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Abstract

Countries differ considerably in terms of the price drivers pay for gasoline. This paper uses data for a large sample of countries to provide new evidence on the implications of these differences for the consumption of gasoline for road transport and the fuel economy of new vehicles. To address the potential for simultaneity bias in ordinary least squares estimation, we use a country's oil reserves as an instrument for its average gasoline pump price. We obtain estimates of the long-run price elasticity of gasoline demand of between –0.2 and –0.4, a smaller elasticity than most existing estimates. The results also indicate that higher gasoline prices induce consumers to substitute to vehicles that are more fuel-efficient, with an estimated elasticity of +0.2. While gasoline demand and fuel economy are both inelastic with respect to gasoline prices, there is considerable scope for low-price countries to achieve gasoline savings and vehicle fuel economy improvements via reducing gasoline subsidies and/or increasing gasoline taxes.

Keywords: vehicle, gasoline demand, fuel use, fuel economy, gasoline price

JEL classification: N70, L91, Q43, Q48

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1. Introduction

By sales, the most popular new vehicles in Japan in 2008 were the Suzuki Wagon R and the Daihatsu Move, which are both classed as mini cars. The most popular vehicles in the United States (US) were the Ford F-Series and the Chevrolet Silverado, both classed as “pickup” trucks (Marklines 2011). The Wagon R and Move have much higher fuel economy ratings than the F-Series and the Silverado. Per capita consumption of gasoline for driving in Japan is only 29% of that in the US (World Bank 2011a). This paper focuses on the importance of differentials in gasoline pump prices in explaining these large differences in both gasoline use and vehicle fuel economy between countries.

The large variation in gasoline pump prices between countries is shown in Figure 1, which uses data from a survey of international gasoline prices carried out by GTZ (2009). Gasoline tends to be cheapest in oil-rich countries, which are represented by the shaded dots in the Figure. The average gasoline pump price was only 2 US cents per liter in Venezuela in 2008, a small fraction of the price prevailing in the median country (111 US cents per liter) or the country with the highest price (Eritrea, 253 US cents per liter). The gasoline price in Japan (142 US cents per liter in 2008) is more than double the average price in the US (56 cents).

-Fig. 1 here-

This paper presents estimates of the price elasticity of demand for both gasoline use and new-vehicle fuel economy for a large sample of countries. Both cross-sectional and pooled cross-section time-series models are estimated using data covering the period 1995-2008. To address the potential simultaneity bias present in ordinary least squares (OLS) estimation, we present specifications that use a country's in-ground proved oil reserves as an instrument for the local gasoline price. Oil reserves are negatively correlated with the gasoline pump price across countries, and serve as a "supply-curve shifter" capable of allowing the identification of the parameters of the demand equations.[1] In line with expectations, the results suggest that higher gasoline prices both reduce per capita road-sector gasoline consumption and see consumers substitute toward more fuel-efficient automobiles. The estimated price elasticities are relatively small, but indicate that countries with very low gasoline prices could see substantial gasoline savings and vehicle fuel efficiency gains by moving toward internationally-normal gasoline price levels.

This paper adds to a large literature on measuring the price elasticity of demand for gasoline and also the gasoline-price elasticity of vehicle fuel economy. The primary contributions are the employment of a new instrumental variable (IV) approach and the use of newly-compiled data on the fuel economy of new passenger vehicles. The use of an IV approach means that this paper has a greater focus on obtaining an internally-valid causal estimate of price impacts than most papers in the literature (which typically use single-equation estimation techniques such as OLS which ignore the potential endogeneity of gasoline prices). The fuel economy data are country averages for large samples of new vehicles at the make-model-configuration level of detail, as calculated by the IEA (2011). Estimations in this paper are also for a larger sample of countries than used in prior contributions (132 in total for the gasoline consumption

[1] The approach is similar to estimates of the elasticity of demand for agricultural products which use weather conditions as an instrument for the price (see Angrist and Krueger 2001). Our strategy relies on exploiting cross-country supply curve differences to identify the demand curve rather than intertemporal supply shocks.

specifications, including countries rarely included in gasoline demand studies, such as Venezuela and Iran). The estimations cover recent years (to 2008) and control for additional potential determinants of gasoline demand, such as vehicle fuel economy standards, vehicle import tariff rates, and a measure of the importance of other forms of transport.

Road transport is an increasingly important sector, accounting for 14% of global energy use, 40% of global oil use, and 17% of global carbon dioxide (CO_2) emissions from energy in 2008 (International Energy Agency [IEA] 2010a, 2010b). Evidence on the responsiveness of consumers to gasoline price levels is of relevance to policymakers in light of heightening concerns about oil scarcity and the environmental impacts of oil use, including global climate change. Evidence on the importance of gasoline prices for gasoline use is of particular policy relevance because gasoline prices have traditionally been subject to substantial government influence. Indeed, taxes contribute a large share of the gasoline pump price in many countries, and differences in tax rates make up a sizeable share of cross-country differences in gasoline pump prices (Rietveld and van Woudenberg 2005).[2] In other countries, such as Venezuela, Saudi Arabia, Iran, and Indonesia, gasoline price subsidies represent a large drain on the government budget.[3] The results in this paper have implications for the potential efficacy of price-based approaches for managing energy use in the transport sector, and more broadly.

The remainder of this paper is organized as follows. Section 2 presents an initial look at the data on gasoline pump prices, gasoline consumption, and new-vehicle fuel economy. The empirical approach is presented and the data are introduced in section 3. Section 4 presents

[2] For instance, in 2008, taxes made up 63% of the final gasoline pump price in Germany, 56% in Portugal, 49% in Korea, 39% in Japan, and 16% in the United States (IEA 2010c).

[3] The international price for crude oil was 30 US cents per liter in November 2008. Countries with gasoline prices below this level are applying very large subsidies to the use of gasoline for driving.

the results and discusses robustness issues. Section 5 relates our results to prior estimates. The final section concludes.

2. Gasoline prices and consumption: Initial evidence

Figure 2 plots per capita road-sector gasoline consumption against the gasoline pump price for 131 countries for the year 2008 (with both variables measured in natural logarithms). An inverse association between the two variables is apparent: countries with higher gasoline prices tend to consume less gasoline within their road sectors. Nevertheless, the Figure also reveals that per capita gasoline consumption varies notably even among countries with similar gasoline pump prices. Additional variables, such as per capita income and a country's population density, need to be considered in explaining this variation.

