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Taxing crude oil: A financing alternative to mitigate climate change?

Arturo Antón

Tecnologico de Monterrey, School of Social Sciences and Government, Av. Carlos Lazo 100, Santa Fe, Mexico City, 01389, Mexico

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ABSTRACT

To date, global cooperation has not provided enough funds to counter climate change, as evidenced by the Green Climate Fund experience. Based on this fact, this document evaluates the revenue potential of an international tax on crude oil to finance programs to mitigate climate change. For this purpose, a dynamic, general equilibrium model for the world economy with two regions is proposed. One region is a net importer of oil, while the other is an exporter. In the model, oil exports are subject to a permanent per-barrel tax. Short- and long-run revenue projections are offered under alternative assumptions. Some exercises suggest that the resources generated from a $5 per-barrel tax on 25% of world oil exports would amount to $18.4 billion dollars in the initial year. To implement such policy at the international level, an "Oil and Climate Club" is proposed, where revenues from oil taxation would be allocated to funding environment-friendly programs. The paper includes a discussion on how to make the club's rules consistent with international trade laws.

1. Introduction

Greenhouse gas (GHG) emissions represent a global risk due to their adverse effects on climate and the well-being of present and future generations. For several years now, these concerns have been addressed at the conferences of the parties to the United Nations Framework Convention on Climate Change (UNFCCC). The current consensus at the global level is reflected in the Paris Agreement outlined in December 2015, which aims to contain GHG emissions. Not surprisingly, the fulfillment of this goal requires considerable and stable resources over time. In this regard, developed countries have proposed the creation of a fund of up to $100 billion per year by 2020 (UNFCCC, 2009). Governments have agreed that a large part of these resources be channeled to the Green Climate Fund, which is one of the institutions responsible for implementing the Paris Agreement. However, today, this goal is still far from being achieved. In its most recent document, the Fund reports contributions equivalent to only $10.2 billion.[1] Therefore, collecting resources with which to combat climate change has become a pressing need worldwide.

This article evaluates the revenue potential of a tax on crude oil with the aim of obtaining resources to mitigate climate change.[2] This estimate is not trivial, since it is required to consider how oil prices and exports respond endogenously to the tax, not only at the time of its implementation but also over time. For this purpose, a dynamic, general equilibrium model inspired by Nakov and Nuño (2013) is proposed. Unlike the work of these two authors, the current model has two regions: a crude oil-exporting region and an importing region. In the model, oil production in the exporting region is entirely destined for consumption in the importing region, which does not produce oil. Thus, a tax on oil exports is equivalent to a tax on production. By construction, both the equilibrium oil price and exports are determined endogenously as a function of the tax and other parameters. As far as is known, there are no such estimates available in the literature.

In the model, the crude oil-exporting region is represented by the major oil net exporters. These countries comprise 94% of worldwide oil exports, as detailed below. The rest of countries encompass the importing region. The simulations assume that the global economy with no tax is initially at steady state. Then, a per-barrel tax on oil exports is introduced permanently, so that the economy transits to a new steady state. Given the equilibrium path of exports, oil revenues can be estimated for a given per-barrel tax. To give an empirical content to the analysis, it is also assumed that the initial price of a barrel of oil is $60 and that initial global exports are equivalent to the levels observed in the year 2016, which is the most recent data available. Oil revenues are computed over time under the assumption that world GDP, oil prices and exports grow at their long-run trends. Projections are made under

E-mail address: arturo.anton@tec.mx.

[1] Green Climate Fund, "Status of Pledges and Contributions Made to the Green Climate Fund," January 24, 2019.

[2] The idea of a tax on oil production and/or exports as a source of financing for sustainable development has been raised by the economist Herman Daly and the Former Ecuadorian President Rafael Correa, among others. For this reason, this tax is known as the "Daly-Correa tax" in certain circles.

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alternative values for the price elasticity of oil demand and supply, and per-barrel taxes equivalent to $1 and $5.

Simulations suggest that oil revenues could be significant. For example, a tax of $1 per barrel would raise $7.4 billion dollars after the first year of implementation, assuming that 50% of worldwide exports are taxed. In real terms, revenues increase gradually over time so that tax collection would amount to between $12.9 and $13 annual billion dollars after 20 years, depending on the value for the price elasticity of demand. On the other hand, if the tax is $5 per barrel and only 25% of global exports are taxed, total revenue after the first year would amount to $18.4 billion dollars. After 20 years, this figure in real terms would increase to between $31.3 and $32.3 annual billion dollars. Compared to what has been raised to date by the Green Climate Fund, these are not negligible numbers.[3] Of course, these results would change if the assumptions on long-run trends for world GDP, oil prices and quantities were different. However, these estimates provide a rough idea of the potential from taxing crude oil exports.

Given the difficulties observed in the past for reaching effective international agreements to fight climate change, the paper discusses a proposal on how these revenues might be obtained. This proposal is based on the premise that international environmental cooperation is subject to free-riding (see, for example, Gollier and Tirole, 2015; Nordhaus, 2015; and Stiglitz, 2015). As discussed by Nordhaus (2015), an effective way to combat the free-rider problem at the global level is through the formation of clubs involving a limited number of countries.[4] Based on these ideas, a voluntary "Oil and Climate Club" is proposed, with the goal of raising revenues through a tax on crude oil aimed at financing programs to mitigate climate change. Specifically, club members that are oil exporters would set a tax on their own oil exports, and oil-importing countries would tax oil imports from non-member countries. A scheme defining how these revenues are shared is also discussed, including the possibility of making transfers to an international fund such as the Green Climate Fund. Given that such proposal might be against the Most Favored Nation (MFN) principle under international trade law, the paper also discusses how this proposal might be compliant with WTO rules.

