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Working Paper 22105

<http://www.nber.org/papers/w22105>

NATIONAL BUREAU OF ECONOMIC RESEARCH

1050 Massachusetts Avenue

Cambridge, MA 02138

March 2016

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NBER Working Paper No. 22105

March 2016

JEL No. H23,Q31,Q41,Q48,Q52,Q53,Q54,Q58,R41

ABSTRACT

Despite increasing calls for reform many countries continue to provide subsidies for gasoline and diesel. This paper quantifies the external costs of global fuel subsidies using the latest available data and estimates from the World Bank and International Monetary Fund. Under preferred assumptions about supply and demand elasticities, current subsidies cause \$44 billion in external costs annually. This includes \$8 billion from carbon dioxide emissions, \$7 billion from local pollutants, \$12 billion from traffic congestion, and \$17 billion from accidents. Government incentives for alternative fuel vehicles are unlikely to cost-effectively reduce these externalities as they do little to address traffic congestion or accidents, and only indirectly address carbon dioxide and local pollutants.

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1 Introduction

In August 2015, the United Arab Emirates (U.A.E.) raised domestic gasoline and diesel prices by 25%. U.A.E.'s energy minister, Suhail Al-Mazrouei, explained that the change was about "building a strong economy that is not dependent on government subsidies."¹ Then, at the beginning of 2016, Saudi Arabia raised domestic gasoline and diesel prices by 40%, in an effort to, "achieve wide structural reforms in the national economy and reduce its dependence on oil."²

These are unprecedented increases for two of the world's largest oil producers. Cheap gasoline and diesel have long been a permanent fixture throughout the Middle East and Northern Africa, so when the two largest OPEC producers reduce fuel subsidies this is a significant change not just for U.A.E. and Saudi Arabia, but for all of OPEC and beyond. Several leading economists are arguing that this is an historic opportunity to eliminate global fuel subsidies worldwide.³

Subsidy reform is happening now because of low crude oil prices. As recent as 2014, crude oil prices were above \$100/barrel, but since plummeting at the end of 2014 have remained below \$50/barrel and as of March 2016 are just above \$30/barrel, the lowest price since 2003. Low crude oil prices reduce government revenue in oil producing economies, increasing budget deficits and making fuel subsidies harder to afford. This fiscal urgency was the main motivation for U.A.E.

¹Bloomberg Business, "U.A.E. Removes Fuel Subsidy as Oil Drop Hurts Arab Economies" by Claudia Carpenter and Sarmad Khan, July 21, 2015.

²Wall Street Journal, "Saudi Arabia Cuts Spending, Raises Domestic Fuel Prices", by Ahmed Al Omran and Summer Said, December 28, 2015.

³See, e.g., Jeffrey Frankel, "Gas Taxes and Oil Subsidies: Time for Reform" August 10, 2015 and Rabah Arezki and Maurice Obstfeld, "The Price of Oil and the Price of Carbon" December 3, 2015.

and Saudi Arabia, and is usually a major part of the motivation for energy subsidy reform.

Much less emphasized in the policy discussion, however, are the large external costs from gasoline and diesel subsidies. Removing fuel subsidies helps balance government budgets, but it also yields enduring benefits in the form of reduced emissions of carbon dioxide and other externalities. Worldwide the transportation sector is responsible for 23% of total energy-related carbon dioxide emissions, more than 7 gigatons annually (IPCC, 2015), so getting prices right in this sector is critical.

This paper quantifies the environmental and other external costs of global fuel subsidies using the latest available data and estimates from the World Bank and International Monetary Fund. Under baseline assumptions about supply and demand elasticities, current subsidies cause \$44 billion in external costs annually. This includes \$8 billion from carbon dioxide emissions, \$7 billion from local pollutants, \$12 billion from traffic congestion, and \$17 billion from accidents.

To put these estimates into context, the paper also calculates the deadweight loss. Fuel subsidies are inefficient because they lead to excess consumption, enabling purchases for which the private benefits are lower than private cost. This inefficiency occurs with or without externalities, and reflects the lost value in the economy whenever fuels are sold to buyers with low willingness-to-pay. Deadweight loss is found to be \$26 billion annually so, combined with external costs, the total economic cost of fuel subsidies is \$70 billion annually.

The paper then turns to discuss prospects for alternative fuel vehicles in countries

that heavily subsidize gasoline and diesel. The current vehicle stock in heavily energy subsidized economies is, not surprising, overwhelmingly composed of gasoline- and diesel- vehicles. The paper reviews the relevant academic literature to evaluate the potential prospects for electric vehicles (EVs), natural gas vehicles, and flex-fuel vehicles operating with biofuels.

Although it might be possible to diversify the vehicle stock with sufficient government incentives, this approach is unlikely to cost-effectively reduce externalities. Alternative fuel vehicles do little, or may even exacerbate traffic congestion and accidents, the two largest components of externalities. In addition, incentives for alternative fuel vehicles only indirectly address carbon dioxide and local pollutants and do so at a high cost per vehicle.

The particular country context also matters a great deal. One of the key findings in an emerging literature on EVs is that the environmental impact depends largely on the electricity generation portfolio (Holland et al., 2015). Most countries that subsidize fuels also have relatively carbon-intensive electricity, so a transition to electric vehicles would be unlikely to significantly reduce carbon dioxide emissions. Overall, the analysis points to “green” vehicle incentives being a poor substitute for subsidy reform.

The paper contributes to a growing literature on global fuel subsidies. Most of the work has focused on quantifying the dollar value of subsidies (IEA, 2012, 2014; Clements et al., 2013), but studies have also calculated deadweight loss (Davis, 2014; Coady et al., 2015) and studied distributional effects (IEA, 2011; del Granado et al., 2012; Sterner, ed, 2012). Most recently, Parry et al. (2014a) estimates external damages from energy for 156 countries and Coady et al. (2015)

uses these estimates to calculate the total economic and environmental cost of global energy subsidies. This paper leans heavily on these previous studies, while doing a deeper dive on the transportation sector and with much more emphasis on heavily energy subsidized economies.

The paper proceeds as follows. Section 2 describes the conceptual framework including graphical and analytical definitions of deadweight loss and external costs. Section 3 discusses the data used for the analysis and presents statistics on gasoline and diesel prices, the total dollar value of subsidies, and deadweight loss. Section 4 then presents the main results, describing the marginal damages estimates from Parry et al. (2014a) that are used for the calculations, then calculating external costs by country. Section 5 discusses the prospects for renewables and diversification in the transportation sector in heavily energy subsidized economies, and Section 6 concludes by summarizing the key lessons.

2 Conceptual Framework

Economic efficiency requires that households and firms pay energy prices that reflect their full cost to society, including both private and external costs. This section reviews the standard economic framework for quantifying the costs that arise from departures from efficient pricing. The section is concerned, in particular, with failures to price energy at its full *private* cost. When gasoline and diesel are priced below private cost this creates waste in the form of deadweight loss and external costs. The section begins by describing these inefficiencies graphically and discussing the key factors determining the magnitude of these inefficiencies. Next

a specific functional form is adopted for the demand curve and analytical representations are derived for deadweight loss and external costs. Finally, the section goes through a specific example, Saudi Arabia, and shows how the calculations work in practice.

2.1 The Economic Cost of Fuel Subsidies

2.1.1 Graphical Analysis

Figure 1 describes the market for fuels. Consider this as the market for gasoline in Saudi Arabia, for example, or in some other heavily energy subsidized economy where the price of fuels (p_0) is below private cost. Here the subsidized price has been drawn to be approximately one-third of private cost, making the subsidy particularly consequential. Fuels consumption at the subsidized price q_0 is well above the level of consumption that would be obtained were fuels priced at private cost (q_1).

Pricing below private cost is inefficient because it enables transactions for which the buyers willingness-to-pay is below private cost. This inefficiency is represented in the figure as the deadweight loss triangle. These transactions destroy economic value by taking a good that costs (p_1) and giving it to a buyer who values it at somewhere between p_0 and p_1 . Each time one of these transactions occurs the economy is made worse off, and the area of the deadweight loss triangle equals this total welfare cost.

Pricing below private cost also imposes external cost. This inefficiency is reflected in Figure 1 as the rectangle between q_0 and q_1 and between private cost and social

cost. The subsidized price leads to excess fuels consumption, and thus increased carbon dioxide emissions and other externalities. The area of this rectangle equals total external costs, and depending on the magnitude of the externalities and other factors, this inefficiency can be bigger or smaller than deadweight loss.

