary considerably across European countries, but recently, members of the European Union have debated whether to adopt a fuel tax system based on $CO_2$ emissions. Although a number of recent studies have found large effects of fuel prices on fuel economy in the United States (e.g., Allcott and Wozny 2010; Busse et al. 2009; and Klier and Linn 2010), studies on Europe have reached widely varying conclusions, from an absence of an effect to a very large effect of fuel taxes on new vehicle fuel economy (e.g., TiS 2002; Clerides and Zachariadis 2008; Ryan et al. 2009; Vance and Mehlin 2009; and Schipper et al. 2010).

Second, most European countries set diesel fuel taxes lower than gasoline taxes to encourage consumers to purchase diesel vehicles. Diesel vehicles typically have about 30 percent higher fuel economy than comparable gasoline-powered vehicles. The increase in diesel market shares in the European Union, from about 20 percent in 1995 to about 50 percent in 2009, may explain a significant share of the increase in average fuel economy of all new vehicles during this period.[2] However, based on an analysis of Belgium, France, and Italy from 1991 to 1994, Verboven (2002) finds evidence of second-degree price discrimination between gasoline and diesel vehicles. His results imply that a reduction in the diesel fuel tax would lead to a higher price for diesel vehicles and a relatively small shift in the diesel market share.

[2] Shipper et al. (2002) argue that the fuel economy advantage of diesel vehicles was offset by other factors, such as a greater weight and more miles driven for diesel vehicles, suggesting a small net reduction in $CO_2$ emissions.

On the other hand, industry observers regularly attribute the increase in diesel market shares at least partially to the fuel tax policy. This argument is commonly based on a simple comparison between the United Kingdom and other European countries: in the United Kingdom, the diesel fuel tax is relatively high and the diesel market share is relatively low. However, many other variables affect diesel market shares in these countries, and to date no direct empirical evidence supports an effect of diesel taxes on diesel market shares across Europe.

The third question has to do with the effect of expected oil price increases on the cost of $CO_2$ emissions standards for new vehicles. The literature has found fuel taxes to be far more cost-effective for reducing gasoline consumption and $CO_2$ emissions than other policies, such as fuel economy or $CO_2$ emissions standards (e.g., Jacobsen 2010; Parry et al. 2010). In 2009, the European Union adopted a mandatory $CO_2$ emissions standard that will raise average fuel economy of new passenger vehicles to 50 miles per gallon (mpg) by 2015. This standard replaces a voluntary agreement on $CO_2$ emissions between automakers and the European Commission, which did not include penalties for noncompliance and which ended up not meeting its stated targets (European Parliament 2009). Considerable debate in Europe—among economists, industry, and other analysts—has centered on the costs of the upcoming $CO_2$ emissions standards. The resolution of this debate needs to factor in what happens to the price of oil, as the incremental cost of the standards depends, among other things, on whether rising future oil prices would increase the baseline (i.e., unregulated) average fuel economy of new vehicles (Zachariadis 2006).

We investigate the relationship between fuel economy, fuel prices, and fuel taxes, and address each of the three questions outlined above. Several recent studies have investigated these relationships in Europe and found diverging results, but none of them have addressed a major empirical challenge: controlling for other factors that may be correlated with fuel prices across countries or over time. Besides the voluntary $CO_2$ emissions standard, in the past several years, many of the E.U. member countries significantly changed vehicle purchase and ownership taxes to strengthen financial incentives for consumers to purchase high–fuel economy vehicles.[3] Perhaps the most prominent example is the *feebate* or *bonus–malus* program in France, which imposes a tax on vehicles with low fuel economy and offers a subsidy for vehicles with high fuel economy. Consumer preferences further complicate the analysis because vehicle characteristics are hard to observe and may be correlated with fuel prices or fuel economy.

Controlling for these factors is a major focus of this paper. Ideally, we could use recent changes in fuel taxes or permanent changes in gasoline prices to investigate these issues, as Li et al. (2011) did for the U.S. market. However, because within-country fuel tax variation is minimal, we focus on fuel price variation instead. We employ highly detailed vehicle registration data by country for 2002–2007 to estimate the short-run effect of fuel prices on new vehicle fuel economy. The short-run analysis allows us to control for potentially confounding factors and, as we discuss below, provides some insights into the long-run relationships between fuel economy, fuel prices, and fuel taxes.

More specifically, detailed vehicle specification and registration data allow us to control for the presence of the voluntary standards and vehicle taxes. Purchase and ownership taxes depend on characteristics of the vehicle, such as its engine size or $CO_2$ emissions, and therefore do not vary across vehicles that have the same specifications. In addition, firms primarily responded to the voluntary $CO_2$ standards by adding technologies that enhance fuel economy, rather than adjusting vehicle prices. Thus, a simple regression, with fixed effects for each vehicle model and year, can effectively control for vehicle taxes as well as for technological changes caused by the voluntary $CO_2$ standards. Furthermore, using high-frequency data allows us to control for changes in consumer preferences for fuel economy (or other variables that are correlated with fuel economy), which tend to be slow-moving. This approach is similar to the analysis performed by Klier and Linn (2010) for the U.S. market. This similarity enables a direct comparison of the effect of fuel price changes between the U.S. and European markets.

[3] Inefficiencies are probably associated with the overlapping $CO_2$ emissions standards and vehicle taxes. Goulder et al. (2009) show that binding national fuel economy standards in the United States render subnational standards ineffective. Braathen (2011) shows that in Europe, the implicit tax per ton of $CO_2$ emissions from new vehicles varies dramatically across countries.

We find that fuel prices have a positive effect on average fuel economy in Europe, although the effect is smaller than that in the United States. Within Europe, fuel prices have a larger effect on fuel economy in the United Kingdom and France than in the other large European markets; but in no European country do we find as large an effect as for the United States. These results are robust across a variety of regression models, although we note that the level of vehicle aggregation does affect the results, particularly when analyzing the smaller markets of individual European countries. We find no evidence that diesel fuel prices have a large effect on the market share of diesel vehicles, either in aggregate or at the country level.

These results have several implications for energy security and environmental policy. First, our estimates imply that a significant increase in U.S. gasoline prices (or taxes) and a significant decrease in European fuel prices would not have a large effect on the overall differences in fuel economy between the two regions. Perhaps somewhat against conventional wisdom, fuel taxes may be less important in explaining the fuel economy differences between the United States and Europe than other factors. Second, future increases in oil prices would have a small effect on new vehicle fuel economy in Europe (i.e., in the absence of fuel economy standards). This implies that rising oil prices would not affect the incremental costs of $CO_2$ emissions standards. Third, the lower level of diesel taxes can explain only a small share of the recent cross-country variation in the market share of diesel vehicles. Finally, raising fuel taxes in Europe would have a larger effect on new vehicle fuel economy in some countries than in others. This regional variation needs to be considered when evaluating the effects of linking fuel taxes to $CO_2$ emissions.

We note that the implications of our results for permanent tax or fuel price changes depend on the extent to which consumers treat fuel price changes as permanent and how quickly the vehicle supply responds to changes in fuel prices. Anderson et al. (2011) provide support for the consumer assumption in the U.S. market. To the extent that European consumers either (a) believe that prices are mean-reverting or (b) respond gradually to price changes, we may understate the effect of a permanent change in fuel prices or taxes on new vehicle fuel economy. However, we find similar results when looking at longer time horizons, suggesting that the results are informative of the effect of permanent price or tax changes on new vehicle fuel economy.

The paper is organized as follows. Section 2 describes the data for vehicle registrations, sales, and fuel prices. Section 3 provides background to the market and regulatory institutions in the United States and Europe. Section 4 describes the empirical strategy. Section 5 presents the estimates of the effect of fuel prices on new vehicle fuel economy, and Section 6 presents estimates of the effect of diesel fuel prices on market shares. Section 7 concludes.

## 2. Data Sources

This section describes the data sources. The primary variables are sales or registrations of new passenger vehicles by model, month, and country, and fuel prices by month and country. The data span 2001–2007 for the United States and 2002–2007 for Europe.

### 2.1 U.S. Sales and Fuel Economy Data

Total monthly dealer sales by vehicle model are constructed from the Ward's AutoInfoBank (2001–2007) electronic database.[4] The U.S. Environmental Protection Agency (EPA) provides fuel economy ratings at fueleconomy.gov. Two factors complicate merging the sales and fuel economy data. First, the fuel economy data are reported at the submodel level. For example, the EPA data distinguish between versions of a specific model with an automatic or a manual transmission. We use a simple (unweighted) average of mpg across the different versions of the same model.

Second, the fuel economy data are available by model-year and not by month. Although accounts in the trade press suggest that fuel economy varies across models and manufacturers, new models are often introduced in late summer. Therefore, in this paper, we define a model-year as the period of time

[4] Sales data are measured by model and month. Therefore, it is possible that multiple model-years are included in some of the observations; for example, sales of the Honda Civic in September of 2005 could include sales of the 2005 Civic as well as the 2006 Civic.

spanning September of the previous calendar year to August of the current calendar year. For example, the 2002 model-year begins in September of 2001 and ends in August of 2002. The fuel economy data are matched to the sales data by model and model-year.

## 2.2 European Registration and Fuel Economy Data

New vehicle registration and characteristics data were obtained from R.L. Polk. We focus on passenger car data for 2002–2007 for three reasons: (a) data for light commercial vehicles are available only for 2008 and 2009; (b) we found large changes in vehicle purchase and ownership taxes starting around 2008 (see Section 3.3); and (c) many countries introduced vehicle scrappage programs after 2007, the effects of which are difficult to control for.[5] The data include monthly new registrations by vehicle specification and country for the eight largest markets in Europe: Austria, Belgium, France, Germany, Italy, the Netherlands, Spain, and the United Kingdom. A *specification* is defined as a unique combination of model, retail price, engine size, power, and numerous other physical attributes. Thus, the specifications differentiate engine varieties of the same *model*. The vehicle specifications are highly detailed, representing about 30,000–40,000 unique specifications for the largest countries.

Models in the U.S. and European data are assigned to market segments. We use segment definitions that are identical for the two regions (see Section 3.5, below). Note, however, that the definition of a model can differ between the U.S. and European data. In general, models are more aggregated in the U.S. data. For example, in the U.S. data, the BMW 3 Series is a unique model, whereas the European data distinguish the BMW 325, 330, and so on. We return to this issue in Section 5.

The European data include fuel consumption, in liters per 100 kilometers, for each specification, from 2005 to 2007. Fuel consumption by specification is imputed for the years 2002–2004 in two steps. First, fuel consumption varies very little for specifications of the same model that have the same displacement, weight, horsepower, transmission type (automatic or manual), fuel type (gasoline or diesel), number of

[5] A few countries, such as Italy, had scrappage programs before the end of 2007. Our results are robust to dropping these observations.

gears, and number of cylinders. Therefore, we impute the fuel consumption for a specification in 2002–2004 using the fuel consumption of a specification of the same model in 2005–2007 that has the same values for these characteristics. This imputation is made for models accounting for about 90 percent of registrations in 2004, 83 percent of registrations in 2003, and 75 percent of registrations in 2002.

For the remaining specifications, we use the 2005–2007 data to estimate a linear regression of fuel consumption on displacement, weight, horsepower, transmission type, fuel type, number of gears, and number of cylinders. Fuel consumption, displacement, weight, and horsepower enter the equation in logs, and the equation includes separate dummy variables for each value of transmission type, fuel type, number of gears, and number of cylinders. We use the predicted values from this regression to estimate the fuel consumption of specifications in 2002–2004. The imputations are adjusted for the fact that fuel consumption decreases over 2005–2007 for specifications in which these characteristics are constant, presumably as a result of unobserved technological change. A separate adjustment factor is estimated for each country; it amounts to around 1 percent per year. The adjustment factor is used to impute fuel consumption for 2002–2004. Fuel consumption for each specification is aggregated to the level of the model by calendar year, weighted by the registrations of each specification. We have experimented with a number of variations of the imputation procedure, yet the main results appear to be quite robust.[6]

## 2.3 Fuel Price Data

Monthly gasoline prices from September 2001 to August 2007 for the United States are obtained from the Bureau of Labor Statistics. The price is the U.S. city average price of regular unleaded gasoline, in nominal dollars per gallon, and includes all taxes.