Finally, the paper identifies pivotal countries for the eventual formation of an "Oil and Climate Club". According to data, only 19 export and import countries account for 42.3% of global oil trade, including relevant players such as the US, China, India, Saudi Arabia and Russia. As emphasized by some authors (Falkner, 2016; Hovi et al., 2016), the existence of a small but influential group of countries might be crucial for the creation of the club.

The remainder of the document is organized as follows. Section 2 presents the model used for the analysis. Data and parameter values are discussed in section 3. The main results are presented in section 4, whereas section 5 discusses the proposal of the "Oil and Climate Club" in detail, including some alternatives that would make the club compliant with international trade laws. Finally, section 6 offers some conclusions.

[3] As previously mentioned, the Green Climate Fund reports contributions to date of $10.2 billion. The Paris Agreement of 2015 ratified the goal of $100 billion per year in contributions from developed countries through 2025. Prior to 2025, the Conference of the Parties will set a new goal from a floor of $100 billion per year (UNFCCC, 2016).

[4] A club coalition is successful to the extent that the benefits of membership outweigh the costs involved in joining the club. To determine the net benefits of membership, it matters not only the number of members but also who they are. Nordhaus (2015) and Hovi et al. (2017) provide interesting simulations on how net benefits and GHG emissions are affected under alternative "climate club" memberships, including key players such as the US, China and the European Union.

2. The model

The present model is inspired in Nakov and Nuño (2013). Unlike that work, in this case, two groups of countries are considered: oil producers and oil importers. All the production of the former group is exported to the importing region, which produces no oil. Under these assumptions, a tax on oil exports would be equivalent to a tax on oil production.

2.1. Oil-importing region

Households in this region are identical. The utility of the representative household at time t is a function of consumption C_t, leisure L_t, and oil O_t. Following the specification proposed by Nakov and Nuño (2013), this function is given by:

$$U(C_t, O_t, L_t) = \log(C_t) + \frac{\nu_t O_t^{1-\eta}}{1-\eta} - \frac{L_t^{1+\psi}}{1+\psi}, \tag{1}$$

where $\eta > 0$ is the inverse of the price elasticity of oil demand, and $\psi > 0$ is the inverse of the Frisch elasticity of labor supply. The term ν_t denotes efficiency in the use of oil in the importing region. The variable ν_t follows an exogenous path, which will be described in detail later.

The household earns some labor income $w_t L_t$, where w_t is the wage rate denominated in units of the consumption good C, which is the numeraire. It also receives capital revenue $r_t K_{t-1}$, where r_t is the rental rate of capital K_{t-1}. This variable follows its usual law of motion, namely:

$$K_t = I_t + (1-\delta)K_{t-1}, \tag{2}$$

where I_t denotes gross investment and $\delta \in (0,1)$ is the depreciation rate of capital.

Let S_t denote the price of oil per unit of the consumption good. Accordingly, the household budget constraint can be written as:

$$C_t + I_t + S_t O_t = w_t L_t + r_t K_{t-1}. \tag{3}$$

The household's problem is to choose quantities $\{C_t, O_t, L_t, I_t, K_t\}_{t=0}^{\infty}$ to maximize its lifetime utility, namely:

$$\max_{\{C_t, O_t, L_t, I_t, K_t\}} \sum_{t=0}^{\infty} \beta^t U(C_t, O_t, L_t),$$

subject to expressions (1)–(3) and an initial level of capital $K_{-1} > 0$. The discount factor β satisfies $\beta \in (0,1)$

From first-order conditions, oil demand and labor supply may be written as:

$$O_t = \left(\frac{\nu_t C_t}{S_t}\right)^{\frac{1}{\eta}}, \tag{4}$$

$$L_t = \left(\frac{w_t}{C_t}\right)^{\frac{1}{\psi}}. \tag{5}$$

The final good Y_t is produced by identical firms in a competitive framework. The technology is represented by a Cobb-Douglas production function:

$$Y_t = (Z_t L_t)^{\alpha} K_{t-1}^{1-\alpha}, \tag{6}$$

where Z_t is an exogenous productivity variable and parameter α satisfies $\alpha \in (0,1)$. Productivity Z_t is deterministic and grows at a constant rate given by $\exp(g^z)$, with $g^z \equiv \log(Z_t / Z_{t-1})$.

The standard profit maximization problem yields optimal demand for labor and capital:

$$L_t = \frac{\alpha Y_t}{w_t}, \tag{7}$$

$$K_{t-1} = \frac{(1-\alpha)Y_t}{r_t}. \tag{8}$$

Finally, it may be shown that the resource constraint of the region is represented by:

$$C_t + I_t + S_t O_t = Y_t.$$

2.2. Oil-exporting region

Oil production O_t^* is carried out by identical firms in a context of perfect competition.[5] The typical firm requires intermediate inputs X_t and capital K_{t-1}^*. In this case, technology is represented by a Cobb-Douglas production function:

$$O_t^* = Z_t^* X_t^{\gamma} K_{t-1}^{*,1-\gamma}. \tag{9}$$

In expression (9), $\gamma \in (0,1)$ is a parameter related to the price elasticity of supply, as detailed below. At the same time, Z_t^* denotes the exogenous productivity in oil production. This productivity is deterministic and evolves over time according to the expression $Z_t^* = Z_0^* \exp(g^{z^*} t)$, with $g^{z^*} < 0$. The intermediate input X_t is provided by the oil-importing region, while capital K_{t-1}^* is offered by households in the exporting region at a rent price r_t. As mentioned at the beginning of this section, all oil produced is exported.

