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Abstract

Despite increasing calls for reform many countries continue to provide subsidies for gasoline and diesel. This paper quantifies the external costs from 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.

Key Words: Energy Subsidies; Road Transportation; Fossil Fuels; Alternative Fuel Vehicles; Petroleum Products

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1 Introduction

In August 2015, the United Arab Emirates (U.A.E.) raised domestic gasoline 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 end of 2015, Saudi Arabia raised domestic gasoline and diesel prices by more than 50% 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.

Subsidy reform is happening now because of low crude oil prices. As recently as 2014, crude oil prices were above $100/barrel, but since plummeting at the end of 2014 have remained below $60/barrel.[3] 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. and Saudi Arabia, and is typically 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 carbon dioxide emissions and other externalities. Worldwide the transportation sector is responsible for 23% of total energy-related carbon dioxide emissions, more

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

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

[3]See U.S. Department of Energy, Energy Information Administration, "Spot Prices for Crude Oil". Several economists have argued that these low crude oil prices provide an historic opportunity to reduce fuel subsidies. See, 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.

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 gasoline and diesel subsidies. The calculations use the latest available data from the World Bank and externality estimates from an ambitious recent study by the International Monetary Fund (Parry et al., 2014a). 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.

These external costs are in addition to conventional 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 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- powered vehicles. Reviewing the relevant academic literature, the paper concludes that 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 to ameliorate traffic congestion and accidents, two of the largest external costs from driving. 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 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) estimated external damages from energy for 156 countries and Coady et al. (2015)

used 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 particular 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 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 alternative fuel vehicles 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 the welfare loss. 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 these 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 buyer's 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 worth p_1 and giving it to buyers who value it 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 reflects the societal cost of these welfare-destroying purchases.

Pricing below private cost also imposes external costs. This welfare loss 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 gasoline and diesel consumption, and thus increased carbon dioxide emissions, local pollutants, traffic congestion, and accidents. These external costs are in addition to the deadweight loss triangle, so the two areas need to be added together to calculate the total economic cost of fuel subsidies

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. However, 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, i.e. relative to efficient prices excluding any Pigouvian tax to address externalities. Post-tax subsidies, in contrast, are when energy is priced below social cost i.e. relative to efficient prices including a Pigouvian tax. Previous studies have found that post-tax subsidies are several times larger than pre-tax subsidies.[4]

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 counterfactual considered in this analysis is removing subsidies, not the decision to, in addition, impose fuel taxes that would increase fuels prices above private cost. Thus all of the estimates in this paper refer to "pre-tax" subsidies.

In focusing on "pre-tax" subsidies, it does not matter that fuel taxes are not the most efficient approach for addressing the externalities from driving. Traffic congestion and accident risks vary widely depending on when and where driving occurs, as do damages from local pollutants (see, e.g. Fullerton and West, 2002; Knittel and Sandler, 2013). Again, however, the counterfactual in this analysis is removing subsidies, i.e. increasing prices up to the level of *private* cost, not the decision to, in addition, impose fuel taxes or take other steps to price externalities.

[4]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 were \$541 billion in 2013 while post-tax subsidies were 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.

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 crude oil (or refined products) in international markets, so this foregone revenue, and not production cost, is the correct measure of private cost.

Deadweight loss also depends on the elasticities of demand and supply. The more elastic are demand and supply, the larger the deadweight loss from pricing below private cost. In the short-run, demand and supply for crude oil are both inelastic (Hamilton, 2009), but what matters for the economic cost of fuel subsidies are the *long-run* elasticities. The empirical analysis which follows assumes that the price elasticity of demand for fuels is moderately elastic. 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.[5]

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

[5] Studies that have focused specifically on countries with fuel subsidies have tended to find smaller long-run price elasticities (Eltony, 1994; Bhattacharyya and Blake, 2009; Arzaghi and Squalli, 2015). For example, using data from 32 fuel-subsidizing countries Arzaghi and Squalli (2015) estimates a long-run price elasticity of demand ranging from -0.25 to -0.45, depending on whether they use a partial adjustment model or cross-country regressions.

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).

Another more subtle choice reflected in Figure 1 is that external costs have been assumed to be constant. For carbon dioxide emissions this is a very reasonable assumption. From a global perspective the economic cost of carbon dioxide emissions is probably slightly increasing, but when considering a single sector for a single country, this should be viewed as essentially constant. For other externalities, however, costs are almost certainly not constant, and in future work it would be interesting to begin to incorporate these non-linearities.

2.1.4 Fiscal Impacts

An important priority for future work is to better understand the fiscal impacts of fuel subsidies. The total subsidy is reflected in Figure 1 as the rectangle between 0 and q_0, and between p_0 and p_1. Fuel subsides are calculated later in the paper exactly like this, by multiplying total consumption (q_0) by the subsidy per unit ($p_1 - p_0$). Total subsidies are reported by country and fuel type, as well as total subsidies per capita to account for differences in market size.

When borne by the government, this total subsidy is also the fiscal impact. In some countries, these losses may be partially or completely absorbed by firms resulting in negative impacts on their net profits. In this case the subsidy still has a fiscal impact, however, as it reflects foregone potential tax revenue. Regardless of the exact market structure, firms that bear the cost of fuel subsidies will generate less tax revenue, and in some cases, require government transfers to cover losses.

Fuel subsidies can have a large impact on government budgets. As mentioned in the introduction, the high fiscal cost of subsidies has been a major part of the motivation for recent subsidy reform. Before Indonesia's recent subsidy reform, for example, government spending on energy subsidies had grown to exceed public expenditures on health, education, and other key categories. Fuel subsidies inhibit the ability of government to address other fiscal objectives, requiring taxes to be higher than they would be otherwise. These fiscal impacts exacerbate pre-existing distortions in the economy, potentially with severe negative implications for long-run growth (Plante, 2014).