2.1.2 Post-Tax versus Pre-Tax Subsidies

An alternative calculation would have been to measure the deadweight loss relative to the full social cost of fuels. This would incorporate, in addition, the smaller triangle to the left of the external cost rectangle above the demand curve. This is a relatively small area compared to the other inefficiencies for a country with large subsidies, but for a country like the United States, where fuels are priced above private cost but below social cost, this triangle becomes the most important part of the analysis.

Previous studies have used the terms “pre-tax” and “post-tax” to make this distinction. Pre-tax subsidies are when energy is priced below private cost, whereas post-tax subsidies are when energy is priced below social cost. Previous studies have found that post-tax subsidies are several times larger than pre-tax subsidies. Clements et al. (2013), for example, finds that pre-tax subsidies worldwide were \$480 billion in 2011 whereas post-tax subsidies were \$1.9 trillion. Coady et al. (2015) finds that pre-tax subsidies are \$541 billion in 2013 while post-tax subsidies are much larger, \$4.9 trillion in 2013. These estimates are for all energy types including not only transportation fuels but also coal and natural gas, and thus are very large.

This broader exercise of quantifying the post-tax subsidies is extremely important, but is a considerably different thought experiment. In this paper, the focus is on heavily energy subsidized economies that price fuels below *private* cost. Accordingly, the relevant counterfactual is removing subsidies, not the decision to, in addition, impose fuel taxes that would achieve the socially optimal level of consumption. Thus all of the estimates in this paper refer to “pre-tax” subsidies.

2.1.3 Key Assumptions

The size of the deadweight loss triangle in Figure 1 depends critically on private cost, so it is important to be clear about what this means. As usual in economics, the appropriate measure of cost is opportunity cost, i.e. the loss of potential gain from the next best alternative. Gasoline and diesel are both widely traded in international markets, so global spot prices provide the appropriate measure of opportunity cost. Spot prices are the appropriate measure of opportunity cost, regardless of whether the country is a net exporter of petroleum products. Most heavily energy subsidized economies are oil producers, and in many cases, these countries have oil fields with production costs well below market crude oil prices. This doesn't matter, however, for calculating deadweight loss. Regardless of production costs, there is always the alternative of selling oil (or refined products) in international markets, so this foregone revenue, and not production cost, is the correct measure of private cost.

Both in the figure and in the empirical analysis which follows, the supply of fuels has been assumed to be perfectly elastic. This is a common assumption in this literature (Clements et al., 2013; Davis, 2014; Coady et al., 2015) and is likely to

be a very accurate approximation. The infrastructure for transportation, refining, and distribution of fuels can be scaled up at near constant marginal cost, so what matters is the long-run supply elasticity for crude oil. This elasticity is difficult to measure empirically, but in the long-run there is clearly a great deal of scope for global oil producers to respond to crude oil prices. This is particularly true with improved shale oil techniques and other emerging technologies that have opened up vast new production areas (see, e.g. Covert et al., 2016). Incorporating less than perfectly elastic supply would decrease the estimated economic costs only modestly because fuel consumption in most countries is small relative to the world oil market.

The empirical analysis which follows assumes that the price elasticity of demand for fuels is moderately elastic. This choice clearly matters for the magnitude of these inefficiencies. In particular, the more elastic is demand, the larger the deadweight loss and external costs from pricing below cost. Demand for crude oil is relatively inelastic in the short-run (Hamilton, 2009), but much more elastic in the long-run. Estimates in the literature for the long-run elasticity of demand for transportation fuels tend to range from -0.6 to -0.8 (Sterner, 2007; Brons et al., 2008). The analysis which follows adopts -0.6, though estimates are also reported for -0.4 and -0.8.

Another more subtle choice reflected in Figure 1 is that external costs have been assumed to be constant. For carbon dioxide emissions this makes perfect sense. From a global perspective, these costs are probably slightly increasing, but when considering a single sector for a single country, these costs should be viewed as essentially constant. For all other externalities, however, costs are almost surely

not constant, and in future work it would be interesting to begin to incorporate these non-linearities.

Another important priority for future work is to understand the fiscal impacts of fuel subsidies. Neither of the areas indicated in Figure 1 capture the fiscal impacts of fuel subsidies. As mentioned in the introduction, fuel subsidies can have a large impact on government budgets, requiring taxes to be higher than they would otherwise, and inhibiting the ability of government to address other fiscal objectives. Expenditures on energy subsidies in some countries exceed public expenditures on health, education, and other key components of government spending.

2.2 Calculating Deadweight Loss and External Costs

2.2.1 Functional Form

Demand is assumed to take the form of a constant elasticity demand function,

$$q = Ap^\epsilon \tag{1}$$

with a scale parameter A that varies across countries and fuels, price p , and elasticity ϵ . The constant elasticity demand function has been widely used in related studies (Clements et al., 2013; Davis, 2014; Coady et al., 2015) and coincides closely with a substantial empirical literature that has tended overwhelmingly to estimate log-log models. In theory, this ϵ should be the *compensated* demand elasticity (i.e. Hicksian) that reflects substitution but not income effects. However, most of the empirical literature has focused on estimating *uncompensated* elasticities.

ties. With gasoline and diesel, one would generally expect compensated elasticities to be smaller than uncompensated elasticities, which provides another reason for emphasizing the results from the -0.6 elasticity rather than the -0.8.

The first step is to take the assumed price elasticity of demand, e.g., -0.6 , as well as current prices p_0 and consumption levels q_0 to calculate the complete set of scale parameters. Subscripts have been ignored for expositional clarity, but this scale parameter A is allowed to vary across countries and fuels,

$$A = qp^{-\epsilon}. \quad (2)$$

The demand functions (i.e. equation 1) are then used to predict consumption at market prices (p_1) and to calculate deadweight loss. Just as in Figure 1, deadweight loss is the rectangle $(p_1 - p_0)q_0$, minus the area to the *left* of the demand curve between the subsidized price p_0 and market price p_1 . This can be described with the following equation,

$$DWL = (p_1 - p_0)q_0 - \int_{p_0}^{p_1} Ap^\epsilon dp. \quad (3)$$

Evaluating the integral yields,

$$DWL = (p_1 - p_0)q_0 - \frac{A}{(1 + \epsilon)} [p_1^{(1+\epsilon)} - p_0^{(1+\epsilon)}]. \quad (4)$$

Another, equivalent approach for calculating the same area is to start with the inverse demand function,

$$p = (A^{-1}Q)^{1/\epsilon} \quad (5)$$

and calculate the area *below* the demand curve between q_0 and q_1 , and then subtract this from the rectangle $(q_1 - q_0)p_1$,

$$DWL = (q_0 - q_1)p_1 - \int_{q_1}^{q_0} A^{-\frac{1}{\epsilon}} q^{\frac{1}{\epsilon}} dq. \quad (6)$$

Evaluating the integral yields,

$$DWL = (q_0 - q_1)p_1 - A^{-\frac{1}{\epsilon}} \frac{1}{\eta} [q_0^\eta - q_1^\eta]. \quad (7)$$

where $\eta = \frac{1}{\epsilon} + 1$. With the example below equations (4) and (7) are shown to be numerically equivalent. Finally, just as in Figure 1, external costs are calculated as excess consumption multiplied by an estimate of marginal damages per unit of fuels, δ .

$$(q_0 - q_1)\delta. \quad (8)$$

2.2.2 An Example

It is helpful to go through an example. In Saudi Arabia the price of gasoline (p_0) in November 2014 was \$0.16/liter, and consumption in 2014 (q_0) was 24,443 million liters. Rearranging the demand function to solve for A with a -0.6 elasticity yields,

$$A = q_0 p_0^{-\epsilon} = 24443 * 0.16^{0.6} = 8140. \quad (9)$$

So at the global spot market price \$0.57 the demand equation implies that consumption would be equal to,

$$q_1 = Ap_1^\epsilon = 8140 * 0.57^{-0.6} = 11,405. \quad (10)$$

Thus this demand function implies that, in the long run, gasoline consumption would fall from 24,443 million liters to 11,405 million liters were prices to increase to \$0.57. Using equation (4), deadweight loss is equal to,

$$DWL = (\$0.57 - \$0.16) * 24443 - \frac{8140}{(0.4)} [\$0.57^{(0.4)} - \$0.16^{(0.4)}] = \$3546. \quad (11)$$

Or, \$3.6 billion in deadweight loss in the gasoline market for 2014.

