

# DISCUSSION PAPER

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## The Effects of Transport Regulation on the Oil Market

*Does Market Power Matter?*

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## Abstract

Popular instruments to regulate consumption of oil in the transport sector include fuel taxes, biofuel requirements, and fuel efficiency. Their impacts on oil consumption and price vary. One important factor is the market setting. We show that if market power is present in the oil market, the directions of change in consumption and price may contrast those in a competitive market. As a result, the market setting impacts not only the effectiveness of the policy instruments to reduce oil consumption, but also terms of trade and carbon leakage. In particular, we show that under monopoly, reduced oil consumption due to increased fuel efficiency will unambiguously *increase* the price of oil.

**Key Words:** transport regulations, oil market, monopoly, terms-of-trade effects, carbon leakage

**JEL Classification Numbers:** D42, Q54, R48

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# The Effects of Transport Regulation on the Oil Market: Does Market Power Matter?

Snorre Kverndokk and Knut Einar Rosendahl\*

## 1. Introduction

Climate change is high on the global policy agenda, and studies like IPCC (2007) and Stern (2007) have established the need for ambitious international climate agreements and strong domestic climate policies. Countries' early steps include the EU Emission Trading Scheme, the Kyoto Protocol, and the Copenhagen Accord; these and future efforts will have important consequences for the oil market. At the same time, energy-importing countries are concerned about energy security and oil dependence. Most developed countries import oil from the Middle East and worry about macroeconomic disruption costs from the risk of oil price shocks, constraints on foreign policy (e.g., questions about human rights and democratic freedom in oil-exporting nations), and the possible funding of terrorist activities by oil revenues. Europe and the United States are expected to increase their import dependency on oil over the next decades as their own supplies are depleted (EIA 2010), whereas the Organization of the Petroleum Exporting Countries (OPEC) may increase its market share and, consequently, its market power.

Both climate change impacts and energy security call for policies to reduce the demand for oil in most oil-importing countries. These goals can be achieved through such policies as mandated biofuel shares, emissions standards, a quota system for carbon dioxide (CO<sub>2</sub>) emissions, taxation of CO<sub>2</sub> emissions or energy use, support of renewable energy production, and standards for energy equipment.<sup>1</sup> Examples of policies that are rarely cost-effective, yet

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<sup>1</sup> A combination of goals will usually imply a different mix of policies than if one only had the aim of reducing greenhouse gas emissions. For instance, broad taxes are more cost-effective than fuel standards or biofuel shares if the aim is to reduce global warming.

politically popular, are those that target the transport sector, such as a fuel tax, a required share of biofuels in fuel consumption, and emissions standards for vehicles (see Parry et al. 2007). All are either implemented or suggested in the European Union and the United States, but to different degrees. While the United States has rather low tax rates by international standards, fuel taxes are relatively high in many European countries (OECD 2009). On the other hand, the United States aggressively tightened its fuel economy standards in 2007 and 2009.<sup>2</sup>

The transport sector is essential when studying the demand for oil. According to EIA (2010), transportation accounted for 53 percent of the world total liquids consumption in 2007, and the share is expected to increase to 61 percent in 2035. Also, the world's transportation systems are more than 90 percent dependent on oil and oil products, so few alternatives can compete widely with oil in the transport market today.

Policies to regulate transport may have different impacts in a competitive market and a market with a dominant producer. The OPEC cartel dominates the oil market, which can hardly be considered competitive while OPEC exhibits market power (see, e.g., Berg et al. 1997a; Alhajji 2004). Thus, in this paper we study the impacts of different types of transportation regulations in the presence of market power. In particular we compare three different types of policy instruments: a fuel tax, a required share of biofuels in the transport market, and fuel efficiency.

## 2. Literature Review

The literature relevant for our study can be divided into two strands: one that studies regulations in the transport sector in more detail by mainly focusing on the demand side, and one that analyses the oil market by focusing on the supply side. Starting with the first strand of literature, most studies on regulations in the transportation sector are demand-side analyses (assuming fixed producer prices) that use a utility function as the starting point to calculate optimal fuel taxes (e.g., Parry and Small 2005; West and Williams 2007; Parry 2009), measure welfare effects of fuel economy regulations (e.g., Fischer et al. 2007), or calculate costs of different regulations to meet certain levels of gasoline consumption (e.g., West and Williams 2005). Morrow et al. (2010) study the impacts of different policies to reduce oil consumption and greenhouse gas emissions from the U.S. transportation sector but assume an exogenous oil price.

