Fuel Subsidies, the Oil Market
and the World Economy

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Abstract

This paper studies the effects of oil producing countries’ fuel subsidies on the oil market and the world economy. We identify 24 oil producing countries with fuel subsidies with retail fuel prices that are about 34 percent of the world price. We construct a two-country model where one country represents the oil-exporting subsidizers and the second the oil-importing bloc, and calibrate the model to match recent data. We find that the removal of subsidies would reduce the world price of oil by six percent. The removal of subsidies is unambiguously welfare enhancing for the oil-importing countries. Removal of subsidies is welfare improving for the oil-exporting countries as well in the baseline calibration. However, in general, the optimal subsidy from the point of view of oil exporters is not zero.

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1 Introduction

Fuel subsidies are used by many developing countries to help lower the cost of energy for their citizens. According to the International Energy Agency (IEA) there were 37 countries with subsidies on oil products for an estimated total value of $285 billion dollars in 2011. In general, countries which are net exporters tend to have the largest subsidies. The size of the subsidies has skyrocketed over the last 10 years. The existence of such large and widespread subsidies may have important effects on oil demand and world oil prices.

Despite the prevalence of fuel subsidies, there is not a large literature focusing on their impact on the global oil market. There are many ‘case study’ type papers that analyze the subsidies in specific countries such as IMF (2013a, 2013b and earlier IMF studies), Guillaume et al. (2011), Fofana et al. (2009), and Golub and Strukova (1999). A number of papers have also studied the distributional impacts of removing fuel subsidies using social accounting matrix and input-output models including Breisinger et al. (2011), Arze del Granado et al. (2010), Abouleinein et al. (2009), Coady et al. (2006), Kpodar (2006) and Clement et al. (2003). There are also studies that estimate the effects of subsidy removal on the subsidizing country’s welfare, using supply and demand elasticities, such as Larsen and Shah (1992), Salehi-Isfahani (1996) and Gurur and Ban (2000). One paper, Hartley and Medlock (2008), considers how subsidies and other government policies impact the behavior of a national oil company. Finally, using a small open-economy model, Plante (2014) showed that sizable subsidies could introduce significant distortions into the country that put them in place.

The International Energy Agency has studied the impact of subsidy reform on the global oil market using large-scale energy models that aren’t very transparent. IEA (2011) uses a price-gap analysis and simulations from their World Energy Model to quantify the economic effects from removing fossil-fuel subsidies. Their analysis shows that if oil subsidies were completely phased-out by 2020, global oil demand would be reduced by 5.8% in 2020. IEA et al. (2010), using simulations with a CGE model (ENV-Linkages), report that most countries that removed subsidies unilaterally would realize real income gains from a subsidy phase-out. But, if the phase-out is multilateral, GDP gains would be small and oil prices would fall 8% by 2050.

Our first contribution in this paper is to introduce a simple, analytical two-country model to study the effects of fuel subsidies on the oil market. A benefit of the model is that it produces mathematical solutions that are relatively easy to interpret, making it easier to understand what factors play an important role in determining the quantitative size of the effects that subsidies have on various economic variables. We find that the impact of a fuel subsidy on oil prices depends on the share of consumption and production of oil by the exporting and importing countries and the elasticities of supply and demand.

We then develop a full-fledged dynamic, stochastic, general equilibrium (DSGE) model to analyze the quantitative effects that fuel subsidies in oil exporting countries have on the world oil market and the pattern of world trade. We assume both the oil exporters and importers produce oil, with the oil importers also manufacturing a traded, non-oil good. The non-oil good is used in oil production and also consumed by households in both countries. The model fits in with the recent literature on general equilibrium models that include an oil sector and endogenous oil prices, such as Nakov and Nuño (2013), Bodenstein et al. (2011), Nakov and Pescatori (2010), Leduc and Sill (2007), and Backus and Crucini (2000). None of these papers analyze oil subsidies, although Nakov and Nuño (2013) include an analysis of an oil production subsidy to fringe producers in their paper.

We identify 24 oil producing countries which have fuel subsidies. We find that in recent years
they consume about 13.5 percent of the world’s oil, produce nearly 48 percent, and have retail fuel prices around 34 percent of world prices. To analyze the impact of these subsidies on oil markets and the global economy, we calibrate our DSGE model to match this data. We then conduct the policy experiment of permanently removing the subsidies on oil and analyze how this affects the relative price of oil, the consumption of both oil and non-oil goods, oil production, GDP and welfare in the long run.

With our benchmark calibration, the results show that removing the subsidies would reduce the world price of oil by about 6 percent. Consumers in oil exporting countries would re-allocate their consumption away from fuel products towards other goods and consumers and manufacturers in the oil-importing country would consume more oil. The removal of the subsidy and the consequent oil price decline act as a positive oil shock for the oil-importing country, leading to a small increase in non-oil GDP. We also analyze how the removal of subsidies affects welfare in both the oil importing and exporting countries and find that welfare in both countries increases when the subsidies are removed.

Certain factors are particularly important in determining the results. These include the elasticities of oil supply and oil demand, as well as the share of oil production and consumption in the two countries. Given the uncertainty surrounding the values of the elasticities, we considered the robustness of our results to variations in these factors. The qualitative nature of our results generally holds for a variety of calibrations considered, and we find that removal of the subsidies is welfare enhancing for the oil importing countries in all cases considered.

On the other hand, the removal of subsidies can cause welfare to fall in the oil-exporting countries, in certain cases. The subsidy artificially increases the world price of oil, and as the subsidizers are large net exporters of oil they potentially stand to benefit from this distortion, at the expense of the non-subsidizers. How much they benefit depends greatly upon the price elasticity of oil import demand of the oil importers.

For our benchmark calibration, the demand facing the exporting country is elastic, and in this case removing the subsidy is welfare enhancing. When oil supply and demand are very inelastic, though, removing the subsidies can reduce welfare in the exporting bloc. Relatively inelastic oil supply and demand causes the import price elasticity to also become less elastic and the revenue consequences for oil exporting countries of removing the subsidies to become less benign. The oil exporting country, in these cases, is unable to increase its consumption of the non-oil good enough to offset the decrease in oil consumption brought about by removing the subsidies, and experiences a welfare loss from doing so. We also show for several cases that the optimal subsidy rate is not zero and depends on features of the economic environment such as the elasticities of supply and demand, and the size of the subsidizer relative to the world market.

The remainder of the paper is organized as follows. We first discuss the data used in the calibration of the model. In Section 3, we introduce a stylized, analytical model to help explain the intuition behind the results of the paper. Section 4 discusses the two-country DSGE model with endogenous oil supply. In the context of this model, we examine the effects on the world economy of removing oil subsidies. We also consider a sensitivity analysis of these effects to alternative parameterizations of the model. In Section 5, we end with concluding remarks.

2 Data

In this section we present data on the subsidizing countries used in our calibration; how important these countries are to the oil market, and how subsidized their prices are in relation to world
prices.\textsuperscript{1} The data provide a clearer picture as to why subsidies are an important issue for the rest of the world. They will also be a key input into the theoretical models we will use to quantify the importance of these subsidies.

A first step is to decide which oil producing countries to label as subsidizers. We identified 24 countries that we include in the group of subsidizers, and these countries are listed in table 1. These 24 may be a conservative estimate. We limited our attention to those countries for which there was data on retail fuel prices, and for which the data unambiguously pointed to the presence of fuel subsidies. We also left out a few countries that appear to only have had intermittent experience with fuel subsidies, such as Mexico and Brazil.\textsuperscript{2}

The top and middle panels in figure 1 plot the share of world oil consumption and production, respectively, for the group as a whole from 1992 up to 2012. The world oil consumption and production data come from the Energy Information Administration’s International Energy Statistics database. We used their annual data on “Total Petroleum Consumption” and production of “Crude Oil, NGPL, and Other Liquids” to calculate the consumption and production shares. We start in 1992 as that is the first year that the data were available for all of the countries.

Since the early 1990s the share of world oil consumption due to these countries grew slowly, but steadily. Their share of consumption has risen from about 9 percent in 1992 to 13.5 percent in 2012. While the share is not enormous, it is not trivial either. In terms of oil production, these countries have produced a relatively constant share of the world’s oil, between 45 to 50 percent. In 2012 the share was almost 48 percent. Taken as a whole, these countries are large net exporters of oil.

We also need to measure how distorted domestic retail prices are in these countries compared to world prices. Our data on retail fuel prices come primarily from two sources: OPEC Annual Statistical Bulletins and the World Bank’s data on retail gasoline and diesel prices. The former provides annual averages for retail fuel prices in OPEC member countries, in most cases from 1990 to 2012. The World Bank data provides bi-annual estimates of retail fuel prices in a number of other countries, typically starting in 1998. In a few cases, media reports or other sources, such as the GIZ International Fuel Price survey, were also used. The appendix provides more details on the data sources used.

It is necessary to choose a benchmark price against which to compare the subsidized prices. We use the national average retail price for gasoline and diesel in the U.S., excluding taxes, from the U.S. Department of Energy, as our benchmark. These prices may not be a perfect benchmark, but since fuel prices in the U.S. are set in a competitive market and we have a measure of these prices that excludes taxes we believe that a large gap between retail prices in other countries and the U.S. price will almost assuredly be indicative of subsidization.

Within the context of the models we introduce later, a convenient measure of the degree of subsidization is the ratio between the subsidized price and the world price. That is, suppose $P_{s,t}$ is a domestic, subsidized price (in dollars) at time $t$ while $P_{o,t}$ is the retail price in the U.S. (excluding taxes). Then one measure of the degree of subsidization is given by

$$\psi_t = \frac{P_{s,t}}{P_{o,t}}.$$  \hspace{1cm} (1)

To construct $\psi_t$ we need to aggregate across different product prices and different countries. In doing so we want to take into account three important factors. First, gasoline and diesel prices are

\textsuperscript{1}The appendix provides details on the numerous data sources used in this paper. Further details are available from the authors upon request.