Oil exports are subject to a tax τ per unit of production. Accordingly, the representative firm must choose inputs to maximize after-tax benefits:

$$\max_{\{X_t, K_{t-1}^*\}} \left[(S_t - \tau) Z_t^* X_t^{\gamma} K_{t-1}^{*,1-\gamma} - X_t - r_t K_{t-1}^* \right]$$

From first order conditions, optimal input demands are given by:

$$X_t = \gamma (S_t - \tau) O_t^*, \tag{10}$$

$$K_{t-1}^* = \frac{(1-\gamma)(S_t - \tau) O_t^*}{r_t}. \tag{11}$$

After substituting equation (10) in the oil production function (9), the short-run oil supply curve is obtained by:

$$O_t^* = [\gamma (S_t - \tau)]^{\frac{\gamma}{1-\gamma}} (Z_t^*)^{\frac{1}{1-\gamma}} K_{t-1}^*. \tag{12}$$

From (12), it can be shown that the price elasticity of oil supply, ε_s, with $\tau = 0$ is constant and equal to $\gamma/(1-\gamma)$.

On the other hand, the lifetime utility of the representative household is expressed as follows:

$$U^* = \sum_{t=0}^{\infty} \beta^t \log(C_t^*). \tag{13}$$

The household rents its capital to firms and receives a lump-sum transfer T_t from the government. This income is allocated to consumption and investment. Its budget constraint is thus given by:

$$C_t^* + I_t^* = r_{t-1} K_{t-1}^* + T_t, \tag{14}$$

where I_t^* is gross investment. The law of motion of capital is standard, namely:

$$K_t^* = I_t^* + (1-\delta) K_{t-1}^*. \tag{15}$$

In this framework, the representative household's problem consists of choosing consumption, investment and capital to maximize (13) subject to (14) and (15), given an initial level of capital $K_{-1}^* > 0$.

The Euler equation for consumption corresponding to this problem is expressed as:

$$1 = \beta \left(\frac{C_t^*}{C_{t+1}^*} \right) \left[\frac{(1-\gamma)(S_{t+1} - \tau) O_{t+1}^*}{K_t^*} + 1 - \delta \right], \tag{16}$$

which is obtained after substituting equation (11).

2.3. Government

In this context, there is an international institution called "government". The only role of the government is to set a tax τ per unit of oil production and distribute lump-sum transfers T_t in units of the consumption good to the household of the oil-exporting country. The corresponding budget constraint is simply:

$$T_t = \tau O_t^*. \tag{17}$$

After substituting expression (17) into the household's budget constraint (14), it may be shown that the resource constraint in the oil-exporting region is simply:

$$C_t^* + I_t^* + X_t = S_t O_t^*$$

2.4. Market clearing and balanced growth path

Naturally, the market-clearing condition in the oil market is given by:

$$O_t = O_t^*$$

The corresponding condition for the goods market is:

$$Y_t = C_t + I_t + C_t^* + I_t^* + X_t.$$

As discussed, the model exhibits deterministic trends in the technology of both regions. Along the balanced growth path, the production function (9) dictates that oil must grow at rate $g^z + g^{z^*}$. Simultaneously, the ratio $S_t O_t / Y_t$ must be constant. Given that the growth rate of output Y_t is g^z, the oil price S_t must grow at rate $-g^{z^*} > 0$. Also, from first-order condition (4) it is inferred that oil efficiency ν_t evolves at rate $(\eta - 1)(g^z + g^{z^*})$ along the balanced growth path.[6]

Given that variables exhibit a trend over time, the model must be rewritten in terms of non-stationary variables to find a solution (see the Appendix for a non-stationary version of the model). Once the equilibrium path is obtained, oil price S_t and oil exports O_t can be recovered from their corresponding stationary paths s_t and o_t according to the expressions $S_t = s_t \exp(-g^{z^*} t)$ and $O_t = o_t Z_t \exp(g^z t)$. To avoid that τ decreases over time relative to price S_t, per-unit tax adjusts over time according to $\tau_t \equiv \tau \exp(-g^{z^*} t)$.

3. Data and calibration

Following Nakov and Nuño (2013), the model is calibrated on a monthly basis. Most of the parameters are set following typical values reported in the literature. The labor share α is fixed at 0.67, while the depreciation rate δ is set at $1.10^{1/12} - 1$, which is equivalent to a depreciation rate of 10% per year. The value for the discount rate β is fixed at $1.01^{-1/12}$, consistent with a rate of return for capital of 4% per year. Based on the findings of Keane and Rogerson (2012), the inverse of Frisch's elasticity, ψ, is fixed at 1. From Nakov and Nuño (2013), the growth rate of technology in the oil-importing region is set at $\exp(g^z) = 1.03^{1/12}$, which implies an average world output growth rate of 3% per year.

The oil-exporting region is defined by those countries with average

[5] In cases in which oil-importing and -exporting regions share similar variables, the latter are denoted with an asterisk.

[6] Not surprisingly, these conditions are also satisfied in Nakov and Nuño's model.

crude oil *net* exports of 100,000 barrels per day (bpd) or more in the years 2015–2016. Using information from the U. S. Energy Information Administration, there are 29 countries that satisfy such criterion.[7] The rest of countries comprise the oil-importing region. According to this data source, the average growth rate of crude oil imports from the oil-importing region is 1.4% per year for the period 1980–2016. Given the calibrated value for g^z and that oil grows at the rate $g^z + g^{z^*}$ in the balanced growth path, this implies setting $\exp(g^{z^*}) = 0.9987$.

Two parameters in the model require special attention: the price elasticities of oil demand and supply. In both cases, the empirical evidence is abundant, and a distinction can be made between short- and long-run estimates.[8] As discussed in Brook et al. (2004), the estimates for the price elasticity of demand can be sensitive to the econometric specification and the period of study. Although there is some consensus that long-run elasticities are greater than short-run elasticities, the range of estimates is broad, particularly for long-run estimates.

