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The Opportunity Cost of Domestic Oil Consumption for an Oil Exporter: Illustration for Saudi Arabia

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Key Points

- This research values oil from a public perspective for resource allocation, project selection, and policymaking in oil-exporting countries.

- The analysis considers an economic distortion: the domestic oil pricing policy, and a market imperfection, which is a departure from the 'small economy' assumption.

- Formulas for the opportunity cost of oil are derived under various constraints and domestic pricing schemes.

- We produce a formula that quantifies the net welfare gains from reforming the domestic oil price.

- Saudi Arabia's data for 2018 are used for numerical illustration.

- For projects with only short-term impacts on domestic oil demand, the opportunity cost of a barrel of oil for Saudi Arabia is found to range between US$15 and US$25.

- For projects with long-lasting impacts on domestic oil demand, such as investments in energy efficiency or renewables, the range of possible values for the opportunity cost of a barrel of oil is broader, between US$15 and US$59.4.

- Increasing the domestic price of a barrel of oil by US$1 results in a net welfare gain for Saudi Arabia of up to US$200 million per year.

Summary

When appraising investment projects from a public perspective, a barrel of oil displaced from or added to domestic consumption has to be valued at its opportunity cost. This paper develops a partial-equilibrium framework to assess the opportunity cost of domestic oil consumption for an oil-exporting country. The framework takes into account that (i) the usual 'small economy' assumption does not necessarily hold, (ii) the domestic oil price can be set either at a fixed level or as a function of the international price, and (iii) oil production, level of exports, or domestic consumption can be constrained. We derive the opportunity cost for each case considered and a formula quantifying the net welfare gains from reforming the domestic oil price.

We provide a numerical illustration using 2018 data for Saudi Arabia. We find that, for a project with a short-term impact on domestic oil demand, the opportunity cost of a barrel of oil could range between US$15 and US$25. If we consider a project with a long-lasting impact on domestic oil demand, such as an investment in energy efficiency or renewables, the range of possible values for the opportunity cost of oil is much broader and very sensitive to constraints on production. Increasing the domestic price of a barrel of oil by US$1 results in a net welfare increase in Saudi Arabia of up to US$200 million. Our results can inform decision-making in countries that aim to diversify their economies away from oil revenues.

Introduction

What is the opportunity cost of oil for an oil-exporting country? When assessing new investment projects from a public perspective, what is the value of a barrel of oil displaced from or added to domestic consumption? Using a barrel of oil in one project results in the loss of the benefits that it would have yielded in other uses. The opportunity cost is the value that society attaches to the best-rejected option.

Making decisions based on incorrectly calculated opportunity costs could lead to over-investment in some projects and under-investment in others. Using estimates of the opportunity cost of oil can improve the assessment of costs and benefits associated with alternative investments and development strategies, which helps to leverage a country's oil endowment in maximizing the current and future welfare of its citizens. Moreover, setting an appropriate opportunity cost for oil enables a cost-benefit analysis and allows the country to decentralize its decision-making, a necessary component for encouraging investment and, thus, promoting economic growth and development.

Many oil-exporting economies are subject to distortions due to government interventions or market imperfections. Because of these economic distortions, the observed prices do not necessarily reflect the true opportunity costs of the resources. The (non-observed) opportunity costs are then referred to as 'shadow prices' (Pearce and Markandya 1987). We use the terms 'shadow price' and 'opportunity cost' interchangeably throughout this paper. Given the existing distortions, the shadow prices reflect the true value of the resources. They should not be perceived as the equilibrium prices that would be realized in an undistorted economy (Squire and Van der Tak 1975). In the literature (Harberger 1968; Parish 1972, 1973), this approach is called the incremental approach, which, in a partial equilibrium setting, considers policy reform as an incremental process that increases societal welfare. Hence, the shadow price of any good can be defined as the welfare gain from endowing the economy with an additional unit of it (Jones 2005). This implies that the opportunity cost of oil must be computed given the existing oil market structure. Questions relating to hypothetical alternative market structures, such as an oil market without OPEC, are therefore not relevant here. An alternative to this approach is the 'utopian approach,' which consists of using market prices in a non-distorted economy. As Jones (2005) argues, this approach may be appropriate when policy changes remove price distortions altogether, which is rarely the case in reality.

There is a substantial literature on the estimation of shadow prices of non-marketed commodities, such as polluting emissions (Lee and Lee 2014; Zhou et al. 2014). Similarly, oil and other exhaustible resources require special attention. This has led to the further development of the literature on public economics as well as the emergence of the literature on exhaustible resource accounting. The bulk of this literature considers intertemporal welfare maximization and derives the opportunity cost of an exhaustible resource from an optimization problem (see, for instance, El Serafy [1989]; Hartwick [1990]). The shadow price is then defined as the gain from relaxing the constraint on resource availability. Hamilton and Clemens (1999) indicate that in the presence of policy distortions, shadow prices diverge from observed 'real world' prices on the optimal path. Such divergence results in allocative inefficiencies in the domestic economy (Ouyang and Sun 2015), which in turn may distort investment decisions.

Some studies (e.g., Blazquez et al. [2019]) use a general-equilibrium framework to assess the welfare gains of projects or policies that save oil. However, these studies, and the literature in general, do not address the specific question of the opportunity cost of oil for an oil-exporting country whose oil sector is subject to economic distortions. This paper develops an operational framework grounded on economic theory, which meets the needs of decision-makers looking for numerical estimates.

Our analysis focuses on an economic distortion, the domestic oil pricing policy, and a market imperfection, the departure from the 'small economy' assumption. Under this assumption, the country's production represents a negligible fraction of global production, with no effect on the international price. We depart from it by considering a major oil exporter. We examine how these two elements, combined with the specific circumstances of the oil producer, can impact the opportunity cost of its domestic oil consumption.

The next section introduces the partial-equilibrium framework that we use to derive a generic formula for the opportunity cost of domestic oil consumption. Section 3 examines the effects of different sets of constraints imposed on the oil producer. Section 4 derives a formula quantifying the net welfare gains from reforming the domestic oil price using the envelope theorem. Section 5 uses Saudi Arabia's data to provide a numerical illustration of the formulas derived. Section 6 concludes.

The Model

Model structure and assumptions

Like in Harberger (1968), Parish (1972, 1973), and Jones (2005), we adopt a partial-equilibrium approach where the opportunity cost is defined as a variation in the sum of the producer and consumer surpluses. Since our objective is to determine the opportunity cost from a nationwide perspective, the producer's surplus includes both the government revenues and the benefits of the oil-producing company. In other words, the opportunity cost of adding a new barrel of domestic oil consumption reflects the (before-tax) cost of supplying the barrel plus the resulting change in the existing consumer welfare.