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<sup>2</sup> The new Corporate Average Fuel Economy (CAFE) standards for manufacturers are equivalent to 39 miles per gallon for their new car fleets and 30 miles per gallon for their light-truck fleets by 2016 (see, e.g., Parry 2009).

The large literature on fuel-efficiency standards introduces market power when examining effects of such standards under possibilities of price discrimination when consumers have different tastes (e.g., Plourde and Bardis 1999) and the effects of standards on cars sales, prices, and fuel consumption (e.g., Goldberg 1998). But these studies introduce market power in the supply of cars and not in the oil market. The economic literature on biofuels has also emerged the last few years (see, e.g., Rajagopal and Zilberman 2007 for a survey). De Gorter and Just (2007) study the effect of biofuel subsidies on oil consumption in a competitive market, while Hertel et al. (2010) analyze the impacts of biofuel mandates in a global computable general equilibrium model.

A recent paper on biofuels that makes a link to the second strand of literature is Hochman et al. (2010). It focuses on the impact of biofuels when OPEC acts as a cartel. The authors specify two regions in the world—an oil-exporting and an oil-importing region—and study the different impacts on the oil price in the two regions using a static model. However, the paper does not make comparisons with other policy instruments to reduce oil consumption.

Another relevant paper is by Berger et al. (1992), who studied the impact of international agreements to reduce CO<sub>2</sub> emissions on fossil fuel prices based on tradable emissions permits and an international CO<sub>2</sub> tax. They found that while the two instruments have the same effect on the producer price of fossil fuels in competitive fossil fuel markets, direct regulation in the form of tradable quotas tends to imply higher producer prices than an international CO<sub>2</sub> tax giving the same reduction in total CO<sub>2</sub> emissions.

Strand (2009) also studies the impacts of carbon taxes and tradable permits, assuming two blocs of countries: an oil-importing region that regulates fossil fuel consumption and produces alternative fuels, and an oil-exporting region without any regulations. However, the paper focuses on strategic behavior for rent extraction, such as export taxation, rather than effects of market power.

Some studies of carbon taxation consider intertemporal supply under different market settings (e.g., Berg et al. 1997b), but few studies compare policy instruments in an intertemporal setting when market power is taken into account. For instance, Sinn (2008) studies different policy measures from an intertemporal supply-side perspective for a non-renewable resource but does not consider market power on the supply side.

In this paper, we combine the two strands of literature. Instead of focusing on the preferences of consumers, we study the importance of the supply side of the oil market for the effects of transport regulations. We do not consider intertemporal optimization on the supply side

but rather focus on market power. Our interest is on the effects on the price and quantity of oil consumption under different market settings. The price effect is rather important. Assuming, for instance, that transport regulations follow from a climate treaty, signatory countries may be concerned about increased emissions in non-signatory countries due to a lower oil price (a phenomenon called *carbon leakage*; see Felder and Rutherford 1993). It is also widely known that environmental regulations may affect terms of trade (Krutilla 1991), and oil-importing countries may worry about policy measures that can increase the oil price. Therefore, we compare the effects on the oil price of different regulations under different market settings.

The paper is organized as follows. In the next section, we use a static model for a closed economy to study the impacts of the different policy instruments in a competitive market and a monopoly market. While both forms are too simplistic in describing the oil market, they represent useful indicators of the effects of transport regulations when market power is introduced. In the third section, we extend the analysis to an open economy to further study volume effects as well as changes in terms of trade and carbon leakage from regulations in the transport sector. The final section concludes.

### 3. Transport Regulations in a Closed Economy

To focus on the effects of market power, we use a static partial equilibrium model, starting with a closed market. A natural interpretation is to think of this as the global oil market. Nevertheless, we will also discuss implications for a single oil-importing country, and in the following section, we will model an open market explicitly. As the substitution possibilities are small in the transport market, we implicitly keep prices of other energy goods constant.<sup>3</sup>

We study different transport regulations to reduce fossil fuel consumption and hence CO<sub>2</sub> emissions under the assumption that they are widely introduced. If we think of the global oil market, these regulations could be the outcome of an international climate agreement. So far it seems more realistic to consider such regulations within a single country or a group of countries than the entire globe as not all countries are likely to sign a climate agreement, and that is why we examine an open economy in the next section. The analysis of a closed market will still give useful insight, to a situation where a large part of the oil market becomes regulated.

The demand-side regulations we consider are the following:

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<sup>3</sup> To simplify the analysis throughout the paper, we ignore oil consumption outside the transport sector.