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[6] The R-squared value from a regression of fuel economy on displacement, vehicle weight, horsepower, transmission type, fuel type, number of gears, and number of cylinders, is about 0.98. The high value suggests that we probably introduce little measurement error by imputing fuel economy using specifications with identical characteristics. The empirical results are similar using only the vehicle models for which fuel consumption is imputed using specifications that share these characteristics, and dropping the vehicle models for which fuel consumption is imputed using the linear regression. Furthermore, if we use the same regression approach to impute fuel consumption for 2005 based on fuel consumption of specifications in 2008, and regress the log of the imputed 2005 fuel consumption on the log of the actual 2005 fuel consumption, the R-squared value from the regression is 0.98 (the coefficient is 0.99). The high fit suggests that the imputation introduces very little measurement error.

Monthly gasoline and diesel prices from January 2002 to December 2007 for each country in Europe are obtained from Eurostat. The gasoline price is the price of premium unleaded gasoline, and the diesel price is the price of automotive diesel oil. Both prices include all taxes.

All fuel prices are normalized by the monthly consumer price index obtained from Eurostat. The price index is constructed using a harmonized methodology across countries. The real price of gasoline in the United States is measured in 2005 dollars per gallon. Gasoline and diesel prices are measured in 2005 euros per liter in the euro zone and in pounds per liter in the United Kingdom.

# 3. Background to the New Vehicle Markets in the United States and Europe

Because we compare the effect of fuel prices on new vehicle fuel economy in the United States and Europe, this section discusses the major policies in both regions. Both regions impose fuel taxes, regulate fuel economy, and impose taxes and subsidies that aim to increase the average fuel economy of new vehicles. All of these policies vary both temporally and geographically within the United States and Europe. The end of the section reports summary statistics of the new vehicle markets from the two regions.

## 3.1 Fuel Taxes

Fuel taxes vary significantly across countries. In the United States, combined state and federal gasoline taxes were around $0.40/gallon in the late 2000s. Because the average tax level has increased gradually over time, the share of gasoline taxes in total retail prices has varied with oil prices. When oil prices were relatively low in the 1990s, for example, gasoline taxes accounted for about 30 percent of total gasoline prices. But in the late 2000s, taxes were closer to 15 percent of total gasoline prices.[7] The most common rationale for state and federal taxes is to raise revenue for infrastructure needs, particularly for roads.

[7] This estimate assumes that gasoline taxes are fully passed through to retail gasoline prices, which is consistent with Marion and Muehlegger (2011). A similar assumption is made in the subsequent discussion for Europe.

Fuel taxes are much higher in Europe than in the United States. In 2009, the average gasoline tax in Europe was about $3.65/gallon and the average diesel tax was about $2.65/gallon. These taxes account for about half of the total retail price, which in 2009 was about $6.36/gallon for gasoline and about $5.49/gallon for diesel.

There is also considerable variation in taxes across countries. In 2009, Spain had the lowest gasoline tax of the eight countries in the sample, of $2.65/gallon, and the Netherlands had the highest, of $4.42/gallon. Within countries, taxes changed only slightly in the 2000s.

The final type of tax variation in Europe is the differential taxation of diesel fuel. At one end of the spectrum, the United Kingdom places an equal tax on gasoline and diesel fuel. At the other end, Belgium and the Netherlands tax diesel fuel about 40 percent less than gasoline. Many of the other countries tax diesel fuel about 20 percent less than gasoline.

In summary, taxes vary considerably between the United States and Europe. Within Europe, fuel taxes vary greatly across countries, and countries also vary in the extent to which they place lower taxes on diesel fuel. These differences in taxation across countries and fuels motivate the empirical investigation of the effect of fuel prices on new vehicle fuel economy.

## 3.2 Fuel Economy and $CO_2$ Emissions Standards

### 3.2.1 Corporate Average Fuel Economy Regulation in the United States

Fuel economy regulation in the United States began in the 1970s, following the 1973 oil crisis. The regulations impose separate standards on cars and on light trucks, and the light truck standards have always been lower than the ones for cars. From 1985 until 2010, the standard for cars was 27.5 mpg. The truck standard was about 20 mpg in the 1980s and 1990s, and began increasing gradually in the 2000s to 23.5 mpg in 2010.

Corporate average fuel economy (CAFE) standards are administered on the basis of EPA's test procedure for measuring the fuel economy of new vehicles.[8] Firms may also earn credits for overcompliance that they can use in future years. Compliance with the standards is measured by calculating a harmonic sales-weighted average of the fuel economies of each manufacturer's product line. The penalty for noncompliance is $5.50 for every 0.1 mpg below the standards, multiplied by the number of cars in the manufacturer's new car fleet that year. Between 1983 and 2002, total civil penalties were slightly more than $600 million, which mostly small and specialty European manufacturers paid (Yacobucci and Bamberger 2006).

The Energy Independence and Security Act of 2007 established stricter fuel economy standards. They begin phasing in with model-year 2011 and by 2015 they require a combined average fuel economy of 35 mpg.[9] The new CAFE standards include other changes to the program that are not directly relevant to the analysis.

### 3.2.2 Voluntary and Mandatory $CO_2$ Standards in Europe

In 1998, the European Commission and the European Automobile Manufacturers Association, which includes major European and U.S. automakers, reached an agreement to voluntarily reduce the average $CO_2$ emissions rate of new vehicles by about 25 percent by 2008. A similar agreement was reached in 1999 between the European Commission and the Japanese and Korean automobile manufacturers associations. The emissions rate standards were voluntary, in the sense that they did not impose monetary penalties for noncompliance. However, the Commission reserved the option to enact mandatory

[8] The National Highway Traffic Safety Administration regulates the CAFE standards and EPA measures the fuel economy of each vehicle sold. However, the fuel economy data used for compliance with CAFE do not match the fuel economy data shown in the sticker on a new car window. Over time, EPA has adjusted the methodology used to produce the consumer-relevant mpg data to better reflect actual driving conditions. A car that achieves 35 mpg for CAFE will likely have a window sticker that has a combined (city and highway) rating of between 26 and 27 mpg (Abuelsamid 2010).

[9] The final rule for CAFE, which became effective in May 2010, requires the target fleet fuel economy by 2016 to be 34.1 mpg. That number is less than 35 because some of the reductions of greenhouse gas emissions, such as making a vehicle's air conditioning system more efficient, affect the vehicle's fuel economy. If all greenhouse gas reductions result from fuel economy improvements, the greenhouse gas–equivalent mileage requirement would be 35.5 mpg (Yacobucci 2010).

standards, backed by penalties, if the automakers did not meet the voluntary standards. The agreements followed several years of negotiations, and they were intended to represent one of three approaches put in place to reduce $CO_2$ emissions without relying on penalties—tax policy and consumer education were the other two.

According to the agreement, by 2008, European manufacturers would reach an average of 140 grams of $CO_2$ per kilometer (g $CO_2$/km), which is equivalent to about 43 mpg (fuel economy and $CO_2$ emissions are inversely related). The Japanese and Korean automakers would reach the same level by 2009. These standards apply only to passenger cars and do not include light commercial vehicles (light commercial vehicles accounted for about 10 percent of the market in 2009, but their share has been growing). The agreement also stipulated that the manufacturers had to be in the range of 165–170 g $CO_2$/km in 2003 and 2004. If the automakers failed to meet this level, the European Commission would begin considering other regulations.

The automakers reached the interim standard in 2003, and afterwards continued to raise fuel economy (and reduce $CO_2$ emissions). Accounts from the trade press and the academic literature suggest that the automakers primarily increased fuel economy by increasing the market shares of diesel vehicles and by adding new technology. However, by 2005, it became apparent that the manufacturers were very unlikely to meet the 2008/2009 standards and, in 2009, the European Commission imposed mandatory $CO_2$ standards of 130 g $CO_2$/km (about 50 mpg) by 2015, which would be phased in starting in 2012.

Thus, during the period of interest, 2002–2007, fuel economy regulation of cars in the United States did not change. By comparison, compliance toward voluntary standards in Europe was evaluated from 2003–2005, although there were no direct penalties if a manufacturer did not meet the standards. From 2005 to 2007, automakers could anticipate the introduction of mandatory standards, but the details of the standards were not decided until after 2007 and they did not apply until 2012.

## 3.3 Vehicle Taxes in the United States and Europe

In the United States, tax policy has focused on creating incentives for consumers to purchase hybrid electric vehicles. From 2001 to 2005, consumers could claim a $2,000 tax deduction for purchasing a hybrid. After 2005, a tax credit was offered of up to $3,400, depending on the fuel economy of the hybrid relative to the fuel economy of a close substitute. Some state and local governments offered additional incentives, such as tax deductions and credits. Beresteanu and Li (2011) and Gallagher and Muehlegger (2011) conclude that these tax incentives had a significant effect on the sales of hybrid vehicles. The total market share of hybrid vehicles increased through the 2000s, but only reached a peak of about 3 percent toward the end of the decade. Therefore, the effect of these taxes on the U.S. new vehicle market is probably limited to a small segment of the market.

European countries tax new vehicle purchases and new vehicle ownership much more broadly than the United States. Purchase taxes, including the value-added tax and other taxes, are paid at the time of purchase. Ownership taxes must be paid each year an individual owns the vehicle. In many countries, the purchase or ownership taxes depend on the characteristics of the vehicle—most often the engine size, power, or $CO_2$ emissions. The introduction noted the example of France, which taxes and subsidizes new vehicle purchases according to $CO_2$ emissions; other examples include Italy, which imposes ownership taxes that depend on the vehicle's power, and Germany, which imposes ownership taxes based on the vehicle's engine size and $CO_2$ emissions. These taxes vary quite substantially across vehicles within countries. For example, the purchase tax can be several thousand euros higher for a vehicle with very low fuel economy than for a vehicle with very high fuel economy. The taxes also vary by an order of magnitude across countries (Braathen 2011).

Roughly coinciding with the adoption of the mandatory $CO_2$ emissions standards, many countries significantly changed their vehicle tax structure. Most of these changes were implemented in 2008 or later, but in some cases, policy changes were discussed prior to 2008.

## 3.4 Product Cycles in the United States and Europe

We briefly discuss the dynamics of new vehicle characteristics in the United States and Europe. These market features play an important role in the empirical analysis.

An individual model may be produced for a decade or more, but within its production spell, the characteristics of the model, such as its exterior, are regularly updated. These changes may be made for purely aesthetic purposes, such as changing the shape of the headlights or introducing a special paint color. Changes may also be made to the engine or transmission to alter fuel economy, power, or other attributes.

In both the United States and Europe, changes to a model's physical characteristics, as well as its engine and transmission characteristics, follow regular cycles. Consequently, the characteristics of a model are fixed over a 12-month time period. In the United States, for most production lines, the model-year begins in mid-August after a brief, one- or two-week, shutdown period. During that shutdown, which separates model-years, the manufacturer may change the model's characteristics, such as its engine size. In practice, changes across model-years range from very minor to a complete overhaul. Once production begins, however, the features of a model are constant over the model-year; a 2005 Honda Civic purchased in January of 2005 is physically the same as a 2005 Civic purchased in February of 2005.