We consider a country that exports oil and call it 'the Producer.' We design the Producer's welfare problem using the dominant firm framework. Being a major oil exporter, the Producer takes into account the impact of the level of its exports on the international oil price when making decisions on exports. This framework allows us to fully capture the welfare effects of a marginal decision, which is key to determining the opportunity cost of the oil consumed domestically.

In year t, the Producer's oil production o_t meets its domestic demand q_t and the international demand for its oil (exports) x_t. This is represented by the constraint $q_t+x_t \leq o_t$. We do not consider the possibility of drawing from inventories. Let us assume that a new project (not accounted in the existing domestic demand D_t (.) curve) requires an additional barrel of oil. The welfare cost of this barrel of oil is given by the Lagrange multiplier μ_t associated with this constraint. μ_t represents the present value of the opportunity cost of a barrel consumed for the project. In other words, the non-discounted opportunity cost of a barrel of oil made available for domestic consumption in year t is $\mu_t\ (1+d)$^t, where d is the Producer's discount rate.

Determining which shadow price formula is appropriate to obtain the opportunity cost of oil requires understanding of the constraints to which the Producer is subject. These constraints can be caused by structural, technical, logistical, policy or financial factors (see Gochenour [1992] for a description of these factors). For instance, an OPEC quota or logistical constraints can cap production. Existing commercial obligations or the need to earn foreign currency to finance the Producer's national imports can constrain the level of oil exports. Conversely, international sanctions can limit exports. We therefore introduce constraints on the level of exports, with U_t and L_t being the upper and lower bounds on x_t, respectively. We also constrain production with the upper bound M_t.

Let P_t denote the free-on-board (FOB) international oil price in year t. P_t is a function of x_t, $P_t\ (x_t)$, since the Producer's exports impact the international oil price. We frame the domestic pricing policy in general terms by considering that the Producer sets its domestic oil price π_t as a linear function of the international price: $\pi_t=aP_t\ (x_t)+b$, where a and b are two fixed parameters. Domestic sales of oil are managed by a public firm financed by the government. These assumptions cover the pricing policies and administrative setup existing in most of the oil-exporting countries (see, for instance, Fattouh and El-Katiri [2012]; Held and Ulrichsen [2013]; IMF [2017]). Publicly available information on formulas used for domestic oil pricing policy is scarce. We assume a linear functional form but acknowledge that other functional forms might also be used.

The domestic demand function is given by $Dt\ (\pi_t)$. We use an aggregate representation of domestic demand. Our results can be easily extended to the case where different types of consumers, for instance households and industries using oil as an intermediate input, are considered. The total consumer surplus is then a sum of surpluses.

We denote the inverted demand curve by D_t^{-1} (.). We introduce the constraint $D_t(aP_t(x_t)+b) \leq q_t$ when meeting domestic demand is mandatory.

As is standard in the literature, the rate of depletion of oil reserves is given by the rate of oil extraction. Hence, the amount of underground reserves u_t at the end of year *t* decreases by o_t, that is, *ot≤u_(t-1)-u*$_t$. The total cost of production amounts to $c(o_t)$. To avoid incorporating a detailed representation of investment decisions in new capacity, we assume that, because of demand growth and the natural decline of existing fields, investment in new capacity occurs in every period. We, therefore, consider that the marginal cost of production includes the economic depreciation of capital expenditures, in addition to the operating cost. Otherwise, if there is excess capacity and no investment, the marginal production cost includes the operating cost only.

Under these assumptions, the Producer's welfare maximization problem, with the multipliers associated with constraints in parentheses, is written as follows:

$$\sum_{t=0}^{T} \frac{1}{(1+d)^t}\left(x_t P_t(x_t) + \int_0^{q_t} D_t^{-1}(s)\, ds - c(o_t) \right) \tag{1a}$$

$$\text{s.t.} \qquad q_t + x_t \leq o_t \qquad (\mu_t) \tag{1b}$$

$$D_t(aP_t(x_t) + \mathrm{b}) \leq q_t \qquad (\varphi_t) \tag{1c}$$

$$o_t \leq M_t \qquad (\theta_t) \tag{1d}$$

$$x_t \leq U_t \qquad (\beta_t) \tag{1e}$$

$$-x_t \leq -L_t \qquad (\omega_t) \tag{1f}$$

$$o_t \leq u_{t-1} - u_t \qquad (\lambda_t) \tag{1g}$$

Variables have to be non-negative. Further, as can be seen from Eq. (1a), the Producer's welfare function has three components: the benefit of exporting oil, the gain from consuming oil domestically, and the cost of producing oil. Hence, this function will allow us to study welfare impacts of oil price changes for the country as a whole.

Optimality conditions and shadow price equations

We build the Lagrangian of the Producer's welfare maximization problem. We assume that in every period, the Producer delivers oil to both its domestic market and the rest of the world. In short, all quantity variables are positive, except the underground reserves at the end of the last period (which becomes zero when the reserves are depleted). We first determine its derivative with respect to x_t and rearrange the terms to write:

$$\mu_t = \frac{P_t(x_t) + x_t \frac{dP_t}{dx_t}(x_t)}{(1+d)^t} - \varphi_t a \frac{dP_t}{dx_t}(x_t) \frac{dD_t}{d\pi_t}(\pi_t) - (\beta_t - \omega_t) \tag{2}$$

As the Producer cannot have both constraints (1e) and (1f) binding its exports at the same time, the Lagrange multipliers associated with these constraints (i.e., β_t and ω_t) cannot be simultaneously non-zero. Eq. (2) implies that the discounted opportunity cost of a barrel made available for domestic consumption (μ_t) is given by the sum of the incremental export revenue that is foregone, the increase in welfare from domestic oil consumption that would have happened if this barrel had been exported, and an additional cost imposed by the constraint on the Producer's exports. Increasing oil exports results in a decline in the international oil price, which, in turn, results in a decrease in the domestic oil price. Domestic demand – which has to be met – increases by ΔD_t, which imposes the cost $\phi_t \Delta D_t$. This gives:

$$\mu_t = \left(\frac{1 + \frac{1}{\varepsilon_{x,t}}}{(1+d)^t} \right) P_t - \varphi_t a \frac{q_t P_t \varepsilon_q}{x_t \pi_t \varepsilon_{x,t}} - (\beta_t - \omega_t) \tag{3}$$

where ε_q is the elasticity of the domestic oil demand with respect to the domestic price (i.e., $\varepsilon_q = \frac{\Delta q_t}{q_t}\frac{\pi_t}{\Delta \pi_t}$) and ε_x is the price elasticity of international demand for the Producer's oil exports (i.e., $\varepsilon_{x,t} = \frac{\Delta x_t}{x_t}\frac{P_t}{\Delta P_t}$). Presumably, we have $\varepsilon_q \leq 0$ and $\varepsilon_{x.t} \leq 0$.