Using equation (7), deadweight loss is equal to,

$$DWL = (24443 - 11405) * \$0.57 - 8140 \frac{-1}{-0.6} \frac{1}{-2/3} [24443^{-2/3} - 11405^{-2/3}] = \$3546. \quad (12)$$

Or \$3.6 billion. As expected, both approaches yield the same measure for deadweight loss. External costs for gasoline for Saudi Arabia (δ) are \$0.56/liter, as will be shown later. So external costs are,

$$EX = (24443 - 11405) * \$0.56 = \$7301 \quad (13)$$

or \$7.3 billion annually.

3 Data

3.1 Gasoline and Diesel Prices

Gasoline and diesel prices come from the World Bank *World Development Indicators* which, in turn, gets these data from the German Agency for International Cooperation (GIZ). Prices are domestic consumer prices and reflect the total price at the pump including all taxes and/or subsidies. Data are collected every two years and the latest available data come from surveys administered November 2014. Gasoline prices are available for 170 countries and diesel prices are available for 167 countries. In a small number of cases 2014 price data are not available and prices from 2012 are used instead; this includes Bahrain, Grenada, and Libya for gasoline and Bahrain, Grenada, Libya, Belize, Brunei, and North Korea for diesel.

Figure 2 shows the twenty countries with the lowest gasoline and diesel prices worldwide. In November 2014 average prices for gasoline and diesel (unweighted) were \$1.28 per liter and \$1.17 per liter, respectively, so all of these countries have prices that are well below the global average. Indeed, most of these countries have prices that are less than half average global prices and less than one-quarter of the price in countries with large fuels taxes like Norway where in November 2014 gasoline prices were \$2.27 per liter and \$2.11 per liter, respectively.

The lowest prices on the planet in November 2014 were in Venezuela; \$0.02 per liter for gasoline and \$0.01 per liter for diesel. Venezuela has long subsidized transportation fuels and, not coincidentally, gasoline consumption consumption in

Venezuela is 40% higher than any other country in Latin America, and three times the regional average.

Many of the countries listed in Figure 2 are members of the Organization of Petroleum Exporting Countries (OPEC). Currently OPEC has twelve members: Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates and Venezuela. All twelve appear among the first twenty countries with lowest gasoline prices worldwide. And for diesel, ten of the twelve appear among the first twenty countries for diesel, all except for Nigeria (# 31 worldwide with \$0.84/liter) and Iraq, for which no diesel price is available.

The United States manages to just barely make the top 20 for lowest gasoline prices. U.S. retail gasoline prices are above international spot prices so the United States does not subsidize gasoline. But at the same time, it also has very low taxes by international standards. Compared to other OECD countries, for example, the United States has by far the lowest gasoline taxes (see, e.g. Knittel, 2012).

3.2 Fuel Subsidies

Global spot prices for gasoline and diesel in November 2014 were \$0.57 and \$0.59, respectively. These spot prices come from DOE/EIA (2016a) and are average spot prices for conventional gasoline and low-sulfur diesel at New York Harbor in November 2014. In practice, spot prices for fuels tend not to vary much geographically reflecting the low cost of long-distance transportation via ocean tanker. See, for example, DOE/EIA (2013), Figure 8, which plots daily transatlantic spot price differentials for gasoline and diesel between New York Harbor and Rotterdam; dif-

ferences are centered around zero and rarely vary more than \$.05 per liter in either direction.

Figure 3 shows the ten countries with largest fuel subsidies in 2014. The implied subsidy per liter was calculated as the difference between domestic consumer prices and international spot prices. Transport, distribution, and retailing costs were incorporated following Clements et al. (2013). The total subsidy amount was then calculated by multiplying the per-liter subsidy by total road-sector consumption of each fuel. Data on road-sector gasoline and diesel consumption comes from the World Bank *World Development Indicators* and are for 2010, the most recent year for which these data are available.⁴

Total fuels subsidies worldwide in 2014 were \$65 billion, split approximately evenly between gasoline and diesel. There were, in 2014, a total of 16 countries that subsidize gasoline and 21 countries that subsidize diesel, but the ten countries in Figure 3 represent more than 90% of all subsidies. Saudi Arabia alone had \$20 billion in subsidies in 2014. Saudi Arabia has long subsidized fuels and, not surprisingly, has some of the highest fuels consumption per capita in the world. Since 1971, fuels consumption in Saudi Arabia has increased nine-fold and, today, Saudi Arabia is the sixth largest oil consumer in the world while being only the nineteenth largest economy (Gately et al., 2012). Figure 3 shows fuel subsidies per capita. Saudi Arabia remains in the top spot with annual fuel subsidies totaling more than \$600 per capita. Several smaller countries move up, including Kuwait, Bahrain, and Qatar, while several larger countries move down, including Iran and

⁴More recent data on gasoline and diesel consumption are not publicly-available but can be purchased from a company called the International Road Federation <http://www.irfnews.org/>. DOE/EIA has publicly available data on road-sector gasoline consumption and distillate fuel oil consumption, but the latter includes heating oil use in addition to road-sector diesel consumption.

Algeria.

Total global fuel subsidies decreased significantly between 2012 and 2014 because of the decrease in crude oil prices. Davis (2014) finds that total fuel subsidies in 2012 were \$110 billion, so close to twice as high as in 2014. Falling crude oil prices reduce the opportunity cost of fuel, and thus the implicit value of fuel subsidies. Another factor contributing to the decrease in subsidies between 2012 and 2014 is that several countries took steps to reduce subsidies. Most notably, Indonesia sharply increased gasoline and diesel prices in the summer of 2013. Indonesia was third on the list in 2012 for total fuel subsidies after only Saudi Arabia and Iran, so this was a significant reform.

3.3 Deadweight Loss

Total global deadweight loss from fuel subsidies in 2014 is calculated to be \$26 billion. This is split roughly evenly between gasoline (\$12.5 billion) and diesel (\$13.5 billion). Figure 5 reports deadweight loss by country. Saudi Arabia takes the top spot with \$8.8 billion in deadweight loss with Venezuela right behind with \$8.4 billion. These two countries, Saudi Arabia and Venezuela, represent about two-thirds of total global deadweight loss. Figure 6 shows deadweight loss per capita. Saudi Arabia and Venezuela are again in the top two spots, with about \$300 in annual deadweight loss per capita.

It is perhaps surprising that deadweight loss is so high in Venezuela given that the total dollar value of subsidies is considerably larger in Saudi Arabia. However, deadweight loss increases approximately with the *square* of the per liter subsidy

amount so, for example, a \$1.00 per liter subsidy is more than twice as costly as a \$0.50 per liter subsidy. Venezuela has the cheapest fuels on the planet so the subsidies in Venezuela impose particularly large economic costs even though the total quantity of fuels consumption is much lower than in Saudi Arabia. In Venezuela right now there is someone driving around who values gasoline at only \$.10 per liter. Gasoline spot prices in March 2016 are about \$.35 per liter, so each time this person uses a liter of gasoline the world becomes worse off by \$.25.

All of these countries are major oil producers and most are OPEC members. From an economic perspective, there is little reason why fuel subsidies would be correlated with oil production. Transportation costs are small compared to the market price of refined products, so the opportunity cost of selling a gallon of gasoline is similar whether or not it came from domestically-produced oil. Nevertheless, fuel subsidies have long been viewed in many oil-producing countries as a way to share the resource wealth with a nation's citizens. These deadweight loss estimates show, however, that these are not benign transfers from producers to consumers. Fuel subsidies significantly distorting behavior, causing large-scale waste and imposing significant economic costs.

Table 1 provides summary statistics and deadweight loss estimates by country. The price elasticity of demand of -0.6 implies that fuels consumption would be much lower without subsidies. The implied changes in consumption are perhaps too dramatic for Venezuela, but for other countries the predicted changes seem plausible. For example, according to these estimates Saudi Arabia would decrease gasoline consumption from 24 billion liters annually to 11 billion liters annually and Iran would decrease gasoline consumption from 22 billion liters to 17 billion

liters annually. These seem completely plausible, particularly when viewed correctly as *long-run* responses which would encompass not only changes in driving behavior but also increased fuel-efficiency of the vehicle stock, changes in commuting patterns, and, in the very long run, changes in urban form and choices about where households and firms locate.

4 External Costs

This section now turns to quantifying the external costs of global fuel subsidies. Carbon dioxide emissions are an important component of these costs, but the externalities from driving also include emissions of local pollutants, traffic congestion, accidents, and road damage.