- i) A *fuel tax* set interpreted as a tax  $t$  per unit of oil consumed.
- ii) A required *share of biofuels* interpreted as a fraction  $\hat{a}$  of total transport fuel consumption. We define  $\hat{a} = a/(1+a)$ , meaning that for each unit of oil that is sold, one also needs to sell  $a$  units of biofuel (e.g., gasoline mixed with ethanol).
- iii) An *efficiency standard* interpreted as a binding minimum average vehicle efficiency  $m$ , measured as miles per gallon.

We will compare the effects of these policy instruments in a competitive market ( $C$ ) and a monopoly market ( $M$ ), assuming throughout the paper that the changes in  $t$ ,  $a$ , or  $m$  are the same in the two market settings. In the next section we also consider a market with a dominant firm and a competitive fringe.

### 3.1 The Demand for Oil

Let us start by defining the demand for transport services, measured in miles driven ( $q$ ), as a function of mileage ( $m$ ), oil consumption for transport use ( $x$ ), and biofuel requirements ( $a$ ). Then we have

$$(1) \quad q = m \cdot x + m \cdot ax = m(1 + a)x.$$

To drive a mile, one can either use oil or biofuels as the fuel source.<sup>4</sup> As oil is measured in gallons,  $mx$  is the number of miles driven on oil and  $m \cdot ax$  is the number of miles driven on biofuels. Alternatively,  $(1+a)x$  is the blended fuel. We see that for a given demand of transport services  $q$ , increased mileage or share of biofuels means that the consumption of oil is reduced accordingly.

Now, let us turn to the demand for oil. To do this, assume that an increase in  $m$  increases mileage by the same percentage rate for all transport consumers, so that an increase in  $m$  has the same effect on the demand function for all quantities of oil. Moreover, we disregard any costs related to making cars more fuel-efficient and costs related to supplying the necessary amount of biofuels. We assume the government covers these costs, not consumers or producers in the oil

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<sup>4</sup> We disregard other sources, such as electricity and hydrogen, as they are usually not regulated through any policy measures studied here.



market. Thus, we assume that the price of biofuels is equal to the price of oil—e.g., that gasoline is mixed with biofuels when sold at a gas station.<sup>5</sup>

Let  $P_q(q)$  denote the inverse demand function for transport services—i.e., the price consumers are willing to pay for an extra mile as a function of miles driven. Furthermore,  $P_x(x)$  denotes the inverse demand function for oil facing the producer(s) of oil. Note that the consumer price of oil is then  $P_x(x) + t$ —i.e., the producer price plus the fuel tax. Based on this, we find that

$$(2) \quad P_q(q) = \frac{P_x(x) + t}{m}.$$

Thus, the price per mile driven is equal to the consumer price of oil per gallon divided by the mileage.

From (1) and (2) we can write the inverse demand function for oil facing the producer(s) of oil:

$$(3) \quad P_x(x) = mP_q(m(1+a)x) - t,$$

where  $P_x'(x) < 0$  and  $P_q'(q) < 0$ .

Equation (3) shows quite clearly that the three different policy instruments affect the inverse demand function for oil very differently. This is illustrated in Figure 1, where  $P_x^i$  and  $i=a, m, t$  are the new demand functions under the different regulation schemes. A fuel tax,  $t$ , shifts the inverse demand function downward, while a required share of biofuels,  $a$ , makes the function steeper, with the same maximum price as before.

Increased efficiency,  $m$ , also makes the inverse demand function steeper, but the maximum price has increased because it is cheaper to drive a mile if prices are unchanged. Thus, as opposed to the two other instruments, increased efficiency *increases* demand for some (high) price levels.<sup>6</sup> To see this, note that with higher mileage one does not need as much gasoline to