-Fig. 2 here-

It should be expected that consumers react to high fuel prices by purchasing vehicles that are more economical in their use of fuel. Yet there is much less information on average new-vehicle fuel economy at the country level than there is on gasoline consumption. This paper uses recently-released data on the fuel economy of newly-purchased vehicles, which are available for 43 countries (see section 3). The cross-country relationship between fuel economy (measured by kilometers per liter gasoline-equivalent) and the gasoline pump price for these countries in 2008 is presented in Figure 3. A positive association between the variables is apparent: consumers in countries with higher gasoline prices appear to purchase vehicles that have relatively higher fuel economy ratings. The US has the lowest average fuel economy rating in the sample, consistent with our observation that some of the most popular vehicles in the US are large vehicles. Japan has the highest fuel economy rating. Appendix A presents lists of the ten most popular new vehicles by sales for both Japan and the US.

- Fig. 3 here-

This initial evidence is suggestive of an important effect of gasoline prices on both gasoline consumption and new-vehicle fuel economy. Yet the scatterplots in Figures 2 and 3 do not establish directional causality from gasoline prices to the *y*-axis variables and do not control for other determinants of fuel use and passenger car fuel economy. The estimation framework employed in this paper focuses on identifying the causal impact of gasoline prices on both gasoline use and vehicle fuel economy.

3. Empirical approach and data

We model gasoline demand in the road sector (*G*) as follows:

$$G_{c,t} = f(P_{c,t}, Y_{c,t}, D_{c,t}, \mathbf{X}_{c,t}) \quad (1)$$

where *P* is the pump price for gasoline in country *c* in year *t*, *Y* is income per capita, *D* is population density, and **X** is a vector of additional determinants. We adopt a log-log approach so as to be able to estimate elasticities. The estimation equation is:

$$\ln G_{c,t} = \alpha + \beta \ln P_{c,t} + \gamma \ln Y_{c,t} + \delta \ln D_{c,t} + \phi \mathbf{X}_{c,t} + \varepsilon_{c,t} \quad (2)$$

Our focus is on the price elasticity of demand for gasoline, *β*. Most prior studies on this price elasticity have employed OLS estimation or other single-equation estimation approaches such as generalized least squares. A potential problem with such approaches is that gasoline prices are not exogenous: it is well known that OLS regression of quantities on prices fails to identify either the demand curve or the supply curve (Angrist and Krueger 2001). While gasoline is an internationally tradable commodity, within individual countries gasoline markets are typically oligopolistic in nature. In such imperfectly competitive markets, the supply curve is unlikely to be perfectly elastic, and so price levels may be affected by the level of demand. The degree of competition in a country's fuel distribution sector is difficult to control for. Government gasoline tax/subsidy policies, which account for a large share of cross-country differences in gasoline prices, may also be affected by the quantity of gasoline being consumed. For example, a government may levy a higher gasoline tax if car dependence is not particularly high (Hammar et al. 2004). Reverse causality from gasoline consumption to the gasoline price would mean that OLS estimation of equation (2) will not provide a consistent estimate of the price elasticity of demand for gasoline.

Econometric estimation is further complicated by the fact that the error term in equation (2) may include other difficult-to-control-for variables which are correlated with the gasoline price. One such variable may be the occurrence of political disturbances or civil conflicts, which may disrupt oil supply chains and affect both the gasoline price and overall consumption of gasoline. Other variables, such as the ruggedness of the terrain, are also hard to adequately control for, but may influence both gasoline consumption (by affecting driving requirements) and pump prices (by affecting gasoline distribution costs). In any of these cases, OLS estimation of equation (2) would not be expected to provide a consistent estimate of the causal impact of gasoline prices on gasoline consumption.

This paper employs IV estimation to address the potential endogeneity of gasoline pump prices in equation (2) and obtain consistent coefficient estimates. We use a country's in-ground proved reserves of oil as an instrument for the gasoline price. As far as we are aware, this is the first time oil reserves have been used as an instrument for gasoline pump prices. Prior gasoline demand studies using IV approaches include Hughes et al. (2008), who use supply-side production disruptions as sources of temporal variation in gasoline prices, and Davis and Kilian (2010), who instrument for the gasoline price in the US using monthly changes in gasoline tax rates at the state level. Our IV approach is better suited to obtaining estimates of the long-run price elasticity of gasoline demand.

To serve as a good instrument, oil reserves must meet several conditions. First, they must be strongly correlated with the gasoline price. As observed in Figure 1, oil-rich countries tend to underprice gasoline on the domestic market, often as a means of sharing the rents from oil extraction (Rietveld and van Woudenberg 2005). Oil-poor countries are more likely to impose higher taxes on petrol because oil taxes provide a reliable revenue source, and to discourage overconsumption of imported oil. We hypothesize that oil reserves are negatively correlated with the gasoline pump price across countries.

The second requirement for oil reserves to act as a suitable instrument is that the proved reserves of individual countries are not affected by annual road-sector gasoline consumption in these countries. Proved oil reserves differ from actual oil endowments because oil discovery requires exploration investment. It is unlikely that the level of gasoline consumption in a country's road sector has a strong impact on exploration activity in that country, however, because countries' marginal returns to oil discovery are similar given that oil is an internationally traded commodity. Supply-side factors such as development level and the security of property rights are likely to be much more important than transport-sector demand conditions in explaining differences in exploration across countries. Current oil reserves are affected by historical extraction in a country, but we obtain similar estimates instrumenting with historical reserves estimates.

The final requirement for oil reserves to be a suitable instrument for pump prices is that they are only correlated with gasoline consumption via the pump price (i.e. they are a supply-curve shifter, but do not directly affect the demand curve; Angrist and Krueger 2001). We acknowledge that oil reserves might affect gasoline consumption via other channels, and control for measures of these channels where possible (see section 4.3). It is also possible that citizens of oil-rich countries feel an additional entitlement to gasoline consumption which influences their consumption decisions over and above the price they face. Despite the difficulty of fully meeting the IV exclusion restriction, we believe that our IV estimates are a worthwhile addition to the literature on modelling gasoline consumption.

We estimate equation (2) for a sample of 132 countries for each of the years 1995, 1998, 2000, 2002, 2004, 2006, and 2008, and for a pooled cross-section time-series dataset. (These are the years for which gasoline price data are available for a reasonable number of countries from GTZ (2009); data for some countries are missing for individual years.) The countries in the sample represent 95% of the global population and 99% of global road-sector energy use in 2008 (World Bank 2011a). To our knowledge, this is the largest sample of countries to be included in a study on the determinants of vehicle gasoline demand. Many studies utilize single-country time-series data (e.g. Akinboade et al. 2008 for South Africa). Some prior studies also utilize data for samples of countries, with the largest sample we are aware of consisting of 90 countries (Storchmann 2005).