As the domestic demand is a function of the domestic price, the inverted demand function can be written as $D_t^{-1}(q_t) = \pi_t$. Hence, the derivative of the Lagrangian with respect to q_t gives:

$$\frac{\pi_t}{(1+d)^t} - \mu_t + \varphi_t = 0 \tag{4}$$

Eq. (4) simply states that the cost of meeting the domestic demand is the difference between the opportunity cost of oil (i.e., its value) and the domestic oil price.

By combining Eqs. (3) and (4) we obtain:

$$\mu_t = \frac{\left(1+\frac{1}{\varepsilon_{x,t}}\right)P_t + a\frac{q_t P_t \varepsilon_q}{x_t \varepsilon_{x,t}} - (1+d)^t(\beta_t - \omega_t)}{(1+d)^t\left(1 + a\frac{q_t P_t \varepsilon_q}{x_t \pi_t \varepsilon_{x,t}}\right)} \tag{5}$$

We show in the Appendix that the following identity holds:

$$\varepsilon_{x,t} = \frac{g_t\varepsilon_g - a q_t \frac{P_t}{\pi_t}\varepsilon_q - r_t\varepsilon_r}{x_t} \tag{6}$$

where g_t is the global oil demand with the price elasticity of $\varepsilon_g \leq 0$, whereas r_t denotes non-Producer oil supplies with the price elasticity of $\varepsilon_r \geq 0$. Using Eq. (6), the denominator of Eq. (5) can be written as: $(1+d)^t\frac{g_t\varepsilon_g - r_t\varepsilon_r}{x_t\varepsilon_x}$. Hence, we obtain:

$$\mu_t = \left(\frac{\left(g_t\varepsilon_g - a q_t\frac{P_t}{\pi_t}\varepsilon_q - r_t\varepsilon_r + x_t\right) + a q_t\varepsilon_q - \frac{x_t\varepsilon_{x,t}(1+d)^t(\beta_t - \omega_t)}{P_t}}{g_t\varepsilon_g - r_t\varepsilon_r}\right)\frac{P_t}{(1+d)^t}$$

which gives:

$$\mu_t = \left(1 + \frac{x_t + a q_t\varepsilon_q\left(1 - \frac{P_t}{\pi_t}\right) - \frac{x_t\varepsilon_{x,t}(1+d)^t(\beta_t - \omega_t)}{P_t}}{g_t\varepsilon_g - r_t\varepsilon_r}\right)\frac{P_t}{(1+d)^t} \tag{7}$$

Eq. (7) presents the general formula for the discounted opportunity cost of oil.

Now, if we take the derivative of the Lagrangian with respect to o_t, then we have:

$$-\frac{c_m(o_t)}{(1+d)^t} + \mu_t - \theta_t - \lambda_t = 0$$

with $c_m(o_t) = \frac{dc}{do_t}(o_t)$. Rearranging the terms yields:

$$\mu_t = \frac{c_m(o_t)}{(1+d)^t} + \lambda_t + \theta_t \tag{8}$$

Eq. (8) indicates that the present value of the opportunity cost is the sum of the present value of the marginal cost, the present value of the economic cost of a barrel of reserves, and an extra cost imposed by the constraint on production.

Finally taking the derivative with respect to u_t results in $\lambda_t = \lambda_{t+1}$. This shows that the economic value of a barrel of oil in underground reserves remains constant in present value. Note that $\lambda_t > 0$ if $u_T = 0$.

The framework described in this section shows that constraints on oil production, the level of exports, and domestic consumption play key roles in determining the opportunity cost of oil. Further, different domestic oil pricing schemes may yield different opportunity costs. The next section aims to explore these issues and derives the opportunity cost for each case considered.

Determination of the Opportunity Cost of Oil: The Role of Constraints

Meeting domestic demand is mandatory; no other constraints

We assume that neither production nor exports are constrained (i.e., Eqs. [1d]-[1f] are non-binding). Thus, the opportunity cost can be defined as the Producer's marginal cost of supplying oil. It is the sum of:

- the operating cost of producing an additional barrel;
- the capital cost of developing an additional barrel of reserves;
- the economic value of a barrel of underground reserves.

Note that this sum is given by Eq. (8) without the constraint on production (θ_t): $\mu_t = \frac{c_m(o_t)}{(1+d)^t} + \lambda_t + \theta_t$. Furthermore, the opportunity cost formula given by Eq. (7) holds. As we have in this case $\beta_t = \omega_t = 0$, the formula for the opportunity cost of oil can also be written as:

$$\mu_t(1+d)^t = \left(1 + \frac{x_t + a q_t \varepsilon_q \left(1 - \frac{P_t}{\pi_t}\right)}{g_t \varepsilon_g - r_t \varepsilon_r}\right) P_t \qquad (9)$$

As mentioned above, the domestic oil price is set as a fraction of the international price. The Producer can apply different domestic pricing schemes, and the opportunity cost of oil can differ between these schemes. We use Eq. (9) to derive the opportunity cost for four types of domestic oil pricing policies: a fully deregulated price, a fixed administered price, a fixed fraction of the international price, and an international price less a fixed subsidy.

Case 1: A fully deregulated price

In this case, a = 1 and b = 0. Since $\pi_t = P_t$, Eq. (9) gives:

$$\mu_t(1+d)^t = \left(1 + \frac{x_t}{g_t \varepsilon_g - r_t \varepsilon_r}\right) P_t \qquad (10)$$

If the rest of the world's demand for the Producer's oil is negligible (i.e., $x_t \rightarrow 0$), the opportunity cost of oil for the Producer is its international market price. This corresponds to the well-known result that under the 'small economy' assumption, the opportunity cost of a tradable good is its border price (Little and Mirrlees 1974; Squire and Van der Tak 1975).