In contrast to the U.S. market, Europe does not distinguish model-years. Yet, similarly to the United States, characteristics change over time in a regular pattern, and characteristics are constant for a 12-month time period. Across the European countries, January is by far the most common month in which new models are introduced to the market. Because of the way the data sets were constructed, we do not observe the exact month in which a new specification is introduced. However, we do have data on the first month of production of each new vehicle *program*, where a program is a collection of related specifications.[10] Using proprietary data provided by CSM, an automobile industry consulting firm, Figure 1 plots the frequency with which new vehicle programs were introduced in Europe by calendar month from 2000 to 2007. The figure indicates that nearly half of the vehicle programs began production in January, and no other month was above 0.08. This suggests that new vehicle specifications are also likely to be introduced in January.

## 3.5 Summary Statistics for the U.S. and European New Vehicle Markets

We next present some summary statistics from the U.S. and European new vehicle markets to characterize some of the major differences between these markets. Because the passenger car data for Europe are more complete than the light commercial vehicle data, we focus on passenger vehicles in both regions. In the United States, we exclude pickup trucks, which are more likely than other vehicle types to be used as commercial vehicles.

Figure 2 compares total new car sales, registrations, fuel economy, and the price of gasoline in the United States and Europe from 2002 to 2007. Both markets exhibit regular seasonal patterns and total sales were fairly stable over this period (the data end just prior to a major decline in total sales for the U.S. market in 2008). Fuel economy increases steadily in both regions over time. The difference between the two regions also increases steadily over time. Gasoline prices are highly correlated across the two regions, although they are more volatile and increase more in the United States. Klier and Linn (2010) suggest that fuel prices explain much of the fuel economy increase in the United States, but the causes for the fuel economy trend in Europe are less well understood.

Figure 3 provides a more complete picture of the fuel economy distribution in Europe and the United States. The figure plots the estimated density function of fuel economy in 2002 and 2007. The European fuel economy distribution is clearly far to the right of the U.S. distribution. It is noteworthy that the

[10] A program is similar to a model, but the term refers to vehicle production rather than vehicle sales. A new vehicle program refers to the introduction of an entirely new product, as well as the successor to an existing model, for example, the 7th generation Honda Civic vs. the 6th generation Honda Civic.

support of the U.S. distribution changed very little between 2002 and 2007, whereas a large number of high–fuel economy (i.e., 45–60 mpg) specifications were introduced in Europe during this period. This difference may be due, at least partly, to the level of the voluntary standards in Europe.

Table 1 includes some of the same information as Figure 1, reports the average market share of diesel cars in Europe, and compares the U.S. car and light truck markets. Note that the diesel market share is about 12 percentage points higher in 2007 than in 2002.

Table 2 provides further background on the U.S. and European vehicle markets. The table provides examples of models in each global market segment and shows the market shares and fuel economy by market segment for 2002 and 2007. The same market segment definitions are used in the United States and Europe.[11]

In Europe, the B and C segments, which are generally small- and medium-sized cars, account for most of the market. The two columns on the right of the table show that the fuel economy within every segment increased between 2002 and 2007. The bottom of the panel reports the registration-weighted average fuel economy in 2002 and 2007 (repeated from Table 1) as well as the registration-weighted average fuel economy in 2007 using the actual fuel economy of each segment and the 2002 market shares. The similarity between this number and the actual number implies that most of the increase in overall fuel economy arose from within-segment increases in fuel economy, rather than substitution across segments.

The bottom of Table 2 shows the same statistics for the U.S. vehicle segments. The table shows the extent to which market shares are weighted more heavily toward the physically larger D and E segments. Similar to Europe, most of the increase in fuel economy between 2002 and 2007 was due to within-segment changes in fuel economy.

[11] We use a set of global segments designed by CSM to provide a consistent set of definitions for each vehicle produced throughout the world. The global segments are constructed based on a vehicle's wheelbase, architecture (unibody or body-on-frame construction), and the vehicle's overall length.

In summary, we observe large differences in fuel economy, market shares, and fuel prices across countries and over time. The summary statistics suggest that a variety of factors affected market shares over the sample period, including the voluntary agreements in Europe, changes in vehicle taxes, fuel prices, and possibly other factors. The next section discusses how we control for other factors as we estimate the effect of fuel prices on new vehicle market shares.

## 4. Estimating the Effect of Fuel Prices on Average New Vehicle Fuel Economy

Our objective is to estimate the effect of fuel prices on new vehicle fuel economy in the United States and Europe as well as the effect of diesel prices on diesel market shares in Europe. We first discuss consistency and then interpretation of the estimating equation.

Our basic approach is to estimate the effect of fuel prices on registrations (in Europe) or sales (in the United States) of individual models. We use the estimated relationship to simulate the effect of a fuel price change on registrations or sales, from which we calculate the change in average new vehicle fuel economy. Following the recent literature, we begin by specifying a linear equation that describes the equilibrium relationship between new registrations or sales of model $i$ at time $t$, $q_{it}$, and lifetime discounted fuel costs, $F_{it}$, of the model

$$ln q_{it} = \alpha + \beta F_{it} + X_{it}\delta + Z_{it}\gamma + \tau_t + \epsilon_{it}, \tag{1}$$

where $X_{it}$ is a vector of model characteristics that are observed by the econometrician and which consumers use to differentiate models, such as horsepower, size, and price; $Z_{it}$ includes the reduced-form effect of government policies on sales (for example, purchase taxes may affect the price of the model as well as its characteristics, which in turn affect the sales of the model); $\tau_t$ is a set of time dummies; $\alpha$, $\beta$, $\delta$, and $\gamma$ are coefficients; and $\epsilon_{it}$ is an error term, which includes the price of the model, consumer characteristics, and unobserved model characteristics.

To estimate equation (1), it is necessary to estimate the fuel costs of each model. We assume that fuel prices follow a random walk and that fuel prices affect miles traveled by the same amount for each model, so that lifetime discounted fuel costs are proportional to the cost of driving the model 1 kilometer. Thus, $F_{it} = P_{it}FC_{iy}$, where $P_{it}$ is the price of fuel in month $t$ for model $i$ and $FC_{iy}$ is the fuel consumption of model $i$ in model-year $y$ (fuel consumption is the inverse of fuel economy). Note that fuel prices vary by model, depending on whether the model uses diesel fuel or gasoline. Below, when we analyze Europe as a whole, we use the average fuel price across countries. The analysis of each country uses the fuel prices in that country.

The parameter of interest is $\beta$, which captures the effect of fuel costs on model sales. An increase in the fuel price raises fuel costs more for models with high fuel consumption. This causes consumers to substitute to models with lower fuel consumption, and therefore we expect $\beta$ to be negative. A fuel price increase may affect average registrations or sales. Note that the time dummies control for the average effect of the fuel price increase. Therefore, $\beta$ captures the change relative to the average, and the time dummies control for the possibility that fuel prices affect the average.

Equation (1) could be estimated by ordinary least squares using data on sales, fuel costs, other model characteristics, and policies. For two main reasons, however, fuel costs are likely to be correlated with the error term, which would bias the estimates. First, although data are available for many model characteristics that are likely to be correlated with fuel consumption and fuel costs, such as the model's horsepower and weight, many characteristics are subjective and hard to measure. These may be correlated with fuel consumption. Second, consumer preferences for model characteristics may be correlated with fuel costs across regions or over time. For example, consumers may have stronger preferences for fuel economy in markets that happen to impose low fuel taxes.

We address the omitted variables problem by taking advantage of the fact that characteristics of a given model tend to remain stable for a specific period of time in each market. Based on the patterns documented in Section 3.4, we add to equation (1) a separate intercept for each model and model-year. In the United States, the model-year is defined to begin in September of the previous calendar year and end in August of the current year. In Europe, a model-year corresponds exactly to a calendar year. This yields equation (2)

$$lnq_{it} = \alpha + \beta F_{it} + \varphi_{iy} + \tau_t + \epsilon_{it}, \tag{2}$$

where $\varphi_{iy}$ is a unique intercept for each model and model-year. The intercept absorbs the observed characteristics, $X_{it}$, as well as the unobserved characteristics from equation (1). Recall that the error term in equation (1) also includes consumer preferences. The model by model-year intercepts control for average consumer preferences for each model over the model-year. Although consumer preferences in each market may vary considerably, and preferences may change over time within a region, we argue that such changes are likely to be slow-moving. Therefore, by focusing on within–model-year variation in registrations and fuel costs, consumer preferences are less likely to be correlated with fuel costs than if we were to use year-to-year variation or cross-region variation. The appendix reports a number of regression models that partially relax this assumption by adding control variables that vary by model and time.

The intercept also provides a flexible means of controlling for the effect of the voluntary $CO_2$ standards and the vehicle purchase and ownership taxes—that is, $Z_{it}$ in equation (1). As noted above, manufacturers primarily responded to the standards by changing the engine or transmission technology to reduce emissions. Following the production patterns in the European market, such changes are likely to have been introduced at the beginning of the calendar year, and thus are constant over the year. The intercepts therefore control for changes in fuel economy and other model characteristics made in response to the $CO_2$ standards.

The model by model-year intercepts control for all taxes that do not change over the model-year. Alternatively, we could include in equation (2) variables that measure the tax for each model. We prefer to control less parametrically for the effects of these taxes by using the model by model-year intercepts.

This approach raises the issue that a change in purchase or ownership taxes could affect purchases before implementation. Firms may change model characteristics in anticipation of a tax change, but this is not a concern because the model by model-year intercepts control for this response. However, consumers could respond in anticipation of a change in purchase taxes. For example, if a country announces that it will increase taxes on large vehicles, consumers who wish to purchase large vehicles may do so before the tax change takes effect to avoid the higher tax. We address this possibility by omitting the years 2008 and 2009 from the analysis; tax changes were much more common in these years than in previous years.

We briefly discuss the interpretation of $\beta$. Because of the model by model-year intercepts, $\beta$ is identified by within-model and model-year variation in model sales and fuel costs. The coefficient corresponds to the effect of fuel prices on equilibrium model sales. The model by model-year intercepts control for the average price of each model over the model-year, but monthly fuel prices may affect monthly model prices. Because we do not control for model prices, equation (2) describes the reduced-form relationship between fuel prices and model sales.

Equation (2) imposes the assumption that $\beta$ is constant over time and across models. In practice, because of heterogeneity in how much consumers drive, their discount rates, or other factors, the coefficient may vary across models. For example, drivers of small models tend to drive fewer miles, in which case a fuel price increase would have a smaller effect on the lifetime discounted fuel costs of a small car; $\beta$ would be smaller for small cars. We obtain similar results if we partially relax this assumption and allow $\beta$ to vary across market segments.

Related to the assumption of a constant $\beta$ is the fact that it is fairly common in Europe for companies to purchase models for use by their employees. The effect of fuel prices on sales of company cars may be less than the effect on privately owned cars. The registration data do not distinguish company cars, and we interpret the estimate of $\beta$ as the average effect of fuel prices on model sales across company cars and privately owned cars. For predicting the effect of fuel price or tax changes out-of-sample, however, the results are robust as long as fuel prices do not affect the share of company car sales in the total sales of each model.

Because we use monthly data, this is a short-run analysis. For three reasons, the long-run response could be greater. First, consumers may respond gradually to fuel prices. Second, although a random walk assumption is consistent with the fuel price data, it is possible that at least some consumers assume that there is mean reversion. These consumers would respond less to monthly changes in fuel prices than to permanent price changes such as would occur if fuel taxes change. Third, firms may not adjust supply immediately to price changes, or they may change characteristics of their models over time. We can partially address this issue by using quarterly observations instead of monthly, which allows for lags of consumers' or firms' responses to fuel prices. Nonetheless, the quarterly analysis does not account for changes in vehicle characteristics (Gramlich 2010), and may understate the full long-run effect.

# 5. Fuel Prices and New Vehicle Fuel Economy

This section reports estimates of the effect of fuel prices on new vehicle sales and registrations. We use the results to estimate the effect of fuel prices on average new vehicle fuel economy and the effect on the full distribution of fuel economy.