Because our instrument does not display strong temporal variation, we focus primarily on the cross-sectional estimations. We assume that countries are in long-run equilibrium and interpret coefficient estimates from the cross-country specifications as long-run elasticities (Baltagi and Griffin 1983). Because we have a relatively small-*T* panel and our instrument does not vary much over time, we do not present estimates using country fixed effects. We supplement our OLS and IV estimates with estimates using the between estimator, which can provide consistent estimates of long-run relationships given standard assumptions about the error term and its relationship with the explanatory variables (Stern 2010). We also present estimates using historical gasoline price averages in recognition of the possibility that gasoline demand and fuel economy adjust over time to price changes in a way that is not fully picked up by a static specification.

Our estimation of the determinants of new-vehicle fuel economy (*F*) employs a similar functional specification:

$$\ln F_{c,t} = \varphi + \eta \ln P_{c,t} + \kappa \ln Y_{c,t} + \lambda \ln D_{c,t} + \tau \mathbf{X}_{c,t} + \varepsilon^{F}_{c,t} \qquad (3)$$

A strength of our analysis is that we use new data on new-vehicle fuel economy collated by the IEA (2011) to measure *F*. The data are indicative country-level fuel economy averages based on test drive results for samples of new vehicles at the make-model-configuration level. The samples cover around three-quarters of new vehicle registrations in each country. Because the fuel economy averages use ratings by vehicle configuration (i.e. sub-model), the data provide a more accurate measure of average new-vehicle fuel economy than those used in some prior studies (e.g. Wheaton 1982). (Fuel economy ratings of automobiles can vary widely among vehicle models with different configurations e.g. engine and transmission types.) The fuel economy data allow estimation for cross-sections of 42 countries in 2005 and

43 countries in 2008, and also a pooled sample using data for both years. The sample represents around 90% of global vehicle sales, and includes more countries than prior studies on the determinants of fuel economy (e.g. Clerides and Zachariadis 2008 used a sample of 18 countries). The IEA (2011) fuel economy data have not been used in prior regression analyses.

There are several different test drive cycles in use internationally, and fuel economy readings differ depending on the testing procedure used. To account for this, we adjust the IEA data for differences in vehicle testing procedures using conversion factors provided by An and Sauer (2004). The fuel economy data employed in this study are consistent with the New European Drive Cycle (NEDC). We also convert the fuel economy ratings from liters per 100 kilometers to kilometers per liter to be consistent with the dominant approach to measuring fuel economy in the literature (output/input).

Other data sources include the U.S. Energy Information Agency [EIA] (2011) and the World Bank (2011a). Average income is measured using gross domestic product (GDP) per capita in purchasing power parity (PPP) terms. The gasoline price data are in 2008 US dollars per liter, and are not converted to PPP terms in keeping to the standard practice (and because PPP differences between countries are taken into account by the GDP control). Summary statistics for the year-2008 estimation dataset are presented in Table 1. A full list of data sources and definitions for all variables is provided in Appendix B.

-Table 1 here-

Existing evidence indicates that gasoline prices affect gasoline consumption via influencing vehicle ownership rates and driving distance, in addition to vehicle fuel economy choices (Brons et al. 2008). Unfortunately, data availability currently precludes a full decomposition of the channels via which gasoline prices affect gasoline consumption for a many-country sample of the size used in this paper (see Small and van Dender 2007 for the case of the US). (As for fuel economy, data on average driving distance at the country level are available for less than one-third of countries in our sample, for example.)

Gasoline consumption and vehicle choice are part of a joint decision from among various (transport and non-transport) consumption alternatives. Yet because the same explanatory variables are included in equations (2) and (3), the efficient estimator is single-equation OLS rather than system estimation (Greene 2000). Robust standard errors are presented. Standard errors for the pooled cross-section time-series estimates are clustered at the country level to account for within-country serial correlation.

4. Results

4.1. Results: Gasoline consumption

Results for estimations of equation (2) are presented in Table 2. Gasoline prices, GDP per capita, and population density explain around 80% of the cross-country variation in gasoline consumption. The OLS estimates (Panel A) suggest that the price elasticity of gasoline demand is –0.4 to –0.5. Generally similar estimates are obtained for each of the seven years and for the pooled OLS estimation and the between estimation for the period 1995-2008.

-Table 2 here-

The IV specifications (Panel B) provide slightly smaller price elasticity estimates, with a range of –0.2 to –0.4 (for all years apart from 1995 and 1998). The IV estimations are also less precise (i.e. have higher standard errors), although most are statistically different from zero at the 5% significance level. The first stage of the IV regressions is satisfactory: the coefficient on oil reserves per capita is negative (as expected), and oil reserves provide sufficiently strong first-stage identification to allow confidence in the results. Specifically, the null hypothesis of the Stock-Yogo weak instrument test of 25% maximal IV size is rejected for each specification, and the stronger null of 10% maximal IV size is rejected for some specifications. Similar estimates of the elasticities are obtained using IV estimators that are robust to weak instruments, such as the Fuller (1977) estimator.

The results suggest an income elasticity of gasoline demand of +1.0 to +1.3. As found elsewhere in the literature, the cross-country variation in per capita gasoline consumption is thus much more sensitive to income differences than differences in gasoline pump prices. The estimates also provide evidence that higher population density is associated with lower per capita gasoline consumption, holding the gasoline price and per capita GDP constant.

4.2. Results: New-vehicle fuel economy

Results on the fuel economy of new vehicles are presented in Table 3. The OLS estimates (Panel A) indicate that higher gasoline prices are associated with better fuel economy of new vehicles, with an elasticity of +0.2. This confirms the positive association observed in Figure 3. The results also indicate that more densely-populated countries tend to use more fuel-efficient vehicles. This accords with the intuition that drivers in countries with high population density are likely to have to deal with narrower and more congested streets and scarcer opportunities for vehicle parking than otherwise comparable countries, and so are more likely to opt for smaller cars.

-Table 3 here-

Simultaneity bias is likely to be a smaller issue for the fuel economy regressions than for the gasoline consumption regressions because fuel-economy choices are one step removed from the gasoline price (whereas gasoline price and quantity are determined in the same market). Nevertheless, results for fuel economy with the log gasoline price instrumented by oil reserves per capita are presented in Panel B of Table 3. Unfortunately, per capita oil reserves are a weak instrument for the log gasoline pump price for the smaller sample for which the fuel economy data are available, as this sample excludes many oil-endowed countries. The instrument fails to pass the Stock-Yogo weak instrument test in both the cross-sectional and pooled samples. The second-stage estimates continue to indicate that higher gasoline prices result in the purchase of vehicles with higher fuel economy ratings, yet these estimates are associated with a high level of imprecision. Accordingly, our discussion of the results on fuel economy will focus on the OLS estimations.