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 long-run price elasticity of demand 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.

The first step in calculating deadweight loss 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 for all countries and fuels. The demand function (i.e. equation 1) is 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,

$$DWL = (p_1 - p_0)q_0 - \int_{p_0}^{p_1} Ap^{\epsilon} dp. \tag{2}$$

Evaluating the integral yields,

$$DWL = (p_1 - p_0)q_0 - \frac{A}{(1+\epsilon)}[p_1^{(1+\epsilon)} - p_0^{(1+\epsilon)}]. \tag{3}$$

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

$$p = (A^{-1}Q)^{1/\epsilon} \tag{4}$$

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

$$DWL = (q_0 - q_1)p_1 - \int_{q_1}^{q_0} A^{-\frac{1}{\epsilon}} q^{\frac{1}{\epsilon}} dq. \tag{5}$$

Evaluating the integral yields,

$$DWL = (q_0 - q_1)p_1 - A^{-\frac{1}{\epsilon}} \frac{1}{\eta}[q_0^{\eta} - q_1^{\eta}]. \tag{6}$$

where $\eta = \frac{1}{\epsilon} + 1$. With the example below equations (3) and (6) 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.

$$(q_0 - q_1)\delta. \tag{7}$$

As described later, the estimates used in the analysis for δ come from Parry et al. (2014a) and are specific to each country and fuel type.

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 total gasoline consumption in 2014 (q_0) was 24,443 million liters. Rearranging the demand function to solve for A with a -0.6 elasticity yields,

$$A = q_0 {p_0}^{-\epsilon} = 24443 * 0.16^{0.6} = 8140. \tag{8}$$

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

$$q_1 = A{p_1}^{\epsilon} = 8140 * 0.57^{-0.6} = 11,405. \tag{9}$$

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 (3), deadweight loss is equal to,

$$(\$0.57 - \$0.16) * 24443 - \frac{8140}{(0.4)}[\$0.57^{(0.4)} - \$0.16^{(0.4)}] = \$3546. \tag{10}$$

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

Using equation (6), deadweight loss is equal to,

$$(24443 - 11405) * \$0.57 - 8140^{\frac{-1}{-0.6}} \frac{1}{-2/3}[24443^{-2/3} - 11405^{-2/3}] = \$3546. \tag{11}$$

Or \$3.5 billion. As expected, both approaches yield the same measure for deadweight loss.

Finally, marginal damages (δ) from Parry et al. (2014a) for gasoline for Saudi Arabia (δ) are \$0.56/liter. Thus using equation (7), total annual external costs are,

$$(24443 - 11405) * \$0.56 = \$7301 \tag{12}$$

or \$7.3 billion annually. Thus for this example the externalities costs exceed deadweight loss, and total welfare loss is \$10.8 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 subsidies. Data are collected every two years and this paper uses the latest available data from surveys conducted worldwide during mid-November 2014 (GIZ, 2015).

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. The GIZ data has gasoline prices for "super" gasoline (95-octane) only. In many countries there is more than one octane level of gasoline available for sale. These different grades of gasoline are typically sold at different prices, but comprehensive data is not available on prices for these different grades.

Figure 2 shows the twenty countries with the lowest gasoline and diesel prices worldwide. In November 2014 average global 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 worldwide 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 per capita in Venezuela is 40% higher than any other country in Latin America, and three times the regional average (Davis, 2014).

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 twenty countries with lowest gasoline prices worldwide. And ten of the twelve appear among the twenty countries with the lowest diesel prices, all except for Nigeria (number

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 but the United States also has very low gasoline 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/liter and $0.59/liter, 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 vary little 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; differences 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 publicly available.[6]

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

[6]DOE/EIA has publicly available data on gasoline and distillate fuel oil consumption, but these data do not distinguish between road- and non-road consumption. Distillate fuel oil, for example, is used not only for diesel but also for space heating, electric power generation, railroads, and industrial use.

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 4 shows fuel subsidies per capita. Saudi Arabia is 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 Algeria.

Total global fuel subsidies decreased significantly between 2012 and 2014, primarily because of the sharp 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 Triangle

As discussed in Section 2, fuel subsidies are inefficient because they enable transactions for which buyers' willingness-to-pay is less than private cost, and because they impose externalities. These inefficiencies were shown in Figure 1 as the deadweight loss triangle and as an external cost rectangle. This section reports estimates for the deadweight loss triangle, and then later in the paper external costs are calculated and discussed.

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 smaller than 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.

All of the countries in Figures 3 and 4 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 comes 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. 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 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

The estimates of marginal damages come 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. 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.[7] 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 average \$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

[7] Previous studies (Parry and Small, 2005; Parry et al., 2007) have found that these are quantitatively the most important externalities from driving. Other potential externalities include noise and urban sprawl.

of current gasoline and diesel taxes in most countries.[8]

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). For alternative values of the social cost of carbon these damages scale proportionally. For example,Greenstone et al. (2013) find a social cost of carbon of \$65 per metric ton for the 95th percentile with a 3% discount rate. With this value the marginal damages are \$.17 and \$.19, respectively, making the carbon impacts the second largest component of externalities after only traffic congestion.