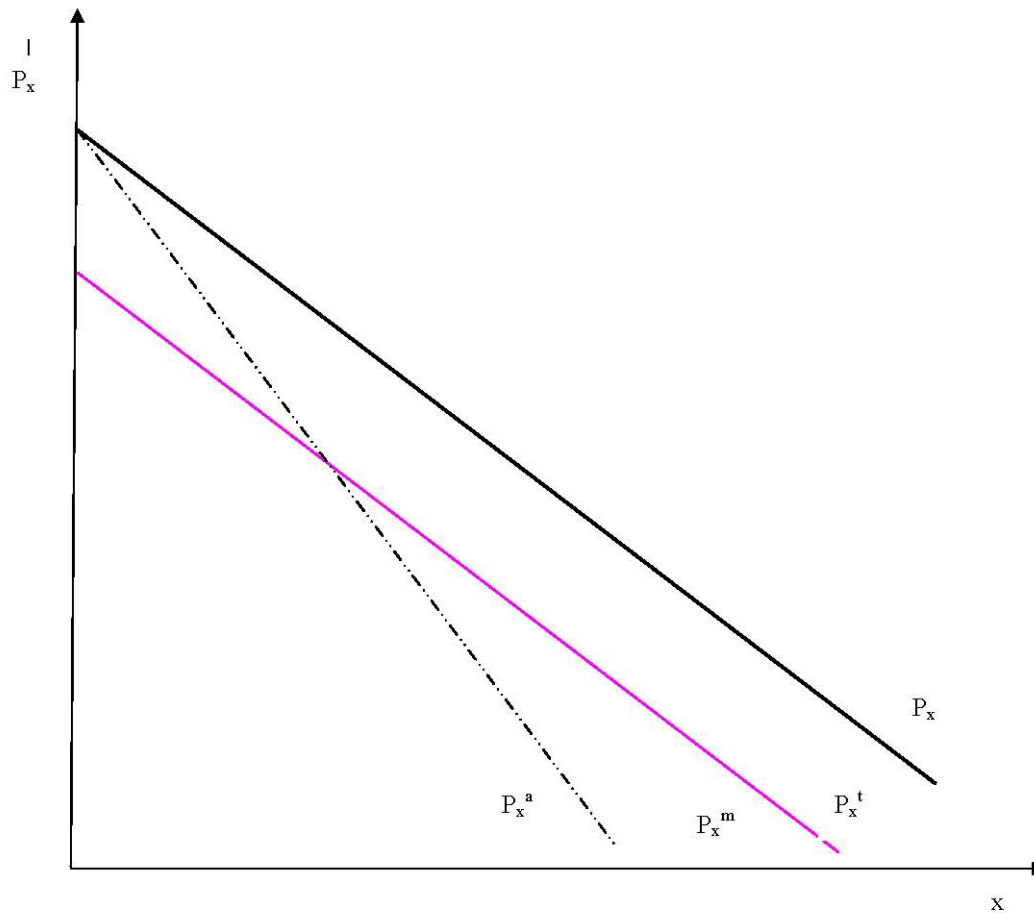
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<sup>5</sup> This also follows the assumption in Hochman et al. (2010) that biofuels and gasoline are supplied to the same price. If we assumed, for instance, that the oil producer has to buy the biofuels at a price different than its marginal costs and then supply the blend in the market, a change in the blending requirement,  $a$ , would also give a change in the marginal cost of the blended fuel.

<sup>6</sup> The demand curves will not cross if the price elasticity is constant. In this case, the new demand function will either be above or below the old one. One example where the  $P_x^m$ -curve will be below the  $P_x$ -curve for all  $x$  is  $P_x = x^{-k}$ , where  $k < 1$  (i.e., price elasticity below one in absolute value).

drive the same distance as before, which lowers oil demand. On the other hand, it is cheaper to drive a mile when the car uses less fuel, and the demand for transport services increases. This is called the *rebound effect* in the literature (see, e.g., Portney et al. 2003; Small and Van Dender 2007) because it increases demand for gasoline and oil. Thus, there are two opposite effects.<sup>7</sup>

**Figure 1. Impacts of Different Policy Instruments on the Demand for Oil**



### 3.2 Quantity Effects

Consider first the quantity effects of the different policies in competitive and monopoly markets. For simplicity we assume that  $a = t = 0$  and  $m = 1$  initially. In other words, we study the

<sup>7</sup> The crossing demand functions can also be seen from equation (3). Increasing  $m$  has two effects as  $m$  is multiplied with  $P_q(q)$  and also increases  $q$  everything else given. As  $P'_q(q) < 0$ , we see that  $P_x(x)$  may either increase or decrease for an increase in  $m$ .

effects of introducing transport regulations where there are no prior regulations. To simplify the notation we use  $P(x)$  instead of  $P_x(x)$ .