4.3. Robustness

It is important to consider robustness issues. The first is that the process of adjustment to price changes requires time, and so a static representation might underestimate long-run price elasticities. To consider this issue, we estimate the specifications for the cross-sectional sample using the 1998-2008 average price instead of the 2008 price.[4] The results for gasoline consumption are reported in columns 1-2 of Table 4. The estimated elasticities are slightly

[4] Additional lags of the log gasoline price are statistically insignificant if included in the year-2008 regression.

larger in this estimation, with the IV estimate of the long-run price elasticity of gasoline consumption being –0.4. The second issue to consider is that in many countries drivers are increasingly using diesel to fuel their vehicles. Columns 3-4 of Table 4 present estimates of the combined demand for gasoline and diesel, using the average of the gasoline and diesel pump prices as the primary explanatory variable. The estimated elasticities are somewhat smaller than those presented in column 1 of Table 2, most likely because drivers are left with fewer substitution possibilities once diesel is also included in the demand equation. Columns 5-6 of Table 4 include OLS results for new-vehicle fuel economy using the historical and gasoline-diesel average price variables. These fuel economy results are similar to those obtained in Table 3.

-Table 4 here-

An important issue with respect to the IV results in Table 2 is that oil reserves may affect gasoline consumption through channels other than the gasoline price, and so violate the IV exclusion restriction. Oil reserves may affect government policies related to the transport sector, such as vehicle import tariffs or the use of alternative fuels, for instance. (Oil-poor countries may seek to restrict car imports and/or support biofuels to reduce gasoline import requirements.) To attempt to minimize this possibility, Table 5 presents estimates for the year-2008 cross-section that control for additional variables that might be correlated with gasoline consumption and also potentially correlated with oil reserves. Specifically, Table 5 controls for measures of national new-vehicle fuel economy standards (using data provided by the International Council on Clean Transportation [ICCT] 2011), a measure of the availability of alternative transport options (proxied by the non-road sector share of transport energy), a measure of the availability of alternative sources of fuel for the road sector, the average tariff level for new vehicle imports, and a dummy for whether the country was an early ratifier of the Kyoto Protocol (a proxy of environmental policies). Table 5 also uses alternative measures of income: gross national income (GNI) and gross domestic income, terms-of-trade adjusted (GDI).

-Table 5 here-

The OLS and IV estimates of the price elasticity of gasoline demand and of new-vehicle fuel economy remain generally similar across the specifications in Table 5, and remain significantly different from zero in all but the IV estimate for gasoline consumption using GDI per capita (column 6). Interestingly, we find no evidence that countries with higher fuel economy standards are likely to have more fuel-efficient vehicles or use less gasoline in road transport, although because fuel economy standards are not exogenous, the estimates on this variable are unlikely to represent a causal effect. (The effect of standards is better identified in time-series studies, which need to focus on smaller groups of countries due to limitations on gasoline price data; see Clerides and Zachariadis 2008, for instance.) Countries in which drivers have alternative fuel options (e.g. Brazil, which uses a large amount of bio energy as a transport fuel) tend to have lower per capita demand for gasoline. The estimates also indicate that higher border tariffs are associated with lower gasoline demand, most likely because fewer people are able to afford their own vehicle. We find no evidence that early ratification of the Kyoto Protocol affected year-2008 gasoline consumption or vehicle fuel economy decisions.

A final issue to consider with respect to the IV estimates is that current oil reserves are affected by historical extraction within a country, and extraction is likely to be higher in countries with high gasoline demand. If this is the case, the exogeneity of the instrument could be called into question. To address this, we ran additional specifications using historical (1980) reserves as an instrument for the 2008 log gasoline pump price. We obtain very similar estimates using this approach, with an estimated price elasticity of gasoline demand of –0.4. (Results available on request.)

5. Relating the results to prior studies

There is a voluminous literature on the price responsiveness of gasoline consumption. Reviews and meta-analyses of this literature include Espey (1998), Graham and Glaister (2002), Goodwin et al. (2004), Basso and Oum (2007), Brons et al. (2008), Dahl (in press), and Havranek et al. (in press). Existing evidence indicates that road-sector gasoline demand is inelastic, reflecting the relative lack of alternatives to gasoline use. Our estimates are smaller than the median long-run price elasticity of gasoline demand reported in most studies, with most estimates being in the range –0.6 to –0.9 (Graham and Glaister 2002, Goodwin et al. 2004, Brons et al. 2008). Nevertheless, our estimates are not dissimilar to the long-run price elasticity estimates obtained in some papers using cointegration techniques, such as Bentzen (1994), Eltony and al-Mutairi (1995), Ramanathan (1999), and Akinboade et al. (2008). Espey's (1998) meta-analysis reports that the median estimate of the long-run price elasticity of gasoline demand is –0.4, which is similar to our OLS estimates (but, in absolute value terms, larger than most of our IV estimates). Dahl (in press) finds a median gasoline price elasticity of –0.3 for models employing static estimation equations as we have here, which is similar to our IV estimates. Our estimates are also consistent with recent meta-analysis evidence from Havranek et al. (in press), who estimate an average long-run price elasticity of gasoline demand of –0.3 after adjusting for publication bias. Our results thus serve to shoreup Havranek et al.'s inference that gasoline consumption is more price inelastic than is regularly believed.

Our estimate of the elasticity of new-vehicle fuel economy with respect to the gasoline pump price is similar to that obtained in an eight-country study by Espey (1996), although Espey uses fleet-wide fuel economy generated using top-down data based on kilometers travelled and recorded fuel use. Our estimate is smaller than the gasoline price elasticities for fleet-wide fuel economy of Wheaton (1982) and Johansson and Schipper (1997), and is also smaller than some of the long-run gasoline price elasticities of vehicle fuel economy reported by Clerides and Zachariadis (2008). The estimate here is consistent with the long-run gasoline price elasticity of new-vehicle CO_2 emissions intensity in European countries [+0.2] estimated by Ryan et al. (2009), and exceeds Klier and Linn's (2010) short-run estimate for new-vehicle fuel economy of +0.1 using US data. The evidence that higher gasoline pump prices increase the incentive to purchase vehicles that are more fuel-efficient is consistent with recent evidence that higher fuel prices encourage the purchase of hybrid vehicles in the US (Beresteanu and Li 2011, Gallagher and Muehlegger 2011).