4.1 Marginal Damages

As described earlier, external costs can be quantified as excess consumption multiplied by marginal damages per unit of fuels (δ). The analysis in the previous section provides country-specific measures of excess consumption for gasoline and diesel. This information is combined with estimates of marginal damages from an ambitious recent project undertaken by a team of researchers at the International Monetary Fund (Parry et al., 2014a). The objective of the study was to measure the external costs of energy, including not only gasoline and diesel, but also coal and natural gas and the authors find that the external costs of energy worldwide are dominated by coal with its large carbon and air pollution impacts. Previous

studies had measured marginal damages for particular energy types and for particular individual countries, but Parry et al. (2014a) is the first comprehensive attempt to measure marginal damages for several different types of energy and for a large set of countries.

Table 2 reports marginal damages per liter for five different categories of externalities. Parry et al. (2014a) reports marginal damages for gasoline and diesel by category for 156 countries and this table reports weighted means and standard deviations, with weights equal to gasoline and diesel consumption in each country. In a small number of cases country-level estimates are not available and regional averages are used instead. Total marginal damages are \$0.58 per liter for gasoline and \$0.73 per liter for diesel. These are substantial marginal damages and, as emphasized by Parry et al. (2014a) and Coady et al. (2015), well in excess of current gasoline and diesel taxes in most countries. In the broader analysis of energy subsidies, however, it is coal, not fuels, that dominates the welfare impact. While several countries including the U.K., Germany, and Norway, have fuels taxes that are set close to or even in excess of marginal damages, no country in the world taxes coal at close to Pigouvian prices. Moreover, the local pollutant impacts from coal are large enough that, for most countries, carbon pricing would be welfare improving even if you ignore the benefits that accrue to other countries Parry et al. (2015).

The first category in Table 2 is carbon dioxide emissions, which impose marginal damages equal to \$.09 and \$.10 per liter for gasoline and diesel, respectively. For these estimates Parry et al. (2014a) adopted a social cost of carbon of \$35 per metric ton from Greenstone et al. (2013). Carbon dioxide emissions are a global

pollutant so these costs are the same for all countries, making carbon dioxide unlike all of the other marginal damages from driving.

Local pollutant costs average \$.04 and \$.20 per liter for gasoline and diesel. Parry et al. (2014a) quantify these costs using city-level data on the size of proximate populations and previous estimates from the literature on both the relationship between air pollution exposure and health outcomes and on the monetized value of health. In practice, mortality risks are the largest component in this exercise, and the value of a statistical life is assumed to vary across countries with different income levels based on a parametric relationship. This focus on the mortality risks from air pollution is consistent with a growing body of evidence in the epidemiological and broader scientific literature, for example, World Health Organization (2014) estimates that outdoor air pollution causes 3.7 million deaths annually.

Traffic congestion adds \$.27 and \$.26 per liter. For these estimates, Parry et al. (2014a) use city- and country-level data on travel delays to estimate the reduction in aggregate travel speeds caused by each additional driver on the road. On average each kilometer of driving is found to increase delays for other drivers by 0.0041 hours. These delays are then monetized using country-specific wages and other estimates of the value-of-time from the existing literature. Consistent with a broader literature, congestion costs are estimated to be especially large in urban areas in high-income countries. For example, Parry and Small (2009) estimate that drivers in London during rush hour impose marginal damages equal to \$10.00 per liter.

The marginal damages from accidents are estimated to be \$.18 and \$.13 per liter.

These estimates come from an analysis of country-level fatality data, combined with previous estimates in the literature for the value of statistical life. Care is taken to focus on the *external* costs of accidents and to ignore accident risks borne by drivers themselves. The estimates for marginal damages from accidents range widely across countries driven by differences in accident risk and the value of a statistical life.

Finally, Parry et al. (2014a) assume that road damage from gasoline is zero, and quantifies road damages from diesel using previous estimates in the literature. Large vehicles have been shown to be responsible for the vast majority of vehicle-related road damage, and thus the marginal damages for diesel but not gasoline. Road damage costs end up being small compared to the other components of marginal damages, with average costs only \$.04 per liter for diesel.

4.2 Total External Costs from Fuel Subsidies

Table 3 reports the total external costs from fuel subsidies in 2014. These costs were calculated using the country-specific marginal damages estimates described in the previous section, multiplied by the quantity of excess consumption in each country as in equation (8), and then summed up to reflect total costs by fuel type and external cost component.

Total external damages from fuel subsidies are \$44 billion annually, evenly split between gasoline and diesel. Combined with total deadweight loss (\$26 billion), the total economic cost of fuel subsidies is \$70 billion annually. This is larger than the total dollar value of the subsidies (\$66 billion), so it costs more than \$1 in

economic cost for each \$1 that is transferred from producers to consumers. This is, therefore, a very expensive way to share resource wealth.

External costs include \$8 billion from carbon dioxide emissions, \$7 billion from local pollutants, \$12 billion from traffic congestion, and \$17 billion from accidents. It is perhaps surprising that two-thirds of external costs come from traffic congestion and accidents. These components are rarely mentioned in policy discussions about fuel subsidies, but there is a growing consensus that these are the largest components of the external cost of driving (Parry and Small, 2005; Parry et al., 2007; Parry and Small, 2009; Anderson and Auffhammer, 2013; Parry et al., 2014a). Marginal damages in countries that subsidize fuels tend to be *lower* than global averages for traffic congestion, but *higher* than global averages for accidents. This reflects the fact that, on average, population density and traffic delays tend to be lower in these countries than global averages; and that traffic accidents tend to be relatively more common.

Figure 7 shows external costs by country. Separate bars indicate carbon dioxide, local pollutants, traffic congestion, and accidents. Traffic congestion costs are large. Riyadh, Caracas, Tehran, and even Kuwait City are well-known for severe traffic jams and this is visible in the form of large traffic congestion costs in Saudi Arabia, Venezuela, Iran, and Kuwait. Other countries tend to have lower traffic congestion costs. Accidents are estimated to be particularly costly in Saudi Arabia, Iran, Algeria, and Libya reflecting high baseline levels of vehicle accident fatalities.

Total external costs per capita in Figure 8 range from \$100 to \$600 annually across countries. Small countries like Kuwait, Qatar, and Bahrain move up, while large

countries like Venezuela, Egypt, and Iran move down. Kuwait has the highest external costs per capita. This reflect large fuel subsidies, but also that Kuwait has a relatively high population density and high average income level, so local pollution and traffic congestion are higher than in most other countries.

Finally, Table 4 shows how estimates change with alternative assumptions about the long-run price elasticity of demand for gasoline and diesel. Under the preferred demand elasticity (-0.6), global fuel subsidies yield 63,300 million liters of excess consumption, \$25.6 billion in deadweight loss and \$44.2 billion in external costs. The more elastic is demand, the larger are these economic costs. With a long-run elasticity of -0.8, total economic costs are \$82.2 billion in 2014.

5 Prospects for Renewables and Diversification

This section discusses prospects for alternative fuel vehicles to reduce the negative externalities from gasoline and diesel subsidies. Could a country like Saudi Arabia reduce these externalities *without* eliminating fuels subsidies? The focus continues to be on heavily energy subsidized economies where, not surprisingly, the current vehicle fleet is overwhelmingly composed of gasoline- and diesel-powered vehicles. Although there are many different types of alternative fuel vehicles including natural gas and biofuels, the section focuses mostly on electric vehicles (EVs) as they have the greatest potential for significant environmental benefits (Tessum et al., 2014; Covert et al., 2016).

There is little question that, with sufficient government incentives, it would be possible to diversify the vehicle stock. The United States, Norway, Netherlands,

and Japan all offer subsidies for EVs, and all have experienced large increases in EV sales.⁵ In the United States, for example, federal tax credits have been available for EVs since 2009. Tax credits range from \$2,500 to \$7,500 based on the size of the battery, with longer-range vehicles like the Chevrolet Volt and Tesla Model S qualifying for the full \$7,500 credit. In addition, several U.S. states offer extra subsidies and preferential access to carpool lanes and free charging is widely available.

Norway also has generous subsidies for EVs. Most significantly, EVs are exempt from Norway's otherwise hefty 25% import tax on all new cars and trucks. EVs in Norway also qualify for reduced license fees, preferential access to carpool lanes and free charging in municipal facilities. Combine these incentives with Norway's very high gasoline prices, and it is no surprise that Norway has the highest market penetration of EV's worldwide.⁶

Teasing out the exact causal relationship between government incentives and EV adoption is difficult because of potential endogeneity and omitted variables, but it seems uncontroversial to assert that government incentives have played a major role in fostering EV adoption in these countries. Moreover, an older literature on hybrid vehicle adoption makes it clear that vehicle sales indeed respond significantly to government incentives (Chandra et al., 2010; Gallagher and Muehlegger, 2011).