### 3.2.1 Competitive Oil Market

Assume that a representative producer faces a cost function  $c(x)$ , with the following properties:  $c'(x) > 0$  and  $c''(x) \geq 0$ . The market outcome of this producer can easily be derived by considering the maximization problem when the price is taken as given:

$$(4) \quad \text{Max}[P(x)x - c(x)].$$

This gives the well-known first-order condition,

$$(5) \quad P = c'(x).$$

Inserting from (3) and then differentiating (setting  $a = t = 0$  and  $m = 1$ ) gives the following equation:

$$(6) \quad (c''(x) - P'(x)) dx = (P(x) + xP'(x)) dm + xP'(x) da - dt.$$

Thus, we get the following effects of the different instruments in a competitive market:

$$(7) \quad \begin{aligned} \text{i) } & \frac{dx^C}{dt} = -\frac{1}{c''(x) - P'(x)} < 0, \\ \text{ii) } & \frac{dx^C}{da} = \frac{xP'(x)}{c''(x) - P'(x)} < 0, \text{ and} \\ \text{iii) } & \frac{dx^C}{dm} = \frac{P(x) \left(1 + \frac{1}{\varepsilon(x)}\right)}{c''(x) - P'(x)}, \end{aligned}$$

where  $\varepsilon(x) = \frac{P(x)}{xP'(x)}$  (price elasticity of demand).<sup>8</sup>

Not surprisingly, and also shown in earlier studies, oil consumption drops if either a tax or a required share of biofuels is introduced. On the other hand, we notice from (7) iii) that the effect of increased mileage on oil consumption is ambiguous, also shown in Figure 1. If the marginal cost function crosses above the intersection of the  $P_x$ - and the  $P_x^m$  curves, oil

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<sup>8</sup> Note that  $x(P)$  is the demand function for oil, which is the inverse of  $P(x)$ .

consumption increases when mileage is raised; otherwise it will fall. Furthermore, we see from (7) iii) that the direction of change in consumption depends on the size of the price elasticity of demand.

As a reference point to the analysis in a monopoly market, we summarize these conclusions in a proposition:

**Proposition 1:** *In a competitive oil market, introducing fuel taxes and biofuel requirements will reduce oil consumption. Increased fuel efficiency will increase oil consumption if and only if the price elasticity in the market equilibrium is above one in absolute value.*

*Proof:* This is easily seen from (7) i)–iii).

Most recent empirical analyses seem to conclude that price elasticities are rather low in absolute value and most likely below one in the short run (e.g., Hughes et al. 2006; Parry 2009). Thus, if the oil market can be viewed as a competitive market, introducing an efficiency standard for transportation will most likely reduce total consumption of oil in the short run. In the long run, however, the price elasticity can be quite high (e.g., Sterner 2007).<sup>9</sup>

### 3.2.2 Monopoly Market

To see the effect of transport regulations when market power is introduced, we confront the conclusions above with an analysis of a market with a monopoly on the supply side. As we will use linear demand and marginal cost functions in Section 3, we will also briefly report the results for linear functions.

A monopolist also considers the maximization problem in (4) but does not take the price as given. This gives the standard first-order condition,

$$(8) \quad MR(x) = xP'(x) + P(x) = c'(x),$$

and the second-order condition,

$$(9) \quad \Gamma(x) = c''(x) - 2P'(x) - xP''(x) > 0.$$

From (3) we find that  $P'(x) = m^2(1+a)P'_q(m(1+a)x)$ . Differentiating this expression gives the following:

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<sup>9</sup> If the price elasticity is above unity at high prices (as with some linear and concave demand functions), a gradual increase in unit production costs over time due to resource scarcity will increase the likelihood that increased mileage will stimulate consumption.

$$(10) \quad dP' = (1+a) \left[ 2mP'_q dm + m^2 P''_q ((1+a)x dm + m x da + m(1+a) dx) \right] + m^2 P'_q da.$$

Inserting from (3) in (8) and then differentiating, using (10),  $a = t = 0$ ,  $m = 1$ ,  $P' = P'_q$ , and  $P'' = P''_q$  (see equation (2) for  $a = t = 0$  and  $m = 1$ ), gives the following expression:

$$(11) \quad \begin{aligned} & (c''(x) - 2P'(x) - xP''(x)) dx = \\ & (P(x) + 3xP'(x) + x^2P''(x)) dm + (2xP'(x) + x^2P''(x)) da - dt. \end{aligned}$$

Thus,

$$(12) \quad \begin{aligned} \text{i)} \quad & \frac{dx^M}{dt} = -\frac{1}{c''(x) - 2P'(x) - xP''(x)} = -\frac{1}{\Gamma(x)} < 0, \\ \text{ii)} \quad & \frac{dx^M}{da} = \frac{2xP'(x) + x^2P''(x)}{c''(x) - 2P'(x) - xP''(x)} = \frac{xP'(x)(2 + \gamma(x))}{\Gamma(x)}, \text{ and} \\ \text{iii)} \quad & \frac{dx^M}{dm} = \frac{P(x) + 3xP'(x) + x^2P''(x)}{c''(x) - 2P'(x) - xP''(x)} = \frac{xP'(x)(3 + \varepsilon(x) + \gamma(x))}{\Gamma(x)}, \end{aligned}$$

where  $\gamma(x) = x \frac{P''(x)}{P'(x)}$ , and  $\Gamma(x) > 0$  is given from (9). In a monopoly market we recall that