6. Conclusion

This study has presented estimates of the impact of gasoline pump prices on road-sector gasoline demand and the fuel economy of new passenger vehicles for a large sample of countries. An IV estimation approach has been employed in order to identify a causal estimate of the impact of gasoline prices on gasoline demand. The IV results suggest a long-run price elasticity of gasoline demand of –0.2 to –0.4, which is smaller than many of the estimates in the existing literature. The results suggest that gasoline pump prices affect vehicle choice decisions also: a country with gasoline prices 10% higher than an otherwise similar country is likely to have new vehicles of 2% higher fuel economy. Underlying country characteristics such as population density and income level were also found to have important implications for road-sector gasoline consumption and fuel economy.

While the estimated price elasticities of gasoline demand and fuel economy are relatively small, the large differences in fuel prices between countries account for an important share of the differences in gasoline consumption and fuel economy. A simple counterfactual is informative: the estimation in column 1 of Table 3 indicates that a shift to Japan-level gasoline prices in the US would result in an improvement in the fuel economy of new vehicles in the US of around one-quarter, for instance (all else held constant). Because the US accounts for 40% of global road-sector gasoline consumption (IEA 2010a), the estimates also indicate that higher gasoline prices in the US would translate to a sizeable reduction in the quantity of global oil demand.

There are a number of countries with gasoline prices much lower than those in the US, and on a per capita basis these countries also tend to be relatively large consumers of gasoline. Increasing gasoline prices is politically challenging, and would likely reduce the welfare of some motorists. Nevertheless, the results in this study indicate that moves toward internationally-normal gasoline prices in countries such as Venezuela and Iran would result in substantial energy efficiency improvements in the transport sectors of these countries. Cutting fossil fuel subsidies would also free up resources that could be used for other purposes.

Several international agencies have joined together in a Global Fuel Economy Initiative, which has the aim of doubling new light-duty vehicle fuel economy (in terms of kilometers per liter) globally by 2050 (see www.globalfueleconomy.org). The results in this paper provide a timely reminder of the importance of price effects in stimulating the adoption of energy-efficient technologies. Upward pressure on fuel prices over time would create an impetus for vehicle fuel efficiency improvements and would complement other policy efforts aimed at improving the energy efficiency of the transport fleet. Future research for large-N country samples focusing on the effects of vehicle tax/subsidy policies on the adoption of fuel-efficient cars would complement the focus on the importance of pump prices here.

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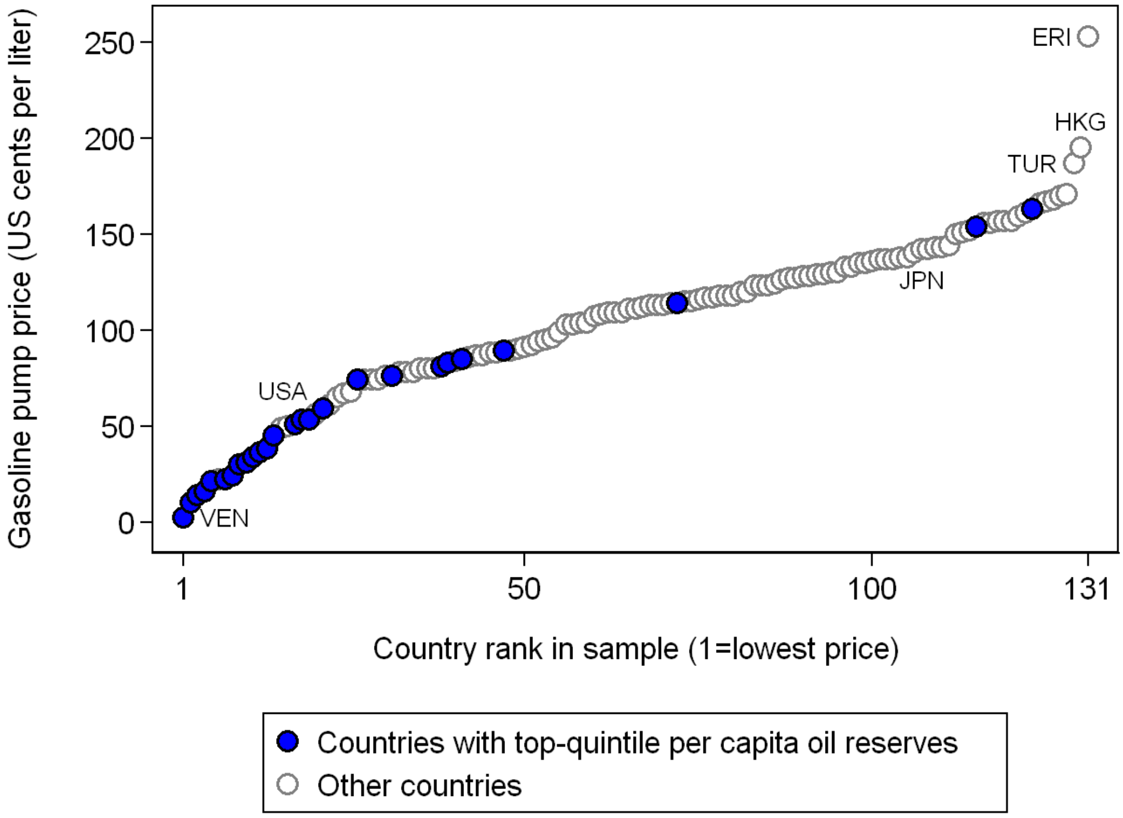
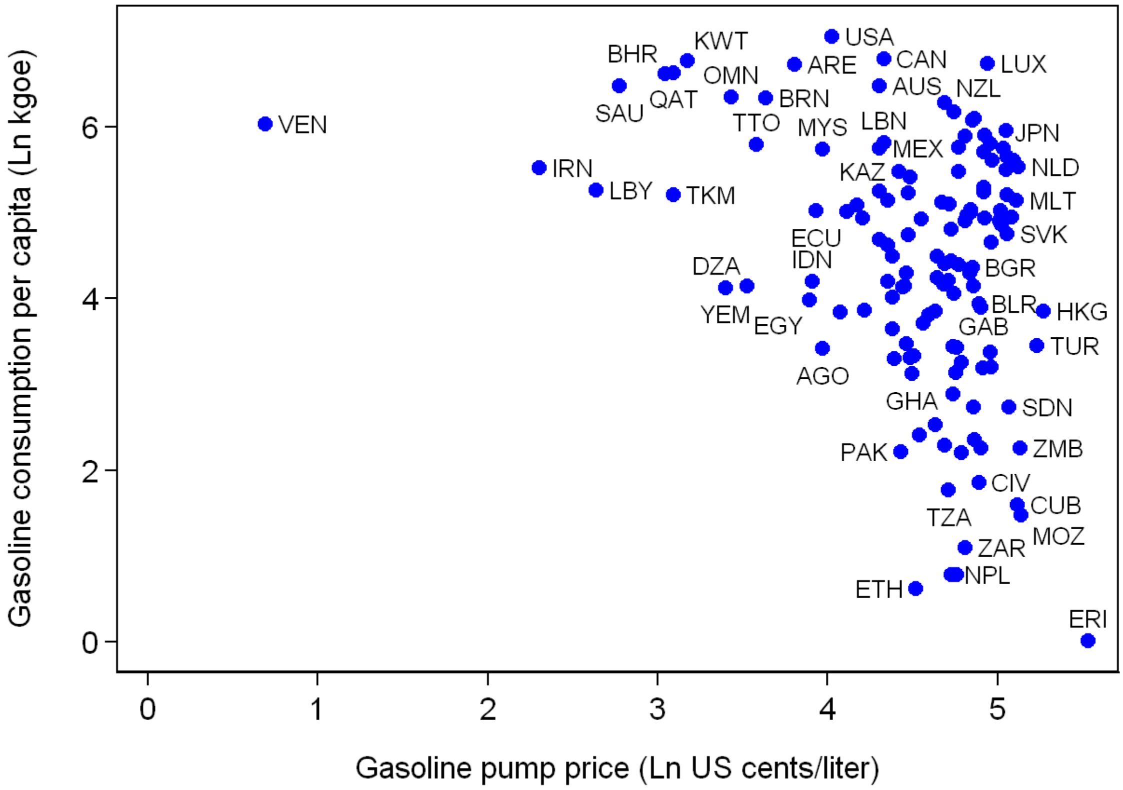
Figures