For the price elasticity of oil demand, Cooper (2003) uses a multiple regression analysis to estimate short- and long-run elasticities. The author uses annual data from 23 countries for the period 1971–2000. The results suggest that oil demand is quite inelastic in the short-run, with estimates typically between -0.02 and -0.11. As expected, long-run elasticities are generally higher (in absolute value), with values ranging between -0.03 and -0.57. In his literature review, Smith (2009) reports that short-run elasticities of -0.05 and long-run elasticities of -0.30 are typical estimates in the literature.[9] Recently, Caldara et al. (2019) and Baumeister and Hamilton (2019) estimate short-run price elasticities of -0.14 and -0.35, respectively. On the other hand, Gately and Huntington (2002) report a long-run price elasticity of -0.64 for a sample of OECD countries for the period 1971–1997. Based on this result, the OECD (2004) uses a long-run price elasticity of -0.6 for OECD countries in a model for the global oil market.

In relation to the price elasticity of supply, it is more difficult to provide reliable estimates due to the difficulty of distinguishing between the effects of resource depletion and technical innovation (Smith, 2009). Notwithstanding these difficulties, several authors report that the supply of conventional oil is very inelastic, particularly in the short run. In this regard, Kilian and Murphy (2012) estimate a short-run price elasticity of 0.026, whereas Caldara et al. (2019) and Baumeister and Hamilton (2019) find higher values (0.10 and 0.15, respectively). Gately (2004) uses short-run elasticities of between 0.03 and 0.05, and long-run elasticities of between 0.15 and 0.58. The OECD (2004) uses intermediate values of these intervals in a model for the global oil market; that is, 0.04 and 0.35 for the short and long run, respectively. On the other hand, Smith (2009) reports that the Energy Information Administration (EIA) works with even more inelastic supply curves, assuming values of 0.02 and 0.10 in the short and long run, respectively.

Based on this evidence, the model is calibrated under different values for the price elasticity of demand. Specifically, three alternative values are considered for parameter η: 10, 3.33, and 2. This corresponds to price elasticities (in absolute value) of 0.1, 0.30 and 0.5, respectively. Similarly, the parameter γ is alternatively set at 0.09 and 0.26, which imply price elasticities of supply of 0.10 and 0.35.

Regarding the productivity parameter in the oil-exporting region, Z^*, it is set so that the oil price s in the model with no taxes is 0.1 at the steady state.[10] Because Z^* is also a function of γ, two alternative values for Z^* are required. Specifically, $Z^* = 0.228$ is set for $\gamma = 0.09$, and $Z^* = 0.642$ is required for $\gamma = 0.26$. The oil efficiency parameter ν_0 is calibrated in such a way that the value of crude oil imports as a percentage of GDP in the oil importing region, sO/Y, is consistent with the data for the period 2015–2017. The value of crude oil imports for the oil-importing region is obtained from the United Nations' Comtrade Database. GDP from the oil-importing region is estimated from the World Bank Open Data. These numbers yield an average sO/Y ratio of 1.1%, which is the value used to estimate ν_0. Unless otherwise noted, numbers are reported in US dollars.

Finally, two alternative values for the per-unit tax on oil exports are considered. Given that $s = 0.1$ at the steady state, τ is set at $\tau_L = 0.0017$ and $\tau_H = 0.0083$. Translated in relation to oil prices observed in the data, a value of $\tau_L = 0.0017$ would be equivalent to a \$1 per-unit tax assuming an oil price of \$60 (\$1/\$60 = 0.017, which is the same as 0.0017/0.1). Similarly, $\tau_H = 0.0083$ would be equivalent to a \$5 per-unit tax if the oil price is \$60. Under this assumption, these taxes are reported as $\tau = \$1$ and $\tau = \$5$ hereafter.

4. Results

4.1. Dynamics of stationary variables

In this section, the paths of oil price and exports are presented after the introduction of a tax on oil exports. As is typical in this type of exercises, the assumption is that the world economy with no taxes is initially at steady state. Then, an unexpected, permanent tax on oil exports is set. As a result, endogenous variables transit gradually over time to a new steady state. As mentioned earlier, results are reported under alternative values for parameters η and γ.

Fig. 1 presents the effects of a \$1 per-barrel tax under alternative values for the price elasticity of demand. In these simulations, a low-price elasticity of supply is assumed. As expected, the price hike at the time the tax is introduced is larger if oil demand is more inelastic. For the case $\eta = 10$, the oil price jumps by 0.8% relative to its initial steady-state value at the time of the tax shock. In the long run, the oil price increases by 1.7% regardless of the value for η, implying that the tax incidence falls entirely into consumers. Consistent with the previous result, the fall in oil exports in the long-run is lower if the demand is more inelastic. Specifically, oil exports decrease by 0.17% if $\eta = 10$, and by 0.83% if $\eta = 2$.

The corresponding simulations under a \$5 per-barrel tax are reported in Fig. 2. Naturally, the effects on both oil price and exports are qualitatively similar but larger in magnitude. Recalling that such a tax represents 8.3% of the initial price (= 0.0083/0.1), the initial price hike of 4.2% under $\eta = 10$ implies that roughly 50% of the tax is borne by consumers in the oil importing region. As in the previous case, the tax incidence falls into consumers in the long-run.

The results assuming a more elastic labor supply ($\gamma = 0.26$) are qualitatively similar to those presented in Figs. 1 and 2, and hence are not reported here. As expected, the price hike at the time of the shock is now larger for all values of η. Therefore, the tax incidence on consumers is also higher. For a given per-barrel tax, the percentage change in the long-run oil price is the same irrespective of the elasticity of demand, and the fall in long-run oil exports is larger if demand is more elastic.

[7] These countries are the following: Algeria, Angola, Azerbaijan, Brazil, Brunei, Canada, Chad, Colombia, Republic of the Congo, Ecuador, Egypt, Equatorial Guinea, Gabon, Iran, Iraq, Kazakhstan, Kuwait, Libya, Malaysia, Mexico, Nigeria, Norway, Oman, Qatar, Russia, Saudi Arabia, United Arab Emirates, Venezuela and Vietnam. Exports from these 29 countries represent nearly 94% of world oil exports. The most recent data available is for the year 2016.