\textsuperscript{2}This number also reflects a lower bound on the total number of countries as it excludes some oil-importing countries with fuel subsidies. A more complete list of countries can be found in Plante (2014).
often subsidized to different degrees both within and across countries. Second, consumption levels of gasoline and diesel may also vary within and across countries. Finally, some of the countries found in table 1 are larger consumers than others.

We perform the following calculations to take these factors into account. First, where necessary we convert prices into dollars using nominal exchange rates. Then, in a given year, for each country we calculate one ratio for gasoline prices and one for diesel prices. Then in each year, for each country, we combine the gasoline and diesel price ratios by weighting them according to the importance of gasoline consumption vis-a-vis diesel consumption in that particular country. Finally, in a given year we weight each country’s ratio with that country’s share of oil-consumption relative to the other countries as a whole, and then sum across all countries to produce $\psi_t$.

Using the OPEC data, we can construct an annual series for $\psi_t$ from 1990 to 2012 for 10 countries. The World Bank data allow us to construct a bi-annual series from 1998 to 2012 for all 24 countries. The bottom panel of figure 1 plots the ratios for the two groups. For the small set of countries, $\psi_t$ indicates that they have subsidized prices over the entire sample period, and that the subsidies have increased significantly over the last 15 years. In 2012, prices in these countries were under 30 percent of U.S. prices. For the whole set of countries, we find a similar pattern in the behavior of $\psi_t$. In 2012, prices for the 24 countries were 34 percent of those found in the U.S.

The ratio for the whole group is somewhat higher than the ratio for just OPEC members, reflecting the fact that certain OPEC members heavily subsidize fuel products. However, the differences are not particularly dramatic. The reason for this is that a majority of the oil that is consumed by the 24 countries is due to just a handful of countries, many of which are also in the smaller set of 10 countries, and they have price ratios that are very low. For example, in 2012 half of the consumption of oil out of the 24 countries was due to Indonesia, Iran, and Saudi Arabia, which had price-ratios of .55, .24 and .12, respectively. The next three largest consumers were Egypt, Iraq, and Venezuela, which had price ratios of .32, .41, and .02 respectively. As such, the subsidization policies of these countries dominate the behavior of $\psi_t$.

In the next section we use a simple model to highlight the important channels through which these subsidies could affect the oil market and the world economy. In section 4 we introduce a more sophisticated general equilibrium model which is calibrated to match the data introduced in this section. We use our calibrated model to gauge the quantitative importance of the subsidies.

3 Motivating example

In this section we introduce a highly stylized two-country model. The simple setup employed here produces analytical results that explicitly show how the presence of a subsidy in the oil exporting countries can affect the world price of oil and the consumption of both oil and non-oil goods. Our goal here is to highlight the important channels through which subsidies distort economic variables and highlight what factors may determine the quantitative importance of these distortions. Although the model is very simple in nature, the findings here provide good intuition for many of the results found in the more complicated model we introduce in section 4.

3.1 The model

We consider a world where there are two countries, country $a$ and country $o$. The latter represents the group of net oil exporters that subsidize domestic residents’ consumption of fuel products. The
former represents the rest of the world. In terms of notation, we use superscripts to refer to the two countries, so that \(Z^o\) and \(Z^a\) refer to variable \(Z\) in country \(o\) and \(a\), respectively.

Both country \(a\) and country \(o\) produce oil. Country \(o\)'s supply of oil is given by \(Y^o_o\), while country \(a\)'s production of oil is given by \(Y^a_a\). Country \(a\) also produces a non-oil good that one can view as manufactures and other goods that are primarily produced outside of oil exporting countries. The two goods are consumed by households in both countries. The countries trade with each other and country \(a\) is a net importer of oil. We assume the non-oil good is the numeraire and denote the relative price of oil on the world market as \(P_o\).

Total demand for oil in \(o\) and \(a\) is given by \(O^o\) and \(O^a\), respectively. Demand for oil on the part of country \(a\) can be broken down further into demand due to household consumption, \(O^c^a\), and demand for oil for use in production of the non-oil good, \(O^g^a\), so that \(O^a = O^c^a + O^g^a\). However, for this section we only model the behavior of overall demand \(O^o\). Consumers in \(a\) pay the world price for oil, \(P_o\), while consumers in \(o\) pay a potentially subsidized price given by \(P_s\). We define \(\epsilon^o \geq 0\) and \(\epsilon^a \geq 0\) as the absolute value of the price-elasticity of demand for fuel products for country \(o\) and country \(a\), respectively. We assume that the supply of oil is responsive to changes in the world price of oil. The elasticity of supply of oil for country \(o\) and country \(a\) is denoted as \(\epsilon^o\) and \(\epsilon^a\).

Let \(\chi^o\) denote the share of world oil production due to country \(o\),

\[\chi^o = \frac{Y^o_o}{Y^o_o + Y^a_o}.\]

Similarly, the share of world oil consumption due to country \(o\) is given by \(\theta^o\),

\[\theta^o = \frac{O^o}{O^a + O^o}.\]

Note that since country \(o\) exports oil to country \(a\), \(\chi^o > \theta^o\).

The market clearing condition for the oil market is given by

\[O^a + O^o = Y^a_o + Y^o_o.\]  \hspace{1cm} (2)

The world oil price, \(P_o\), adjusts to ensure this condition holds. The revenue country \(o\) receives from exporting oil to country \(a\) is given by \(P_o (Y^a_o - O^o)\). This can also be re-written as \(P_o (O^o - Y^a_o)\), which is the oil import bill for country \(a\).

For the non-oil good, we assume country \(a\) is endowed with a fixed supply given by \(Y^a_a\). The non-oil good is either consumed or used as an input to produce oil (rigs, services, etc.). Let \(A^a_c\) and \(A^a_y\) be amounts consumed by country \(a\) and country \(o\), respectively, while \(A^a_y\) and \(A^a_y\) are the quantities of the non-oil good used in the production of oil. The use of the non-oil good in the production of oil implies that for both countries there is an opportunity cost of producing more oil.\(^4\) The market clearing condition for non-oil good is given by

\[Y^a_a = A^a_c + A^a_y + A^a_c + A^a_y.\]  \hspace{1cm} (3)

3.2 Effects of the subsidy on the oil market

Consider a policy in country \(o\) which changes the domestic price of fuel products, \(P_s\). We consider an unspecified percent change in the price, \(\%\Delta P_s\). In the context of the simple model above, the change in oil consumption in country \(o\) would be given by

\[\%\Delta O^o = -\epsilon^o \%\Delta P_s.\]  \hspace{1cm} (4)

\(^4\)One can obviously consider other resources that might be used in the production of oil, such as labor, non-traded services, etc. All of these would introduce the notion that there is an opportunity cost associated with changing the supply of oil, and would introduce various distortions in the model.
Not surprisingly, a reduction in $P_s$ would lead to an increase in consumption of oil products in country $o$, with the size of the response being determined by its price-elasticity of demand.

In turn, the increase in demand for oil by country $o$ will result in a change in the world market price of oil, $P_o$. From equation (2), the change in the world price of oil must satisfy:

$$-(1 - \theta^o) e^a \Delta P_o - \theta^o e^o \Delta P_s = [(1 - \chi^o) \eta^a + \chi^o \eta^o] \% \Delta P_o.$$  
(5)

Solving (5) for $\% \Delta P_o$ yields:

$$\% \Delta P_o = \frac{-\theta^o e^o}{(1 - \theta^o) e^a + (1 - \chi^o) \eta^a + \chi^o \eta^o} \% \Delta P_s.$$  
(6)

Thus, a change in the subsidized price moves the world oil price in the opposite direction, as the world price adjusts to clear the oil market. As a result of higher world oil prices, consumption of oil in country $a$ is crowded out by the subsidy,

$$\% \Delta O^a = e^a \frac{\theta^o e^o}{(1 - \theta^o) e^a + (1 - \chi^o) \eta^a + \chi^o \eta^o} \% \Delta P_s.$$  
(7)

The size of the changes in $P_o$ and $O^a$ depend upon the elasticities of demand and supply as well as the shares of the two countries in the consumption and production of oil. In general, the larger the share of country $o$ in world oil usage ($\theta^o$), the bigger the effect a change in the subsidized price has on the world oil price. Intuitively, if the subsidizing countries are large then even a small change in $P_s$ will have a large effect on the world price of oil. Similarly, a large elasticity of demand in the subsidizing countries ($e^o$) implies greater changes in the world price.

On the other hand, the larger the elasticity of world oil supply ($\eta^a$), the smaller effect a change in the subsidized price has on the world oil price. With supply more responsive, less crowding out of country $a$’s oil consumption needs to occur to clear the market and as a result prices need to change by less in response to the increase in oil demand by the subsidizing country. Likewise, a larger elasticity of demand in the importing countries ($e^a$) also mutes the price response needed to clear the market.

Finally, total world consumption of oil may also be affected when $P_s$ changes. Note that the supply elasticities play a key role in this result. If supply elasticities are zero then increases or decreases in $P_s$ merely re-allocate consumption across countries but have no impact on overall consumption. When $\eta^a$, $\eta^o$ or both are non-zero then reductions in $P_s$ would increase world oil consumption.

### 3.3 Effects of the subsidy on export revenues and trade

Since the subsidy affects the world price of oil, $P_o$, it has implications for the terms of trade between the two countries. More specifically, as an exporter of oil, country $o$’s terms of trade are positively (negatively) affected by the presence (removal) of a subsidy. This may have implications for country $o$’s oil export revenues and its ability to purchase non-oil goods from $a$.

The amount of the non-oil good that country $o$ can purchase depends on the revenue it receives from exporting oil to $a$. The current account equation for country $o$ links up these two quantities and is given by:

$$P_o (O^a - Y^a) = A^c_o + A^y_o.$$  
(8)

A change in the subsidized price $P_s$ will change country $o$’s export revenue through two channels. First, it will affect the price $o$ receives for the oil it exports. Second, the subsidy will also affect the quantity of oil that country $a$ imports. The total impact of these two effects on the oil import
bill of a will depend upon how responsive country a’s production and consumption of oil are to the change in \( P_o \).