Case 2: A fixed administered price

In this case, $a = 0$ and the domestic price is given by $\pi_t = b$. Eq. (9) gives:

$$\mu_t(1+d)^t = \left(1 + \frac{x_t}{g_t \varepsilon_g - r_t \varepsilon_r}\right) P_t \qquad (11)$$

Since we have from Eq. (6) $\varepsilon_{x,t} = \frac{g_t \varepsilon_g - r_t \varepsilon_r}{x_t}$, Eq. (11) becomes:

$$\mu_t(1+d)^t = \left(1 + \frac{1}{\varepsilon_{x,t}}\right) P_t \qquad (12)$$

According to Eq. (12), the opportunity cost of oil, smaller than the international price, is simply the marginal revenue generated by the export of an additional barrel. The formula does not show any direct impact of the value set for the administered price on the opportunity cost. However, by determining the level of domestic consumption, the domestic price also determines the quantity available for export, which impacts the value of the opportunity cost.

We obtain the same formula if the domestic price is fully deregulated or administered. However, this similarity is only apparent since the definition and numerical value of ε_g are specific to each case, as shown by Eq. (A.4) in the Appendix.

Case 3: A fixed fraction of the international price

Since $b = 0$ and $\pi_t = aP_t$, Eq. (9) gives:

$$\mu_t(1+d)^t = \left(1 + \frac{x_t + q_t\varepsilon_q(a-1)}{g_t\varepsilon_g - r_t\varepsilon_r}\right)P_t \qquad (13)$$

Case 4: The international price less a fixed subsidy

We have $a = 1$, $\pi_t = P_t + b$ with $b < 0$. We obtain:

$$\mu_t(1+d)^t = \left(1 + \frac{x_t + \frac{bq_t\varepsilon_q}{P_t + b}}{g_t\varepsilon_g - r_t\varepsilon_r}\right)P_t \qquad (14)$$

The domestic price of oil generally differs from its opportunity cost. However, it is interesting to investigate which domestic pricing policy could match the opportunity cost. Since all opportunity cost formulas depend on the international price, the only pricing scheme that can replicate the opportunity cost is to set the domestic price as a fraction of the international price. It is easy to show that to have $\mu_t = \pi_t$, we must have $\pi_t = \left(1 + \frac{1}{\varepsilon_{x,t}}\right)P_t$ i.e., the domestic price is equal to the incremental revenue generated by exporting an additional barrel.

Meeting domestic demand is mandatory; exports are constrained

We assume that exports are currently constrained. Current exports are limited by Eq. (1e) (because of ongoing sanctions, or a policy aiming to benefit other producers who need a high oil price for their economies), or the volume of exports is constrained to be above a certain threshold as in (1f) (for commercial purposes such as the need for export earnings to finance imports). The Lagrange multiplier associated with the constraint binding exports (either β_t or ω_t) appears in Eq. (7) and is positive. As the value of the multiplier is not directly observable, the current opportunity cost cannot be determined by applying Eq. (7) to the current year. However, under the assumption that the constraints on exports will in the future no longer be binding, the current opportunity cost can be calculated as the marginal cost of supplying the domestic market (given by Eq. [8]). The current economic value of underground reserves can be calculated by applying Eq. (7) and Eq. (8) to a future year when the constraints on exports are no longer binding (since the opportunity cost in that year will not depend on non-observable Lagrange multipliers associated with export constraints). We provide a numerical application of this procedure later in the paper.

Meeting domestic demand is mandatory; production is constrained

We now assume that the constraint on production (Eq. [1d]), due to an OPEC quota or logistical or financial constraints, is binding. This imposes the extra cost θ_t on the opportunity cost of domestic oil consumption. Because of this extra cost, the opportunity cost exceeds the marginal cost of supply, defined here as the sum of the marginal production cost [$c_m(o_t)$] and the economic value of a barrel of reserve oil (λ_t). This extra cost is not directly observable. Therefore, using Eq. (9) directly is the most straightforward approach, since it depends on observable quantities and prices and on price elasticities that can be taken from the literature.

Abandoning the obligation of meeting domestic demand

Let us assume that meeting domestic demand is no longer imposed. Thus, we do not include the constraint (1c) in the welfare maximization problem. If the Producer rations its domestic demand by constraining the supply available to its domestic market, then the market does not clear at the domestic price and we have $D_t^{-1}(q_t) > \pi_t$, with Eq. (4) becoming:

$$\mu_t(1+d)^t = D_t^{-1}(q_t)$$

The opportunity cost of oil is the marginal value of the barrel allocated to the domestic market. The marginal value of the last barrel supplied is higher than the domestic price as a scarcity premium emerges from rationing. The efficiency of the mechanism used to deal with the excess demand generated by the price control matters (i.e., an efficient mechanism ensures that only the 'left part' of the demand curve is served). Dreze and Stern (1990) and Papps (1993) show that deriving the appropriate opportunity cost requires information about this allocative mechanism. Murphy et al. (2019) discuss how governments can engage in some forms of rationing because of price controls and how the effect of rationing can be measured in a multi-sector model.

Note that Eq. (3) reduces to $\mu_t = \left(1 + \frac{1}{\varepsilon_{x,t}}\right) P_t - (\beta_t - \omega_t)$. In the case where there is no constraint on exports (i.e., $\beta_t = \omega_t = 0$), the opportunity cost of oil is also equal to the marginal revenue from exporting an additional barrel. For the reasons mentioned in section 3.2, if there is a constraint restricting oil exports, which represents the only alternative to using oil domestically, the opportunity cost of domestic oil consumption should be lower. Indeed, as we have $\beta_t > 0$, the opportunity cost of oil is less than the marginal revenue of exports. On the other hand, if the volume of oil exports has to be above a certain threshold, we have $\omega_t > 0$, and using oil domestically has a higher opportunity cost, which, in this case, is given by the marginal export revenue augmented by the implicit cost of this constraint.

Comparison of opportunity cost formulas

Table 1 summarizes all the different cases examined. A critical point to clarify is the potential role of intertemporal considerations when determining the opportunity cost of oil. Discussing this point is especially important, given that oil is an exhaustible resource.

When there is no constraint (subsection 3.1), the nature of the problem is intertemporal. However, the intertemporal dependencies are implicitly captured through the economic value of underground reserves. The value of a barrel of oil in reserves is given by the present value of its future net marginal revenue at the time it will be sold. It, therefore, depends on future global oil market conditions. The opportunity cost of a barrel of oil is also given by a fraction of the international price, as depicted in Table 1.

Constrained production (or the supply available for domestic consumption), with no above-ground storage, removes all potential intertemporal dependencies and renders the problem static. The fact that there is a binding constraint on supply implies that the same quantity of oil is produced with or without the project. The cost of producing and depleting the resource is, therefore, a sunk cost that does not matter from a marginal perspective.