## 5.1 Estimation Results

### 5.1.1 Comparison of the United States and Europe

Table 3 reports estimates of equation (2) for the U.S. and European vehicle markets. To account for persistence in sales and registrations, equation (2) is first differenced by model and model-year for the United States and by model fuel type–year for Europe. The transformed regression equation includes fuel costs as the main independent variable of interest, plus a set of year–month interactions to account for aggregate shocks to the market. The dependent variable is the log of total registrations by model, fuel type, and month in Europe, and the log of sales by model and month in the United States. To compare results across regions, the fuel cost variable is normalized to have a mean of one in each region; the coefficient estimate can be interpreted as the elasticity of sales or registrations to fuel costs.

Column 1 of Table 2 shows the estimated coefficient on fuel costs. For both the United States and Europe, the estimates are statistically significant at the 1 percent level. The point estimate is more than three times as large for the United States as Europe, which suggests that a proportional change in fuel costs in both regions would affect sales or registrations three times as much in the United States.

It may not be valid to compare estimation results in which a model is the unit of observation in both regions. As indicated by the number of observations in column 1, the European market has many more models than the U.S. market. Because models are more narrowly defined in the European data, one might expect a larger estimate for Europe if consumers respond to a change in fuel prices by substituting across closely related models—that is, the higher level of aggregation in the U.S. sample would mask some of this substitution. This would suggest that the difference between the U.S. and European markets is even greater than that in column 1. On the other hand, estimating the regression in logs could create aggregation bias, the sign of which is ambiguous.

To address these concerns, we aggregate models to the brand-segment level and reestimate equation (2). The number of unique brand-segments in the European market is very similar to the number of models in the U.S. market, so this may be a more appropriate comparison. Column 2 shows that the estimate for the European market (−1.00) is larger than the estimate in column 1 (−0.46), but the estimate is still much smaller than the U.S. estimate in column 1. The results thus suggest that sales or registrations respond more to changes in fuel costs in the United States than to those in Europe. Below, we compare these estimates with the existing literature, but we first focus on robustness.

Using monthly observations may underestimate the long-run effects, particularly in Europe, where inventories are typically lower and it may take several months for registrations to respond to a price change. To address this possibility, we estimate regressions similar to columns 1 and 2, except that we use quarterly rather than monthly observations (i.e., total quarterly registrations and average quarterly fuel costs). For Europe, the estimates using quarterly observations are much smaller than the monthly estimates. This suggests that we do not underestimate the long-run response.

We next address several potentially confounding factors. Previously, we noted the challenge of controlling for the effects of vehicle purchase and ownership taxes and of the $CO_2$ emissions standards. Recall that we control for taxes in two ways, first by limiting the sample to 2002–2007, during which time taxes were relatively stable compared to the post-2007 period. Second, because taxes depend on observable characteristics of the model (weight, horsepower, and so on), the model fixed effects control for the effects of taxes on registrations. Nonetheless, it is possible that small, within model-year, tax changes affect the results. From 2002 to 2007, many of the purchase and ownership taxes depended on the engine displacement and fuel type of the model. We test whether these taxes affect our results by adding interactions of time with a set of quartile dummies for engine displacement. We have also estimated equation (2) adding interactions of time with a dummy variable for whether the model uses diesel fuel. In both cases, the brand-segment level estimates are similar to those reported in Table 3 (see Appendix Table 1).

The approaches used to control for taxes also help us control for the $CO_2$ emissions standards; the sample ends before the mandatory standards were implemented, and the fixed effects control for technology that was introduced at the beginning of each year to reduce emissions rates. However, it is possible that certain firms were particularly concerned with meeting the voluntary standards and that they therefore introduced technology during a model-year or adjusted model prices to reduce their average emissions rates, for example by reducing prices of diesel vehicles. In such cases, the fixed effects would not fully control for these changes. Although we cannot observe such decisions, we can construct a proxy variable for the emissions rate constraint that is similar to an approach used by Small and Van Dender (2007) to control for CAFE in the U.S. market. For each brand and year, we construct the difference between the registration-weighted actual emissions of the models sold by the firm and the value of the voluntary standard. Larger positive values of this variable would indicate a firm that is far from complying with the voluntary standards. We add to equation (2) the interaction of the one-year lag of this variable with the fuel cost variable, and we test whether the interaction term is statistically significant (also including the main effect of the variable). The results (not reported) are not affected, particularly for the larger firms in the sample (for example, for the top 20 brands, which account for 90 percent of registrations).[12] Alternatively, adding brand–year–month interactions may be a more flexible way of controlling for the voluntary standards; doing so yields results similar to those reported in Table 3. As an additional check, the interim standard was assessed in 2003, when firms may have experienced greater pressure to meet the standards than in other years. Omitting observations from 2003 further supports the finding of a smaller effect in Europe (the latter two results are reported in Appendix Table 1).

Appendix Table 1 reports a number of additional regressions that address potential bias from consumer preferences. We use a semiparametric approach by including interactions of time with market segment, by including brand–time interactions, and by omitting models with low fuel economy. We have also estimated regressions that include lag-dependent variables and lags of fuel costs to explore dynamics, and we have estimated a number of different functional forms. The results reported above and in Appendix Table 1 reveal no evidence that vehicle taxes, the voluntary $CO_2$ emissions standards, or changes in consumer preferences affect the main conclusions. Klier and Linn (2010) report similarly robust estimates in the U.S. market. Thus, using monthly and quarterly data, we find a much smaller effect of fuel prices on sales or registrations in Europe than in the United States.

#### 5.1.2 Comparison of the Five Largest European Markets

We use data on country-level model registrations to investigate whether the effect of fuel prices across countries differs significantly. We focus on the five largest markets in Europe (in descending order of annual registrations): Germany, Italy, the United Kingdom, France, and Spain.

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[12] The effect of fuel costs on registrations appears to be greater for the larger brands overall. However, the estimate is about half as large as for the full U.S. sample, and the main conclusions are the same for this subsample.

Before showing the estimation results, Table 4 provides some background by documenting some of the variation across these markets in registrations, fuel prices, and diesel market shares. Fuel economy in Germany and the United Kingdom are substantially lower than fuel economy in the other countries. At first glance, this does not appear to be driven by differences in average fuel prices: although the United Kingdom has the lowest gasoline and diesel prices, Germany's prices are about as high as those in Italy and France. For additional background, Appendix Table 2 shows market shares by global market segment and country, which reflect the cross-country fuel economy differences in Table 4.

Table 5 reports estimates of equation (2) separately for the five largest markets in Europe. Panel A reports model-level regressions, and Panel B reports regressions at the brand-segment level. The country-level sample sizes are only slightly smaller than in Table 3 because many models are sold in all countries. For reasons discussed above, we focus on the brand-segment level results, but we present the model-level results for completeness. The regressions are otherwise identical to the Europe-wide analysis in Table 3. As before, fuel costs are normalized by the mean in each country so that the magnitudes can be interpreted as elasticities.

Panel B shows the considerable differences across European countries. Fuel prices have a relatively large effect on registrations in the United Kingdom and France (although the U.K. estimate is not statistically significant). However, these estimates are much smaller than the U.S. estimates in Table 3. The effect of fuel prices on registrations in the other countries is much smaller, and the coefficient estimates are not statistically significant. We can reject the hypothesis that the coefficients are as large as the U.S. estimate in Table 3.

We briefly discuss several possible explanations for the observed differences across countries. On the demand side, consumer preferences for fuel economy or expectations of fuel prices may vary across countries, or consumers may respond more at lower price levels than at higher levels. On the supply side, supply may be more elastic in some countries or for some firms. Finally, fuel economy regulation could explain the differences across countries—for example, consumers may be less responsive to fuel prices when overall fuel economy is increasing, as it was in Europe.

In general, data limitations make it difficult to distinguish among the hypotheses. On the demand side, company car purchases could explain differences in the consumer response to fuel prices across countries, as company car market shares vary across countries and such purchases may be less sensitive to fuel prices. Vance and Mehlin (2009) find little difference in the effect of fuel prices for company cars in Germany, but without complete data on company car ownership by model across Europe, this remains an open question. Furthermore, because fuel prices in Europe were noticeably higher than in the United States during the time period analyzed, and because not all models sold in the two markets are identical, it is not possible to investigate whether the differences in fuel prices explain the differences in consumer response across the two regions. However, we can make some headway in Europe. We do not find evidence of a strong correlation between the estimated $\beta$ and fuel prices, which suggests that differences within Europe are not explained by differences in how consumers respond to fuel prices when prices are low compared to when prices are high. Further investigation of the underlying causes of the cross-country differences is a subject for future research.

## 5.2 The Effect of Fuel Prices on Average Fuel Economy and the Fuel Economy Distribution

We quantify the economic importance of the estimated coefficients by simulating the effect on fuel economy of a change in fuel prices. We consider a $1/gallon increase as a benchmark—such a change is outside of our estimation sample, but using a relatively large change illustrates how small in magnitude our estimates are for Europe.

### 5.2.1 Average Fuel Economy

Table 6 reports the change in sales- or registrations-weighted average fuel economy caused by increasing fuel prices by $1/gallon in each market. We use the coefficient estimates to compute the log sales of each model in 2002 if fuel prices had been $1/gallon higher throughout the year. The counterfactual sales are then used to compute the counterfactual sales–weighted fuel economy, which is compared against the actual sales-weighted fuel economy. The table reports the results of these calculations for the United States, Europe, and the five countries within Europe. For reference, the table also reports the average price of fuel in 2002. Prices are reported in 2005 dollars per gallon, rather than the local currency, to provide a sense of the relative price levels.

The results are consistent with the relative magnitudes of the estimated coefficients from Table 3. The effect of the fuel price increase on average fuel economy is three times as large for the United States as for Europe. Note that the U.S. fuel economy change is three times as large as the European change even though the elasticity estimate in Table 3 is less than two times as large; this difference is explained by the fact that Table 6 considers the effects of a $1/gallon price increase, which represents a smaller percentage change in Europe.

The estimates in Table 6 correspond to an elasticity of fuel economy to fuel prices of 0.06 in the United States and 0.03 in Europe. The European estimates are substantially smaller than those of Vance and Mehlin (2009) as well as some other empirical studies of European vehicle markets. This difference may be due to time-varying demand and supply shocks that are correlated with model characteristics, which are not accounted for in previous research. The other studies typically use annual data and may therefore correspond to more of a long-run analysis, which could also explain the discrepancy. On the other hand, Table 3 shows that the estimates are not larger if we use quarterly data, which suggests that omitted variables, rather than a distinction between the short run and the long run, explain the differences across studies.

We found large differences within Europe as well. For several of the countries, a significant increase in fuel prices would have no effect on average fuel economy.

### 5.2.2 Fuel Economy Distribution

The estimation results in Table 3 allow us to investigate the effect of fuel prices on the entire fuel economy distributions of new vehicle sales in Europe and the United States. We consider the effect of fuel price convergence on fuel economy in the United States and Europe—specifically, an increase in the gasoline price of $1/gallon in the United States, and a decrease of $1/gallon in Europe. This scenario represents a significant amount of convergence, as the difference in gasoline prices in 2002 would decrease from $2.74/gallon ($4.22/gallon in Europe minus $1.48/gallon in the United States) to $0.74/gallon (see Table 1).

Figure 4 replots the fuel economy distributions in 2002 from Figure 2 for the United States and Europe. The dashed curves represent the counterfactual fuel economy distributions that would have occurred if fuel prices in 2002 were $1/gallon higher in the United States and $1/gallon lower in Europe. The vertical lines indicate the means of the corresponding distributions.