Marginal damages from local pollutants average \$.04 and \$.20 per liter for gasoline and diesel, respectively. 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 damages equal to \$.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-

[8] One of the interesting findings from the broader analysis in Parry et al. (2014a) is the degree to which coal dominates the total external damages from energy subsidies. 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. The local pollutant impacts from coal are large enough that, for most countries, carbon pricing would be welfare improving even ignoring the benefits that accrue to other countries (Parry et al., 2015).

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.

Fuel subsidies increase total driving and thus accidents. Parry et al. (2014a) estimate that the marginal damages from accidents are $.18 and $.13 per liter for gasoline and diesel, respectively. 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 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, 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 and fuel-specific marginal damages estimates described in the previous section, multiplied by the quantity of excess consumption in each country as in equation (7), and then summed up to reflect total costs by fuel and externality type.

Total external damages from fuel subsidies are $44 billion annually, including $8 billion from carbon dioxide emissions, $7 billion from local pollutants, $12 billion from traffic congestion, and $17 billion from accidents. 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 transfered from producers to consumers. This is, therefore, a very expensive way to share resource wealth.

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 more costly 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 annually 63,300 million liters of excess consumption, \$25.6 billion in deadweight loss and \$44.2 billion in external costs. With a lower price elasticity of demand (-0.4), annual deadweight loss and external costs are lower, \$19.6 billion and \$34.0 billion, respectively.

5 Prospects for Alternative Fuel Vehicles

This section discusses prospects for alternative fuel vehicles to reduce the negative externalities from gasoline and diesel subsidies. Could incentives for alternative fuel vehicles reduce these externalities *without* eliminating fuels subsidies? 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.[9] 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 additional subsidies and other benefits like preferential access to carpool lanes and free charging.

An even more extreme example is Norway. 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 high gasoline prices, and it is no surprise that Norway has the highest percentage of EV's worldwide.[10]

[9] As of September 2016 the top five countries for EV sales were the United States, China, Japan, Norway, and the Netherlands. See `http://www.hybridcars.com/global-plug-in-car-sales-cruise-past-1-5-million/`

[10] See Stoll, John D. "Tesla Breaks Norway's All-Time Sales Record," *Wall Street Journal*, April 2, 2014 and Catherine Wolfram, "Energy Tourism: The Tesla Taxi in Oslo", *Energy Institute*

Teasing out the causal relationship between government incentives and EV adoption is difficult because of potential endogeneity and omitted variables, but government incentives clearly have played a major role in fostering EV adoption in these countries. Moreover, an older literature documented that hybrid vehicle sales respond significantly to government incentives (Chandra et al., 2010; Gallagher and Muehlegger, 2011) and there is no reason to believe that EVs would be any different.

What is much less clear is whether government incentives for alternative fuel vehicles are a cost-effective approach for reducing externalities. Probably most importantly, alternative fuel vehicles do little to reduce traffic congestion and accidents, two of the largest components of externalities. Subsidies for alternative fuel vehicles might even exacerbate these externalities as these subsidies reduce the total cost of vehicle ownership and the marginal cost of driving.

Incentives for alternative fuel vehicles 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 (Babaee 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 conventional 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. (forthcoming) is the most comprehensive attempt to date to quantify these tradeoffs empirically. The study assesses the environmental impact of EVs in the United States by combining an econometric analysis of the marginal emissions from electricity with a state-of-the-art air pollution model. The results show that local conditions matter. In states like California, with high population density and relatively clean electricity, EVs represent a net environmental benefit

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Blog, April 13, 2015.

of \$2800 over the lifetime of the vehicle. However, in states like North Dakota with low population density and carbon-intensive electricity, EVs represent a net environmental lifetime cost of \$5,000.[11].

No similar analysis has been performed for a heavily energy subsidized economy. However, most countries that subsidize fuels also tend to have relatively carbon-intensive electricity generation, so EVs could cause total carbon dioxide emissions to increase. Venezuela is an important exception, with 65% of its electricity from hydroelectric power, though the *marginal* source of generation even in Venezuela is typically fossil fuels. Moreover, electricity generation in most other heavily energy subsidized economies is 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.[12]

Incentives for alternative fuel vehicles also require significant fiscal expenditures. In the United States, Norway, Denmark, and elsewhere the total subsidy per EV routinely exceeds \$10,000.[13] These expenditures must be financed through taxes, which distort labor and capital markets (Parry, 1998). Moreover, incentives often go to buyers who would have purchased an EV anyway, adding cost to these programs without yielding any reduction in externalities.[14]

In addition to these concerns, subsidizing alternative fuel vehicles also tends to be highly regressive. Incentives for alternative fuel vehicles tend to go overwhelmingly

[11]Local air pollution impacts of gasoline-powered vehicles are measured in Holland et al. (forthcoming) using an integrated pollution assessment model that captures spatial heterogeneity of damages. Air pollution impacts from electricity generation are measured with the same air pollution assessment model combined with an econometric analysis of the U.S. electric grid that identifies the marginal generating source at different locations. Where air pollution damages from gasoline-powered vehicles exceed the marginal damages from electricity generation there are net environmental benefits from EVs.

[12]This 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`.

[13]See, e.g. *Wall Street Journal*, "Voters Should be Mad at Electric Cars", by Holman W. Jenkins, March 11, 2016 and *New York Times* "Norway is a Model for Encouraging Electric Car Sales,", by David Jolly, October 16, 2015.

[14]There is not yet much direct evidence on the causal impact of EV incentives on adoption, but a broader literature on hybrid vehicles and other types of "green" products has found that a large fraction of buyers are inframarginal (Chandra et al., 2010; Gallagher and Muehlegger, 2011; Mian and Sufi, 2012; Boomhower and Davis, 2014).

to high-income households. For example, Borenstein and Davis (2015) find that 90% of U.S. EV tax credits have gone to the top income quintile. This regressivity reflects that EVs are expensive and tend to be purchased mostly by high-income households.