⁵As of September 2015 the top five countries for EV sales were the United States, China, Japan, Norway, and the Netherlands. See <http://www.hybridcars.com/one-million-global-plug-in-sales-milestone-reached/>

⁶See Stoll, John D. "Tesla Breaks Norway's All-Time Sales Record," *Wall Street Journal*, April 2, 2014; Catherine Wolfram, "Energy Tourism: The Tesla Taxi in Oslo", *Energy Institute Blog*, April 13, 2015; and Jolly, David "Norway is a Model for Encouraging Electric Car Sales," *New York Times*, October 16, 2015.

What is much less clear is whether government incentives for alternative fuel vehicles would be a cost-effective approach for reducing externalities. The biggest limitation with promoting alternative fuel vehicles is that it would do little to reduce traffic congestion and accidents, the two largest components of externalities. Subsidies for alternative fuel vehicles might even exacerbate these externalities if the subsidies reduce the total cost of vehicle ownership or the marginal cost of driving below current levels. Norwegians probably drive more total kilometers today than they would have otherwise because of the generous incentives for EVs.

Incentives for alternative fuel vehicles would also only indirectly address environmental externalities. Gasoline emits less carbon dioxide than coal, but more carbon dioxide than natural gas, so the impact of EVs on carbon dioxide emissions is ambiguous (Babae et al., 2014; Tessum et al., 2014). The local pollutant impacts are complicated as well. Vehicle emissions occur at ground level, and thus tend to be more damaging than power plant stack emissions. However, these potential advantages from EVs are mitigated by emissions control equipment at the tailpipe. When vehicles have high-quality catalytic converters then the local pollution benefits from EVs are reduced significantly. Moreover, local pollution damages in both cases depend on the size of the affected populations as well as on prevailing meteorological conditions.

Holland et al. (2015) is the most comprehensive attempt to quantify these tradeoffs empirically. The study assesses the environmental impact of EVs by combining an econometric analysis of the marginal emissions from electricity with a state-of-the-art air pollution model. Overall, the results are surprisingly mixed for EVs. In states like California, with high population density and relatively clean elec-

tricity, EVs represent an environmental benefit of about \$3000 over the lifetime of the vehicle. However, in states like North Dakota with low population density and relatively carbon-intensive electricity, EVs represent an environmental cost of \$4,700.

No similar analysis has been performed for Saudi Arabia, Venezuela, or other heavily energy subsidized economies. However, the characteristics of the electricity sectors in these countries suggests that EV impacts are likely to be somewhere between North Dakota and California. Most countries that subsidize fuels also tend to have relatively carbon-intensive electricity generation, so power plant emissions would increase substantially with more EVs. Venezuela is an important exception, with 65% of its electricity from hydroelectric power. But most other heavily energy subsidized economies are dominated by fossil fuels. Saudi Arabia, for example, generates all of its electricity from oil and natural gas, and Iran generates 90%+ of its electricity from oil and natural gas.⁷

In addition to being inefficient, subsidizing alternative fuel vehicles would also likely be highly regressive. U.S. tax credits for alternative fuel vehicles, for example, have gone overwhelmingly to high-income households. Borenstein and Davis (2015) find that 90% of U.S. electric vehicle tax credits since 2009 have gone to the top income quintile. Even after the subsidy, EVs are expensive compared to similar-sized gasoline-powered vehicles so they are purchased mostly by high-income households.

Overall, this discussion points to “green” vehicle incentives being quite a poor

⁷This information about electricity generation in Saudi Arabia, Iran, and Venezuela comes from DOE/EIA International Energy Statistics, accessed online March 2016 at <https://www.eia.gov/beta/international/analysis.cfm>.

substitute for subsidy reform. Incentives for alternative fuel vehicles would not address congestion or accidents and the environmental impacts are ambiguous. Moreover, incentives for alternative vehicles would require substantial fiscal expenditures. It takes large government incentives to induce households and firms to adopt alternative fuel vehicles, and this is particularly true in heavily energy subsidized economies where cheap fuels make conventional vehicles so inexpensive to operate.

6 Conclusion

Recent subsidy reform in U.A.E. and Saudi Arabia provides a clear roadmap for other countries looking to roll back energy subsidies. Most immediately these reforms offer fiscal relief, helping to balance government budgets and freeing up public funds for investments in education, health, and other productive uses. Over the longer-run, these reforms offer enduring benefits in the form of reduced economic waste and decreased externalities.

This paper focuses on this last component, the external costs of fuel subsidies. The results are striking, indicating that external costs are large in magnitude, almost twice as large as total deadweight loss. Also striking is the degree to which external costs are driven by traffic congestion and accidents. These externalities are rarely mentioned in policy discussions about fuel subsidies but they are quantitatively important components, as will come to no surprise to people have spent time driving or being a pedestrian in Riyadh or Caracas.

It is important not only to increase prices, but also to remove government discretion

in fuels markets. In U.A.E., for example, prices have been increased to market levels but are not truly deregulated. Instead, prices continue to be set by a *Fuels Prices Committee*, which meets on the 28th of each month. This may sound relatively benign, but when crude prices increase again this committee is going to come under political pressure to freeze retail rates, thus threatening to undo the hard-won economic gains from reform.

Inevitably efforts to reform energy subsidies also run up against distributional concerns. Citizens of Saudi Arabia, for example, strongly believe that this resource wealth “belongs to the people”. The broader lesson from this analysis, however, is that fuel subsidies are an expensive way to transfer resources. According to these estimates, it costs more than \$1 in inefficiencies for each \$1 transferred to consumers. This is very expensive, particularly when alternative approaches exist that could achieve the same distributional goals at much lower cost.

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Figure 1: Deadweight Loss and External Cost from Fuel Subsidies