Figure 1: Gasoline pump price by country, 2008



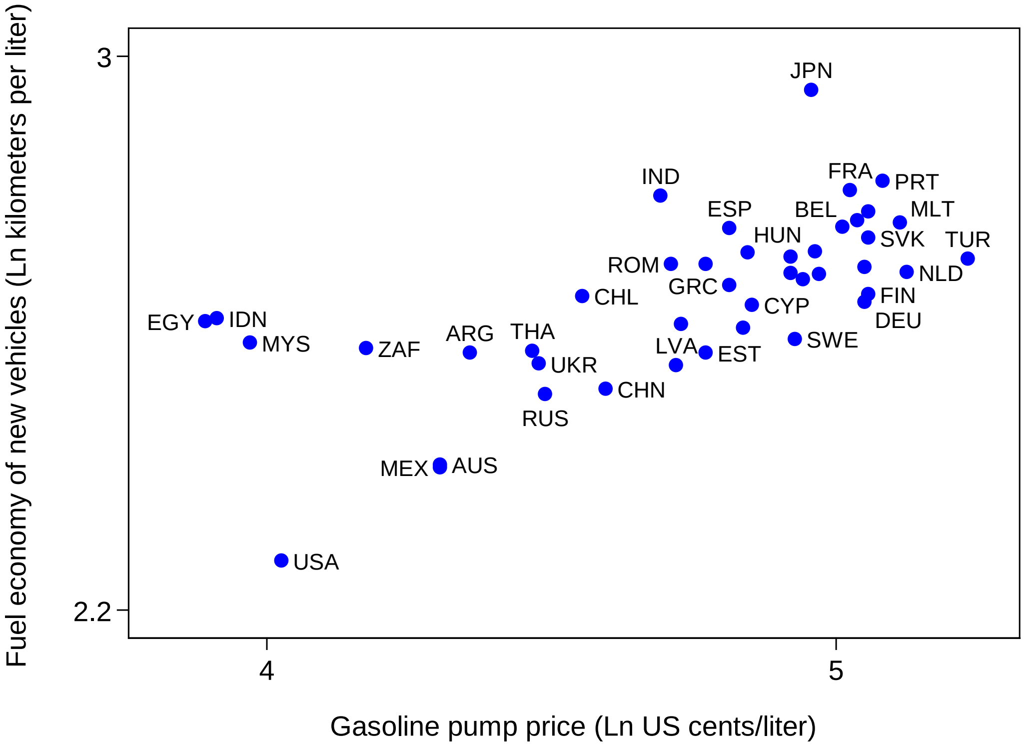
Notes: 131 countries included, as per regression sample in Table 2. Uses GTZ (2009). Gasoline pump prices are those collected in a mid-November survey. Shows World Bank codes for selected countries.

Figure 2: Road-sector pump price and gasoline consumption, 2008



Notes: Gasoline consumption is in the road sector. 131 countries covered. kgoe: kilogram of oil equivalent. Shows World Bank codes for selected countries. Uses World Bank (2011a) and GTZ (2009).

Figure 3: Road-sector pump price and new-vehicle fuel economy, 2008



Notes: Fuel economy is measured in kilometers per liter gasoline-equivalent and is adjusted to be consistent with the NEDC test drive cycle. 43 countries covered. Shows World Bank codes for selected countries. Uses IEA (2011) and GTZ (2009).

Tables

Table 1: Summary statistics for 2008 dataset

Variable	Mean	Standard deviation	Median	Minimum	Maximum	Countries of data availability
Ln Gasoline consumption per capita in the road sector (kilograms of oil equivalent)	4.42	1.47	4.65	0.01	7.05	131
Ln Gasoline pump price (current US cents per liter)	4.51	0.65	4.71	0.69	5.53	131
Ln GDP per capita (2005 international PPP dollars, chain series)	9.03	1.29	9.19	4.91	11.92	131
Ln Population density (per squared kilometer of land area)	4.20	1.42	4.36	0.53	8.84	131
Oil reserves per capita (tonnes oil equivalent)	119.40	560.11	0.45	0.00	5199.92	131
Ln Fuel economy of new vehicles (kilometers per liter)	2.65	0.12	2.67	2.27	2.95	43
Ln GNI per capita (international PPP dollars)	9.09	1.20	9.26	5.67	11.12	126
Ln GDI per capita (terms of trade adjusted, 2005 PPP dollars)	9.05	1.30	9.16	4.96	11.66	131
New-vehicle fuel economy standard (km per liter)	3.93	6.87	0.00	0.00	16.67	131
Non-road sector share of transport energy (%)	8.93	11.42	6.01	0.00	53.51	131
Other energy use in road transport (%)	7.45	5.60	5.43	2.09	35.50	131
Average tariff on vehicle imports (%)	16.83	17.16	10.00	0.00	100.00	127
Kyoto Protocol ratification prior to 2003 (dummy)	0.55	0.50	1.00	0.00	1.00	131