Table 1. Opportunity cost formulas.

Opportunity cost	Case
$\left(1+\frac{x_t+aq_t\varepsilon_q\left(1-\frac{P_t}{\pi_t}\right)}{g_t\varepsilon_g-r_t\varepsilon_r}\right)P_t$	- No other constraints - Constraint on production
$c_m(o_t)+(1+d)^t\lambda_t$	- No other constraints - Constraint on exports
$D_t^{-1}(q_t)\quad(\geq\pi_t)$	- Meeting domestic demand is not mandatory

Net welfare gains from reforming the domestic oil price

Given the above framework, one interesting question is to what extent changes in domestic pricing affect the Producer's welfare. To study this question, we assume that the value of the Producer's welfare problem is a function of the parameters *a* and *b*, denoted *V(a,b)*. From a marginal perspective, the net welfare gains generated by an immediate reform of the domestic oil price can, therefore, be assessed through the derivatives of *V* with respect to *a* and *b*. For this purpose, we apply the envelope theorem to the problem's Lagrangian.

First, for the parameter *a*, we have:

$$\frac{\partial V}{\partial a}(a,b)=-\sum_{t=0}^{T}\varphi_t P_t\frac{dD_t}{d\pi}(\pi_t).$$

Using Eq. (4) to replace φ_t we get

$$\frac{\partial V}{\partial a}(a,b)=\sum_{t=0}^{T}P_t\left(\frac{\pi_t}{(1+d)^t}-\mu_t\right)\frac{dD_t}{d\pi}(\pi_t).$$

Substituting μ_t with the opportunity cost formula given in Eq. (7) we obtain:

$$\frac{\partial V}{\partial a}(a,b)=\sum_{t=0}^{T}P_t\left(\frac{\pi_t}{(1+d)^t}-\left(1+\frac{x_t+aq_t\varepsilon_q\left(1-\frac{P_t}{\pi_t}\right)-\frac{x_t\varepsilon_{x,t}(1+d)^t(\beta_t-\omega_t)}{P_t}}{g_t\varepsilon_g-r_t\varepsilon_r}\right)\frac{P_t}{(1+d)^t}\right)\frac{dD_t}{d\pi}(\pi_t) \qquad (15)$$

Similarly, for the parameter *b*, we can write:

$$\frac{\partial V}{\partial b}(a,b)=-\sum_{t=0}^{T}\varphi_t\frac{dD_t}{d\pi}(\pi_t)=\sum_{t=0}^{T}\left(\frac{\pi_t}{(1+d)^t}-\mu_t\right)\frac{dD_t}{d\pi}(\pi_t).$$

$$\frac{\partial V}{\partial b}(a,b)=\sum_{t=0}^{T}\left(\frac{\pi_t}{(1+d)^t}-\left(1+\frac{x_t+aq_t\varepsilon_q\left(1-\frac{P_t}{\pi_t}\right)-\frac{x_t\varepsilon_{x,t}(1+d)^t(\beta_t-\omega_t)}{P_t}}{g_t\varepsilon_g-r_t\varepsilon_r}\right)\frac{P_t}{(1+d)^t}\right)\frac{dD_t}{d\pi}(\pi_t) \qquad (16)$$

Since we have $\varepsilon_q=\frac{\Delta q_t}{q_t}\frac{\pi_t}{\Delta\pi_t}$ and $D_t(\pi_t)=q_t$, we can write $\frac{dD_t}{d\pi}(\pi_t)=\frac{q_t}{\pi_t}\varepsilon_q$. Then Eqs. (15) and (16) become:

$$\frac{\partial V}{\partial a}(a,b)=\sum_{t=0}^{T}\frac{\varepsilon_q q_t P_t}{(1+d)^t}\left(1-\left(1+\frac{x_t+aq_t\varepsilon_q\left(1-\frac{P_t}{\pi_t}\right)-\frac{x_t\varepsilon_{x,t}(1+d)^t(\beta_t-\omega_t)}{P_t}}{g_t\varepsilon_g-r_t\varepsilon_r}\right)\frac{P_t}{\pi_t}\right) \qquad (17)$$

$$\frac{\partial V}{\partial b}(a,b)=\sum_{t=0}^{T}\frac{\varepsilon_q q_t}{(1+d)^t}\left(1-\left(1+\frac{x_t+aq_t\varepsilon_q\left(1-\frac{P_t}{\pi_t}\right)-\frac{x_t\varepsilon_{x,t}(1+d)^t(\beta_t-\omega_t)}{P_t}}{g_t\varepsilon_g-r_t\varepsilon_r}\right)\frac{P_t}{\pi_t}\right) \qquad (18)$$

Assume that the domestic price is a fixed fraction of the international price, with $\pi_t=aP_t$ (see case 3 in section 3.1). The value of *a* that maximizes the Producer's welfare in Eq. (17) is obtained by setting $\frac{\partial V}{\partial a}$ equal to zero. This value is $1+\frac{1}{\varepsilon_{x,t}}-\frac{(1+d)^t(\beta_t-\omega_t)}{P_t}$. Inserting this value into Eq. (7) leads to $\mu_t(1+d)^t=\left(1+\frac{1}{\varepsilon_{x,t}}\right)P_t-(1+d)^t(\beta_t-\omega_t)$. The most efficient pricing policy is therefore to set the domestic price equal to the incremental revenue generated by exporting an additional barrel adjusted for the cost of the constraints on exports. This pricing policy corresponds to Eq. (3) when φ_t is equal to zero, knowing from Eq. (4) that φ_t is zero when the domestic price is equal to the opportunity cost. In other words, the most efficient pricing policy is to set the domestic price equal to the opportunity cost.

Eqs. (17) and (18) can be used to assess the effects of a marginal change in the domestic pricing policy on the Producer's welfare. For instance, assuming that the domestic price of oil is fixed by the government (see case 2 in section 3.1), using Eq. (18) we can compute the net welfare gain from an increase in the domestic price.

Illustration with Saudi Arabia

For numerical illustration, we use data for Saudi Arabia for 2018 to compute the opportunity cost of oil in each of the cases examined in the previous section. We end the section with a discussion of their respective relevance.

Meeting domestic demand is mandatory, no other constraints

As depicted in Table 1, we begin our empirical analysis by applying data for Saudi Arabia to Eq. (9). Saudi Arabia presents some features that will impact the opportunity cost of its oil consumption: it is the world's largest exporter of oil, it administers its domestic price of oil, and meeting domestic demand is mandatory. We use crude oil data provided by the International Energy Agency for 2018 (IEA 2019). Global oil demand (g) is 99.21 million barrels per day (b/d), non-Saudi oil supplies (r) amount to 88.88 million b/d, and Saudi oil exports (x) amount to 7.23 million b/d. The corresponding price elasticities (i.e., ε_g, ε_r, *and* ε_x) are depicted in the upper panel of Table 2.