[8] For a detailed review of the literature on the price elasticity of oil demand, see Dahl (1993, 1995). For the price elasticity of oil supply, see Dahl and Duggan (1998) and Watkins and Streifel (1998). Brook et al. (2004) offer a summary on short- and long-run estimates of price elasticities of supply and demand. A more recent review of both elasticities can be found in Smith (2009).

[9] Huntington (2010) reports a long-run price elasticity of -1.54 for the United States. The same author recognizes that his estimation is quite uncertain, and the value obtained is not realistic.

[10] Given the parameter values described above, a steady-state solution is supported by low values for the equilibrium oil price s.

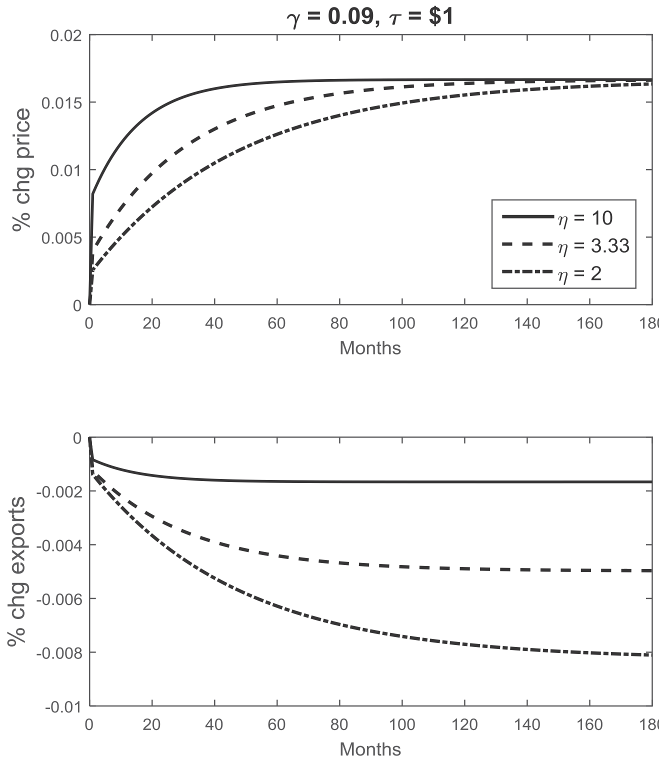

Fig. 1. Oil price and exports under a $1 per-barrel tax on oil exports (percentage change with respect to initial steady state).

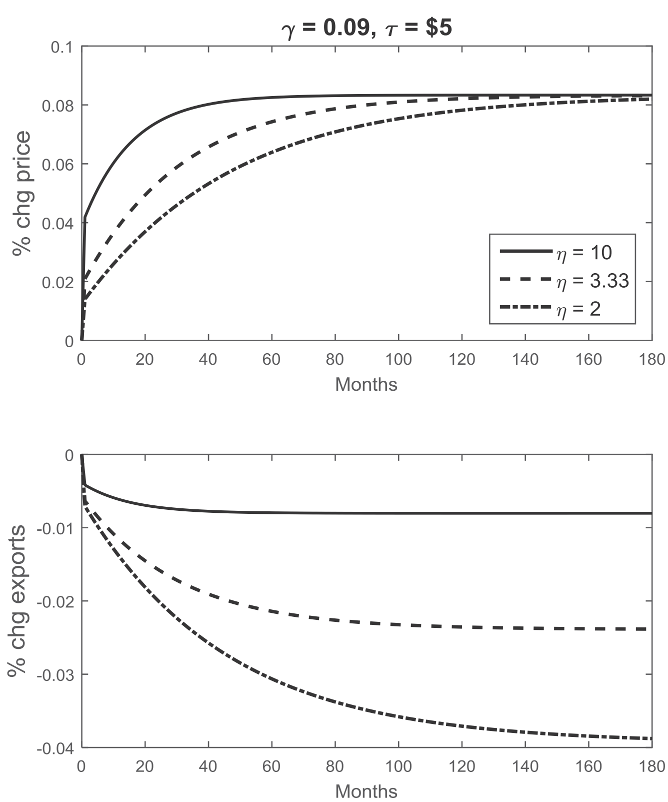

Fig. 2. Oil price and exports under a $5 per-barrel tax on oil exports (percentage change with respect to initial steady state).

4.2. Tax revenue

Tax revenue is simply computed as the per-barrel tax times oil exports. Given the equilibrium path o_t, (non-stationary) tax revenue R_t may be recovered from the expression $R_t = \tau_t o_t Z_t \exp(g^{z^*} t)$. To give an empirical content to the analysis, oil exports at the initial steady state are scaled to replicate the data. Information on exports from the oil-exporting region is obtained from the U. S. Energy Information Administration. The most recent data is only available for the year 2016. According to this source, total exports from the oil-exporting region average 40.7 million of bpd. Because tax revenues are reported on an annual basis, this number is multiplied by 360 to give total oil exports per year.

The results for tax revenues under alternative assumptions and per-barrel taxes are reported in Table 1. Only estimates for the supply elasticity parameter $\gamma = 0.09$ are reported, since simulations under the alternative value ($\gamma = 0.26$) yield similar results. The first panel assumes that all exports from the oil-exporting region are taxed. Clearly, this is an unrealistic assumption. However, this analysis is provided to give an idea of the revenue potential of the tax. For a tax of $1 per barrel, revenue is estimated in $14.8 billion dollars after the first year of implementing the tax. This revenue increases over time until reaching $26 billion dollars in the year 20 under the low-elasticity of demand scenario. Naturally, lower revenues should be expected as the demand is more elastic. However, the differences are not substantial.