Thus, overall, it would seem that alternative fuel vehicle incentives are a poor substitute for subsidy reform. Subsidies for alternative fuel vehicles would do little to reduce externalities from driving in economies that heavily subsidize energy, and would do so at high cost, both in terms of efficiency and equity.

6 Conclusion

Recent subsidy reform in U.A.E. and Saudi Arabia represents an important step in the right direction. 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, $44 billion annually. 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 those who 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 have not been truly deregulated. Instead, prices continue to be set by a quasi-government committee which meets monthly. This may sound relatively benign, but when crude prices increase again this committee will 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 many of these countries 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

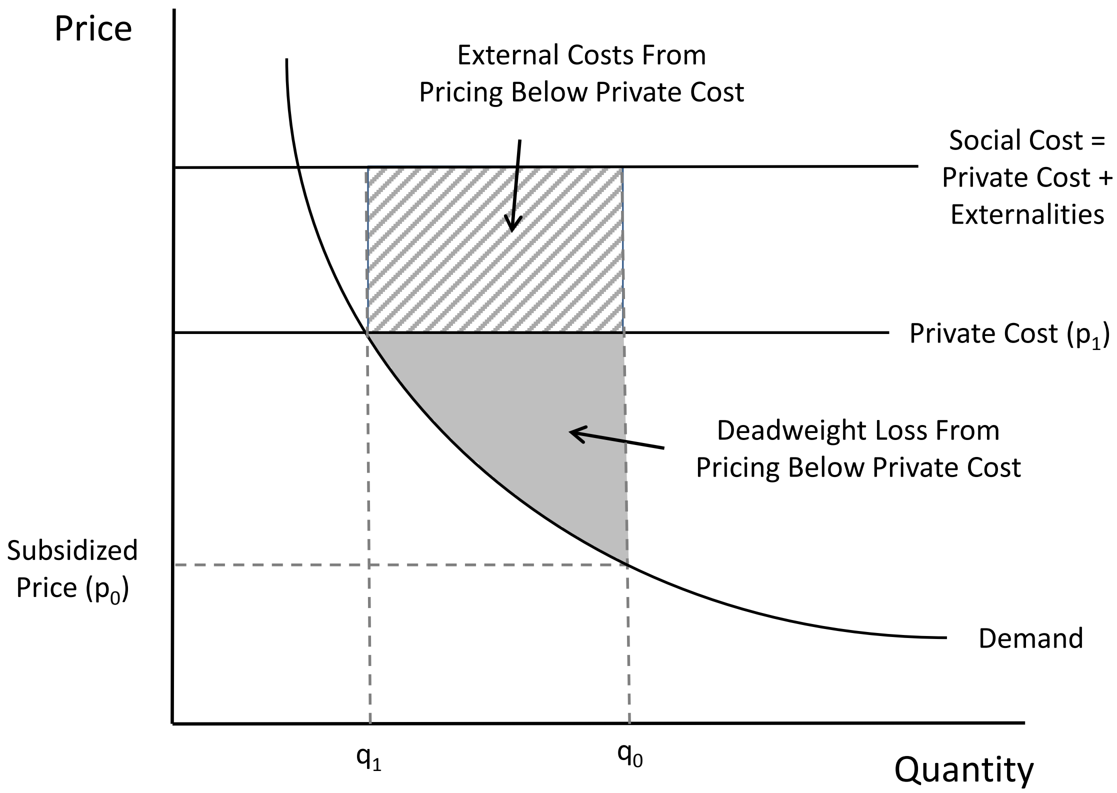