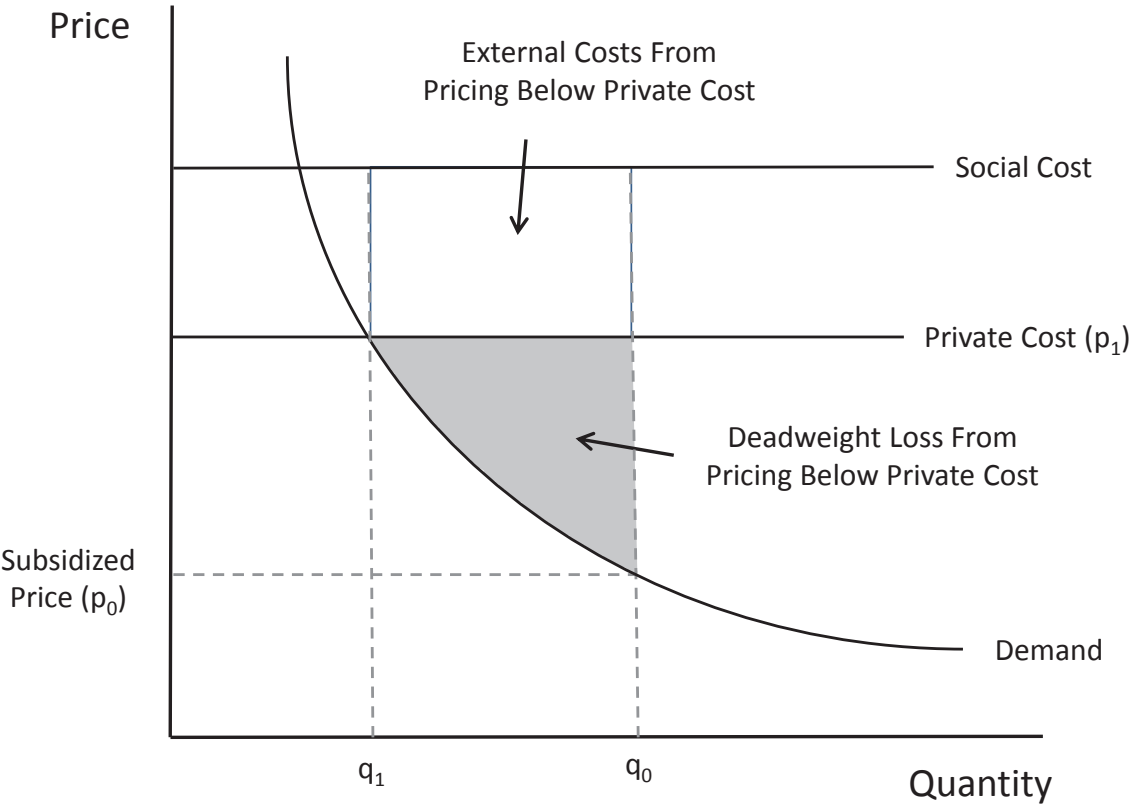


Figure 2: Lowest Global Gasoline and Diesel Prices

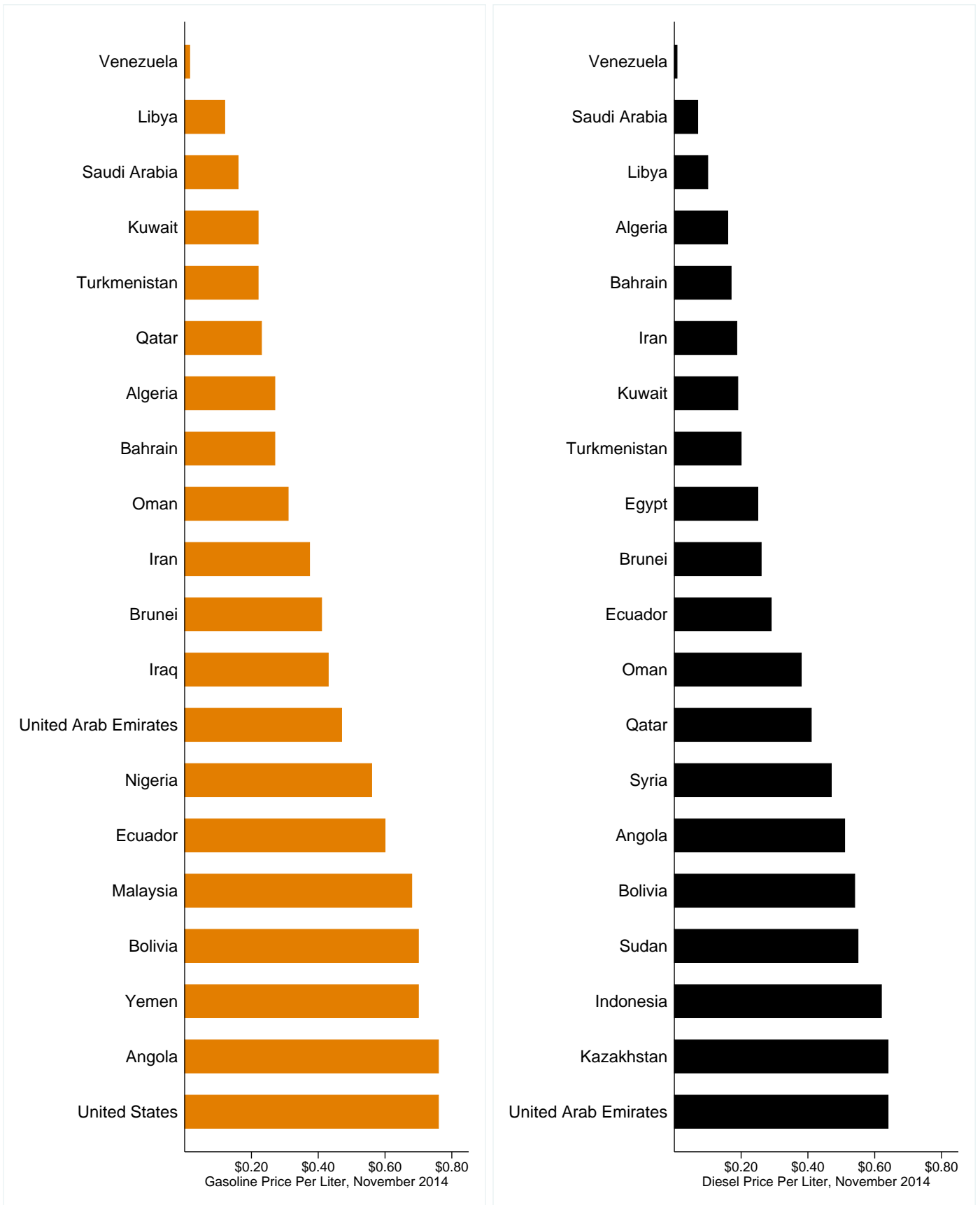


Figure 3: Total Fuel Subsidies in 2014, Top Ten Countries

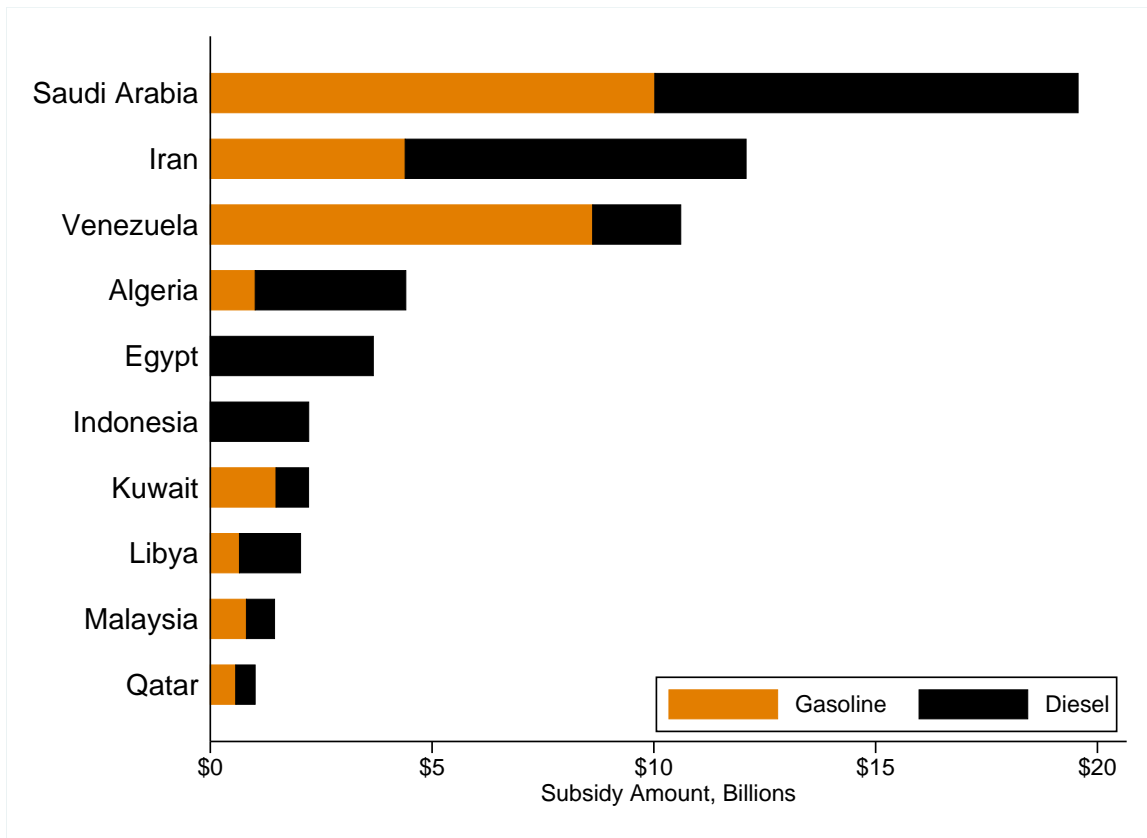


Figure 4: Fuel Subsidies Per Capita in 2014, Top Ten Countries