A convenient way to think about the total impact is to consider the price elasticity of oil import demand in country \( a \), which we define as \( \xi^a \). The response of export revenue to changes in the world price of oil is then given by

\[
%\Delta[P_o(O^a - Y^o_a)] = (1 - \xi^a) %\Delta P_o. \tag{9}
\]

By definition, whether oil export revenue for country \( o \) rises or falls when the market oil price rises depends on whether \( \xi^a \) is less than or greater than 1. If import demand is inelastic (\( \xi^a < 1 \)) then a rise in \( P_o \) will increase country \( o \)’s oil export revenue, as the increase in \( P_o \) more than compensates for the decline in the quantity of oil imported by country \( a \). If import demand is elastic (\( \xi^a > 1 \)) the opposite occurs and country \( o \)’s export revenue falls when \( P_o \) increases.

The solution for \( \xi^a \) can be derived using the left-hand side of equation (8). Formally, the import demand elasticity is given by

\[
\xi^a = \frac{(1 - \theta^o)\epsilon^a + (1 - \chi^o)\eta^a}{\chi^o - \theta^o}. \tag{10}
\]

Note that the import demand elasticity depends not just on country \( a \)’s oil demand elasticity (\( \epsilon^a \)) but also on country \( a \)’s elasticity of supply and the shares of country \( a \) in world oil use and production. Only in the special case where country \( a \) imports all of its oil (\( \chi^o = 1 \)) is \( \xi^a = \epsilon^a \).

Small elasticities of demand (\( \epsilon^a \)) and supply (\( \eta^a \)) make it more likely that import demand is inelastic. Similarly, the more country \( a \) relies on imports of oil (the higher \( \chi^o \) is relative to \( \theta^o \)) the more likely import demand will be inelastic. While empirical evidence suggests that the elasticity of demand for oil (\( \epsilon^a \)) is less than one, this does not necessarily guarantee that country \( o \)’s oil export revenues will rise when \( P_o \) rises.

What happens to oil export revenue is important because it helps determine how much of the non-oil good country \( o \) can purchase. If the imposition of the subsidy (which increases the world price of oil) raises oil export revenue (\( \xi^a < 1 \)), income is transferred from \( a \) to \( o \) which allows country \( o \) to purchase more of the non-oil good. On the other hand, if oil export revenues fall when the price of oil increases (\( \xi^a > 1 \)), country \( o \) would be able to purchase less of the non-oil good.

### 3.4 Effects of the subsidy on welfare

The previous results have interesting implications for the welfare effects of the subsidy in country \( o \). Specifically, when \( \xi^a < 1 \) the subsidy, by raising the world price of oil, inflates country \( o \)’s oil export revenue. This creates a benefit for country \( o \) at the expense of country \( a \) and allows \( o \) to increase its consumption of both the oil and non-oil good, i.e. both \( O^o \) and \( A^o \) rise. In this case, the subsidy appears to be welfare enhancing for country \( o \). In some sense, the subsidy allows the oil exporting countries to inadvertently exercise market power by diverting oil supply from the export market.\(^5\)

In general, however, an increase in export revenue is not sufficient to ensure that country \( o \) will actually be better off. To the extent that country \( o \) produces more oil, this increases the costs associated with producing oil, given by \( A^o_y \). The increase in costs offsets the benefit that accrues to \( o \) from the inflated world price of oil because they spend part of the extra income on importing goods used to produce oil instead of on consumption goods.

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\(^5\)This suggests that oil exporters, rather than directly influencing market prices by coordinating production, could alternatively exert market power by coordinating their subsidy policies.
When $\xi^a > 1$, it is much likely that the subsidy will reduce welfare in country $o$. In this case, its oil export revenues fall as the subsidies rise. While domestic consumption of oil increases, the subsidy brings about a decline in the consumption of the non-oil good.

The effect of the subsidy on country $a$ appears likely to be negative, especially if $\xi^a \leq 1$. The subsidy, by raising the world oil price, crowds out the consumption of oil in $a$. Furthermore, to the extent that country $a$ ends up increasing its domestic oil production, the quantity of the non-oil good used in production of oil ($A^a_y$) will rise, leaving fewer resources available for consumption. When $\xi^a < 1$, the subsidy also inflates country $a$’s oil import bill, transferring income from $a$ to $o$. If $\xi^a > 1$ this effect works to the benefit of $a$, although we suspect that this channel will be relatively more important for $o$ than $a$.

3.5 Summary

The results in this section highlight several channels through which fuel subsidies can distort both the oil market and the world economy. The solutions suggest that the quantitative importance of the subsidies will depend upon factors such as how much oil the subsidizing countries consume, how much oil the non-subsidizing countries produce, the values of elasticities of demand and supply in the two countries, and how large the subsidies are.

We have also found that the various channels may have different implications for the two countries. For country $o$, at least one of the channels may operate as a benefit from their perspective, at the expense of country $a$. The strength of this channel depends upon the price elasticity of oil import demand in country $a$, the value of which is determined by how much oil country $a$ produces and consumes relative to country $o$, as well as on country $a$’s elasticities of oil supply and demand. If import demand is inelastic enough, the subsidy could actually be welfare enhancing for country $o$.

To help with the exposition of the simple model, we wrote the model as if the country shares in production and consumption of oil and the elasticities of supply and demand were primitives. However, it is clear that quantitative values of these parameters are in fact related to one another. In the next section we introduce a more sophisticated general equilibrium model where these key share and elasticity parameters are related to underlying parameters describing tastes and technology. We calibrate the general equilibrium model to match various features of the data, including those outlined in section 2. We then use this model to quantify the impacts of the subsidies on both countries.

4 Model and results

We now introduce a two-country dynamic general equilibrium model. In this model we make the production of both oil and non-oil goods endogenous. As before, the countries are denoted as $a$ and $o$, and superscripts are used to distinguish the countries. A representative firm in country $a$ produces the non-oil good using labor, capital, and oil as inputs. Oil is produced in both countries using the non-oil good as an input. As before, country $a$ is a net importer of oil.

In our policy experiments, we work primarily with the steady state version of the model. However, we introduce the fully dynamic version here to describe where the steady state equations come from. At certain points in the discussion we simplify the presentation of the equations for brevity’s sake. All of the equations from the model, along with their steady state versions, can be found in the appendix.
4.1 Country a

4.1.1 The Household

A representative household in country a derives utility from the consumption of oil and non-oil goods, given by $O_{c,t}^a$ and $A_{c,t}^a$, respectively. The household also derives dis-utility from providing labor, denoted as $N_t^a$, to the firms that produce good $A$. We assume that aggregate consumption, given by $C_t^a$, is a CES aggregation of the two consumption goods,

$$C_t^a = \left[\left(1 - \gamma^a_o\right)A_{c,t}^a \frac{1}{1-\mu_c} + \left(\gamma^a_o\right)O_{c,t}^a \frac{1}{1-\mu_c}\right]^{\frac{1}{1-\mu_c}},$$

(11)

where $\gamma^a_o$ is the consumption-expenditure share of oil in country $a$ and $\mu_c$ is the inverse of the price-elasticity of demand for fuel.

The household maximizes lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^a}{1-\sigma} - \kappa \frac{N_t^a}{1+\mu_n}\right),$$

(12)

where $\beta$ is the discount factor, the parameter $\sigma$ is the relative risk aversion parameter, $\kappa$ reflects the weight that households place on leisure relative to consumption, and $\mu_n$ is the inverse of the Frisch elasticity of labor supply.

Utility is maximized subject to the budget constraint

$$A_{c,t}^a + P_{o,t}^a C_{c,t}^a + A_{I,t}^a = W_t^a N_t^a + r_t^a K_{t-1}^a + \Pi_{o,t}^a + \Pi_{a,t}^a,$$

(13)

where $P_{o,t}$ is the relative price of oil, $A_{I,t}^a$ is gross investment in the capital good, $W_t^a$ is the wage, and $r_t^a$ is the return to capital. Households own the firms that operate in the economy and as a result receive any profits from both the oil sector, $\Pi_{o,t}^a$, and the non-oil sector, $\Pi_{a,t}^a$.

Capital accumulation follows the standard law of motion

$$K_t^a - K_{t-1}^a = A_{I,t}^a - \delta K_{t-1}^a.$$

(14)

Our notation implies that $K_{t-1}^a$ is a pre-determined state variable in the model. When deriving first order conditions for the household’s problem we substitute out $A_{I,t}^a$ using the law of motion for capital.

First-order conditions for the household’s problem are given by

$$MU_{a,t}^a = \lambda_t^a,$$

(15)

$$MU_{a,t}^a = P_{o,t}^a \lambda_t^a,$$

(16)

$$MU_{n,t}^a = W_t^a \lambda_t^a,$$

(17)

$$\lambda_t^a = \beta E_t^a \left[r_{t+1}^a + (1-\delta)\right],$$

(18)

where $MU_{a,t}^a$, $MU_{o,t}^a$, and $MU_{n,t}^a$ are the marginal utilities for the consumption of the non-oil good, the oil good, and labor, respectively, and $\lambda_t^a$ is the multiplier on the budget constraint.

4.1.2 Production of the non-oil good

Production of the non-oil good is done by a representative firm in country $a$ using capital, labor, and oil. In the production function, capital and oil are combined to produce a capital service which is then combined with labor to produce good $A$. The exact production function is

$$Y_{a,t}^a = Z_{y,t}^a N_{t}^a \left[\omega_y^a K_{t-1}^a \frac{1}{1-\nu} + \left(1 - \omega_y^a\right) O_{y,t}^a \frac{1}{1-\nu}\right],$$

(19)
where \(Y_{a,t}^{a}\) is production of the non-oil good in country \(a\), \(Z_{y,t}^{a}\) is total factor productivity, and \(O_{y,t}^{a}\) is oil used by the firm in country \(a\). The parameter \(\alpha\) is the share of labor in gross-output and \(\nu\) is the elasticity of substitution between oil and the capital in the production of capital service.\(^6\)

The representative producer of the non-oil good maximizes profit

\[
\Pi_t^a = Y_{a,t}^a - r_t^a K_{t-1}^a - W_t^a N_t^a - P_{o,t} O_{y,t}^a.
\]

(20)

The first order conditions are:

\[
MP_{n,t}^a = W_t^a, \tag{21}
\]

\[
MP_{k,t}^a = r_t^a, \tag{22}
\]

\[
MP_{o,t}^a = P_{o,t}. \tag{23}
\]

Here \(MP_{i,t}^a\) is the marginal product of output with respect to capital, labor, and oil for \(i = k, n, o\), respectively.