Figure 2: Lowest Global Gasoline and Diesel Prices

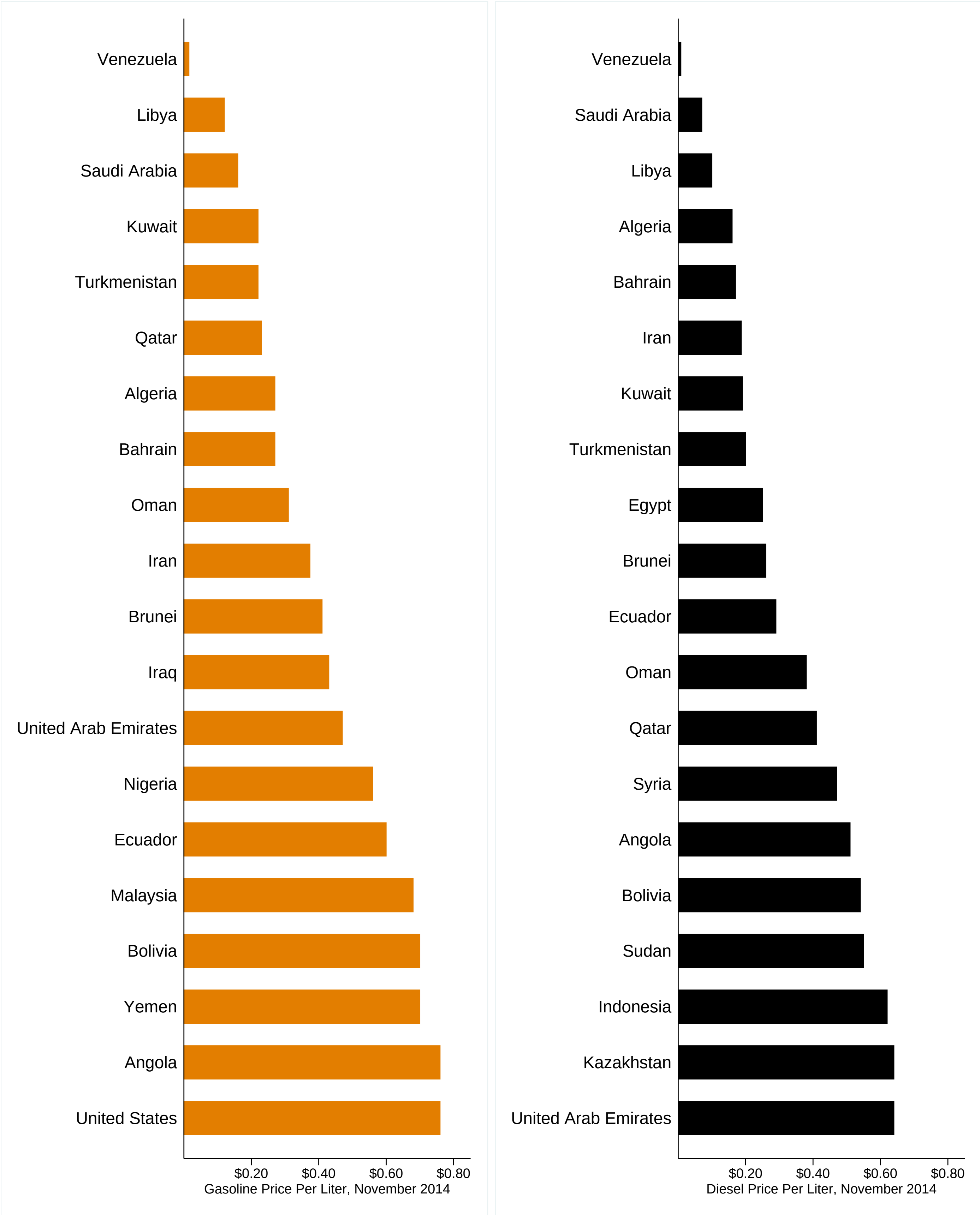

Figure 3: Total Fuel Subsidies in 2014, Top Ten Countries

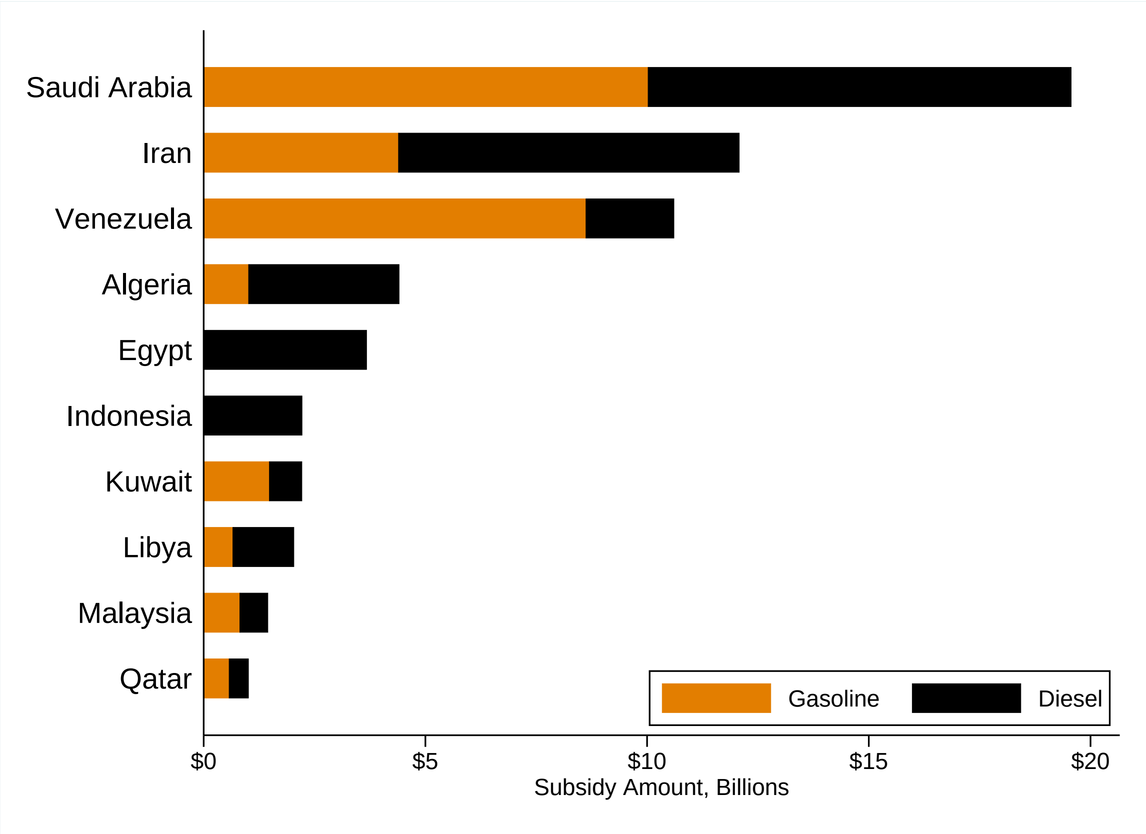

Figure 4: Fuel Subsidies Per Capita in 2014, Top Ten Countries

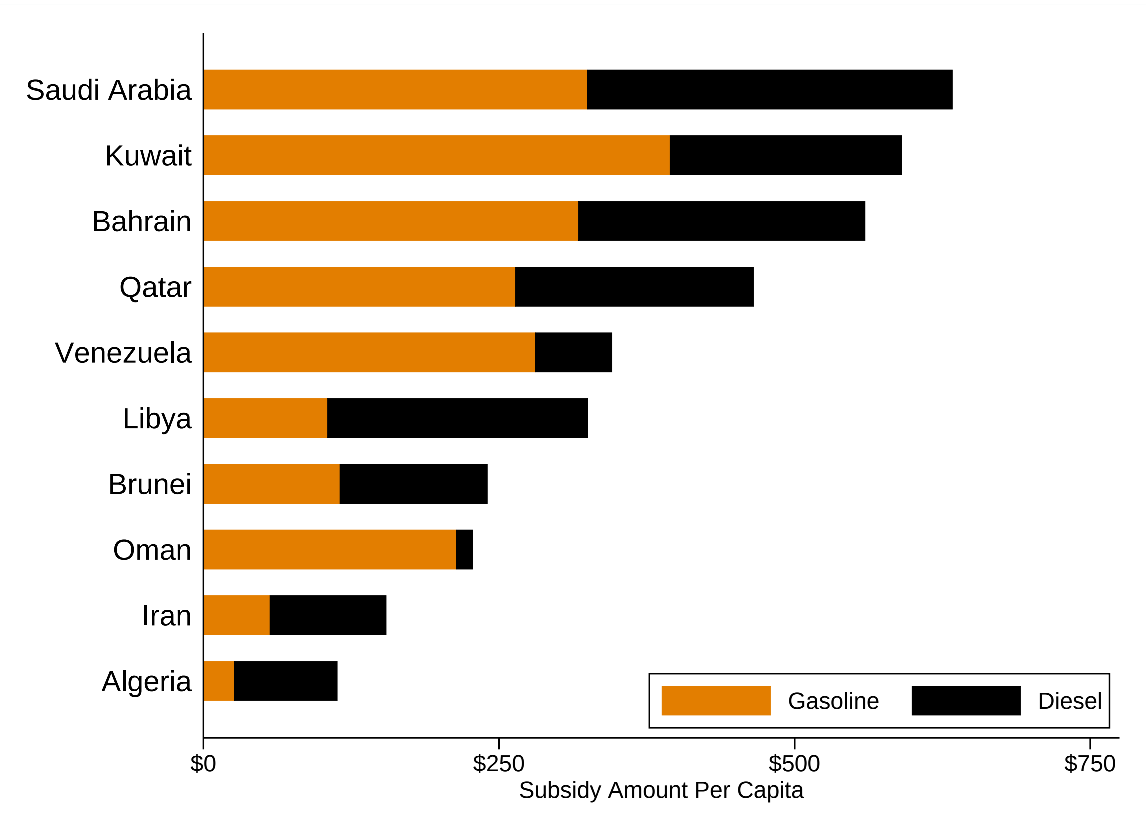

Figure 5: Deadweight Loss from Fuel Subsidies in 2014, Top Ten Countries

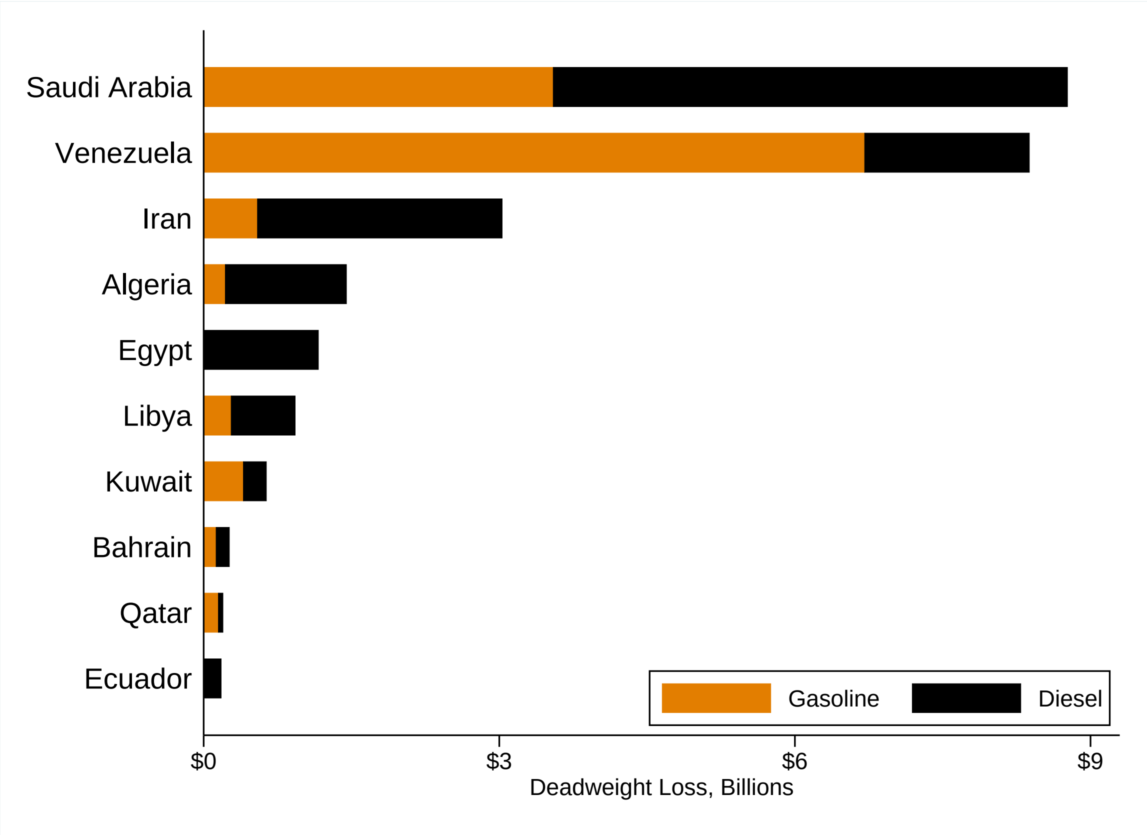

Figure 6: Deadweight Loss from Fuel Subsidies Per Capita in 2014, Top Ten Countries