The price changes would have decreased average fuel economy by about 0.30 mpg in Europe and would have increased average fuel economy by about 1 mpg in the United States. The figure shows that the price changes have a very small effect on the European distribution, whereas the U.S. distribution shifts noticeably to the right. The change in the U.S. distribution is greatest for models with very low fuel economy, meaning that there is more substitution among low–fuel economy models than among high–fuel economy models.[13] Thus, we find that fuel prices have a relatively small effect on the fuel economy distribution in Europe.

[13] The change in the distribution reflects the predicted change in sales or registrations for the vehicles in the sample. Therefore, these results—as well as the average fuel economy results above—could be affected by the fact that we have assumed that the coefficient on fuel costs is the same across vehicles. Klier and Linn (2010) find that relaxing this assumption does not affect the results for the United States. Similar results pertain for Europe.

## 6. Diesel Fuel Prices and Diesel Market Shares

Table 4 shows that diesel fuel prices are usually lower than gasoline prices in Europe, and the difference (or percentage difference) between diesel fuel and gasoline prices varies across countries. France discounts diesel fuel the most, in absolute and relative terms, and the United Kingdom the least. It is widely believed that the lower price of diesel fuel has significantly increased the market share of diesel models but, using data from 1991 to 1994 for Belgium, France, and Italy, Verboven (2002) suggests that this effect may be overstated because of second-degree price discrimination. Earlier studies (for example, Rouwendal and de Vries 1999) find an effect of fuel prices on diesel market shares, but little recent Europe-wide empirical evidence supports an effect of diesel fuel prices on diesel market shares. This section presents estimates of the effect of diesel fuel prices on diesel market shares—specifically, how different diesel market shares would have been in 2007 if diesel fuel and gasoline prices had been equal. To preview the results, we find no evidence that diesel fuel prices between 2002 and 2007 had a large effect on the market share of diesel vehicles.

We employ two strategies to estimate the effect of diesel fuel prices on the registrations of diesel models. First, we reestimate equation (2) but replace the fuel cost variable with two variables, the first of which is equal to the fuel costs for gasoline models, and the second of which is equal to the fuel costs for diesel models (the gasoline variable equals zero for diesel vehicles and vice versa). Note that the regression is similar to adding to equation (2) the interaction of fuel costs with a dummy variable equal to one if the model is a diesel. Instead, we report the coefficients on the gasoline and diesel fuel costs, which can be interpreted as the elasticity of registrations to gasoline or diesel fuel costs. The regressions are estimated at the level of the brand–segment–fuel type–month.

Panel A of Table 7 reports the results of this exercise, where the first column uses the full European sample, and the remaining columns use the samples for the individual countries. Column 1 shows that gasoline costs affect model registrations slightly less than diesel fuel costs across Europe as a whole. At the country level, the coefficient on diesel fuel costs is typically smaller than in column 1, and is not statistically significant.

Panel A of Table 8 shows the implications of the point estimates. The first row reports the actual diesel market share in 2007 for the corresponding sample. We estimate the counterfactual market share by assuming that the price of diesel fuel was as high as the price of gasoline for every month in 2007. We use the counterfactual prices to estimate the registrations of diesel models, from which we calculate the counterfactual diesel market share. The table shows that the counterfactual market shares are very close to the actual market shares; the largest difference is three percentage points in the case of France. Furthermore, although we do not report standard errors in Table 8, the standard errors in Table 7 imply that we can statistically reject a large effect of diesel fuel prices on diesel market shares (i.e., if we use the delta method to approximate standard errors in Table 8). Note that this estimation relies on the assumption that the diesel fuel price does not affect registrations of gasoline models. For that reason, the estimates in Table 8 may understate the effect of diesel fuel taxes, but the small point estimate on gasoline costs in Table 7 suggests that this bias is likely to be small (we return to this issue below).

The second empirical strategy is to make use of the fact that, for many models in Europe, consumers may choose between a gasoline and a diesel version. Although the prices and some physical attributes of these versions vary, they are generally fairly similar to one another. The similarity suggests the following regression, which estimates the effect of the relative price of gasoline on the share of diesel registrations in total registrations of the model

$$\frac{q_{pt}^d}{q_{pt}^d+q_{pt}^g} = \alpha + \beta \ln(\frac{p_t^g}{p_t^d}) + \varphi_{py} + \tau_m + \epsilon_{pt}. \quad (3)$$

The dependent variable is the monthly diesel registrations divided by the total registrations of the gasoline–diesel pair (which is indexed by $p$). The main independent variable of interest is the log of the price of gasoline divided by the price of diesel fuel. The regression includes model by model-year interactions as well as month dummies, and the equation is estimated by taking first differences by model and year to eliminate the model by model-year interactions. It is expected that $\beta$ is positive, as an increase in the price of gasoline relative to the price of diesel should cause consumers to substitute toward the diesel alternative. Note that because the fuel prices vary by month, it is not possible to include month-by-year interactions as in equation (2).

There are tradeoffs between the two approaches. On the one hand, the price ratio is not as persistent as the price levels. If the log price ratio is regressed on its lag, the coefficient on the lag is 0.8, whereas the coefficient is one if either fuel price is regressed on its own lag. In that case, the coefficient on the log price ratio in equation (3) would understate the effect of a permanent price change. On the other hand, focusing on diesel–gasoline pairs is similar to Verboven (2002), and may better control for unobserved factors that affect diesel market shares. This approach also relaxes the assumption made above that diesel fuel prices do not affect registrations of gasoline models.

Panel B of Table 7 reports the estimate of $\beta$ in equation (3) using all gasoline–diesel pairs in the European sample in the first column, and all such pairs in the individual countries in the remaining columns. The coefficient is not statistically significant in any of the regressions. Table 8 reports the actual diesel market and the counterfactual diesel market share that would have occurred if the price of diesel fuel were equal to the price of gasoline each month in 2007; the table shows that equating diesel fuel and gasoline prices would have a very small effect on diesel market shares.[14] We can address the concern about the persistence of the price ratio by using annual rather than monthly observations. That exercise yields similar conclusions (not reported). Thus, neither estimation approach reveals evidence suggesting that diesel fuel prices had a large effect on diesel market shares during the sample period.

[14] The diesel market share would decrease in the United Kingdom because the diesel fuel price is slightly higher than the gasoline price in the United Kingdom. The diesel market share would decrease in Italy because the coefficient estimate in Table 7 is negative for Italy.

## 7. Conclusions

This paper investigates the effect of fuel prices on new vehicle fuel economy in the United States and Europe. The econometric analysis focuses on monthly variation in fuel prices, registrations, and sales, and includes model by model-year fixed effects to control for the potentially confounding effects of $CO_2$ emissions standards, vehicle taxes, and consumer preferences. We document considerable differences across countries. Fuel economy responds more than three times as much to fuel prices in the United States than on average in Europe. Within Europe, we find a much larger effect in the United Kingdom and France than in Italy, Germany, and Spain. Although this paper constitutes a short-run analysis, it suggests that the long-run effects of fuel prices on new vehicle fuel economy are small in Europe.

These results suggest that firms or consumers differ significantly across countries in how they respond to fuel prices. Furthermore, if we interpret these results as indicative of the long-run relationship between fuel prices and fuel economy, they suggest that fuel taxes probably explain only a small share of the differences in fuel economy between the United States and Europe.

The results also have implications for energy security and environmental policy. First, the differences across countries should be considered when designing policies for individual countries. Second, although these are short-run estimates, they suggest that raising fuel taxes would be far more effective at raising fuel economy in some European countries than in others. Overall, however, the effect would be much smaller than in the United States, where fuel taxes have been much lower. The small estimates also suggest that large increases in fuel taxes would significantly reduce total fuel consumption only if fuel costs reduce the amount that people drive (Frondel et al. 2010).

## 8. References

Abuelsamid, Sam. 2010. The Truth about the New 34.1-mpg CAFE Standards. *Popular Mechanics,* April 8.

Allcott, Hunt, and Nathan Wozny. 2010. Gasoline Prices, Fuel Economy, and the Energy Paradox. Working paper 2010-003. Cambridge, MA: Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research.

Anderson, Soren T., Ryan Kellogg, and James M. Sallee. 2011. What Do Consumers Believe about Future Gasoline Prices? NBER working paper no. 16974. Cambridge, MA: National Bureau of Economic Research.

Beresteanu, Arie, and Shanjun Li. 2011. Gasoline Prices, Government Support, and the Demand for Hybrid Vehicles. *International Economic Review* 52(1): 161–182.

Braathen, Nils Axel. 2011. $CO_2$-Based Taxation of Motor Vehicles. Unpublished manuscript, OECD.

Busse, Meghan R., Christopher R. Knittel, and Florian Zettelmeyer. 2009. Pain at the Pump: How Gasoline Prices Affect Automobile Purchasing in New and Used Markets. NBER working paper no. 15590. Cambridge, MA: National Bureau of Economic Research.

Clerides, Sofronis and Theodoros Zachariadis. 2008. The Effect of Standards and Fuel Prices on Automobile Fuel Economy: An International Analysis. *Energy Economics* 30: 2657-2672.

European Parliament. 2009. Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 Setting Emission Performance Standards for New Passenger Cars as Part of the Community's Integrated Approach To Reduce $CO_2$ Emissions from Light-Duty Vehicles. *Official Journal of the European Union* L 140, vol. 52, 1–15.

Frondel, M., N. Ritter, and C. Vance. 2010. *Heterogeneity in the Rebound Effect—Further Evidence for Germany*. Ruhr Economic Papers No. 227. Essen, Germany: Rheinisch–Westfälisches Institut für Wirtschaftsforschung.

Gallagher, Kelly Sims, and Erich Muehlegger. 2011. Giving Green to Get Green? Incentives and Consumer Adoption of Hybrid Vehicle Technology. *Journal of Environmental Economics and Management* 61: 1–15.

Goulder, Lawrence H., Mark R. Jacobsen, and Arthur V. van Benthem. 2009. Unintended Consequences of Nested State and Federal Regulations: The Case of the Pavley Greenhouse-Gas-per-Mile Limits. NBER working paper no. 15337. Cambridge, MA: National Bureau of Economic Research.

Gramlich, Jacob. 2010. Gas Prices, Fuel Efficiency, and Endogenous Product Choice in the U.S. Automobile Industry. Unpublished manuscript, Georgetown University.

Jacobsen, Mark R. 2010. Evaluating U.S. Fuel Economy Standards in a Model with Producer and Household Heterogeneity. Unpublished manuscript, University of California, San Diego.

Klier, Thomas, and Joshua Linn. 2010. The Price of Gasoline and the Demand for Fuel Economy: Evidence from Monthly New Vehicles Sales Data. *American Economic Journal: Economic Policy* August: 134–153.

Li, Shanjun, Joshua Linn, and Erich Muehlegger. 2011. Gasoline Taxes and Consumer Behavior. Unpublished manuscript, Resources for the Future and Harvard University.

Muehlegger, Erich, and Justin Marion. 2011. Fuel Tax Incidence and Supply Conditions. *Journal of Public Economics* 95: 1202-1212.

Parry, Ian W.H., David Evans, and Wallace C. Oates. 2010. Are Energy Efficiency Standards Justified? Discussion paper 10-59. Washington, DC: Resources for the Future.

Rouwendal, Jan, and Frans de Vries. 1999. The Taxation of Drivers and the Choice of Car Fuel Type. *Energy Economics* 21: 17–35.

Ryan, Lisa, Susana Ferreira, and Frank Convery. 2009. The Impact of Fiscal and Other Measures on New Passenger Car Sales and $CO_2$ Emissions Intensity: Evidence from Europe. *Energy Economics* 31: 365–374.

Schipper, Lee, Polly Hand, and Kenneth Gillingham. 2010. The Road from Copenhagen: Fuel Prices and Other Factors Affecting Car Use and $CO_2$ Emissions in Industrialized Countries. Paper presented at the 12th World Conference on Transport Research, July 11–15, Lisbon, Portugal.