### 4.1.3 Production of oil

A profit maximizing firm produces oil in country \(a\). Oil production costs are given by \(A_{a,y,t}^a\) and are an increasing function of oil output. The oil producing firm in country \(a\) chooses its production level to maximize:

\[
\Pi_{o,t}^a = P_{o,t} Y_{o,t}^a - A_{a,y,t}^a
\]

(24)

where

\[
A_{a,y,t}^a = \kappa_a \left( Y_{a,t}^a \right)^{1 + \frac{1}{\eta_a}} \left( 1 + \frac{1}{\eta_a} \right). \tag{25}
\]

The production costs are in terms of the non-oil good \(A\). One can think of this as the drilling rigs, oil equipment, or any non-oil good that is used to produce oil. Although we don’t model depletion, costs increase with increased oil production, reflecting the difficulty of finding additional oil as more oil is produced. The optimal quantity of oil production satisfies:

\[
P_{o,t} = \kappa_a \left( Y_{o,t}^a \right)^{\frac{1}{\eta_a}}. \tag{26}
\]

Using equation (26), one observes that country \(a\)’s elasticity of oil supply is given by \(\eta_a\).\(^7\)

### 4.2 Country o

#### 4.2.1 The Household

Like that in country \(a\), the representative household in country \(o\) derives utility from the consumption of the non-oil and oil goods, given by \(A_{c,t}^o\) and \(O_{c,t}^o\), respectively. As in country \(a\), these two goods are aggregated using a CES production function to generate aggregate consumption, \(C_t^o\). The household maximizes

\[
E_0 \sum_{t=0}^{\infty} \beta^t \left( C_t^o \right)^{1-\sigma} \left( 1 - \sigma \right), \tag{27}
\]

\(^6\)Like much of the macroeconomics literature, we assume the elasticity of substitution between labor and capital service is one.

\(^7\)The cost function also implies that the higher the elasticity of supply the lower the marginal cost of producing a given amount of oil.
with
\[ C_t^o = \left(1 - \gamma_o^o\right)A_{c,t}^o \frac{1}{1-\mu_c} + \left(\gamma_o^o\right)O_{c,t}^o \frac{1}{1-\mu_c}, \]
and subject to the budget constraint
\[ A_{c,t}^o + P_{s,t}O_{c,t}^o = T_t. \]

Here \( P_{s,t} \) is the potentially subsidized price of oil products in country \( o \) and \( T_t \) are lump-sum transfers from the government to the representative household.

The first-order conditions for the household are
\[ MU_{a,t}^o = \lambda_t^o, \]
\[ MU_{o,t}^o = P_{s,t} \lambda_t^o, \]
where \( MU_{a,t}^o \) and \( MU_{o,t}^o \) are the marginal utilities for the consumption of the manufactured good and the oil good, respectively, and \( \lambda_t^o \) is the multiplier on the budget constraint.

### 4.2.2 Production of oil

In many of the countries found in Table 1 the government is heavily involved in the production of oil, often through a national oil company. In line with this we assume the government, through a national oil company, controls the production of oil in country \( o \). The company sells a portion of its production domestically at the subsidized prices \( P_{s,t}^o \), exports the remainder at the world price \( P_{w,t}^o \), and then transfers its revenue to the government.

The oil producer hence chooses production, \( Y_{o,t}^o \), to maximize:
\[ \Pi_t^o = P_{o,t}^o (Y_{o,t}^o - O_{c,t}^o) + P_{s,t}^o O_{c,t}^o - A_{y,t}^o \]
where the cost function is similar to country a’s:
\[ A_{y,t}^o = \kappa_o \left(\frac{Y_{o,t}^o}{1 + \eta} \right)^{\frac{1}{\eta}}. \]

The optimal quantity of production satisfies:
\[ P_{o,t}^o = \kappa_o (Y_{o,t}^o) \frac{1}{\eta}, \]
where the elasticity of supply is given by \( \eta^o \).

Oil revenues are infused into the economy in a lump-sum manner, with the value given by \( T_t \). Each period the government must satisfy its budget constraint,
\[ P_{o,t}^o (Y_{o,t}^o - O_{c,t}^o) + P_{s,t}^o O_{c,t}^o - A_{y,t}^o = T_t. \]

The transfer \( T_t \) in the household budget constraint is equal to net revenue from oil production, taking into account the subsidy and the costs of production. Note that if the government decides to sell oil at a reduced price to domestic households this lowers its overall revenue from the sale of oil, holding all else constant. This means that there is no free lunch from the subsidy as higher subsidies mean lower distributions of income flow to the representative household.

Note also that at the aggregate, the subsidy does not, by itself, directly affect national income in country \( o \). This can be seen by combining the government budget constraint, equation (35),
with the household budget constraint, equation (29). This produces the current account equation for country \( o \)
\[
P^o_t(Y^{o}_{o,t} - O^{o}_{o,t}) = A^{o}_{c,t} + A^{o}_{y,t}. \tag{36}
\]
The subsidy only affects the income available to country \( o \) indirectly by changing the amount of oil consumed by domestic residents in turn altering the quantity of oil available for export, by changing the world price of oil, and oil production levels which then affect the level of costs.

### 4.3 Market clearing and the current account

Market clearing conditions for both goods impose that total demand must equal total supply. The market clearing condition in the oil market is
\[
O^{a}_{c,t} + O^{a}_{y,t} + O^{o}_{o,t} = Y^{o}_{o,t} + Y^{a}_{a,t}. \tag{37}
\]
For the non-oil good the condition is
\[
A^{a}_{c,t} + A^{a}_{y,t} + A^{o}_{c,t} + A^{o}_{y,t} = Y^{a}_{a,t}. \tag{38}
\]
Combining the market clearing conditions and the current account equation for country \( o \) (36), yields a current account equation for country \( a \) given by
\[
P^o_t (O^{a}_{c,t} + O^{a}_{y,t} - Y^{a}_{a,t}) = Y^{a}_{a,t} - A^{a}_{c,t} - A^{a}_{y,t} - A^{a}_{I,t} + A^{a}_{c,t} + A^{a}_{y,t} = A^{o}_{c,t} + A^{o}_{y,t}. \tag{39}
\]
This equation simply states that the dollar value of the oil imported into country \( a \) at time \( t \) must equal the dollar value of the goods it exports to country \( o \).\(^8\)

### 4.4 Calibration

The model is calibrated to an initial steady state that is consistent with recent economic data. The frequency is annual. Units are chosen so that GDP in the oil-importing countries equals 1. The steady state values of the model’s variables are chosen so as to match a set of statistics outlined in table 2.

We calibrate the consumption-expenditure share of oil in the oil-importing countries at 5 percent.\(^9\) This is based on recent CPI-weights for the U.S., the EU-28, and Japan. Firm use of oil products in \( a \) is set at 2 percent of GDP, based on data from input-output tables for some OECD countries. Investment spending in \( a \) is set at 20 percent of GDP. Consistent with recent data, oil consumption in the oil-exporting countries is equal to 13.5 percent of world consumption. Their share of world oil production is set at 48 percent. The value of \( P_s \) is set so that the subsidized price is 34 percent of the world price.

Table 2 also lists the calibration for the model’s parameters. We choose the discount factor to be consistent with annual real interest rates in the U.S. Many of the other parameters are calibrated using settings frequently found in the macro literature.

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\(^8\)The assumption that current account is balanced implies financial autarky. In general, allowing countries to borrow and lend could have important consequences on the analysis. If financial markets are complete, then households could insure against reallocations in wealth which will play a prominent role in our analysis. However, in the more empirically realistic formulation that financial markets are incomplete, the response of households to the kind of permanent shocks we are considering is likely to look more like the financial autarky than complete markets ((see Baxter and Crucini (1995), Corsetti, et. al. (2008), Bodenstein et. al (2011)). The ability to borrow/lend, albeit restricted or at some cost, is more likely to have important effects on the transitional dynamics or in the face of temporary shocks, as households attempt to smooth consumption. We leave the examination of transitional dynamics to future research.

\(^9\)The appendix provides more details on the data used for this calculation.
The oil-related elasticities merit further discussion. The elasticities of substitution are calibrated to match longer-run price elasticities of demand for fuel products. We use previous estimates in the literature to guide our calibration. Hausman and Newey (1995) found a long-run price elasticity near -0.80 for gasoline demand in the U.S. Yatchew and No (2001) found a similar elasticity for Canada. Kilian and Murphy (2014) found a short-run elasticity of global demand for oil of -0.26. Baumeister and Peersman (2012) found estimates slightly below that. Graham and Glaister (2002) surveyed estimates of short and long-run elasticities of demand for fuel. Short-run estimates were clustered between -0.35 and -0.25, while longer-run elasticities were larger and typically closer to -0.80. Given our model’s annual frequency and the focus on longer-run implications of subsidies, we choose a baseline calibration for the elasticities of substitution of -0.75. We consider several other possibilities for sensitivity analysis.

Supply elasticity estimates are sparse in the literature, but tend to be small. Baumeister and Peersman (2012) find that recent estimates of short-run global supply elasticity are less than 0.2. The results in Kilian and Murphy (2012) also suggest small supply elasticities. We set our supply elasticities to 0.3 but also consider several other possibilities for sensitivity analysis. The elasticities are set equal across countries, consistent with the data that two blocs have produced a relatively stable share of world oil production.

### 4.5 Policy experiment

Our policy experiment is as follows. We first assume the world is in an initial steady state consistent with our calibration and the model’s equations. We then ask what would happen if the subsidies in country $o$ were permanently removed. In the context of the model, this is done by equalizing fuel prices across countries.