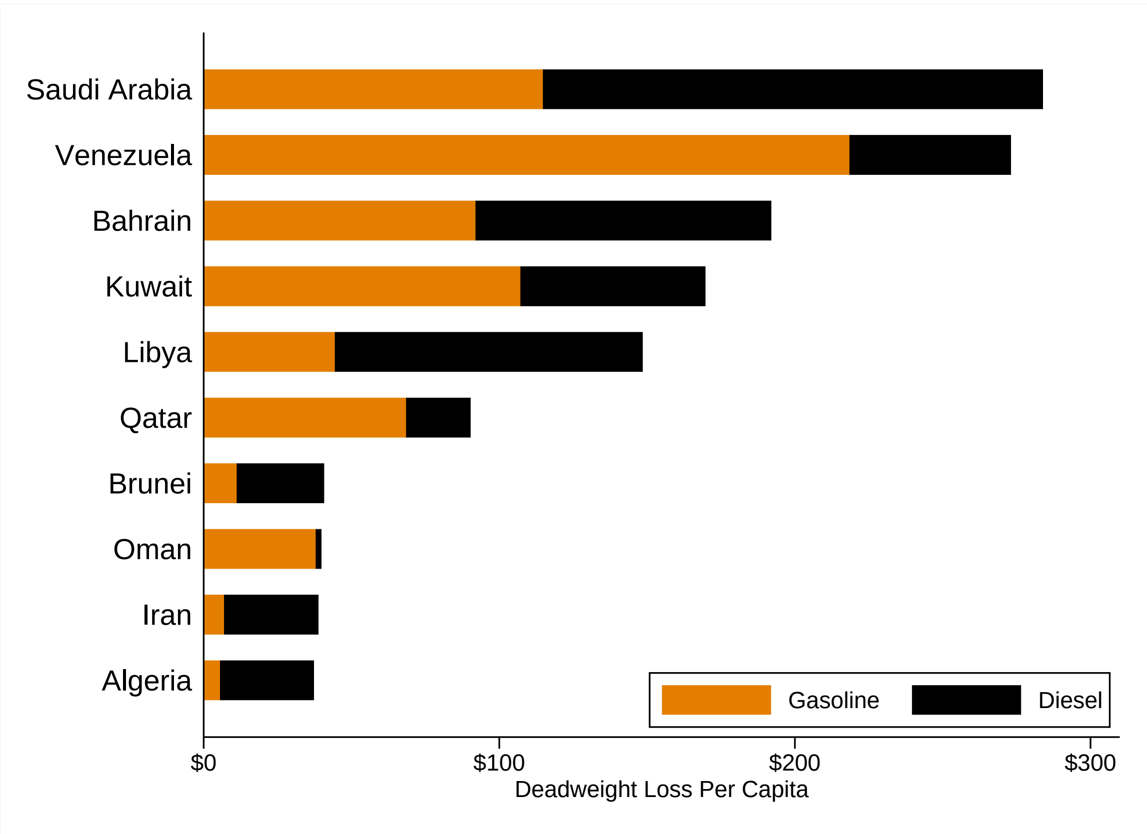

Figure 7: External Costs from Fuel Subsidies in 2014, Top Ten Countries

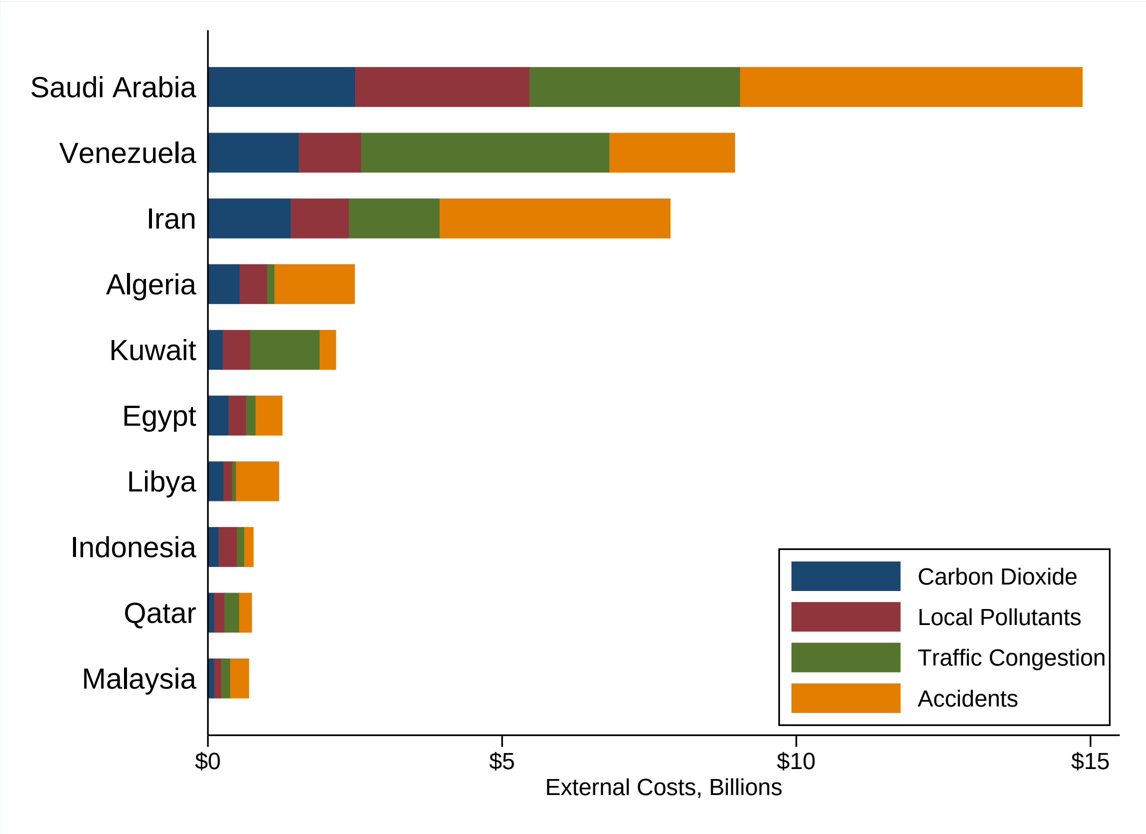

Figure 8: External Costs from Fuel Subsidies Per Capita in 2014, Top Ten Countries

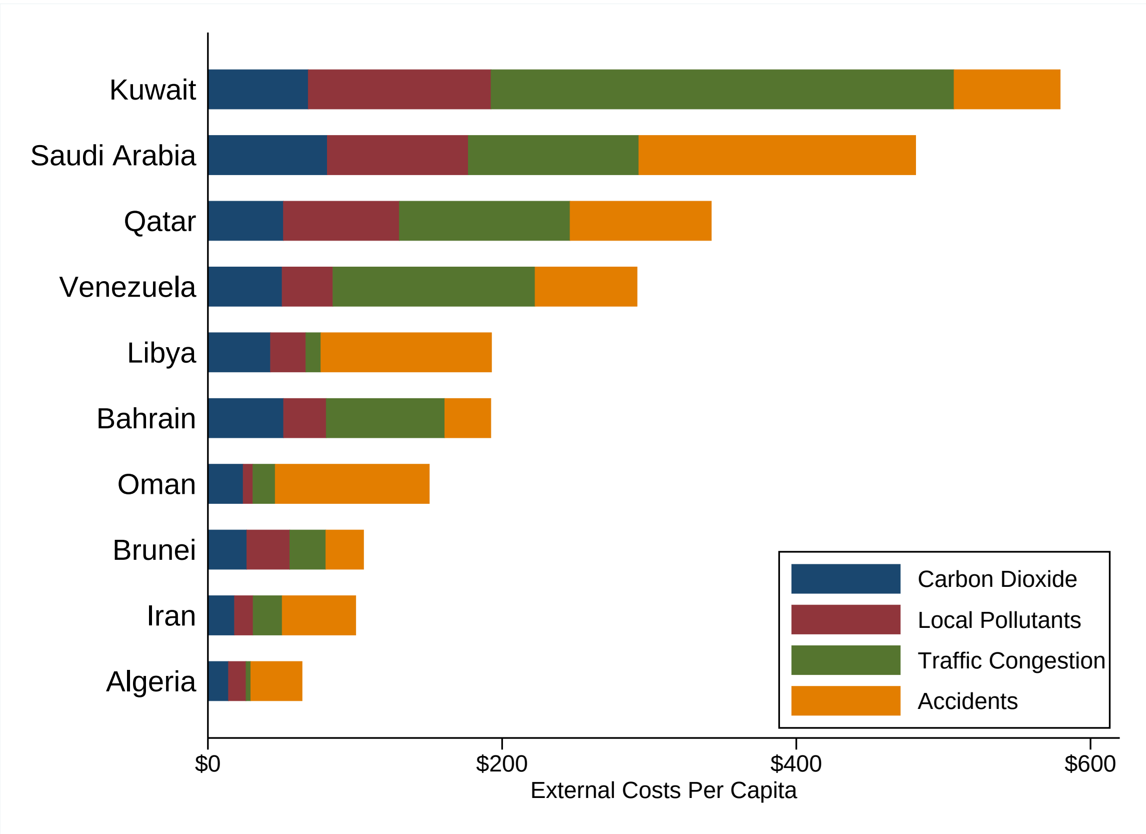

Table 1: Summary Statistics and Deadweight Loss Estimates

	Price per Liter (Nov 2014) (1)	Consumption in 2014 (millions of liters) (2)	Predicted Consumption at Market Price (millions of liters) (3)	Deadweight Loss in 2014 (billions $) (4)
	Panel A. Gasoline			
Venezuela	$ .02	15532	1751	6.7
Saudi Arabia	$ .16	24443	11405	3.5
Iran	$ .37	22410	17404	0.5
Kuwait	$ .22	4231	2390	0.4
Libya	$ .12	1460	573	0.3
Algeria	$ .27	3372	2154	0.2
Oman	$ .31	3482	2416	0.2
Qatar	$ .23	1686	978	0.1
Bahrain	$ .27	900	487	0.1
Turkmenistan	$ .22	1022	577	0.1
	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	$ .10	2812	969	0.7
Kuwait	$ .19	1837	931	0.2
Ecuador	$ .29	2880	1881	0.2
Indonesia	$ .62	14791	12988	0.1
Bahrain	$ .17	550	222	0.1

Table 2: Marginal Damages per Liter

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

Note: Author's calculations based on Parry et al. (2014a). For each fuel and externality category the table reports the mean and standard deviation for marginal damages across 156 countries.

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