Price elasticities are not directly observable, and estimates vary widely across the literature. For the short-run global demand elasticity and supply elasticity of non-Saudi production, we use the estimates derived by Caldara et al. (2019), who reported two elasticity values obtained from different but complementary methods. The first is based on both the mean group estimator of Pesaran and Smith (1995) and instrumental variable (IV) panel regressions, which use exogenous drops in oil production as instrumental variables for oil prices. The results indicate a demand elasticity of -0.055, which, as stated by the authors, is a value in the ballpark of empirical estimates. In the second method, the IV results are used as restrictions on price elasticities to identify a structural vector autoregression of the global oil market. The results indicate a higher demand elasticity of -0.14. In this paper, we use both -0.055 and -0.14 to assess the sensitivity of our opportunity cost estimates to the price elasticity of oil demand.

Caldara et al. (2019) show that short-run oil supply elasticities for OPEC countries, excluding Saudi Arabia and non-OPEC countries, are 0.191 and -0.004, respectively. We, therefore, calculate a weighted average of these elasticities, with the weights being given by the shares of these two groups in non-Saudi global oil supply. This approach yields a short-run supply elasticity of 0.056 for non-Saudi oil production. Since there is no available estimate for the long-run elasticity of non-Saudi oil supplies in the literature, we assume that it is two times the short-run value obtained from Caldara et al. (2019): 0.112. We use the IMF's (2011) estimate of the long-run price elasticity of global oil demand (-0.35). Finally, we consider the above values and use Eq. (A.1) in the Appendix to obtain the elasticity of international demand for Saudi exports.

Table 2 shows that, without any constraint, the opportunity cost of oil for Saudi Arabia is highly sensitive to the value assumed for the price elasticity of global oil demand. In the long run, both supply and demand are more elastic, which results in a greater opportunity cost of oil.

As indicated in the previous sections, when there is no constraint on exports or production, the opportunity cost of oil is also given by the marginal cost of supplying oil to the domestic market.
The next subsection provides the corresponding numerical illustration since, when exports are constrained, the opportunity cost is the marginal cost of supplying oil.

Table 2. The opportunity cost of oil without constraint.

Type of elasticity	Short-run		Long-run
Global demand elasticity (ε_g)	-0.055	-0.14	-0.35
Supply elasticity of non-Saudi production (ε_r)	0.056	0.056	0.112
Elasticity of international demand for Saudi exports (ε_x)	-1.44	-2.61	-6.12
Opportunity cost as a percentage of the international price	30.6%	61.7%	83.7%

Exports are constrained

We assume here that constraints on exports are binding in 2018. As a result, the opportunity cost of oil cannot be directly computed using Eq. (7) for 2018. We therefore estimate the opportunity cost as the marginal cost of supplying oil to the domestic market.

The economic value of a barrel of reserve oil is the present value of the profit that will be generated by the production of the last remaining barrel of reserve. According to the BP Statistical Review (BP 2019), the reserves-to-production ratio for Saudi Arabia is 66 years as of the end of 2018. On the other hand, the most distant institutional forecast for the oil price is for the year 2050. We assume that export constraints will no longer be binding by 2050. The opportunity cost of oil in 2050 is, therefore, assumed to be the percentage value calculated in Table 2 times the price of oil in 2050. The U.S. Energy Information Administration (EIA) projects a price of US$108 per barrel (in 2018 US$) in 2050 in its Reference Scenario (EIA 2019a).

In April 2019, Saudi Aramco announced the establishment of its Global Medium-Term Note Program and published a base prospectus showing that the company's average upstream operating expenditure was US$2.8 per barrel of oil equivalent produced in 2018. Furthermore, in the same year, its upstream capital expenditures averaged US$4.7 per barrel of oil equivalent (a fully detailed prospectus is available from Saudi Aramco [2019]). This gives a total cost of US$7.5 for producing a barrel of oil reserve. We use the same figure for the year 2050. In line with the value determined by Pierru and Matar (2014) for Saudi Arabia, we use a discount rate of 4%. By applying Eqs. (7) and (8) to the year 2050, and assuming that the short-run price elasticity of global demand is -0.14, the economic value of a barrel of reserve in 2018 is:

$$\frac{0.617\times108-7.5}{(1.04)^{32}} = 16.9 \text{ US\$}$$

The above value decreases to US$7.4 per barrel when the short-run price elasticity of global demand is assumed to be -0.06. Adding the total production cost per barrel to the economic value of a barrel of reserve gives an opportunity cost of a barrel of oil of between US$14.9 and US$24.4.

Production is constrained

As discussed above, the formula given in Eq. (9) provides a convenient means of computing the opportunity cost of oil when production is constrained. Hence, the same results reported in Table 2 hold in this case.

Discussion of the opportunity cost estimates

Table 3 summarizes the numerical results we obtained in this study. To pick up a particular value from Table 3 requires knowing the constraints to which Saudi Arabia's oil sector is subjected. To a large extent, these constraints depend on decision-makers' views and strategies. In addition, they might change over time. We will, therefore, limit ourselves to the following few remarks.

Table 3 suggests that, when the project has only a short-lived impact on domestic oil demand, the opportunity cost of oil lies between US$14.9 and US$43.8 per barrel. Narrowing the range requires making an assumption regarding the absence (or existence) of constraints on production. Saudi Arabia's production was below its OPEC allocation of 10.06 million b/d (IEA 2019; OPEC 2019) until June 2018, and above it for the rest of the year. At the 175th OPEC Meeting on December 6-7, 2018, it was decided to increase Saudi Arabia's quota to 10.31 million b/d from January 2019. Since then, Saudi oil production has been below its OPEC quota. These figures suggest that, most of the time, Saudi oil production has been below the OPEC allocation, and therefore the constraint has not been binding.

Even in the case that production had been constrained, if the project has only an immediate impact on oil demand, the price elasticity of global demand is likely smaller than the figures assumed in our calculations (since they are estimated using monthly data), which could result in an opportunity cost of oil below US$20 per barrel. We find an opportunity cost of oil below US$20 per barrel when the absolute value of the price elasticity of global demand is smaller than 0.05.