Table 2: Results for road-sector gasoline consumption

Dependent variable: Ln Gasoline consumption per capita in the road sector

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Year	2008	2006	2004	2002	2000	1998	1995	Pooled estimate with year dummies	Between estimator
Panel A: Ordinary least squares estimation									
Ln Gasoline pump price	-0.53***	-0.37***	-0.39***	-0.47***	-0.40***	-0.46***	-0.45***	-0.42***	-0.47***
	(0.09)	(0.07)	(0.06)	(0.07)	(0.08)	(0.09)	(0.08)	(0.06)	(0.08)
Ln GDP per capita	0.95***	1.06***	1.05***	1.12***	1.12***	1.14***	1.27***	1.09***	1.10***
	(0.06)	(0.05)	(0.06)	(0.04)	(0.06)	(0.05)	(0.07)	(0.05)	(0.04)
Ln Population density	-0.13***	-0.13***	-0.12***	-0.11**	-0.13***	-0.12***	-0.23***	-0.13***	-0.12***
	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)	(0.04)
R^2	0.80	0.81	0.81	0.84	0.84	0.86	0.88	0.83	0.85
Panel B: Instrumental variable estimation (Instrument: Oil reserves per capita. Instrumented variable: Ln Gasoline pump price)									
Ln Gasoline pump price	-0.35**	-0.21**	-0.24**	-0.37***	-0.24**	-0.10	-0.16*	-0.23**	-0.20
	(0.14)	(0.11)	(0.10)	(0.07)	(0.10)	(0.10)	(0.09)	(0.10)	(0.23)
Ln GDP per capita	0.96***	1.05***	1.04***	1.11***	1.11***	1.10***	1.22***	1.08***	1.08***
	(0.06)	(0.05)	(0.05)	(0.04)	(0.05)	(0.05)	(0.07)	(0.05)	(0.04)
Ln Population density	-0.15***	-0.15***	-0.14***	-0.12***	-0.14***	-0.15***	-0.25***	-0.15***	-0.15***
	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)	(0.05)	(0.05)	(0.04)	(0.05)
Second-stage R^2	0.79	0.81	0.80	0.84	0.84	0.83	0.87	0.82	0.83
First-stage: F statistic on instrument	11.08	13.10	12.83	16.55	19.32	16.51	8.15	14.21	n.a.
First-stage: Partial R^2 on instrument	0.14	0.15	0.14	0.09	0.09	0.13	0.15	0.12	n.a.
Number of observations	131	128	129	129	125	129	80	851	851
Number of countries	131	128	129	129	125	129	80	132	132

Notes: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels. Columns 1-7: robust standard errors are in parentheses. Column 8: robust standard errors clustered by country are in parentheses. Column 9: standard errors in parentheses. Coefficients on constants not reported. Stock-Yogo 5% significance level critical values for weak instrument tests based on 25% and 10% maximal IV size: 5.53/16.38. The null of a weak instrument is rejected if the *F* statistic on the instrument exceeds the Stock-Yogo critical value/s. n.a.: Not available.

Table 3: Results for the fuel economy of new vehicles

Dependent variable: Ln Fuel economy of new vehicles (kilometers per liter)

	(1)	(2)	(3)	(4)
Year	2008	2005	Pooled estimate with year dummy	Between estimator
Panel A: Ordinary least squares estimation				
Ln Gasoline pump price	0.20***	0.15***	0.16***	0.19***
	(0.06)	(0.05)	(0.05)	(0.04)
Ln GDP per capita	-0.03	-0.08**	-0.05*	-0.06***
	(0.03)	(0.03)	(0.03)	(0.02)
Ln Population density	0.04***	0.06***	0.05***	0.05***
	(0.01)	(0.01)	(0.01)	(0.01)
R^2	0.61	0.60	0.57	0.62
Panel B: Instrumental variable estimation				
(Instrument: Oil reserves per capita. Instrumented variable: Ln Gasoline pump price)				
Ln Gasoline pump price	0.22	0.10	0.15	0.14
	(0.14)	(0.08)	(0.09)	(0.17)
Ln GDP per capita	-0.03	-0.06	-0.05	-0.05
	(0.04)	(0.04)	(0.04)	(0.06)
Ln Population density	0.04*	0.06***	0.05***	0.05**
	(0.02)	(0.01)	(0.01)	(0.02)
Second-stage R^2	0.61	0.58	0.57	0.61
First-stage: F statistic on instrument	0.96	3.76	2.33	n.a.
First-stage: Partial R^2 on instrument	0.03	0.08	0.05	n.a.
Number of observations	43	42	85	85
Number of countries	43	42	43	43

Notes: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels. Estimates for year 2005 use the one-year lag of Ln Gasoline pump price due to the absence of data for 2005 for this variable. Columns 1, 2: robust standard errors are in parentheses. Column 3: robust standard errors clustered by country are in parentheses. Column 4: standard errors in parentheses. Coefficients on constants not reported. Stock-Yogo 5% significance level critical values for weak instrument tests based on 25% and 10% maximal IV size: 5.53/16.38. The null of a weak instrument is rejected if the *F* statistic on the instrument exceeds the Stock-Yogo critical value/s. n.a.: Not available.

Table 4: Results using alternative price measures, 2008

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Ln Gasoline consumption per capita in the road sector		Ln (Gasoline + diesel) consumption per capita in the road sector		Ln Fuel economy of new vehicles	
	OLS	IV	OLS	IV	OLS	OLS
Ln Gasoline pump price (historical real average)	-0.56***	-0.38***			0.20**	
	(0.10)	(0.15)			(0.06)	
Ln Pump price (year-2008 gasoline and diesel average)			-0.24***	-0.22***		0.17**
			(0.05)	(0.08)		(0.06)
Ln GDP per capita	1.00***	0.99***	0.96***	0.96***	-0.05*	-0.03
	(0.06)	(0.06)	(0.05)	(0.05)	(0.03)	(0.03)
Ln Population density	-0.13***	-0.14***	-0.09***	-0.09***	0.05***	0.05***
	(0.04)	(0.05)	(0.03)	(0.03)	(0.01)	(0.01)
R^2	0.79	0.79	0.86	0.86	0.62	0.56
First-stage: *F* statistic on instrument	-	13.21	-	12.06	-	-
First-stage: Partial R^2 on instrument	-	0.15	-	0.12	-	-
Number of countries	130	130	129	129	43	43

Notes: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels. Robust standard errors are in parentheses. Coefficients on constants not reported. Stock-Yogo 5% significance level critical values for weak instrument tests based on 25% and 10% maximal IV size: 5.53/16.38. The null of a weak instrument is rejected if the *F* statistic on the instrument exceeds the Stock-Yogo critical value/s. IV estimations use oil reserves per capita as an instrument for the relevant price variable. The historical gasoline pump price averages the real pump price in the years 1998, 2000, 2002, 2004, 2006, and 2008, and uses linear interpolations of the log price in the case of missing price data. Early historical or diesel prices are not available for several countries in the sample.