Schipper, Lee, C. Marie-Lilliu, and L. Fulton. 2002. Diesels in Europe: Analysis of Characteristics, Usage Patterns, Energy Savings and $CO_2$ Emission Implications. *Journal of Transport Economics and Policy* 36(2): 305–340.

Small, Ken A., and Kurt Van Dender. 2007. Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect. *The Energy Journal* 28(1): 25–51.

TiS. 2002. *Study on Vehicle Taxation in the Member States of the European Union, Final Report*. Prepared for the European Commission.

Vance, Colin, and Markus Mehlin. 2009. *Tax Policy and $CO_2$ Emissions: An Econometric Analysis of the German Automobile Market*. Ruhr Economic Papers No. 89. Essen, Germany: Rheinisch–Westfälisches Institut für Wirtschaftsforschung.

Verboven, Frank. 2002. Quality-Based Price Discrimination and Tax Incidence: Evidence from Gasoline and Diesel Cars. *Rand Journal of Economics* 33: 275–297.

Yacobucci, Brent. 2010. EPA and NHTSA: The New Auto Greenhouse Gas and CAFE Standards. Presentation at "After the perfect storm - competitive forces shaping the auto industry"**.** May 11, Detroit, MI. http://www.chicagofed.org/digital_assets/others/events/2010/automotive_perfect_storm/2010_Detroit_autoconference_Yacobucci.pdf (accessed September 29, 2010).

Yacobucci, Brent, and Robert Bamberger. 2006. *Automobile and Light Truck Fuel Economy: The CAFE Standards.* Report RL33413 (updated December 12, 2006). Washington, DC: Congressional Research Service.

Zachariadis, Theodoros. 2006. On the Baseline Evolution of Automobile Fuel Economy in Europe. *Energy Policy* 34: 1773–1785.

Figure 1: First Month of Production of Vehicle Programs in Europe

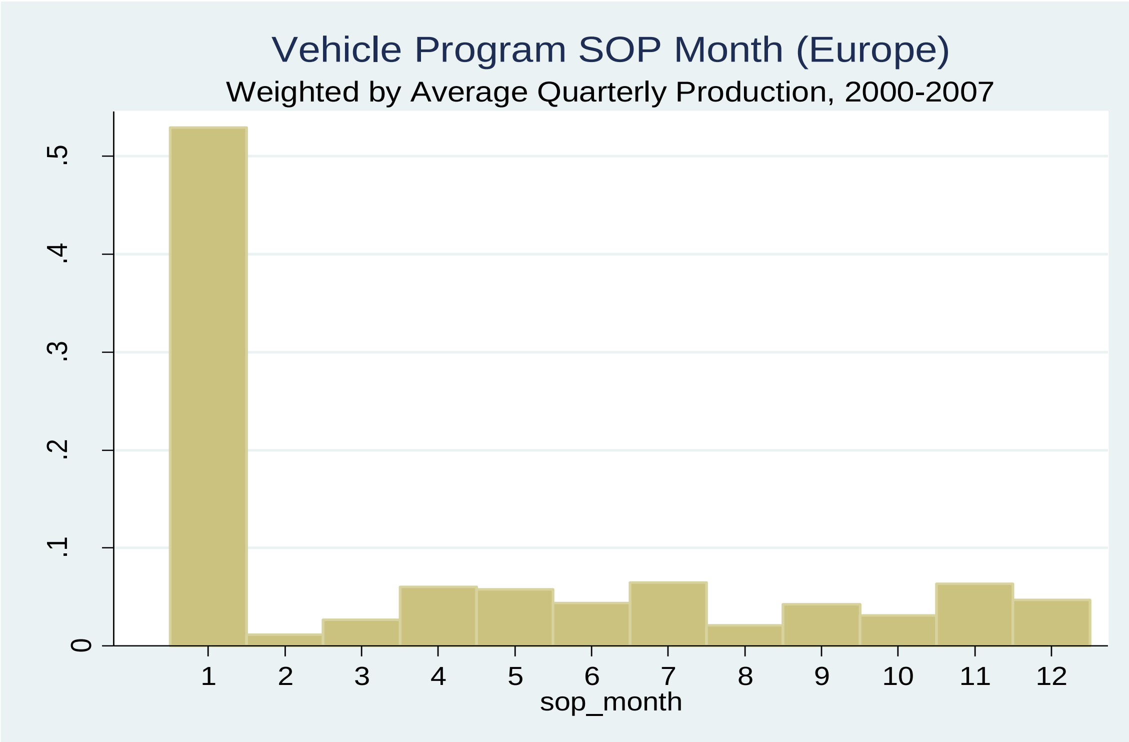
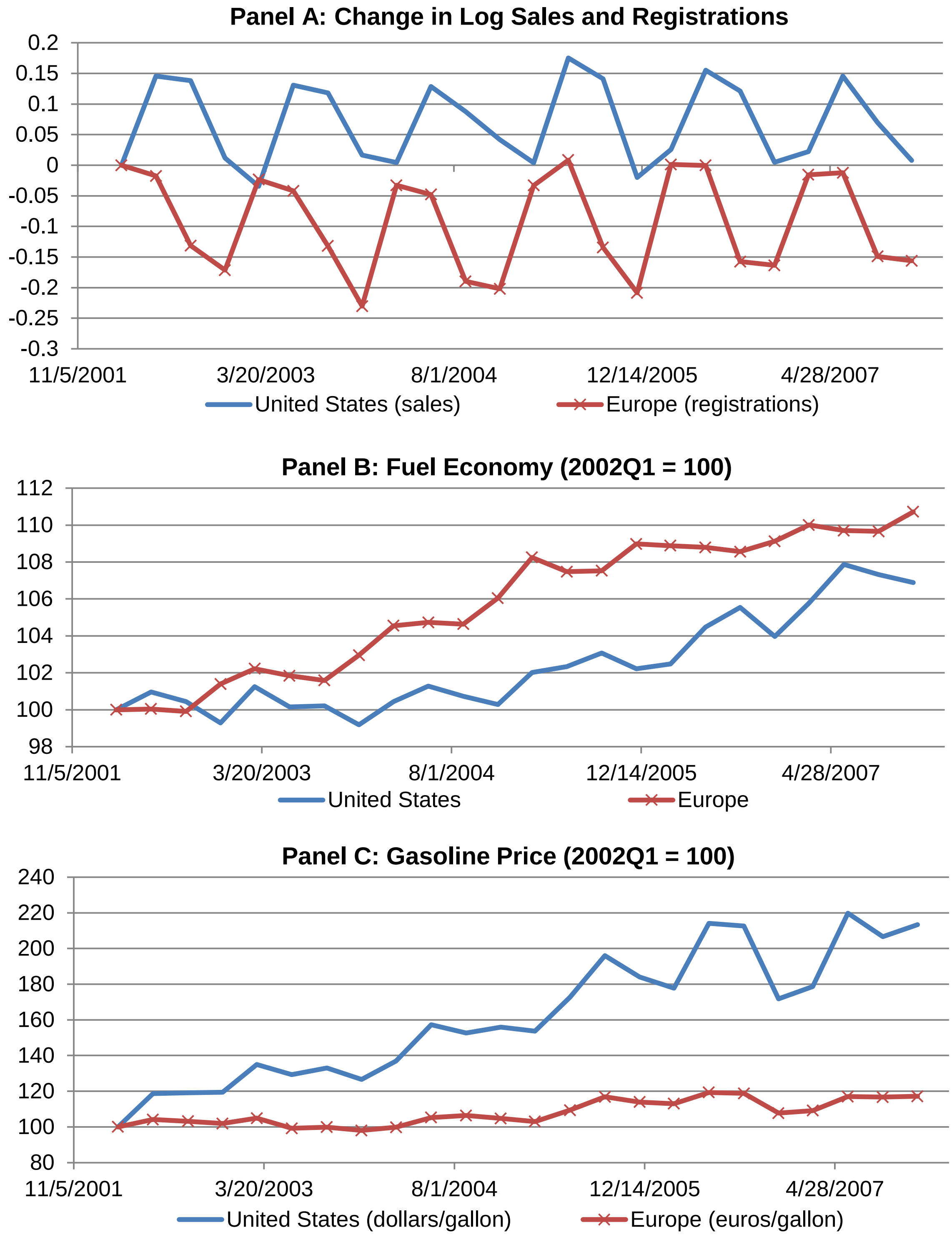
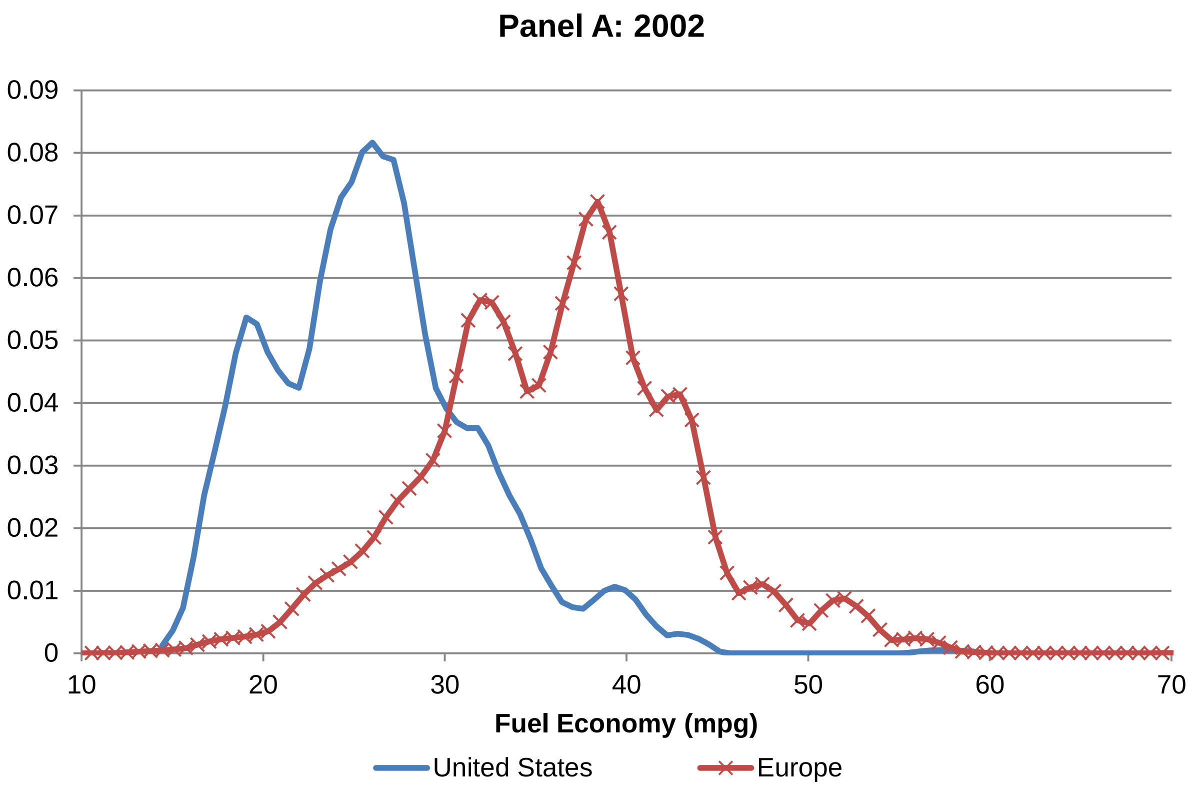