$\varepsilon(x^M) \leq -1$  for the marginal revenue to be positive.<sup>10</sup>

We notice that the value of  $\gamma$  is crucial for the impact of the policies. This parameter is the elasticity of  $P'(x)$  with respect to  $x$  and characterizes the curvature of the demand function. Throughout the paper we will distinguish between three cases: i)  $\gamma > -1$ , which means that the inverse demand function is either concave ( $\gamma > 0$ ), linear ( $\gamma = 0$ ), or “slightly convex” ( $-1 < \gamma < 0$ ), in the sense that the price derivative does not change too fast when  $x$  changes; ii)  $-2 < \gamma < -1$ ,

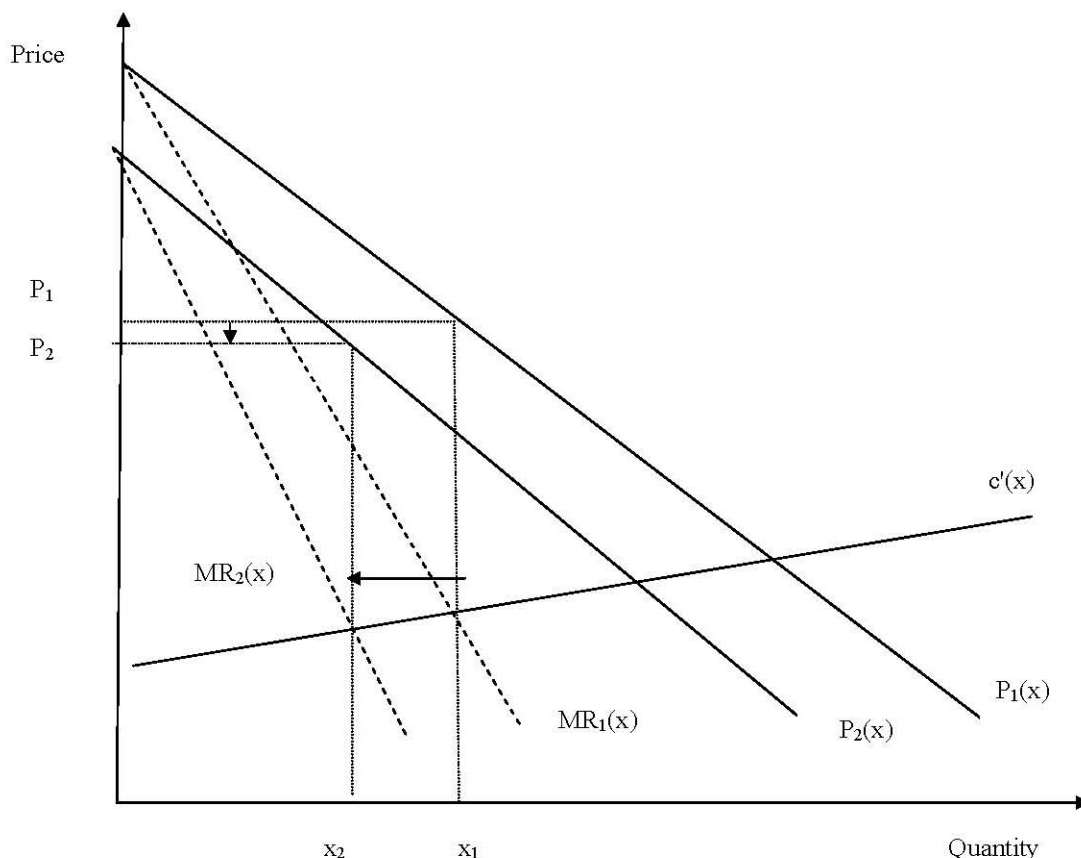
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<sup>10</sup> As mentioned in Section 2.2 above, empirical studies find the short-run price elasticity to be less than one (in absolute value) in the oil market. However, this does not rule out market power in this market. If the oil market can be characterized as having a dominant producer (OPEC) and a competitive fringe (see, e.g., Hansen and Lindholt 2008), it is profitable for a dominant producer to adjust its production to a level where the price elasticity of the residual demand is larger than one (in absolute value). This elasticity will be larger than the demand elasticity (in absolute value), so we may still have a dominant producer in the oil market even if the demand elasticity is “low.” Also, Hochman et al. (2010) argue that import demand elasticities observed by OPEC countries are much larger than price elasticities observed in macro, and they set these to be above one in absolute value. In section 3.2, we will investigate the model with a dominant producer.

in which case we will refer to a “quite convex” inverse demand function; and iii)  $\gamma < -2$ , which means that the inverse demand function is “very convex.”<sup>11</sup>

From equations (12) we first observe that a tax will unambiguously reduce consumption of oil, just as in the competitive market. This is shown in Figure 2. In the linear case of  $P''(x) = 0$ , we can easily show that the relative output reduction will be the same in the two market settings.