If we switch to a long-run perspective, we must consider projects that have long-lasting impacts on domestic oil demand, such as investments in energy efficiency or renewables. The range of possible values for the opportunity cost of oil is broader than that estimated for the short run, at between US$14.9 and US$59.4 per barrel in 2018, based on the figures in Table 3. The cost imposed by a constraint on production that persists, in the long run, is high (and greater than the cost imposed by a constraint that would only persist in the short run). This explains the broad range of values and reinforces the need to understand which constraints may be binding in the future.

Table 3. The opportunity cost of oil under various assumptions.

Opportunity cost (US$ per barrel)		Case
22 [a] – 43.8[a]	(with short-run elasticity)	- No other constraints
59.4[a]	(with long-run elasticity)	- Constraint on production
14.9 – 24.4		- No other constraints
		- Constraint on exports [b]

Notes: [a] For the international oil price, we consider the average Brent price FOB, US$71 per barrel in 2018 (EIA 2019b). [b] Results are derived under the assumption that export constraints will no longer be binding by 2050.

Net welfare gains from reforming the domestic oil price

We now use Eq. (18) to estimate the net welfare gains that can be obtained by increasing the domestic oil price by US$1 per barrel (i.e., increasing *b* by 1). To do so, we need to know the administered price of a barrel of oil (i.e., π) and the elasticity of domestic oil demand in Saudi Arabia (i.e., ε_q), along with some of the elasticity and quantity data used so far in this paper.

Table 4 presents the domestic prices of crude oil in Saudi Arabia in 2018 and the consumption levels of crude oil and oil products in 2017 (as data for 2018 are not yet available at the time of writing).

Since petroleum products are derived from crude oil, to get the administered prices of a barrel of crude oil corresponding to each product's administered price, we subtract the refining costs from the administered price. We use Haverly's Crude Oil Management Evaluation Tool (H/COMET) and the Nelson-Farrar Refinery Cost Index to compute the capital expenditure (capex) per barrel of crude oil for each refinery. Next, we consider several industry-standard benchmarks to obtain the operating expenses (opex) per barrel of crude oil for each refinery. Maintenance costs are assumed to be 3% of capex. The insurance cost is 1.5% of capex and is obtained from AspenTech. The labor cost is US$41,000 per person per year and is obtained from QUE$TOR. We do not describe the steps for calculating capex and opex in detail, which is beyond the scope of this paper.

We take the weighted averages of refinery-level expenditures separately for capex and opex, with the weights being given by the refinery capacities. Capex and opex are found to be, respectively, US$0.58 per barrel and US$1.43 per barrel, which implies a total cost of US$2.01 per barrel. Hence, we subtract US$2.01 from the fuel prices presented in Table 4 (except for crude oil prices). Finally, taking the average of the resulting prices weighted by consumption levels, we find the administered price of a barrel of oil to be US$26. This result is close to the figure of US$27 published by Jadwa Investment (2018).

There is no available estimate of the elasticity of Saudi Arabia's oil demand with respect to its domestic price. We therefore use Atalla et al. (2018) who, using structural time series modeling technique, find that the price elasticity of gasoline

Table 4. Domestic prices and consumption levels of petroleum products.

Fuel type	Price (US$/b)	Consumption (million b/d)
Gasoline	58.03 (low grade), 86.49 (high grade)	0.6
Diesel	19.07 (transport), 16.15 (industry)	0.48 (transport), 0.09[a]
Fuel oil	4.25 (180 cst), 3.8 (380 cst)	0.48
Kerosene	25.7	0.1
Crude oil	6.35 (Arab light), 4.4 (Arab heavy)	0.39[a], 0.07[b]

Notes: [a] Consumption in electricity generation and seawater desalination. [b] Consumption in other industries.
Data sources: Saudi Aramco (2018), ECRA (2018), MEIM (2018), and APICORP (2018).

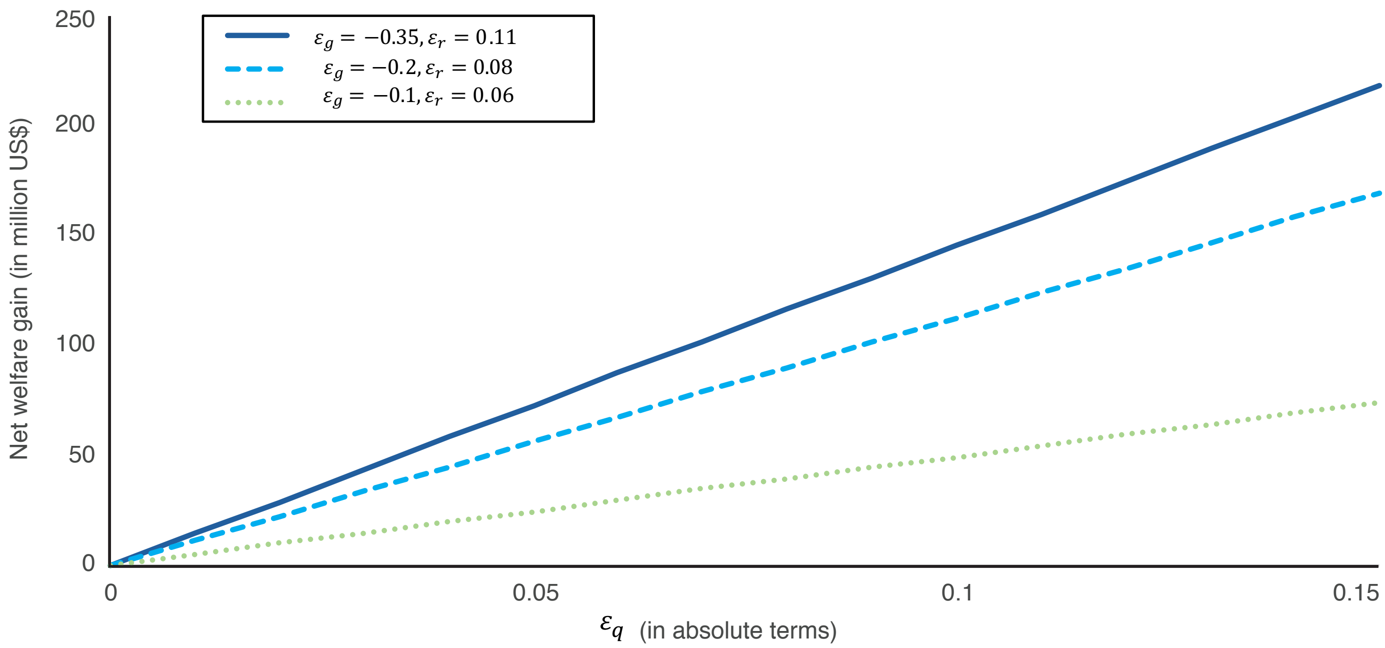
demand in Saudi Arabia is –0.1 in the short run, while it is –0.15 in the long run. In the absence of elasticity estimates for the other petroleum products in Saudi Arabia, we use these values for the price elasticity of crude oil demand. We consider that Saudi oil exports have not been constrained: $\beta_t=\omega_t=0$. We now plug all numerical values into Eq. (18). The results are shown in Figure 1.