We focus on the long-run impact of this policy change, i.e. we ask how the steady state of the model is affected. Technically, we conduct a comparative statics exercise. For each variable of interest we numerically calculate the percent change of that variable across steady states.

### 4.6 Results

Our results are presented in table 3. The first column lists the variables considered with prices first, followed by variables for country $o$, variables for country $a$, and finally world oil consumption. The second column shows the percent changes across steady states for the different variables.

Under the baseline we find that the removal of the subsidy has a non-trivial impact on the world price of oil: the model predicts that prices would decline by over 6 percent. Because of the fall in world oil prices, the production of oil declines in both countries, by the same amount because the supply elasticities are equal. Domestic prices in $o$ need to rise by over 175 percent to get them equal to the new world price of oil.

The equalization of fuel prices across the two blocs of countries leads to a re-allocation of oil consumption: oil consumption declines in the subsidizing countries by over 45 percent, while consumption by households and firms in country $a$ rises by about 5 percent.

In country $o$, the removal of the subsidy eliminates the price distortions which had led to over-consumption of oil and over-investment in the oil industry. Consumers increase their consumption of good $a$, with non-oil consumption rising by about 15 percent. This increase occurs for two reasons. First, the relative price of fuel in country $o$ is now significantly higher. Second, the fall in oil production lowers production costs and releases some of good A that was used in the oil sector, for consumption.
In terms of GDP (non-oil) in country $a$, the decline in the world price of oil leads to a small positive increase in country $a$'s non-oil GDP. Intuitively, the elevated prices that were due to the subsidies being in place before the policy change acted like an oil supply shock which reduced (non-oil) GDP in country $a$. With the subsidies removed, world oil prices decline and act like a positive oil supply shock for country $a$.

4.6.1 Welfare Implications

In addition to asking how variables changed across steady states, we also calculated how steady state welfare in country $a$ and $o$ were affected by the policy change. To do this, we solve for how much aggregate consumption would need to be increased or decreased in the new steady state (with no subsidies) in order for welfare to be the same as in the old steady state (with subsidies). We convert these numbers into percentages which show the welfare gain (or loss) from removing the subsidies. If this number is positive, it means that the country experienced a welfare gain. The opposite holds if the number is negative. The exact details of the calculations can be found in the appendix.

The welfare results are also presented in Table 3. We find that removing the subsidies is welfare enhancing for both blocs of countries. For country $a$, the welfare gain is about 0.2 percent of steady state aggregate consumption. The welfare gains are higher for country $o$, which sees a welfare gain of close to 0.9 percent.

Based on the intuition derived in Section 3 the results for country $a$ are not entirely surprising. The subsidy drives up the world price of oil and essentially acts as a negative oil supply shock that reduces consumption of oil by both households and firms in $a$. It also introduces other distortions as it leads to over-production of oil in country $a$. When the subsidy is removed, these distortions are eliminated which improves welfare in $a$.

As discussed in Section 3, there was a possibility that removal of the subsidy could either increase or decrease welfare in country $o$. This is due to the fact that the subsidy artificially inflates the world price of oil, which could raise country $o$’s oil export revenue. But whether this actually occurs depends on the price elasticity of oil import demand in country $a$, which we had denoted as $\xi^a$. For our baseline calibration, equation (10) suggests an estimate for $\xi^a$ at around 2.33 implying that removing the subsidies actually increases country $o$’s export revenues. As a result, country $o$’s welfare improves when the subsidy is removed.

4.6.2 Varying supply and demand elasticities

The solutions in Section 3 suggest that both supply and demand elasticities can play an important role in the results. Given that there is some uncertainty about these elasticities, we also considered a range of alternative values for these parameters. For each alternative calibration we consider, we repeat our policy experiment as described before.

Alternative supply elasticities

We considered four alternative values for the supply elasticities: 0.1, 0.2, 0.3, and 0.4. The results for each parameter setting are found in table 4. We find that the less elastic the supply, the larger is the decline in world oil prices. Oil prices decline almost 8 percent when $\eta^a$ and $\eta^o$ are set to 0.1. When supply is inelastic, world oil prices rise by more with the subsidy in place, and therefore prices fall by more when the subsidy is removed. A larger fall in oil prices implies there is less of a price differential to be made up by the new domestic price ($P_s$) in country $o$. Hence, there is a smaller percentage increase in fuel prices in $o$ for lower supply elasticities.
The benefits of removing the subsidy are larger for country $a$ as supply becomes more inelastic. Oil prices fall more, and consumption of both oil and non-oil goods rise by a larger amount, as does non-oil GDP. Not surprisingly, the welfare gains that accrue to country $a$ from the removal of the subsidy increase as $\eta^o_a$ increases.

For country $o$ we find that the benefits of removing the subsidy decrease as supply becomes more inelastic. Oil consumption falls by more and non-oil consumption rises by less. We also find that removing the subsidy can actually lead to a welfare decline in country $o$ when supply is very inelastic ($\eta^j = 0.1$). One reason is that the mis-allocation of resources devoted to producing oil is less (supply responds less to distorted oil prices), which reduces a potential benefit of removing the subsidy. Furthermore, the price elasticity of oil import demand in country $a$ becomes smaller as country $a$’s oil supply becomes less elastic. If the oil import demand elasticity for country $a$ falls below one, oil export revenue for country $o$ falls when the subsidy is removed (and market price of oil falls).

**Alternative demand elasticities**

For the demand elasticities, we considered alternative smaller calibrations for the elasticities of substitution of 0.45, 0.55, 0.65. We also considered one larger setting of 1.25. We view these as plausible ranges given the time-frame we are considering with our policy experiment and the estimates of price elasticities in the literature. Table 5 contains the results for the alternative elasticities of substitution.

We find that lowering or increasing the elasticities has a minor impact on the world price of oil. The price decline ranges from 6.1 percent to 5.7 percent. The fact that less elastic demand generates smaller price responses is somewhat counter-intuitive but follows from the logic in equation (6). Namely, a lower elasticity of demand has two implications for the consumption of oil. On the one hand, it reduces the responsiveness of consumer demand in country $o$ to changes in their domestic price. As a result, removing the subsidy brings about a smaller decline in their consumption, which means that oil exports from country $o$ also increase by less. This creates less pressure on world oil prices. On the other hand, the lower elasticity also implies that consumers in $a$ need to see bigger declines in prices to get them to consume more oil. Overall, the effects of lower demand elasticity on the part of country $o$ demand tend to outweigh effects of country $a$ and, as a result, the decline in world oil prices is less than in the baseline calibration.

For country $o$, there are important quantitative and qualitative differences in the results as demand becomes more inelastic. Oil consumption falls by less, non-oil consumption rises by less, and welfare in $o$ is significantly affected. If demand is inelastic enough, it is possible to experience a welfare loss from removing the subsidy, reminiscent of the results for low supply elasticities. As the elasticity of demand falls, this significantly reduces the price elasticity of oil import demand for country $a$. Therefore, when demand is relatively inelastic removing the subsid, which reduces world oil prices and could lower country $o$’s oil export revenues, negatively affects country $o$’s ability to purchase non-oil goods. The case with the larger price elasticity is qualitatively similar to the baseline, except the quantitative impacts are larger. The higher the elasticity, the more consumers in country $o$ respond to the subsidy so the greater the distortions become.

For country $a$ we find that the implications of less elastic demand are not as dramatic as what occurs in country $o$. Oil consumption rises by less, but non-oil GDP and welfare are not significantly affected. We do note, however, the non-oil consumption rises by more as demand becomes less elastic. This result is due in part to the lower oil import elasticities, which lead to greater consumption of non-oil goods (coming at the expense of country $o$). More elastic demand changes the quantitative results but the overall thrust of the findings is similar to the baseline case.
4.6.3 Different elasticities across countries

Our baseline assumption was to set the elasticities of substitution equal across countries. However, they could differ from each other and, as seen in equation (6), this would have implications for the behavior of prices and quantities in the oil market, amongst other effects. We considered two cases to investigate this. In the first, we lowered the elasticity of substitution in the subsidizing countries to 0.25 and in the second we raised it to 1.25. For both, we hold fixed the elasticity of substitution in the importing countries, and all other parameters as well.

For brevity’s sake, we do not report the full results in a table. We found, however, that the intuition from section 2 once again carried over to the results of the general equilibrium model. A low (high) price elasticity of demand in the exporting countries makes their consumers less (more) responsive to the presence of the subsidy in the first place. Distortions from the subsidy become smaller (larger) and price changes in the world market less (more) pronounced. We found that when oil exporters’ oil demand elasticity is low, removing the subsidy would only lower prices by 2.5 percent. When the elasticity of substitution is high, the quantitative effects of removing the subsidy are larger. Removing the subsidy in this case causes the price of oil to fall by 8.5 percent.

4.6.4 Other factors that affect welfare

Analytical results in Section 3 also suggested that the share of world oil consumption due to $o$, denoted by $\theta^o$, and the share of world oil production due to $o$, denoted as $\chi^o$ could be important. The values of $\theta^o$ and $\chi^o$ jointly determine the degree to which country $o$ is a net exporter and also influence the import elasticity of demand in country $a$, $\xi^a$. The value of $\theta^o$ also plays a key role in determining how big of an impact subsidies have on the world price of oil.

It interesting to ask how varying these two parameters would influence the results. To do so we consider several different cases where we vary the values of $\chi^o$ and $\theta^o$. To motivate the different calibrations, we turn to the data. We first consider a calibration for $\theta^o$ of 0.03 and $\chi^o$ of 0.13. These are motivated by the data for the largest single producer and consumer among the 24 countries: Saudi Arabia. Our second calibration sets $\theta^o$ to 0.082 and $\chi^o$ to .23, consistent with the data for the top five consumers amongst the group of 24: Egypt, Indonesia, Iran, Saudi Arabia, and Venezuela. In each case, we re-calibrate the model and repeat our policy experiment of removing the subsidies. Our results are contained in table 6.