**Figure 2. Impacts of Carbon Taxation in a Monopoly Market**

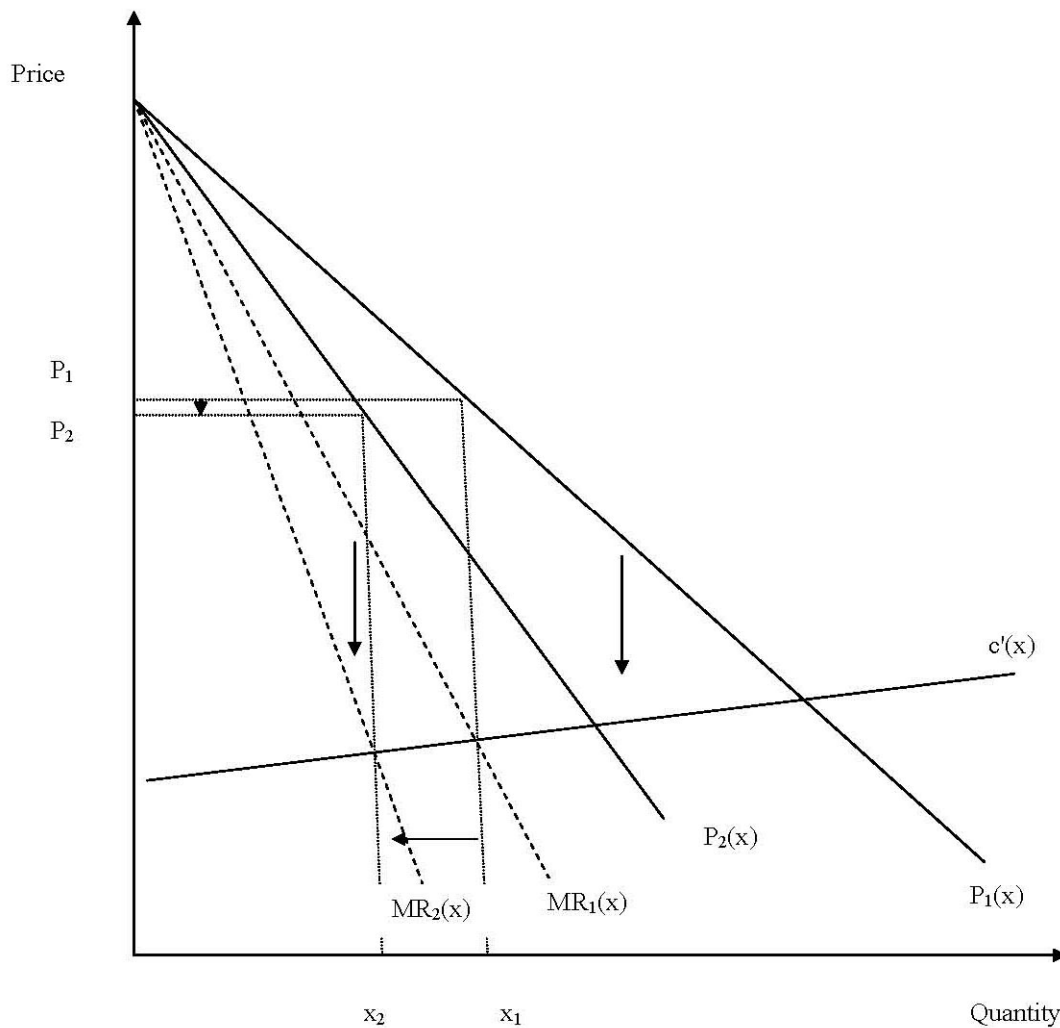


Further, a required biofuels share will reduce oil consumption if and only if the inverse demand function is not very convex ( $\gamma > -2$ ). Figure 3 shows an example with linear functions where oil consumption will fall with a higher share of biofuels. In the linear case, the relative