An energy price reform has long-term price effects. We therefore consider long-run price elasticities. Figure 1 suggests that increasing the domestic price of a barrel of oil by US$1 results in a net welfare increase that could reach US$200 million.

Atalla et al. (2018) studied the welfare implications of the increase in Saudi Arabia's administered price of gasoline at the end of December 2015 and found a net annual gain of between US$360 million and US$500 million, depending on the price elasticity of gasoline demand. When converted to a US$1 increase in the domestic oil price, these figures correspond to US$61 million and US$85 million for ε_q=-0.1 and ε_q=-0.15, respectively. Note that these welfare gains are obtained solely from changes in domestic gasoline consumption.

Matar et al. (2015) assumed end-user prices do not change and investigated the welfare implications of deregulating intersectoral fuel transfer prices. The result represents a net annual economic gain of US$230 million for a domestic price increase of US$1. It is derived from a long-term static framework (where firms and utilities can build new equipment) and includes the economic gain from deregulating the price of natural gas (but not that of gasoline). Overall, the findings from the two previous studies are in line with our welfare results.

Figure 1. Net annual welfare gains from increasing domestic price by US$1 per barrel.



Source: Authors' calculations.

Conclusions

We have developed a framework estimating the opportunity cost of oil for an oil-exporting country. Our partial-equilibrium setting allows us to derive analytical formulas that can be easily used in practice. The first step is to understand the constraints that the country's oil sector is facing.

We have shown that the opportunity cost of domestic oil consumption depends on various factors, including the constraints to which the oil producer is subject and the domestic oil pricing scheme. We have used 2018 data for Saudi Arabia to illustrate the implementation of our results. We find that for a project with a short-term impact on domestic oil demand, the opportunity cost of a barrel of oil likely ranges between US$15 and US$25. For a project that has a long-lasting impact on domestic oil demand, such as an investment in energy efficiency or renewables, the range of possible values for the opportunity cost of oil is broader and very sensitive to the existence of constraints on production. It should be noted that the domestic demand for oil can be influenced by economic distortions in other sectors of the economy, which can bias the estimation of the opportunity cost.

Our framework allows us to assess the welfare implications of an increase in the domestic oil price. It also provides some information on what domestic price would be the most efficient. Our results show that increasing the domestic price of a barrel of oil by US$1 in 2018 would have generated an annual increase in net welfare as high as US$200 million.

This study aims to serve as a reference point for valuing oil from a public perspective for resource allocation, project selection, and policymaking in oil-exporting countries. Besides being an export earner, oil is sometimes seen as a tool for economic development. For instance, it can be used as an input in projects that contribute to economic diversification (which lessens a country's dependence on oil revenues). The economic diversification benefits attributable to these projects are then directly included in the projects' net present value calculation (Pierru and Matar 2014). The oil used in these projects has to be valued at the opportunity cost, such as determined in this paper.

Other views can be brought forward to consider potential additional dimensions to the question. One consideration would be the role of national oil companies (NOCs) in oil-exporting countries. In general, NOCs are viewed as strategic partners that have a social mandate to meet and thus follow noncommercial objectives (see, for instance, Eller et al. [2011]; Hartley and Medlock III [2008], [2013]). Similarly, Dale and Fattouh (2018) argue that the value of oil should be determined not only based on its extraction cost (i.e., the private cost) but also according to the social costs that it incorporates as public services are financed by oil revenues. Studying these kinds of welfare effects would go beyond the partial equilibrium framework used here.

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Appendix: Derivation of ε_x

Let us denote (omitting the time subscripts) the price elasticity of international demand for the Producer's oil exports by ε_x, with $\varepsilon_x = \frac{\Delta x}{x}\frac{P}{\Delta P}$.

Note that if ε_w is the price elasticity of the rest of the world's oil demand, with $\varepsilon_w = \frac{\Delta w}{w}\frac{P}{\Delta P}$, and ε_r is the price elasticity of non-Producer oil supplies, with $\varepsilon_r = \frac{\Delta r}{r}\frac{P}{\Delta P}$, we have:

$$\varepsilon_x = \frac{\Delta x}{x}\frac{P}{\Delta P} = \frac{\Delta w - \Delta r}{x}\frac{P}{\Delta P} = \frac{w\frac{\Delta w}{w}\frac{P}{\Delta P} - r\frac{\Delta r}{r}\frac{P}{\Delta P}}{x} = \frac{w\varepsilon_w - r\varepsilon_r}{x} \qquad (A.1)$$

As in Pierru et al. (2018) we can also write $\varepsilon_x = \frac{\varepsilon_w - (1-\rho)\varepsilon_r}{\rho}$ where ρ is the market share of the Producer's export in the rest of the world (i.e., $\rho = \frac{x}{w}$).

In addition, let ε_q be the elasticity of domestic oil demand with respect to the domestic price, that is: $\varepsilon_q = \frac{\Delta q}{q}\frac{\pi}{\Delta \pi}$. If ε_g is the elasticity of global oil demand *g=w+q* with respect to the international price, we have:

$$\varepsilon_g = \frac{\Delta g}{g}\frac{P}{\Delta P} = \frac{\Delta w}{g}\frac{P}{\Delta P} + \frac{\Delta q}{g}\frac{P}{\Delta P} \qquad (A.2)$$

Since $\Delta\pi = a\Delta P$, we have:

$$g\varepsilon_g = w\frac{\Delta w}{w}\frac{P}{\Delta P} + aq\frac{P}{\pi}\frac{\Delta q}{q}\frac{\pi}{\Delta \pi} \qquad (A.3)$$

which gives:

$$\varepsilon_g = \frac{w\varepsilon_w + aq\frac{P}{\pi}\varepsilon_q}{g} \qquad (A.4)$$

Finally, Eq. (A.1) can be written as:

$$\varepsilon_x = \frac{g\varepsilon_g - aq\frac{P}{\pi}\varepsilon_q - r\varepsilon_r}{x} \qquad (A.5)$$

Notes

Notes

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