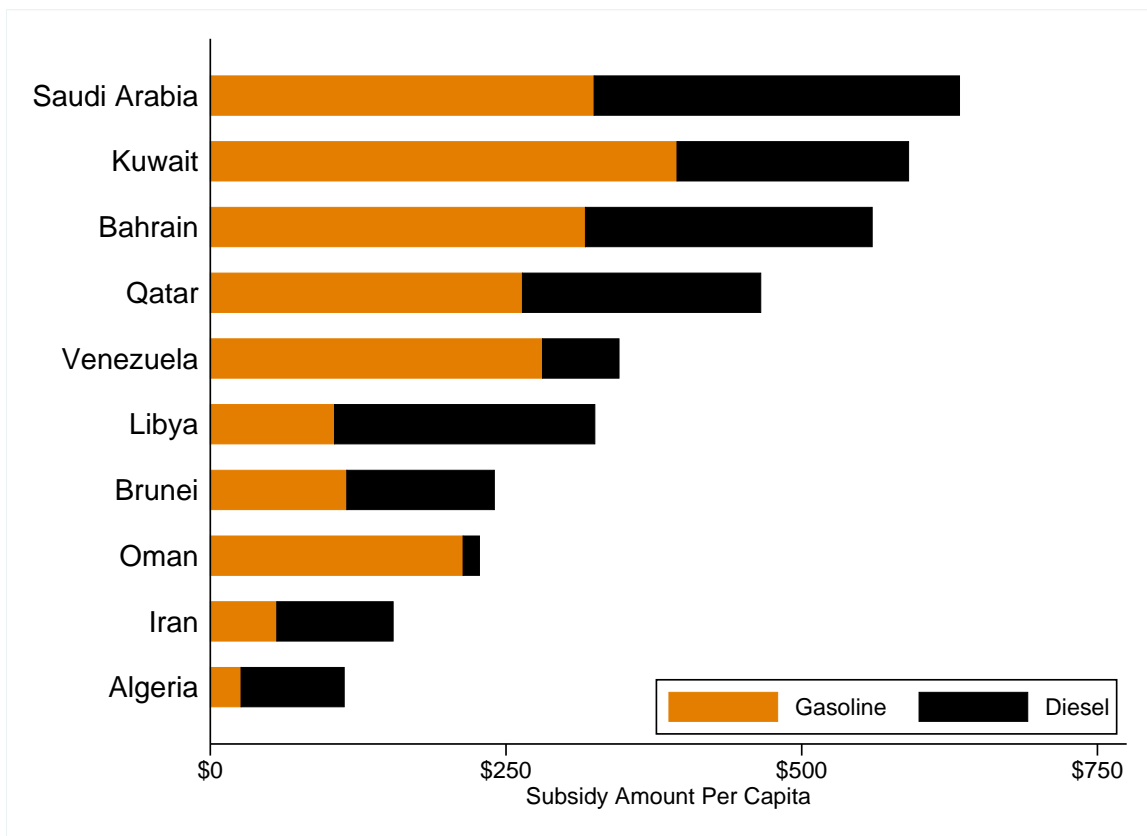


Figure 5: Deadweight Loss from Fuel Subsidies in 2014, Top Ten Countries

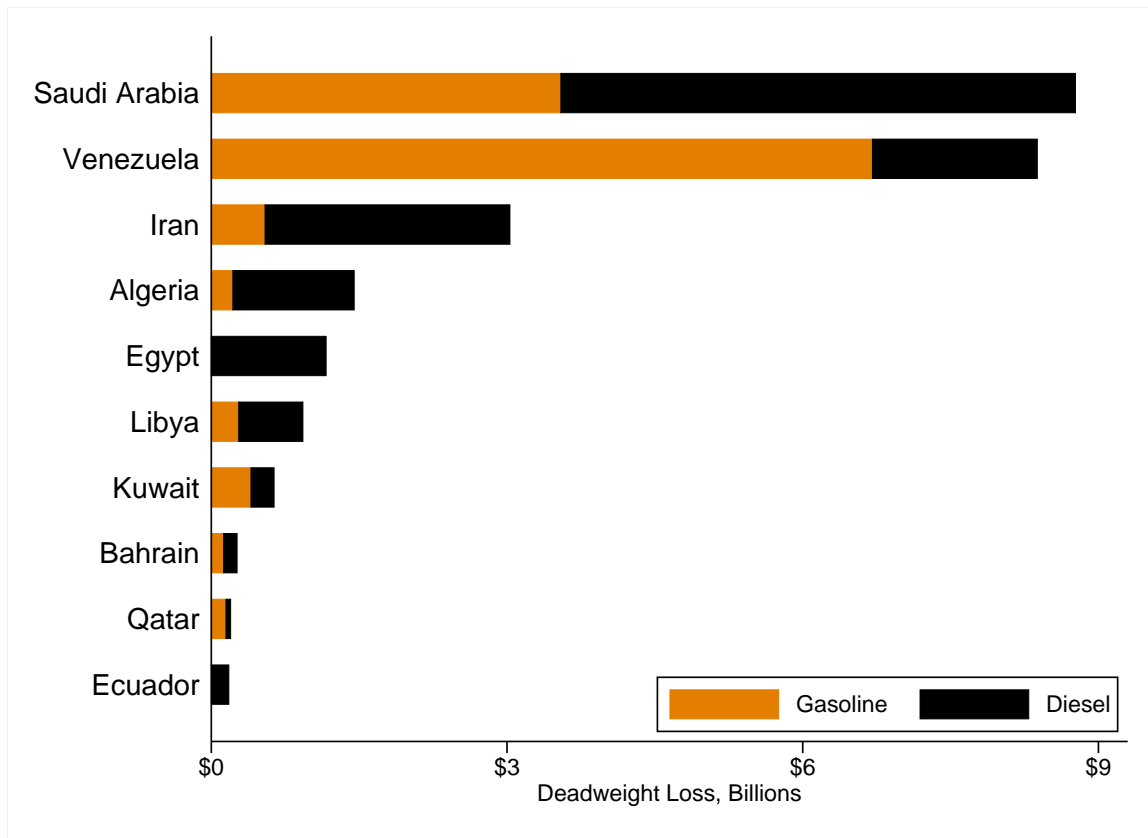


Figure 6: Deadweight Loss from Fuel Subsidies Per Capita in 2014, Top Ten Countries