We find that the change in the world price of oil is larger as more countries are included in the exporting group. This is not surprising, given that their share of world oil consumption rises. We also find that country $a$ is more positively affected by the removal of the subsidy as the subsidizing group becomes a larger producer and consumer of oil. When country $o$ only consumes 3 percent of the world’s oil, the price impact of removing subsidies is relatively small, and therefore the impact this policy change has on country $a$ is small. These impacts become larger the greater the number of subsidizing countries.

From country $o$’s perspective, we find that the results are qualitatively similar to the baseline case in that oil consumption falls, non-oil consumption rises, and country $o$ sees welfare gains from removing the subsidy in all three cases. We note that the gains are significantly larger in the two alternative calibrations. This is in line with the intuition from Section 3: in both alternative calibrations the import elasticity of demand in country $a$ is significantly higher than the baseline calibration. This makes it much more likely that removing the subsidy increases welfare in country $o$.

We note, though, that the above welfare results are mixing together the implications of varying $\chi^o$ and $\theta^o$. To better understand the individual affects of varying production and consumption
shares, we varied $\chi^o$ while holding $\theta^o$ fixed at the baseline calibration of 0.135 and using the baseline calibration for the elasticities of oil supply and demand. We find that there is a critical value of $\chi^o$ around 0.52 where the welfare effect of removing the subsidies on country $o$ switches from positive to negative; values of $\chi^o$ above 0.52 implying negative welfare effects of removing the subsidy. As $\chi^o$ increases, the import elasticity of demand in country $a$ declines and the costs to country $o$ removing the subsidy increase. Eventually this channel dominates the outcome and creates welfare losses when the subsidy is removed. Similarly, we varied $\theta^o$ while holding $\chi^o$ fixed at the benchmark value of 0.48. Here also we find a critical value of $\theta^o$ of around 0.05 where the welfare effects of removing the subsidies switches from positive to negative; values of $\theta^o$ below 0.05 result in a decline in welfare for country $o$.

4.7 What is the optimal subsidy?

As shown in the tables, under certain conditions full removal of the subsidy is welfare reducing for the exporting countries. This has to do with the fact that the subsidy is an indirect method for the subsidizers to take advantage of their market power. When the elasticity of demand for imported oil is less than one, subsidies on consumption, by diverting oil supply from the world market to domestic oil consumption, allow oil exporters to raise their oil export revenue. This acts to transfer income from oil importers to oil exporters.

A natural question to ask is whether there exists an “optimal” level of the subsidy from the exporter’s perspective. In order to answer this question, we calculate the utility level of the representative agent for the subsidizing country for a number of different subsidy rates, $s$, where $P_s = (1 - s)P_o$.\(^\text{10}\) This is done for the baseline calibration and also a calibration where the elasticities of substitution are lower than the baseline case (0.55 versus 0.75).

Figure 2 plots the utility for a range of subsidy rates from 0 (no subsidy) to 0.75 (heavily subsidized prices), in steps of 0.05. We normalize utility so that it equals 0 when the subsidization rate is 65 percent, which is closest to the subsidization rate in our baseline calibration. The solid line is for the baseline calibration and the dashed line for case of the low elasticities of demand. We find that, in general, the optimal subsidy rate is not zero. For the baseline calibration, the optimal subsidy rate is 0.45 which is well below the empirical subsidy rate estimated to be around 0.66. This suggests that, taken as a whole, actual subsidies are too large and that subsidizing countries could improve the welfare of the representative agent in those countries by reducing their subsidies but not all the way to zero. As we have suggested previously, oil subsidizers/exporters face a tradeoff when setting the subsidy rate. Raising the subsidy rate distorts market allocations by causing resources to be allocated to oil production and consumption. This is offset by the effect on oil export revenue of diverting oil supply away from the world market. The optimal subsidy rate in a sense balances these two trade-offs. Note that Figure 2 is consistent with the results in section 4.6. For the baseline calibration, removing subsidies, while not optimal for the subsidizers, does yield higher welfare than current subsidy levels.

When the oil demand elasticity (for both exporting and importing countries) is lower, the optimal subsidy rate is higher ($s = 0.53$) than in the baseline demand elasticity case but still lower than current subsidy levels. However, removing subsidies entirely ($s = 0$) results in lower welfare for the subsizing country compared to current subsidy levels. With low demand elasticity, the payoff of restricting supply to the world market rises as subsidizers/exporters extract more surplus from the importing countries. As a result, the desirability of subsidies rises relative to the baseline demand elasticity. If we decrease the relative size of the subsizing countries (not shown), the

\(^{10}\)Our analysis implicitly assumes the oil subsidizer/exporters take into account how oil importers will react to changes in the world oil price as subsidies change.
optimal subsidy rate tends to fall. For the case where the size of the subsidizing countries is roughly that of Saudi Arabia and baseline demand elasticities, the optimal subsidy level is substantially lower ($s = .12$) but still not zero. In the limit, as the country size gets so small that it has no effect on the world oil market (the small open economy case considered by Plante (2014)), the optimal subsidy approaches zero.$^{11}$

## 5 Concluding Remarks

In this paper, we used a two country, two good, general equilibrium model to examine the impact that oil price subsidies have on the oil market and the trade of non-oil goods. We calibrated the model to match the most recent data. In our baseline case, we found that the removal of subsidies result in a six percent decline in oil prices and were welfare enhancing for both the importing and exporting countries.

We also showed how the effects of removing existing subsidies depend on oil supply and demand elasticities, as well as the share of world oil production and consumption due to the subsidizers. The welfare effects on oil importing countries were unambiguously positive for all the cases considered. However, if oil import demand is sufficiently inelastic, removing the subsidies was found to be welfare reducing for the subsidizing countries. This occurs if oil supply or demand is relatively inelastic, and if the subsidizers produce a large enough share of the world’s oil supply. Here the oil price decline brought about by the elimination of subsidies results in a decline in oil export revenue for the subsidizing producers. We also found that this trade-off worked at the margin; in general, the optimal subsidy rate for oil exporters/subsidizers, while less than current levels, was positive.

Several avenues for future research suggest themselves. First, while our model was explicitly dynamic, our examination of the effect of removing oil price subsidies was entirely steady state. The transition from initial steady state, where there are substantial subsidies, to a new steady state in which the subsidies are removed may give rise to intertemporal trade-offs that might alter the welfare comparisons. In transition, elements such as adjustment costs and the ability of countries to borrow or lend (i.e., run current account deficit or surplus) will affect the welfare considerations. Along similar lines, a richer and dynamic model of oil supply might suggest additional intertemporal trade-offs. Finally, a closer examination of how these subsidies are financed (here we assumed they were financed by lump-sum transfers/taxes) might alter welfare implications of the subsidies.

$^{11}$While our focus has been on the subsidization of domestic oil consumption by oil exporting countries, as pointed out by an anonymous referee one could also examine subsidies on production by oil exporters and oil importers (as in Nakov and Nuño (2014)) or taxes on oil imports by oil importers as in Bergstrom (1982)).
References


Figure 1: This figure plots various data on the subsidizing countries. The top and middle panels plot the share of world consumption and production, respectively, due to the 24 countries. The bottom panel plots the ratio of subsidized prices to U.S. fuel prices for the group of 10 countries and 24 countries. The appendix outlines the formulas used to calculate the price ratios and the data sources.
Figure 2: Welfare of the subsidizers across different subsidization rates. The x-axis is the rate of subsidization (1 minus the ratio of subsidized prices to world prices). The calibration initially sets the rate to .66 (66 percent). The y-axis is the utility of the subsidizers. We normalize utility to be 0 at a subsidization rate of 0.65. Positive numbers, therefore, mean improved welfare while negative numbers imply reduced welfare compared to the subsidization rate of .65.
Table 1: Countries identified as subsidizers

<table>
<thead>
<tr>
<th>Algeria</th>
<th>Brunei</th>
<th>Iraq</th>
<th>Oman</th>
<th>Turkmenistan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angola</td>
<td>Ecuador</td>
<td>Kuwait</td>
<td>Qatar</td>
<td>UAE</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>Egypt</td>
<td>Libya</td>
<td>Saudi Arabia</td>
<td>Venezuela</td>
</tr>
<tr>
<td>Bahrain</td>
<td>Indonesia</td>
<td>Malaysia</td>
<td>Sudan</td>
<td>Yemen</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Iran</td>
<td>Nigeria</td>
<td>Syria</td>
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</tr>
</tbody>
</table>

Table 2: Steady state moments and parameter values

<table>
<thead>
<tr>
<th>Investment to GDP ratio in a ($I^a$)</th>
<th>20 percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expenditure share of fuel in a</td>
<td>5 percent</td>
</tr>
<tr>
<td>Firm oil to GDP ratio ($P_oO^a_y$)</td>
<td>2 percent</td>
</tr>
<tr>
<td>Consumption of fuel in o</td>
<td>13.5 percent of world consumption</td>
</tr>
<tr>
<td>Oil production in o</td>
<td>48 percent of world production</td>
</tr>
<tr>
<td>Subsidy-price ratio ($\frac{P_s}{P_c}$)</td>
<td>.34</td>
</tr>
<tr>
<td>Elasticity of oil supply ($\eta^a, \eta^o$)</td>
<td>.30</td>
</tr>
<tr>
<td>Discount factor ($\beta$)</td>
<td>.96 (pins down real interest rate)</td>
</tr>
<tr>
<td>Elasticities of substitution ($\frac{1}{\mu_c}, \frac{1}{\nu}$)</td>
<td>.75 (pins down price-elasticity of demand)</td>
</tr>
<tr>
<td>Risk aversion parameter ($\sigma$)</td>
<td>2 (common setting in macro literature)</td>
</tr>
<tr>
<td>Frisch elasticity of labor supply ($\frac{1}{\mu_n}$)</td>
<td>1 (common setting in macro literature)</td>
</tr>
<tr>
<td>Cobb-Douglas parameter ($\alpha$)</td>
<td>.70 (pins down labor-share of GDP)</td>
</tr>
</tbody>
</table>
Table 3: Results for the baseline model of removing the oil subsidies