For the $5 per-barrel tax scenario, revenues are significantly larger. After the first year of implementation, between $73.6 and $73.9 billion dollars are collected. In the year 20, revenues are almost 5 times larger than under the $1 per-barrel tax scenario.

The next two panels present revenue estimates assuming that only 50% and 25% of total exports are taxed. It may be easily verified that numbers are proportional to the results reported in the first panel. For a $1 per-barrel tax, revenues after 1 year would be between $3.7 and $7.4 billion dollars. These numbers would be roughly 5 times larger under the $5 per-barrel tax simulation.

In a framework where an international tax on oil exports is voluntarily adopted by a group of countries (see next section for details), the amount of the tax is crucial to incentivize cooperation. For example, it should be expected that a larger group of countries would be willing to

Table 1
Estimated oil tax revenues. (annual billion dollars in real terms).

	Tax: $1/barrel, $\gamma = 0.09$			Tax: $5/barrel, $\gamma = 0.09$		
	$\eta = 10$	$\eta = 3$	$\eta = 2$	$\eta = 10$	$\eta = 3$	$\eta = 2$
Year	Tax on 100% of oil exports					
1	14.85	14.84	14.83	73.94	73.69	73.59
5	16.70	16.65	16.62	82.96	81.89	81.18
10	19.36	19.29	19.24	96.17	94.67	93.38
15	22.44	22.37	22.30	111.48	109.71	108.04
20	26.01	25.93	25.84	129.24	127.17	125.18
Year	Tax on 50% of oil exports					
1	7.42	7.42	7.42	36.97	36.84	36.80
5	8.35	8.33	8.31	41.48	40.94	40.59
10	9.68	9.65	9.62	48.08	47.33	46.69
15	11.22	11.18	11.15	55.74	54.85	54.02
20	13.01	12.96	12.92	64.62	63.59	62.59
Year	Tax on 25% of oil exports					
1	3.71	3.71	3.71	18.49	18.42	18.40
5	4.17	4.16	4.16	20.74	20.47	20.29
10	4.84	4.82	4.81	24.04	23.67	23.35
15	5.61	5.59	5.57	27.87	27.43	27.01
20	6.50	6.48	6.46	32.31	31.79	31.29

Note: η is the inverse for the price elasticity of oil demand (in absolute value). Similarly, γ /(1 - γ) is the price elasticity of oil supply.
Source: Own elaboration.

cooperate if the tax is low, as compared to a situation where the tax is high. Based on this idea, suppose that countries mutually cooperate so that 50% of global oil exports can be taxed at $1 per barrel, but only 25% of oil exports can be taxed if the duty is $5 per barrel. According to the estimates provided in Table 1, revenue collected in year 1 would be between $7.4 and $18.4 billion dollars. These are non-negligible resources, especially if compared to what the Green Climate Fund has raised to date.

5. Is it feasible to implement a global tax on oil?

To date, global efforts to mitigate climate change have been insufficient. As pointed out by authors such as Nordhaus (2015) and Gollier and Tirole (2015), this situation is a clear example of the "tragedy of the commons" at the global level. Specifically, the atmosphere is a resource shared by all countries, in which CO_2 and GHG emissions can be thrown away. All countries would benefit from having a cleaner environment. However, a country acting in isolation does not have enough incentives to decrease its own GHG emissions. This is because the costs of such policies are borne by the individual country, but the benefits are shared by all. To date, international agreements such as the Kyoto Protocol and the more recent Paris Agreement have been unsuccessful to solve this free-riding problem (Cramton et al., 2015; Gollier and Tirole, 2015; Nordhaus, 2015). The reason is that pledges made by individual countries are essentially voluntary, and not subject to punishment in the event of non-compliance. Therefore, a global tax on oil exports based on voluntarism with no punishment for defectors would be doomed to failure.[11]

In this context, Nordhaus (2015) has proposed a "Climate Club" to overcome the free-riding problem for the provision of the global public good, namely, a cleaner environment.[12] What distinguishes a club from other type of voluntary arrangements is that club members can obtain mutual benefits from sharing the cost of contributing to the public good.

Translating this general idea to the issue analyzed here, a tax on crude oil exports would be implemented through an "Oil and Climate Club". The goal of this voluntary club would be to raise resources through a uniform tax on crude oil exports to fund programs aimed at mitigating climate change. This club would be constituted by countries that either import or export oil (or both, such as the United States). For club members, oil exports to oil-importing countries would be subject to a uniform tax (per-barrel or ad-valorem) previously agreed. The revenue would be collected by the oil-exporting economy. A given percentage of the revenue would be allocated to programs aimed at mitigating climate change within the oil-exporting country. If this country is either a developed or middle-income economy, the remaining share of revenue would be transferred to an international fund (e. g., the Green Climate Fund) to finance mitigation programs in less-developed countries.[13] Naturally, this contribution should be large enough to motivate low-income countries to join the club.

To incentivize cooperation, oil-importing countries would set a tax on oil imports from countries outside the club.[14] This tax would be at least similar in magnitude to the one imposed in oil-exporting countries that belong to the club. If oil is taxed, the oil-importing country would have the right to a share of the revenue collected to finance environmental programs in its own country.[15] This revenue share should be the same among club members. Similar to the case of oil-exporters, the remaining revenue would be allocated to (say) the Green Climate Fund if the oil-importing country is either a developed or middle-income economy. If the oil-importing economy is a low-income one, all the collected revenue would be used to fight climate change in its own nation.

From the previous discussion, it is evident that oil-exporters can always have the option to avoid the tax entirely by exporting exclusively to countries that do not belong to the club. This is a clear example of "leakage", where oil exports may be diverted to non-member countries. To increase the costs of non-cooperative behavior, an agreement among club members could be made so that countries outside the club cannot have access to the resources of the recipient international fund. In this manner, such resources would be only available for club members.