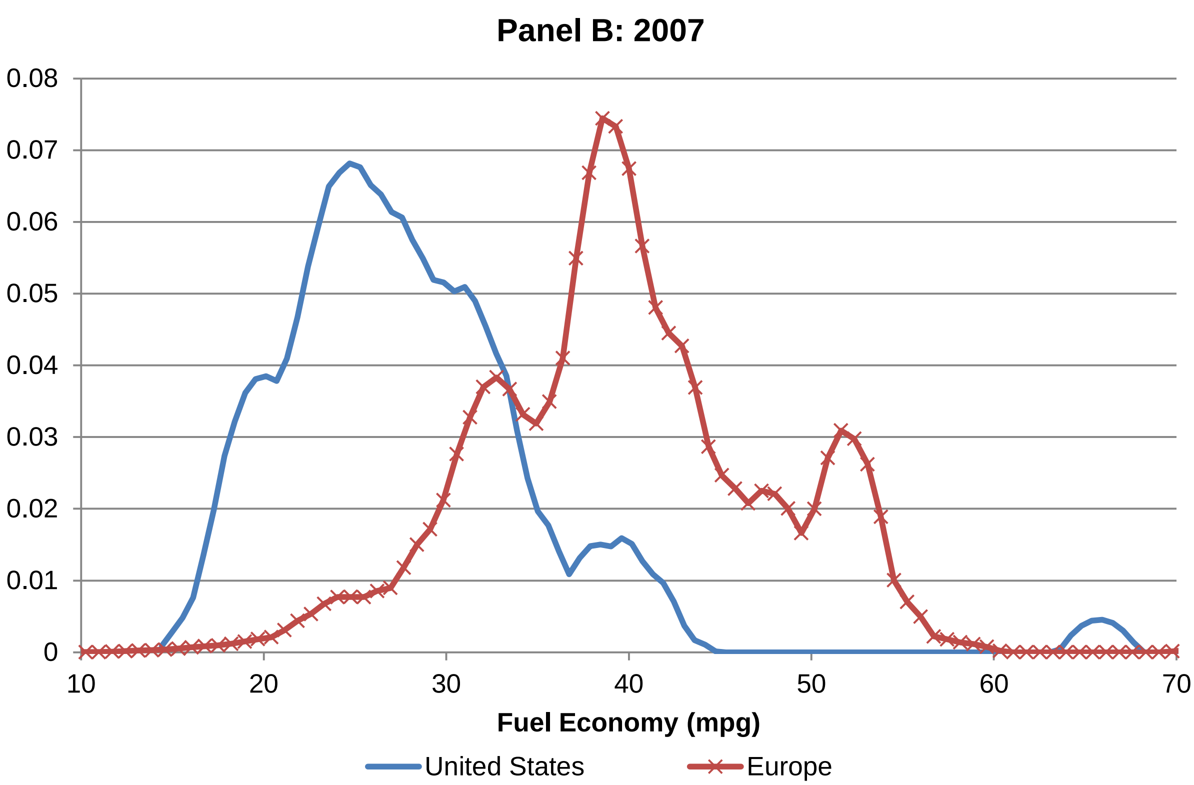
**Figure 2: Quarterly Sales, Registrations, MPG and Gasoline Price for the United States and Europe, 2002-2007**




Notes: See notes to Table 1 for data sources. Panel A plots the change in logs since the first quarter of 2002. In Panel B and Panel C, variables are normalized to equal 100 in the first quarter of 2002.

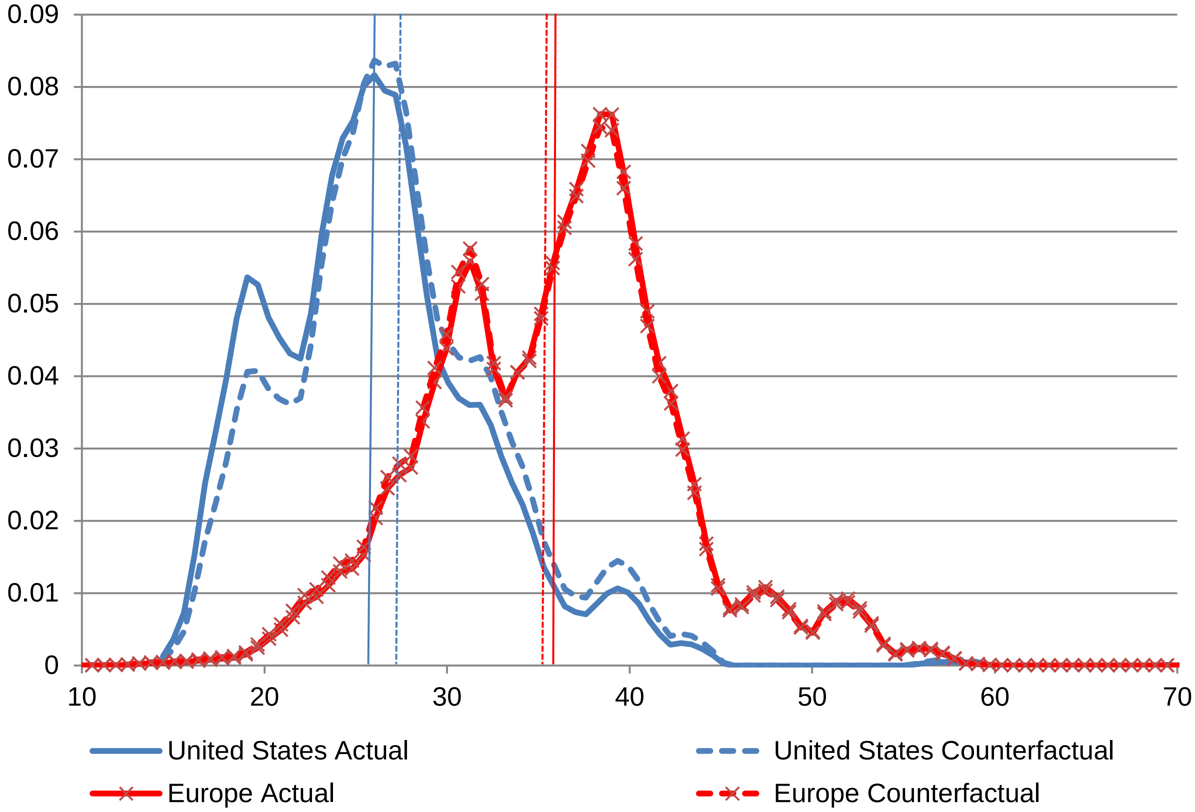
## Figure 3: Estimated Fuel Economy Density Function for the United States and Europe, 2002 and 2007




Notes: Samples include all passenger car sales or registrations from the indicated year and region. Kernel density functions are estimated using a bandwidth of 1.

**Figure 4: Effect of Gasoline Price Convergence on 2002 Fuel Economy Distributions**




Notes: The figure plots the estimated fuel economy distribution in the United States and Europe. Solid lines indicate the estimated distributions using actual sales and registration data in the United States and Europe, and are constructed as in Figure 2. Dashed lines are based on the predicted sales and registrations under a $1/gallon price increase in the United States and a $1/gallon price decrease in Europe, and using the estimated coefficients in column 1 of Table 3 for the United States and column 2 of Table 3 for Europe. The vertical lines indicate the mean fuel economy for the corresponding distribution.

Table 1

## Summary Statistics for the U.S. and Europe (2002 and 2007)

Panel A: Europe

| Year | Vehicle Type | Registrations (millions) | Fuel Economy (mpg) | Diesel Market Share | Gasoline Price (2005 euros/gallon) |
|---|---|---|---|---|---|
| 2002 | Cars | 12.85 | 36.23 | 0.43 | 4.23 |
| 2007 | Cars | 12.81 | 39.74 | 0.55 | 4.76 |

Panel B: United States

| Year | Vehicle Type | Sales (millions) | Fuel Economy (mpg) | | Gasoline Price (2005 dollars/gallon) |
|---|---|---|---|---|---|
| 2002 | Cars | 7.96 | 29.32 | | 1.48 |
| 2007 | Cars | 7.62 | 31.18 | | 2.66 |
| 2002 | Cars and Light Trucks | 13.46 | 26.09 | | 1.48 |
| 2007 | Cars and Light Trucks | 13.28 | 27.86 | | 2.65 |

Notes: Data sources for Panel A are R.L. Polk and Eurostat. Data sources for Panel B are Wards Auto and BLS. Panel A reports total registrations in millions and Panel B reports total sales in millions. Both panels report fuel economy in miles per gallon (mpg) as measured by the CAFE test cycle and European test cycle. The gasoline price in Panel A is reported in euros per gallon and the gasoline price in Panel B is reported in dollars per gallon. Fuel prices are reported in 2005 dollars using the consumer price index from Eurostat. Because the table reports annual sales-weighted average prices, the average price for cars and light trucks in the United States is not identical. The average exchange rate in 2002 was 0.95 dollars/euro and in 2007 it was 1.37 dollars/euro. The top 2 rows in Panel B include cars and the bottom two rows include cars and light trucks, except that pickup trucks are not included.

Table 2

## Market Shares and Fuel Economy by Segment (2002 and 2007)

Panel A: Europe

| | Market Share | | Fuel Economy (mpg) | |
|---|---|---|---|---|
| Global Segment (example) | 2002 | 2007 | 2002 | 2007 |
| A-Segment (Smart Fortwo) | 0.07 | 0.08 | 40.32 | 46.17 |
| B-Segment (Ford Fiesta) | 0.30 | 0.29 | 39.77 | 43.23 |
| C-Segment (Ford Focus) | 0.38 | 0.38 | 35.73 | 39.39 |
| D-Segment (VW Passat) | 0.19 | 0.18 | 32.78 | 36.04 |
| E-Segment (Range Rover) | 0.04 | 0.05 | 28.33 | 29.16 |
| Mini Full (Jeep Wrangler) | 0.00 | 0.00 | 15.13 | 25.99 |
| Compact F (Toyota Land Cruiser) | 0.01 | 0.01 | 24.83 | 25.70 |
| Full Size (Chevrolet Tahoe) | 0.00 | 0.00 | 32.86 | 33.22 |
| Average | | | 36.23 | 39.74 |
| Average, 2002 Market Shares | | | | 39.47 |

Panel B: United States

| | Market Share | | Fuel Economy (mpg) | |
|---|---|---|---|---|
| Global Segment (example) | 2002 | 2007 | 2002 | 2007 |
| A-Segment (Smart Fortwo) | 0.00 | 0.00 | 22.49 | 24.22 |
| B-Segment (Ford Fiesta) | 0.02 | 0.05 | 32.02 | 34.77 |
| C-Segment (Ford Focus) | 0.24 | 0.26 | 32.38 | 32.55 |
| D-Segment (VW Passat) | 0.32 | 0.33 | 26.62 | 29.35 |
| E-Segment (Range Rover) | 0.19 | 0.22 | 24.42 | 24.10 |
| Mini Full (Jeep Wrangler) | 0.09 | 0.07 | 18.38 | 18.43 |
| Compact F (Toyota Land Cruiser) | 0.13 | 0.06 | 20.05 | 20.38 |
| Full Size (Chevrolet Tahoe) | 0.01 | 0.01 | 21.74 | 21.91 |
| Average | | | 26.09 | 27.86 |
| Average, 2002 Market Shares | | | | 27.06 |

Notes: Global segments are defined by CMS, and the table provides an example of a vehicle model in each segment. Average fuel economy is the sales- or registration-weighted fuel economy, computed as in Table 1. At the bottom of both panels, Average 2002 Market Shares uses the 2002 market share and the 2007 fuel economy for each segment to compute the weighted average fuel economy. The Mini Full, Compact F, and Full Size are all full frame segments. The large fuel economy change for Mini Full vehicles in Europe is explained by entry and exit of a few specifications.