<table>
<thead>
<tr>
<th>Variables</th>
<th>market oil price ($P_o$)</th>
<th>subsidized oil price ($P_s$)</th>
<th>oil production ($Y_o$)</th>
<th>oil consumption ($O_o$)</th>
<th>consumption of good A ($A_o$)</th>
<th>transfers (T)</th>
<th>welfare</th>
<th>oil production ($Y_a$)</th>
<th>oil used in consumption ($O_a$)</th>
<th>oil used in production ($O_y$)</th>
<th>consumption of good A ($A_a$)</th>
<th>non-oil GDP</th>
<th>welfare</th>
<th>World oil consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prices</td>
<td>-6.1</td>
<td>176.0</td>
<td>-1.9</td>
<td>-45.9</td>
<td>15.9</td>
<td>21.4</td>
<td>0.86</td>
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</tbody>
</table>

Note: Variables are in percent change across steady states. The new steady state is the one without subsidies. Welfare is in consumption-equivalent percentages.
<table>
<thead>
<tr>
<th>Variables</th>
<th>$\eta' = 0.4$</th>
<th>$\eta' = 0.3$</th>
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<th>$\eta' = 0.1$</th>
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<tr>
<td>(Baseline)</td>
<td>-</td>
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<tr>
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<tr>
<td>subsidized oil price ($P_s$)</td>
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<td>176.0</td>
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<td>171.0</td>
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<td><strong>Country o variables</strong></td>
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<tr>
<td>oil production ($Y_o^o$)</td>
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<td>15.9</td>
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<td>10.7</td>
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<td>14.8</td>
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<tr>
<td>oil production ($Y_o^a$)</td>
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<td>oil used in consumption ($O_c^a$)</td>
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<td>4.9</td>
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<td>0.004</td>
<td>0.005</td>
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<tr>
<td>welfare</td>
<td>0.20</td>
<td>0.23</td>
<td>0.26</td>
<td>0.29</td>
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<tr>
<td>World oil consumption</td>
<td>-2.2</td>
<td>-1.9</td>
<td>-1.4</td>
<td>-0.8</td>
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Note: Variables are in percent change across steady states. The new steady state is the one without subsidies. Welfare is in consumption-equivalent percentages.
Table 5: Effects of removing the oil subsidies for different demand elasticities

<table>
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<tr>
<th>Variables</th>
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<th>.55</th>
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<td><strong>Prices</strong></td>
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</tr>
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<td>market oil price ($P_o$)</td>
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<td>-6.1</td>
<td>-5.9</td>
<td>-5.7</td>
</tr>
<tr>
<td>subsidized oil price ($P_s$)</td>
<td>176.5</td>
<td>176.0</td>
<td>176.3</td>
<td>176.7</td>
<td>177.4</td>
</tr>
<tr>
<td><strong>Country o variables</strong></td>
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<td></td>
<td></td>
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<tr>
<td>oil production ($Y_o^o$)</td>
<td>-1.8</td>
<td>-1.9</td>
<td>-1.9</td>
<td>-1.8</td>
<td>-1.7</td>
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<td>oil consumption ($O_o^c$)</td>
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<td>-41.3</td>
<td>-36.5</td>
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<tr>
<td>consumption of good A ($A_o^c$)</td>
<td>26.3</td>
<td>15.9</td>
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<td>11.2</td>
<td>8.7</td>
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<td>transfers (T)</td>
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<td>welfare</td>
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<td>0.14</td>
<td>-0.54</td>
<td>-1.15</td>
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<td><strong>Country a variables</strong></td>
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<td></td>
</tr>
<tr>
<td>oil production ($Y_o^a$)</td>
<td>-1.8</td>
<td>-1.89</td>
<td>-1.86</td>
<td>-1.82</td>
<td>-1.74</td>
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<tr>
<td>oil used in consumption ($O_a^c$)</td>
<td>7.9</td>
<td>4.88</td>
<td>4.19</td>
<td>3.49</td>
<td>2.77</td>
</tr>
<tr>
<td>oil used in production ($O_y^a$)</td>
<td>8.1</td>
<td>5.19</td>
<td>4.51</td>
<td>3.80</td>
<td>3.07</td>
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<td>consumption of good A ($A_a^c$)</td>
<td>-0.2</td>
<td>0.004</td>
<td>0.036</td>
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<td>non-oil GDP</td>
<td>0.18</td>
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<td>0.23</td>
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<tr>
<td>welfare</td>
<td>.21</td>
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<td>.23</td>
<td>.22</td>
<td>.22</td>
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<td><strong>World variables</strong></td>
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</tr>
<tr>
<td>World oil consumption</td>
<td>-1.8</td>
<td>-1.9</td>
<td>-1.9</td>
<td>-1.8</td>
<td>-1.7</td>
</tr>
</tbody>
</table>

Note: Variables are in percent change across steady states. The new steady state is the one without subsidies. Welfare is in consumption-equivalent percentages.
Table 6: Effects of removing oil subsidies for alternative shares of oil consumption and production

<table>
<thead>
<tr>
<th>Variables</th>
<th>Saudi</th>
<th>Top 5 consumers</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Share of world consumption</strong> ($\theta^o$)</td>
<td>3%</td>
<td>8.2%</td>
<td>13.5%</td>
</tr>
<tr>
<td><strong>Share of world production</strong> ($x^o$)</td>
<td>13%</td>
<td>23%</td>
<td>48%</td>
</tr>
<tr>
<td><strong>Prices</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>market oil price ($P_o$)</td>
<td>-1.34</td>
<td>-3.27</td>
<td>-6.15</td>
</tr>
<tr>
<td>subsidized oil price ($P_s$)</td>
<td>190.19</td>
<td>184.50</td>
<td>176.04</td>
</tr>
<tr>
<td><strong>Country o variables</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>oil production ($Y_o^o$)</td>
<td>-0.40</td>
<td>-0.99</td>
<td>-1.89</td>
</tr>
<tr>
<td>oil consumption ($O_o^o$)</td>
<td>-46.95</td>
<td>-41.01</td>
<td>-45.89</td>
</tr>
<tr>
<td>consumption of good A ($A_o^o$)</td>
<td>17.95</td>
<td>29.21</td>
<td>15.89</td>
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<tr>
<td>transfers (T)</td>
<td>22.53</td>
<td>37.98</td>
<td>21.37</td>
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<tr>
<td>welfare</td>
<td>4.96</td>
<td>5.77</td>
<td>0.86</td>
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<td><strong>Country a variables</strong></td>
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</tr>
<tr>
<td>oil production ($Y_a^o$)</td>
<td>-0.40</td>
<td>-0.99</td>
<td>-1.89</td>
</tr>
<tr>
<td>oil used in consumption ($O_a^o$)</td>
<td>1.00</td>
<td>2.51</td>
<td>4.88</td>
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<td>oil used in production ($O_a^g$)</td>
<td>1.10</td>
<td>2.73</td>
<td>5.19</td>
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<td>consumption of good A ($A_a^o$)</td>
<td>-0.01</td>
<td>-0.02</td>
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<tr>
<td>non-oil GDP</td>
<td>0.07</td>
<td>0.16</td>
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<tr>
<td>welfare</td>
<td>0.02</td>
<td>0.06</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Note: Variables are in percent change across steady states. The new steady state is the one without subsidies. Welfare is in consumption-equivalent percentages.
6 Appendix

6.1 Calculating the welfare changes across steady states

Suppose $X_1$ and $X_2$ are the steady state values of variable $X$ in the original and the new steady state, respectively. Then the change in aggregate welfare across steady states for country $a$ is given by

$$
\frac{1}{1-\beta} \left\{ \left[ \frac{(C^a_2)^{1-\sigma} - \kappa (N^a_2)^{1+\mu_n}}{1-\sigma} \right] - \left[ \frac{(C^a_1)^{1-\sigma} - \kappa (N^a_1)^{1+\mu_n}}{1-\sigma} \right] \right\}.
$$

The change in welfare in country $o$ can be calculated similarly.

Looking at the change in aggregate welfare across steady states is not very informative because of the units. To make the comparisons more concrete, we solve for how much aggregate consumption in the new steady state would need to be increased or decreased, in percentage points, to make welfare equal across the two steady states. Mathematically we solve for $\omega$ in the following equation,

$$
\left\{ \left[ \frac{(\omega C^a_2)^{1-\sigma} - \kappa (N^a_2)^{1+\mu_n}}{1-\sigma} \right] - \left[ \frac{(C^a_1)^{1-\sigma} - \kappa (N^a_1)^{1+\mu_n}}{1-\sigma} \right] \right\} = 0.
$$

In general $\omega$ will be non-zero as welfare will be higher or lower across steady states. The welfare losses are calculated as

$$
W_l = 100 \ast (1 - \omega).
$$

$W_l$ will be negative when $\omega > 1$, which occurs when aggregate welfare is lower in the new steady state. Aggregate consumption would need to be increased by $W_l$ percent to get utility in the new steady state back up to its initial level in the old steady state.

On the flip side, $W_l$ will be positive when $\omega < 1$, which occurs when aggregate welfare is higher in the new steady state. In that case, aggregate consumption would need to be lowered by $W_l$ percent to get utility in the new steady state back down its lower level in the old steady state.
6.2 Data sources for CPI weights and firm oil usage

We need to calibrate the consumption-expenditure share of oil and firm use of oil in the oil-importing bloc of countries. To the best of our knowledge, there is no exact way to map the available data to the model. We use the following data to guide our calibration. For the consumption-expenditure weights we use recent data on CPI weights for the U.S., the EU-28, and Japan. The weights for the U.S. are the annual CPI-U weights (relative importance) while the EU weights are the annual HICP weights. Both come from the Haver database. The data for Japan comes from Statistics Japan in their publication “Outline of the 2010-Base Consumer Price Index.” The weights for all three countries take into account spending on oil products both for transportation purposes and for home heating. A weight of five percent was chosen as a rough estimate based on recent values for the weights in the data.