The natural concern is the feasibility of such an arrangement under international laws, especially under the WTO rules. From the perspective of the oil-exporting country, it is important to clarify that export taxes are not prohibited by the WTO. GATT Article XI bans imports or export restrictions "other than duties, taxes or other charges". In fact, according to Piermartini (2004) about one third of WTO members make use of export taxes. However, an oil-importing country with club membership imposing differentiated taxes on oil imports (zero taxes to member countries, and positive taxes to non-members) would be in a clear violation of the MFN principle, which is a cornerstone of the international trade system.

In this regard, there are at least three arguments under which the "Oil and Climate Club" proposal might avoid violating the MFN principle. The first argument is raised by Stiglitz (2006): club members would agree that the oil-export tax required to price the environmental externality is just an additional cost of doing business. Therefore, an oil-producing country that does not impose a tax on crude oil would be in fact subsidizing their own firms. Export subsidies are prohibited by the WTO, and thus oil imports from countries outside the club would be subject to legal countervailing duties. Even though this is a solid argument from an economic perspective, it is not at all clear that it abides by the WTO rules (see Pauwelyn, 2013, for a thorough explanation). Therefore, the consistency of such argument with WTO rules remains to be tested.

Based on the literature on carbon markets, a second option would be to establish the club through a WTO Annex 4 agreement (ICTSD, 2016). Annex 4 contemplates plurilateral trade agreements that allow a subset of WTO members to sign issue-specific negotiations with rights and obligations exclusive for signatories. Under such agreements, club members are not obliged to grant MFN treatment to non-club members. A potential disadvantage of this proposal is that it requires consensus of the WTO Ministerial Conference for approval (Draper and Dube, 2013). Therefore, the agreement might be subject to opposition from those countries not interested in joining the club.

A third option to avoid violating the MFN principle is by invoking GATT Article XX section g (Pauwelyn, 2013; Mavroidis and de Melo, 2015). This article allows exemptions to the MFN principle if trade measures are related to "the conservation of exhaustible natural resources". In this regard, it might be claimed that clean air is an "exhaustible natural resource". In fact, the WTO in the past has validated restricting trade measures by invoking Article XX(g). A complementary

[11] Gollier and Tirole (2015), Weitzman (2015) and Cramton et al. (2015), among others, have emphasized the relevance of reciprocity (rather than unilateral voluntarism) for successful cooperation, especially in contexts where the free-riding problem is present. Of course, the lack of monitoring and enforcement institutions at the global level are also important factors that exacerbate countries' free-riding behavior.

[12] For a literature review on climate clubs, see Hovi et al. (2016).

[13] Gollier and Tirole (2015), Stiglitz (2015) and Cramton et al. (2015) underscore the importance of a mechanism for side transfers in an international negotiation of this sort.

[14] The idea of imposing trade sanctions on non-participants in environmental agreements is raised by Barrett (1997), Stiglitz (2006), Lessmann et al. (2009), Metcalf and Weisbach (2009), and Nordhaus (2015), among others.

[15] Major oil importers in the developed world such as the United States, Japan, South Korea, Germany, Spain, Italy and France are also among the major emitters of carbon dioxide (International Energy Association Atlas of Energy). Allowing these economies to receive a share of the revenue to fund programs to mitigate climate change in their own countries would not only be incentive-compatible but also presumably more effective to fulfill the club's goal.

step would be to demonstrate a connection between the tax on oil imports and the protection of clean air. Of similar importance would be to prove that such policy is consistent with other related domestic measures (see Pauwelyn, 2013, for details).

Overall, this discussion has provided some alternatives under which the rules of the "Oil and Climate Club" might be consistent with international trade laws. Given that each of these alternatives can be subject to objections by threatened countries, a set of "climate amendments" might be necessary to avoid retaliation and simultaneously make WTO rules more sympathetic to the environment (Nordhaus, 2015).

To illustrate what set of countries might integrate the "Oil and Climate Club", Table 2 presents selected crude oil imports of the 12 world largest importers in 2017, as a share of global oil imports. Data are collected from the UN Comtrade Database. Information is classified into three major oil exporting regions/countries: Middle East (Kuwait, Oman, Saudi Arabia and United Arab Emirates), Developed countries (Canada, Netherlands, Norway, United Kingdom and United States), and Russia. This nation is included because it is the second largest oil exporter. Note that all countries listed in Table 2 belong to the WTO.[16]

The first number in the table indicates that Chinese imports of crude oil from the Middle East region (as defined above) represent 5.1% of world imports. The row "Total" reports that oil imports of the largest 12 importers from the Middle East and Developed regions, and Russia represent 22.5%, 12.3% and 7.5% of world imports, respectively. This means that 42.3% of global oil trade is made by this small but influential group of 19 countries.[17] Even if China, India and Russia are excluded, the remaining countries still capture 25.7% of world oil imports. Using the numbers reported in section 4, these remaining countries would raise slightly more than $18.4 billion dollars in the initial year under a $5 per-barrel tax.

It is not at all clear how an "Oil and Climate Club" might be formed. In fact, the discussion above does not imply that a club of this nature would be relatively easy to create, or that it would be integrated exclusively by such countries. In this regard, it is possible that coordinated actions taken by a group of "enthusiastic" countries might permeate to "reluctant" countries (Hovi et al., 2016). This might be especially important for countries belonging to the European Union. On the other hand, as discussed by Hovi et al. (2016), pivotal founding members would probably be those with large economies and high GHG emissions. For all these reasons, a club with significant influence and impact to mitigate climate change would arguably need the leadership of some or all the key players identified in Table 2.

Table 2
Crude oil imports of major importers from selected regions in 2017. (% of world oil imports).