Table 3

## Effect of Fuel Costs on Market Shares in Europe and the United States

Panel A: Europe

Dependent variable: log registrations

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Fuel Costs | -0.46<br>(0.18) | -1.00<br>(0.29) | -0.13<br>(0.30) | -0.12<br>(0.39) |
| Number of Observations | 44,218 | 19,884 | 12,781 | 5,595 |
| $R^2$ | 0.23 | 0.32 | 0.01 | 0.01 |
| Unit of observation | Model-fuel type-month | Brand-segment-fuel type-month | Model-fuel type-quarter | Brand-segment-fuel type-quarter |

Panel B: United States

Dependent variable: log sales

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Fuel Costs | -1.84<br>(0.24) | -3.43<br>(0.62) | -1.59<br>(0.39) | -2.60<br>(0.71) |
| Number of Observations | 14,596 | 7,732 | 4,009 | 2,109 |
| $R^2$ | 0.11 | 0.18 | 0.04 | 0.22 |
| Unit of observation | Model-month | Brand-segment-month | Model-quarter | Brand-segment-quarter |

Notes: The table reports coefficient estimates with standard errors in parentheses. Standard errors in Panel A are clustered by model-fuel type in columns 1 and 3 and by brand-segment-fuel type in columns 3 and 4. Standard errors in Panel B are clustered by model in columns 1 and 3 and by brand-segment in columns 3 and 4. Panel A reports results using the Europe sample and Panel B for the U.S. sample. In Panel A, the dependent variable is log registrations. In column 1 observations are at the model-fuel type-month level, where fuel type indicates whether the model uses diesel or gasoline. In column 2 observations are at the brand-fuel type-month level. Columns 3 and 4 are analogous to columns 1 and 2, using a quarterly time-step rather than a monthly time step. Fuel costs are measured by multiplying the model's fuel consumption by the appropriate fuel price. In Panel B, the dependent variable is log sales. Observations are at the model-month level in column 1, brand-segment-month in column 2, model-quarter in column 3, and brand-segment-quarter in column 4. Fuel costs are measured by dividing the monthly gasoline price by the model's fuel economy. In both Panel A and B, fuel costs are normalized to have a mean value of 1 for the estimation sample. All variables are in first differences and all equations include a full set of year-month or year-quarter interactions.

Table 4

## Summary Statistics by European Country (2002)

| | Germany | Italy | United Kingdom | France | Spain |
|---|---|---|---|---|---|
| Registrations | 3.17 | 2.30 | 2.19 | 2.13 | 1.38 |
| Fuel economy | 34.76 | 38.82 | 34.50 | 39.53 | 38.39 |
| Gasoline Price | 4.23 | 4.32 | 2.96 | 4.15 | 3.44 |
| Diesel Price | 3.39 | 3.54 | 3.05 | 3.16 | 2.91 |
| Diesel market share | 0.37 | 0.43 | 0.24 | 0.63 | 0.58 |

Notes: For each country, the table reports summary statistics for 2002. Registrations are reported in millions, fuel economy is in mpg, and fuel prices are in 2005 euros or pounds per gallon. Real fuel prices are computes using a country-specific consumer price index, as in Table 1.

Table 5

## Effects of Fuel Costs by European Country

| | Panel A: Model-fuel type-month | | | | |
|---|---|---|---|---|---|
| | Germany | Italy | United Kingdom | France | Spain |
| Fuel Costs | 0.19<br>(0.21) | 0.36<br>(0.18) | -0.53<br>(0.42) | -0.17<br>(0.23) | -0.20<br>(0.23) |
| Number of Observations | 31,558 | 27,056 | 25,609 | 28,336 | 27,802 |
| $R^2$ | 0.09 | 0.27 | 0.70 | 0.12 | 0.12 |
| | Panel B: Brand-segment-fuel type-month | | | | |
| | Germany | Italy | United Kingdom | France | Spain |
| Fuel Costs | -0.02<br>(0.25) | 0.31<br>(0.23) | -0.78<br>(0.57) | -0.66<br>(0.29) | -0.36<br>(0.29) |
| Number of Observations | 15,572 | 14,405 | 13,091 | 14,809 | 14,713 |
| $R^2$ | 0.11 | 0.35 | 0.76 | 0.15 | 0.17 |

Notes: The table reports separate regressions by country. In Panel A the unit of observation is the model-fuel type-month, and in Panel B the unit of observation is a brand-segment-fuel type-month. The dependent variable is the log of registrations. Fuel costs are constructed as in Table 3. All variables are first-differenced by model-fuel type-year or by brand-segment-fuel type-year. All specifications include year-month interactions. Standard errors are clustered by model-fuel type in Panel A and by brand-fuel type in Panel B.

Table 6

## Effects of a $1/Gallon Fuel Price Increase on Average New Vehicle Fuel Economy

| | United States | Europe | Germany | Italy | United Kingdom | France | Spain |
|---|---|---|---|---|---|---|---|
| Change in Fuel Economy (MPG) | 1.03 | 0.30 | 0.00 | -0.05 | 0.19 | 0.21 | 0.14 |
| Average Fuel Price ($2005/gallon) | 1.48 | 3.76 | 3.72 | 3.78 | 4.50 | 3.35 | 2.97 |

Notes: The first row reports the change in sales- or registration-weighted average fuel economy in 2002 if fuel prices were $1/gallon higher than they actually were. Counterfactual market shares are calculated using actual market shares and the coefficient estimates from equation (2). The U.S. calculation uses the estimate from column 1 of Panel B in Table 3. The Europe calculation uses the coefficient estimate from column 2 in Panel A in Table 3. The calculation for each country in Europe uses the corresponding coefficient estimate from Panel B of Table 5. The second row reports the sales- or registration-weighted average fuel price in 2002. Prices are reported in 2005 dollars per gallon.

Table 7

## Effects of Diesel Prices on Market Shares

Panel A: Dependent Variable is Log Registrations

| | Europe | Germany | Italy | United Kingdom | France | Spain |
|---|---|---|---|---|---|---|
| Gasoline Costs | -1.08 | -0.03 | 0.37 | -0.87 | -0.80 | -0.42 |
| | (0.33) | (0.30) | (0.27) | (0.64) | (0.35) | (0.35) |
| Diesel Costs | -1.40 | -0.34 | 0.31 | -0.67 | -0.47 | -0.27 |
| | (0.35) | (0.28) | (0.37) | (0.64) | (0.34) | (0.33) |
| Number of Observations | 19,884 | 15,572 | 14,405 | 13,091 | 14,809 | 14,713 |
| $R^2$ | 0.32 | 0.11 | 0.35 | 0.76 | 0.15 | 0.17 |

Panel B: Dependent Variable is Diesel Share in Model Sales

| | Europe | Germany | Italy | United Kingdom | France | Spain |
|---|---|---|---|---|---|---|
| Log (Diesel / Gas Price) | 0.05 | 0.04 | -0.04 | 0.21 | 0.01 | 0.03 |
| | (0.07) | (0.06) | (0.04) | (0.15) | (0.05) | (0.08) |
| Number of Observations | 14,887 | 10,360 | 9,939 | 8,433 | 10,104 | 9,897 |
| $R^2$ | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 |

Notes: The dependent variable in Panel A is log registrations. The dependent variable in Panel B is the share of diesel registrations in total registrations of the diesel-gasoline pair (see text for details). In Panel A, the specifications are the same as in Panel B of Table 5, except that a separate coefficient is estimated for gasoline and diesel costs. The specification in the first column is analogous for the full Europe sample used in Table 3. Panel B reports estimates of equation (3). All regressions in Panel B include month dummies, and variables are first-differenced. Standard errors are clustered by brand-segment-fuel type in Panel A and by diesel-gasoline pair in Panel B.

Table 8

## Effect on Diesel Market Shares of Equalizing Diesel and Gasoline Prices

| | Europe | Germany | Italy | United Kingdom | France | Spain |
|---|---|---|---|---|---|---|
| | | | Panel A: Equation (2) | | | |
| Actual Diesel Market Share | 0.551 | 0.465 | 0.563 | 0.420 | 0.735 | 0.707 |
| Counterfactual | 0.543 | 0.452 | 0.572 | 0.424 | 0.721 | 0.703 |
| | | | Panel B: Equation (3) | | | |
| Actual Diesel Market Share | 0.574 | 0.483 | 0.590 | 0.457 | 0.744 | 0.718 |
| Counterfactual | 0.572 | 0.477 | 0.594 | 0.462 | 0.743 | 0.715 |

Notes: The table reports the actual and counterfactual diesel market shares using the corresponding regression results and samples from Table 7. In both panels, the first row reports the actual market share in 2007 for the corresponding sample. The second row uses the coefficient estimates from Table 7 to estimate counterfactual registrations of diesel vehicles if the diesel fuel price were equal to the gasoline price in each month of 2007. The counterfactual registrations are used to compute the market shares of diesel vehicles.

Appendix Table 1

## Additional Specifications for Europe

Panel A: Model-fuel type-month

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| Fuel Costs | -0.52 | -0.46 | -0.27 | -0.95 | -0.56 | -0.46 | -0.01 | -1.68 | -0.50 |
| | (0.23) | (0.20) | (0.08) | (0.26) | (0.20) | (0.17) | (0.17) | (0.28) | (0.14) |
| Lag Dep Var | | | | | | | | | -0.25 |
| | | | | | | | | | (0.01) |
| N | 44,146 | 44,218 | 37,301 | 44,218 | 44,218 | 21,473 | 31,624 | 44,218 | 39,441 |
| $R^2$ | 0.23 | 0.23 | 0.22 | 0.39 | 0.24 | 0.22 | 0.21 | 0.23 | 0.31 |

Panel B: Brand-segment-fuel type-month

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| Fuel Costs | -1.55 | -1.23 | -0.51 | -1.14 | -1.20 | -1.22 | 0.38 | -2.03 | -0.87 |
| | (0.34) | (0.39) | (0.29) | (0.35) | (0.32) | (0.51) | (0.31) | (0.38) | (0.28) |
| Lag Dep Var | | | | | | | | | -0.32 |
| | | | | | | | | | (0.02) |
| N | 19,818 | 19,884 | 16,707 | 19,884 | 19,884 | 9,328 | 14,371 | 19,884 | 17,904 |
| $R^2$ | 0.34 | 0.33 | 0.32 | 0.64 | 0.36 | 0.30 | 0.30 | 0.33 | 0.42 |
| Specification | Engine displ-time interaction | Diesel-time interaction | Drop 2003 | Brand-time interaction | Market segment-time interaction | Drop low fuel economy vehicles | Add lag fuel costs | Log fuel costs | Lag Dependent Variable |

Notes: The table reports variations of the specifications in Panel A of Table 2. Observations in Panel A are at the model-fuel type-month level, and observations in Panel B are at the brand-segment-fuel type-month level. Models and brand-segments are assigned quartiles based on average displacement. Column 1 includes quartile-year-month interactions. Column 2 includes year-month-diesel interactions, where diesel is a dummy variable for whether the model or segment-brand uses diesel fuel. Column 3 omits observations from 2003. Column 4 includes brand-year-month interactions. Column 5 includes market segment-year-month interactions. Column 6 omits models or brand-segments with fuel economy below the median in the sample. Column 7 adds three lags of fuel costs. Column 8 includes log fuel costs instead of the level of the variable. Column 9 includes the one-month lag of log registrations. Standard errors are clustered by model-fuel type in Panel A and by brand-fuel type in Panel B.

Appendix Table 2

## Market Shares by Segment and Country (2002)

| Global Segment | Europe | Germany | Italy | United Kingdom | France | Spain |
|---|---|---|---|---|---|---|
| A-Segment | 0.07 | 0.07 | 0.14 | 0.05 | 0.05 | 0.02 |
| B-Segment | 0.30 | 0.20 | 0.40 | 0.32 | 0.34 | 0.30 |
| C-Segment | 0.38 | 0.40 | 0.32 | 0.36 | 0.37 | 0.45 |
| D-Segment | 0.19 | 0.23 | 0.10 | 0.22 | 0.21 | 0.18 |
| E-Segment | 0.04 | 0.08 | 0.03 | 0.04 | 0.03 | 0.03 |
| Mini Full | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Compact F | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Full Size | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Notes: Global segments are defined as in Table 2 and are reported separately by country for 2002.