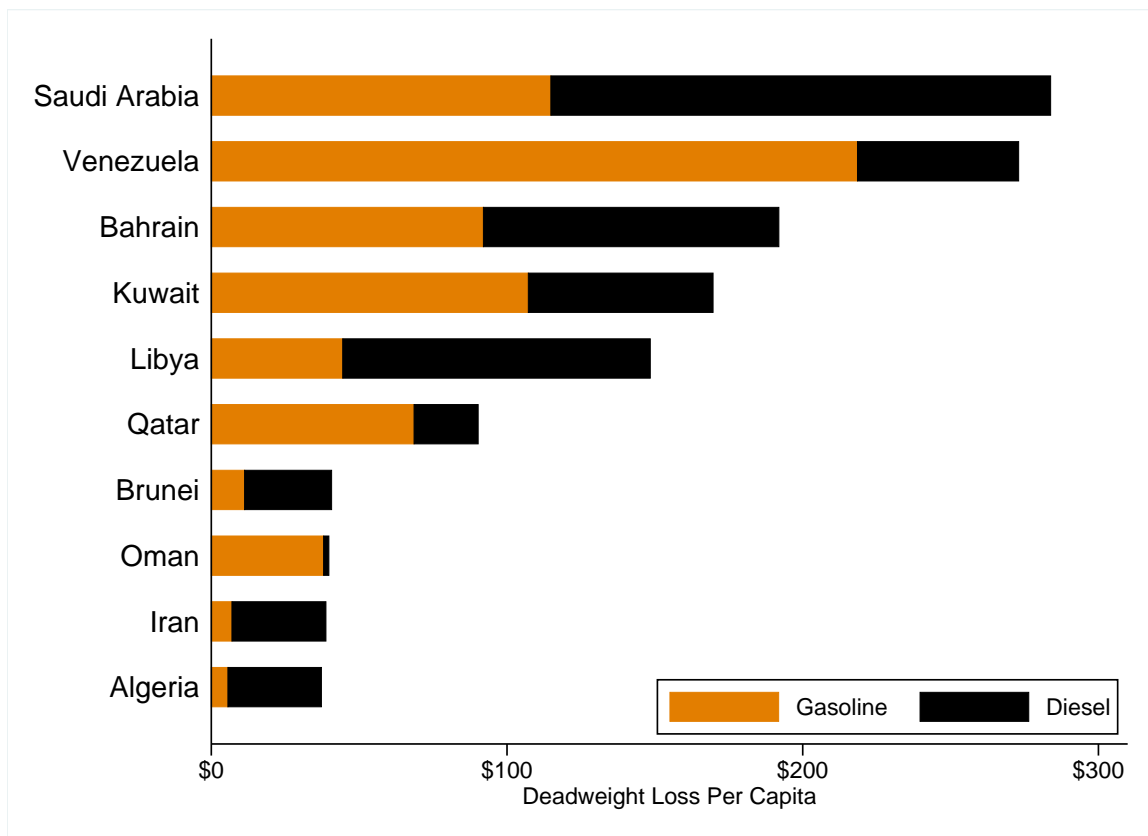


Figure 7: External Costs from Fuel Subsidies in 2014, Top Ten Countries

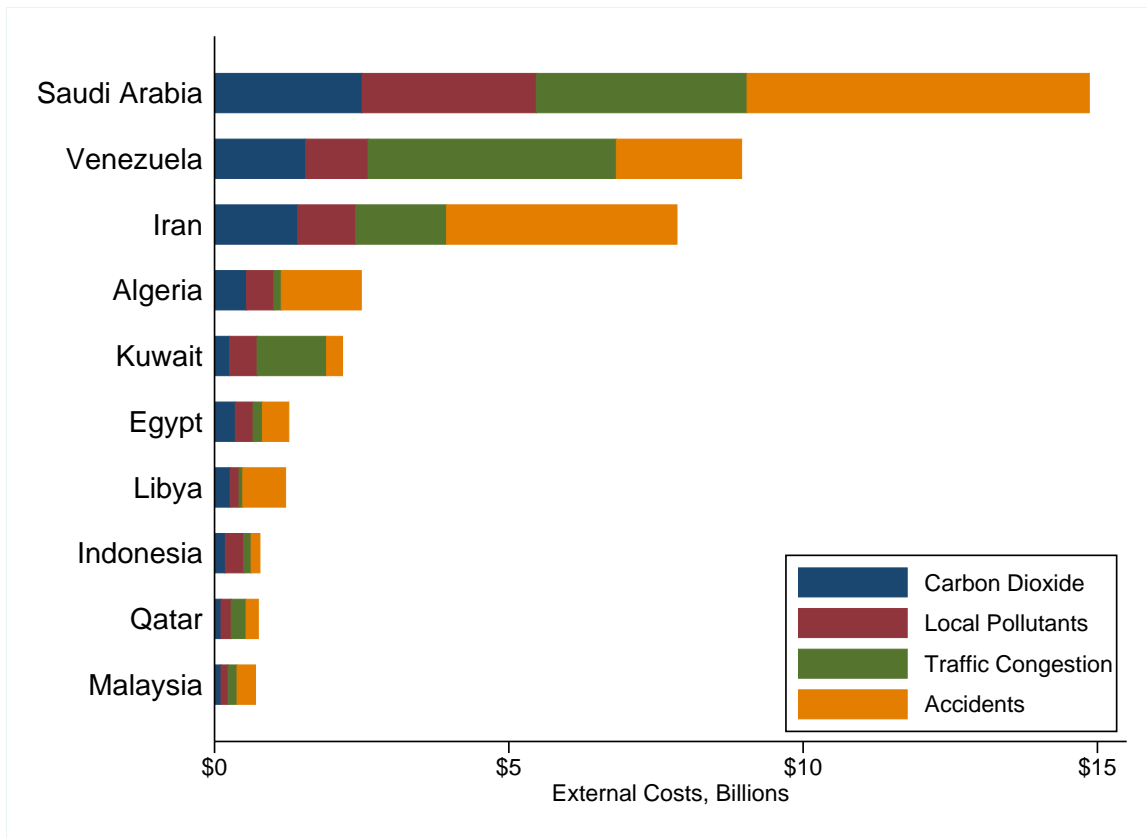


Figure 8: External Costs from Fuel Subsidies Per Capita in 2014, Top Ten Countries

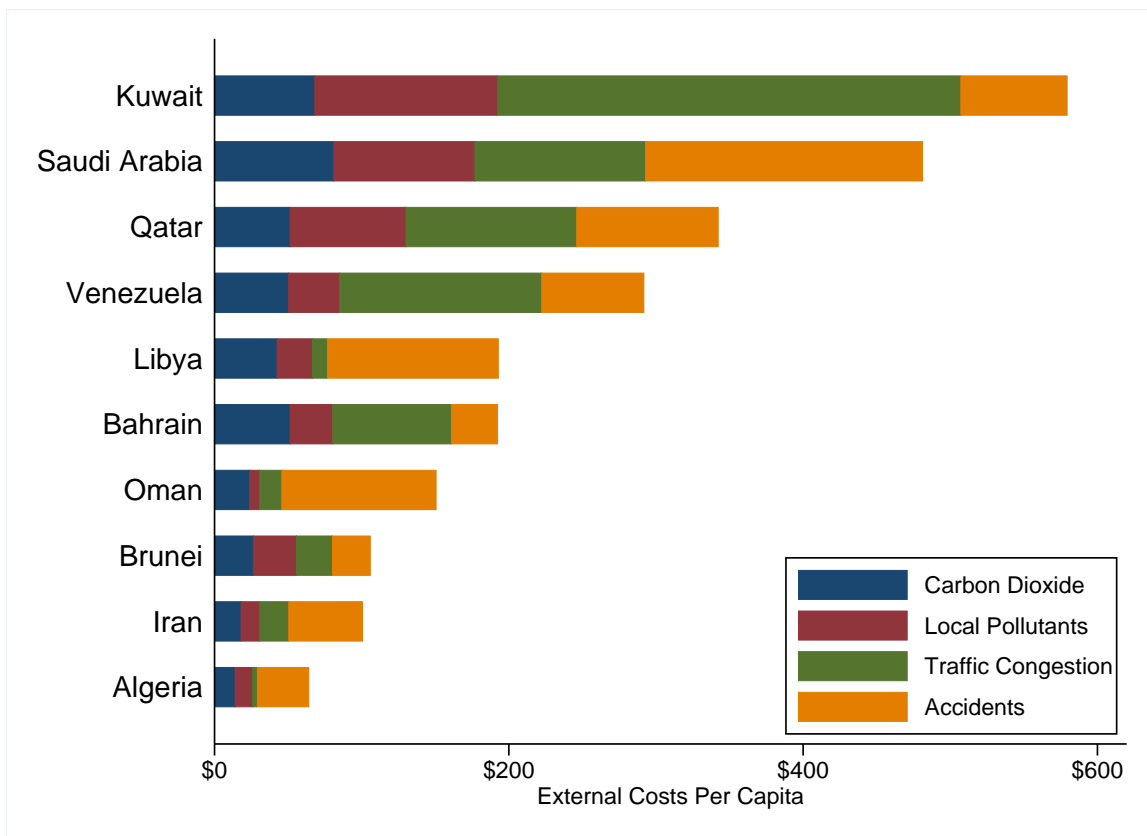


Table 1: Summary Statistics and Deadweight Loss Estimates

	Price per Liter (Nov 2014)	Consumption in 2014 (millions of liters)	Predicted Consumption at Market Price (millions of liters)	Deadweight Loss in 2014 (billions \$)
	(1)	(2)	(3)	(4)
Panel A. Gasoline				
Venezuela	\$.02	15532	1751	6.7
Saudi Arabia	\$.16	24443	11405	3.5
Iran	\$.37	22410	17404	.5
Kuwait	\$.22	4231	2390	.4
Libya	\$.12	1460	573	.3
Algeria	\$.27	3372	2154	.2
Oman	\$.31	3482	2416	.2
Qatar	\$.23	1686	978	.1
Bahrain	\$.27	900	487	.1
Turkmenistan	\$.22	1022	577	.1
Panel B. Diesel				
Saudi Arabia	\$.07	18350	5107	5.2
Iran	\$.19	19074	9573	2.5
Venezuela	\$.01	3412	258	1.7
Algeria	\$.16	7898	3610	1.2
Egypt	\$.25	7067	3598	1.2
Libya	\$.1	2812	969	.7
Kuwait	\$.19	1837	931	.2
Ecuador	\$.29	2880	1881	.2
Indonesia	\$.62	14791	12988	.1
Bahrain	\$.17	550	222	.1

Table 2: Marginal Damages per Liter

	Gasoline (1)	Diesel (2)
Carbon Dioxide Emissions	\$.09 (.00)	\$.10 (.00)
Local Pollutants	\$.04 (.09)	\$.20 (.24)
Traffic Congestion	\$.27 (.20)	\$.26 (.22)
Accidents	\$.18 (.14)	\$.13 (.08)
Road Damage	\$.00 (.00)	\$.04 (.03)
Total	\$.58 (.23)	\$.73 (.35)

Source: Author's calculations based on Parry et al. (2014a).

Table 3: Total External Costs from Fuel Subsidies in 2014, in Billions

	Gasoline (1)	Diesel (2)	Total (3)
Carbon Dioxide Emissions	\$3.6	\$4.2	\$7.9
Local Pollutants	\$1.1	\$6.1	\$7.2
Traffic Congestion	\$7.7	\$4.6	\$12.3
Accidents	\$10.1	\$6.4	\$16.5
Road Damage	\$0.0	\$0.3	\$0.3
Total	\$22.5	\$21.7	\$44.2

Table 4: Alternative Assumptions about Long-Run Price Elasticity of Demand

	Total Excess Consumption of Gasoline and Diesel in 2014 (millions of liters) (1)	Total Deadweight Loss in 2014 (billions \$) (2)	Total External Costs in 2014 (billions \$) (3)
Demand Elasticity -0.4	63,300	\$19.6	\$34.0
Demand Elasticity -0.6	82,300	\$25.6	\$44.2
Demand Elasticity -0.8	96,800	\$30.2	\$52.0