	Middle East	Developed	Russia	Total
China	5.1	0.9	2.8	8.8
United States	2.5	6.4	0.1	9.0
India	3.1	0.1	0.2	3.3
Japan	5.4	0.1	0.4	5.9
South Korea	3.6	0.3	0.3	4.2
Germany	0.0	1.2	1.4	2.7
Netherlands	0.2	0.9	1.1	2.2
Italy	0.4	0.2	0.3	0.9
Spain	0.3	0.3	0.1	0.8
France	0.3	0.4	0.5	1.2
Singapore	1.4	0.0	0.1	1.5
United Kingdom	0.1	1.6	0.1	1.8
Total	22.5	12.3	7.5	42.3
Total excl China and India	14.3	11.4	4.5	30.2

Note. Middle East countries: Kuwait, Oman, Saudi Arabia and United Arab Emirates. Developed countries: Canada, Netherlands, Norway, United Kingdom and United States.
Source: Own elaboration based on data from UN Comtrade Database.

6. Conclusion and policy implications

This article explores the potential revenue from an international tax on oil exports to finance programs aimed at mitigating climate change. For that purpose, a dynamic, general equilibrium model with two regions is used in which one region is an oil exporter and another is an oil importer. The advantage of using such a model is that equilibrium exports and prices are endogenously determined as a function of the oil tax. In the calibration exercise, the oil-exporting region is represented by major net exporters comprising 94% of world oil exports, whereas the rest of countries embody the oil-importing region. Using information on current oil exports, revenue projections for 20 years are provided. These projections assume alternative per-barrel taxes and price elasticities of oil demand and supply. The model suggests that revenues could be significant, depending on the magnitude of the tax and the share of global exports taxed. For example, a per-barrel tax of $1 with 50% of oil exports taxed could generate revenues of $7.4 billion dollars after the first year of implementation. Similarly, a per-barrel tax of $5 over 25% of global exports would raise between $18.4 and $18.5 billion dollars in the initial year. Compared to what has been raised to date by the Green Climate Fund, this tax could generate nonnegligible resources with which to mitigate global climate change in the coming years.

Given that cooperation at the global level to combat climate change is subject to free-riding, an "Oil and Climate Club" is proposed. The rules for such a club are sketched and their compliance with international trade laws are discussed. Under certain conditions, both developed and middle-income countries belonging to the club are entitled to keep a share of the revenues of the tax. The remaining share would be allocated to an international fund such as the Green Climate Club to finance environment-friendly programs in low-income countries. In this manner, the revenue estimates provided are the global revenues that would be used to fight climate change.

Pivotal countries for the creation of an "Oil and Climate Club" are also identified, based on a list of the major crude oil importers and exporters that are members of the WTO. Interestingly, a small but influential group of 19 export and import countries is responsible for 42.3% of global oil trade. Even if China, India and Russia are excluded from this group, the remaining countries still account for 25.7% of world oil imports. Using the numbers reported by the model, these remaining countries could raise more than $18.4 billion dollars in the initial year, assuming a $5 per-barrel tax on oil.

As mentioned in the introduction and section 3, expected revenues assume that both oil imports and prices, and world GDP will continue to grow at their long-run rates for the next 20 years. Of course, the numbers could be very different if these assumptions are changed. For this reason, the revenues reported should not be taken at face value. Rather, the exercise presented here illustrates that a tax on oil exports has great potential to collect revenues at the global level.

One issue that deserves further exploration is how to determine the optimal tax on oil exports. In this model, negative externalities from oil consumption are absent, and thus, the optimal oil tax cannot be determined. Therefore, future research would compare the tax rates considered here against the optimal rate, and analyze how such differences would affect welfare.

[16] Table 2 excludes major oil exporters such as Iraq and Iran because they do not belong to the WTO.

[17] According to Falkner (2016), a small climate club has three major advantages. First, it facilitates dialogue and the likelihood to reach an agreement on climate mitigation. Second, club benefits and enforcement are relatively easier to achieve. Finally, it provides international legitimacy to their members. Hovi et al. (2016) argue that cooperation in small groups could bypass the consensus rule barrier currently present in international environmental agreements.

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Appendix

The model in stationary form

Let N_t denote the set of non-stationary variables $\{Y_t, K_t, C_t, I_t, X_t, K_t^*, C_t^*, I_t^*\}$. A stationary version n_t of a variable N_t is given by the expression $n_t \equiv Z_0 N_t / Z_t$, with $Z_0 = 1$. Similarly, define $s_t \equiv S_t \exp(g^{z^*} t)$ and $o_t = o_t^* \equiv O_t / [Z_t \exp(g^{z^*} t)]$ as the stationary versions for oil price and quantities $\{S_t, O_t, O_t^*\}$. The set of 11 equations that describe the model in its stationary form for the 11 endogenous variables are the following:

$$v_0 c_t = s_t o_t^\eta,$$

$$c_t L_t^{1+\psi} = \alpha y_t,$$

$$1 = \beta \left[\frac{c_t}{c_{t+1}\exp(g^z)}\right]\left[\frac{(1-\alpha) y_{t+1}\exp(g^z)}{k_t} + 1 - \delta\right],$$

$$y_t = c_t + i_t + s_t o_t,$$

$$k_t = i_t + (1-\delta) k_{t-1}\exp(-g^z),$$

$$y_t = L_t^\alpha [k_{t-1}\exp(-g^z)]^{1-\alpha},$$

$$1 = \beta \left[\frac{c_t^*}{c_{t+1}^*\exp(g^z)}\right]\left[\frac{(1-\gamma)(s_{t+1}-\tau) o_{t+1}^*\exp(g^z)}{k_t^*} + 1 - \delta\right],$$

$$x_t = \gamma (s_t - \tau) o_t^*,$$

$$s_t o_t^* = c_t^* + i_t^* + x_t,$$

$$k_t^* = i_t^* + (1-\delta) k_{t-1}^*\exp(-g^z),$$

$$o_t^* = Z_0^* (x_t)^\gamma \left[k_{t-1}^*\exp(-g^z)\right]^{1-\gamma}$$

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