For the firm use of oil, we rely on ratios calculated using input-output tables from the OECD STAN database as guidance for our calibration. Namely, we look at firm spending on “Coke, refined petroleum products and nuclear fuel” in OECD countries. There are (at least) three degrees of uncertainty in using this data. First, it includes spending on products besides oil so it necessarily overestimates firm spending on oil products. Second, the ratio varies across countries. Finally, these data are available relatively infrequently so the ratios may have changed over time. As a rough guestimate, we calibrate this ratio to two percent of GDP. To the extent that this ratio could potentially be larger, the qualitative impacts on the results should be minor. We would expect removal of the subsidies to have a bigger effect on non-oil GDP in the importing countries, and for there to be some changes in the effect on firm and household oil consumption in the importing countries.

6.3 Calculating the price ratios

6.3.1 Data sources

We calculate the ratio of the subsidized prices to U.S. prices for a group of 10 countries and a group of 24 countries. The group of 10 countries includes certain members of OPEC for which it was possible to produce an annual time series starting from 1990 until 2012. The data for the group of 24 countries is bi-annual and starts in 1998.

The group of 10 countries includes Algeria, Indonesia, Iran, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the UAE, and Venezuela. The annual series was generated primarily using data from OPEC Annual Statistical Bulletins (ASB). Domestic prices were converted to dollar values using nominal exchange rates, which were in general provided by the Bulletins. In the case of Indonesia, data on retail fuel prices from 2008 to 2012 was produced from various media reports on government announced fuel price changes. Data for Nigeria in 2007 and Qatar 2009 and 2010 was missing. We assumed these prices were equal to nearest year with available data that had the highest price.

Data for the larger group of 24 countries came mainly from the World Bank. To be as consistent as possible in regards to the data sources across countries, we used World Bank data even for the 10 countries that we had annual data on from OPEC sources. The data from Iraq was constructed from secondary sources including GIZ International Fuel Prices surveys, IMF reports, and OPEC ASBs. The World Bank data was missing observations for Qatar in 2000 and 2002. We replaced the missing values using data from OPEC ASBs.
6.3.2 Calculating the baseline ratio

The price of gasoline and diesel in country \( j \) at time \( t \) is given by \( P^g_{j,t} \) and \( P^d_{j,t} \), respectively. Denote \( \gamma^g_{j,t} \) as the share of gasoline consumption out of total gasoline and middle distillate consumption in country \( j \) at time \( t \). Under this terminology, the ratio for country \( j \) at time \( t \) is calculated as

\[
\psi_{j,t} = \frac{\gamma^g_{j,t} P^g_{j,t}}{P^g_{US,t}} + \left(1 - \gamma^g_{j,t}\right) \frac{P^d_{j,t}}{P^d_{US,t}}.
\]

If \( O_{j,t} \) is oil consumption in country \( j \) then the value for \( \psi_t \) is calculated as

\[
\sum_{j=1}^N \frac{O_{j,t}}{\sum_{j=1}^N O_{j,t}} \psi_{j,t}.
\]

6.3.3 Alternative calculations

There are alternative ways to calculate the ratio \( \psi_t \). One method is to consider the ratio of spending on gasoline and diesel in country \( j \) at subsidized price levels to spending on gasoline and diesel at world price levels. That is, for each country \( j \) at time \( t \) calculate the ratio given by

\[
\psi_{j,t} = \frac{O^g_{j,t} P^g_{j,t} + O^d_{j,t} P^d_{j,t}}{O^g_{j,t} P^g_{US,t} + O^d_{j,t} P^d_{US,t}},
\]

and then aggregate across countries using the same procedure as in the baseline case.

A second alternative method expands upon the idea of the first alternative method and simply calculates the overall ratio as

\[
\psi_t = \frac{\sum_{j=1}^N \left[ O^g_{j,t} P^g_{j,t} + O^d_{j,t} P^d_{j,t} \right]}{\sum_{j=1}^N \left[ O^g_{j,t} P^g_{US,t} + O^d_{j,t} P^d_{US,t} \right]}.
\]

We calculated the time series for the ratios using both alternative measures for both sets of countries. The time series in all cases were little changed from the baseline method. Given this, we do not report any additional results in the paper using the alternative price ratios.
6.4 Model equations

First order conditions for household in

\[ (1 - \gamma_o^a)(A_{c,t}^a)^{1-\mu_c} + (\gamma_o^a)(O_{c,t}^a)^{1-\mu_c} \frac{1-\gamma_o^a}{1-\mu_c} - (1 - \gamma_o^a)(A_{c,t}^a)^{-\mu_c} = \lambda_t^a, \]

\[ (1 - \gamma_o^a)(A_{c,t}^a)^{1-\mu_c} + (\gamma_o^a)(O_{c,t}^a)^{1-\mu_c} \frac{1-\gamma_o^a}{1-\mu_c} - \gamma_o^a(O_{c,t}^a)^{-\mu_c} = P_{o,t}\lambda_t^a, \]

\[ \kappa(N_t^a)^{\mu_c} = W_t^a \lambda_t^a, \]

\[ \lambda_t^a = \beta E_{t+1}^a \left[ \gamma_{t+1}^a + (1 - \delta). \right] \]

Law of motion for capital

\[ K_t^a - K_{t-1}^a = A_{t,t}^a - \delta K_{t-1}^a. \]

Production function for good a

\[ Y_{a,t}^a = Z_{y,t}^a N_t^a \left[ \omega_y^a K_{t-1}^a - (1 - \omega_y^a) O_{y,t}^a \right] \frac{1}{1-\nu}. \]

First order conditions for the firm

\[ \frac{Y_{a,t}^a}{N_t^a} = W_t^a \]

\[ (1 - \alpha)Y_{a,t}^a \frac{\omega_y^a(K_{t-1}^a)^{-\nu}}{\omega_y^a K_{t-1}^a - (1 - \omega_y^a) O_{y,t}^a 1-\nu} = r_t^a \]

\[ (1 - \alpha)Y_{a,t}^a \frac{(1 - \omega_y^a) O_{y,t}^a^{-\nu}}{\omega_y^a K_{t-1}^a - (1 - \omega_y^a) O_{y,t}^a 1-\nu} = P_{o,t} \]

Market clearing condition for good A

\[ A_{c,t}^a + A_{t,t}^a + A_{c,t}^o + A_{y,t}^o = Y_{a,t}. \]

Market clearing condition for the oil market

\[ O_{c,t}^a + O_{y,t}^a + O_{c,t}^o = Y_{o}^o + Y_{o}^a. \]

Current account equation for country a

\[ P_{o,t} \left( O_{c,t}^a - Y_{o}^a \right) = Y_{a,t}^a - A_{c,t}^a - A_{t,t}^a. \]

First order conditions for household in o

\[ (1 - \gamma_o^o)(A_{c,t}^o)^{1-\mu_c} + (\gamma_o^o)(O_{c,t}^o)^{1-\mu_c} \frac{1-\gamma_o^o}{1-\mu_c} - (1 - \gamma_o^o)(A_{c,t}^o)^{-\mu_c} = \lambda_{o,t}^o, \]

\[ (1 - \gamma_o^o)(A_{c,t}^o)^{1-\mu_c} + (\gamma_o^o)(O_{c,t}^o)^{1-\mu_c} \frac{1-\gamma_o^o}{1-\mu_c} - \gamma_o^o(O_{c,t}^o)^{-\mu_c} = P_t^o \lambda_{o,t}. \]

Government budget constraint in country o

\[ P_{o,t} \left( Y_{o}^o - O_{o}^o \right) + P_{s,t} O_{c,t}^o = T_t. \]
6.5 Steady state equations

\[ \left[ (1 - \gamma_o^a)(A_c^o)^{1-\mu_c} + (\gamma_o^a)(O_c^o)^{1-\mu_c} \right]^{1-\mu_c} \left( 1 - \gamma_o^a \right) (A_c^o)^{-\mu_c} = \lambda_o, \]

\[ \left[ (1 - \gamma_o^a)(A_c^o)^{1-\mu_c} + (\gamma_o^a)(O_c^o)^{1-\mu_c} \right]^{1-\mu_c} \left( 1 - \gamma_o^a \right) (O_c^o)^{-\mu_c} = P_o \lambda_o, \]

\[ \kappa N^o \mu_c = W^o \lambda^o, \]

\[ \frac{1}{\beta} - 1 + \delta = r^o. \]

\[ \delta K^a = A_t^o. \]

\[ Y_o^a = Z_y N^a \alpha \left[ \omega_y^a K^a 1-\nu + (1 - \omega_y^a) O_y^a 1-\nu \right]^{1-\nu}, \]

\[ \alpha^o \frac{Y_o^a}{N_o^a} = W^a \]

\[ (1 - \alpha)Y_o^a \frac{\omega_y^a (K^a)^{-\nu}}{\omega_y^o (K^a)^{1-\nu} + (1 - \omega_y^a) (O_y^a)^{1-\nu}} = r^a \]

\[ (1 - \alpha)Y_o^a \frac{(1 - \omega_y^a)O_y^a^{-\nu}}{\omega_y^a K^a 1-\nu + (1 - \omega_y^a) O_y^a 1-\nu} = P_o \]

\[ A_c^o + A_t^o + A_y^o = Y_o^a \]

\[ O_c^o + O_y^o + O_c^o = Y_o^o + Y_o^a \]

\[ P_o (O_c^o - Y_o^o) = Y_o^a - A_c^o - A_t^o. \]

\[ \left[ (1 - \gamma_o^o)(A_c^o)^{1-\mu_c} + (\gamma_o^o)(O_c^o)^{1-\mu_c} \right]^{1-\mu_c} \left( 1 - \gamma_o^o \right) (A_c^o)^{-\mu_c} = \lambda_o, \]

\[ \left[ (1 - \gamma_o^o)(A_c^o)^{1-\mu_c} + (\gamma_o^o)(O_c^o)^{1-\mu_c} \right]^{1-\mu_c} \left( 1 - \gamma_o^o \right) (O_c^o)^{-\mu_c} = P_s \lambda^o, \]

\[ P_o (Y_o^o - O_c^o) + P_s O_c^o = T. \]