Table 5: Results with additional controls and alternative income measures, 2008

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable	Ln Gasoline consumption per capita in the road sector						Ln Fuel economy of new vehicles		
	OLS	IV	OLS	IV	OLS	IV	OLS	OLS	OLS
Ln Gasoline pump price	-0.70***	-0.43**	-0.71***	-0.43***	-0.68***	-0.26	0.21***	0.22***	0.21***
	(0.14)	(0.22)	(0.15)	(0.11)	(0.14)	(0.21)	(0.08)	(0.08)	(0.08)
Ln GDP per capita	0.83***	0.88***					-0.05		
	(0.08)	(0.09)					(0.03)		
Ln GNI per capita			0.93***	0.97***				-0.06	
			(0.07)	(0.08)				(0.04)	
Ln GDI per capita					0.82***	0.90***			-0.05
					(0.07)	(0.10)			(0.03)
Ln Population density	-0.13***	-0.15***	-0.11**	-0.13**	-0.11***	-0.14***	0.04**	0.04*	0.04**
	(0.04)	(0.04)	(0.05)	(0.05)	(0.04)	(0.04)	(0.02)	(0.02)	(0.02)
New-vehicle fuel economy standard (km per liter)	0.02*	0.01	0.00	-0.00	0.02*	0.01	-0.00	-0.00	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
Non-road sector share of transport energy (%)	0.00	-0.00	0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
Other energy use in road transport (%)	-0.02**	-0.02**	-0.02*	-0.02**	-0.02*	-0.02**	-0.00	-0.00	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
Average tariff on vehicle imports (%)	-0.01**	-0.01	-0.01***	-0.01*	-0.01**	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Kyoto Protocol ratification prior to 2003 (dummy)	0.04	-0.04	0.15	0.08	0.07	-0.05	0.03	0.03	0.03
	(0.14)	(0.15)	(0.13)	(0.13)	(0.14)	(0.16)	(0.04)	(0.04)	(0.04)
R^2	0.82	0.81	0.83	0.82	0.82	0.80	0.63	0.63	0.63
First-stage: *F* statistic on instrument	-	9.49	-	9.55	-	8.67	-	-	-
First-stage: Partial R^2 on instrument	-	0.08	-	0.20	-	0.07	-	-	-
Number of countries	127	127	122	122	127	127	43	43	43

Notes: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels. Robust standard errors are in parentheses. Coefficients on constants not reported. Stock-Yogo 5% significance level critical values for weak instrument tests based on 25% and 10% maximal IV size: 5.53/16.38. The null of a weak instrument is rejected if the *F* statistic on the instrument exceeds the Stock-Yogo critical value/s. IV estimations use oil reserves per capita as an instrument for the Ln Gasoline pump price.

Appendix A – Most popular passenger vehicles in Japan and the United States, 2008

Rank	Make	Model	Vehicle type	Sales (volume, '000)
Japan				
1	Suzuki	Wagon R	Mini car	205
2	Daihatsu	Move	Mini car	190
3	Honda	Fit (Jazz)	Car	175
4	Daihatsu	Tanto	Mini car	159
5	Toyota	Vitz (Yaris)	Car	123
6	Toyota	Corolla	Car	115
7	Honda	Life	Mini car	97
8	Daihatsu	Mira (Cuore)	Mini car	85
9	Toyota	Prius	Car	73
10	Toyota	Passo	Car	73
Share of all sales (%)				26
United States				
1	Ford	Ford F-Series	Light truck	516
2	Chevrolet	Silverado	Light truck	465
3	Toyota	Camry	Car	437
4	Honda	Accord	Car	373
5	Toyota	Corolla	Car	351
6	Honda	Civic	Car	339
7	Nissan	Altima	Car	270
8	Chevrolet	Impala	Car	266
9	Dodge	Ram	Light truck	246
10	Honda	CR-V	Light truck	197
Share of all sales (%)				26

Notes: Uses Marklines (2011).

Appendix B – Variable descriptions

Ln Gasoline consumption per capita in the road sector: Natural logarithm of road-sector gasoline consumption per capita (kilograms of oil equivalent). World Bank (2011a).

Ln Gasoline pump price: Natural logarithm of the average gasoline retail pump price in year-2008 US cents per liter of gasoline. Prices were collected in a survey carried out in mid-November. GTZ (2009). The US GDP deflator from the World Bank (2011a) is used to deflate prices.

Ln GDP per capita: Natural logarithm of GDP per capita in 2005 international purchasing power parity dollars (chain series). Heston et al. (2011).

Ln Population density: Natural logarithm of the population per squared kilometer of land area. World Bank (2011a).

Oil reserves per capita: Proved reserves of crude oil, tonnes oil equivalent per capita. U.S. EIA (2011).

Ln Fuel economy of new vehicles (kilometers per liter): Natural logarithm of the average fuel economy of new passenger vehicles in kilometers per liter gasoline-equivalent based on data from fuel economy tests. Averages were calculated for representative samples of new vehicle registrations by the IEA (2011), using data at the make-model-configuration level. For Australia and the US, the fuel economy average covers some light commercial vehicles that are commonly used as passenger vehicles. We have made the data NEDC-consistent by adjusting the fuel economy ratings of Japan, Mexico, and the US using conversion factors from An and Sauer (2004).

Ln GNI per capita: Natural logarithm of GNI per capita in international purchasing power parity dollars. World Bank (2011a).

Ln GDI per capita: Natural logarithm of GDI per capita (terms of trade adjusted, 2005 international purchasing power parity dollars). Heston et al. (2011).

New-vehicle fuel economy standard (km per liter): Fuel economy standard for new passenger vehicles, normalized to the NEDC test drive cycle. Includes both voluntary and regulatory standards. ICCT (2011).

Non-road sector share of transport energy (%): Share of transport energy use for forms of transport other than road transport (e.g. aviation, rail). IEA (2010a, 2010d).

Other energy use in road transport (%): Share of road-sector energy use that comes from sources other than gasoline and diesel. World Bank (2011a).

Average tariff on vehicle imports (%): Simple average of most-favored-nation tariff rates for passenger motor vehicles (HS 870321 through 870390). World Bank (2011b).

Kyoto Protocol ratification prior to 2003 (dummy): A dummy equal to 1 if a country ratified the Kyoto Protocol in 2002 or earlier; 0 otherwise.

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