<sup>11</sup> Note that  $\gamma$  is a function of  $x$ —i.e., it is not necessarily constant. We have ruled out  $\gamma = -1$  and  $\gamma = -2$ . For  $\gamma = -2$ ,  $dP/dx$  is not defined for  $da > 0$ ; see equation (14) below. For  $\gamma = -1$ , we see from (13) and (14) below that  $dP/dx$  is similar in a monopoly and a competitive market for both  $dt > 0$  and  $da > 0$ .

output reduction will be bigger in a monopoly market than in a competitive market (unless marginal costs are constant). The reason is that the demand function becomes steeper, and thus the monopolist finds it profitable to reduce output relatively more than in the tax case.

**Figure 3. Impacts of a Required Share of Biofuels in a Monopoly Market for Oil**



However, for more convex inverse demand functions ( $\gamma < -2$ ), oil consumption will actually increase. Note that in this case, the marginal revenue function will in fact increase in  $x$ .<sup>12</sup>

<sup>12</sup> By differentiating (8), we find that  $\partial MR(x)/\partial x > 0$  for  $\gamma < -2$ . For the second-order condition in (9) to be fulfilled,  $c'(x)$  has to increase faster than  $MR(x)$ .

An increase in the biofuels share will then give a higher marginal revenue for a given production level even if the price goes down (remember that the inverse demand function moves down). The reason is that the price function will be less steep for a given  $x$ . Thus, whereas a required share of biofuels always reduces consumption in a competitive market, oil consumption will actually increase in a monopoly market if the inverse demand function is very convex. Notice, however, that a very convex inverse demand function typically (but not necessarily) will have negative marginal revenue even for low values of  $x$ , which conflicts with (8) and thus makes increased oil consumption rather unlikely.<sup>13</sup>

As for the competitive market, the effect of increased fuel efficiency on oil consumption is generally ambiguous in a monopoly market. The sign of the numerator in (12) iii) depends on the sum of  $\gamma$  and the price elasticity  $\varepsilon$ . As  $\varepsilon < -1$  in a monopoly market, we see that if the inverse demand function is very convex ( $\gamma < -2$ ), oil consumption will increase when fuel efficiency is increased. The reason is the same as for biofuels; the marginal revenue will increase in  $x$  in this case. Oil consumption can also increase with  $\gamma \geq -2$  if  $\varepsilon + \gamma < -3$ . Nevertheless, a more realistic scenario may be that  $-2 < \varepsilon < -1$  and  $\gamma > -1$ , so that the numerator in (12) iii) is negative, in which case oil consumption decreases.

The conclusion can be summarized by the following proposition:

**Proposition 2:** *With a monopoly supplying oil,*

- *introducing fuel taxes will reduce oil consumption;*
- *introducing a biofuel requirement will reduce oil consumption if the inverse demand function is not very convex ( $\gamma > -2$ ) but increase consumption if the demand function is very convex ( $\gamma < -2$ ); and*
- *increasing fuel efficiency will reduce oil consumption if the inverse demand function is not very convex and not very price elastic ( $\varepsilon + \gamma > -3$ ) but increase consumption if  $\varepsilon + \gamma < -3$ .*

*Proof:* See equation (12) and the text above.

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<sup>13</sup> One example is  $P(x) = x^{-2}$ , in which  $\gamma = -3$  and  $MR = -x^{-2}$ . A demand function where we get higher oil consumption by introducing biofuel requirements is  $P(x) = \text{Min}(3; 2 + x^{-2})$ .



An example of increased fuel efficiency in the oil market is shown in Figure 4. We have assumed that the price elasticity is above one in absolute value in the competitive outcome, so that higher fuel efficiency will increase oil demand in this market setting (from  $x^{C1}$  to  $x^{C2}$ ). On the other hand, it will decrease oil demand (from  $x^{M1}$  to  $x^{M2}$ ) in the presence of a monopoly. This is not accidental. In the special linear case, it is more likely that increased efficiency leads to reduced consumption in a monopoly market than in a competitive market. More precisely, we will never get higher  $x^M$  and lower  $x^C$  for the same set of demand and cost functions. Again, the reason is that the demand function is more inelastic with fuel-efficiency requirements making it profitable for the monopolist to reduce supply. If we rather assumed a flatter marginal cost curve lying below the crossing point for the two demand curves (which we know is equivalent to inelastic demand in the competitive outcome), oil demand would decrease in the competitive case, too. From the figure, we notice that the oil price increases in both market settings, even though the quantity effect goes in different directions. The price effects will be further studied below.

To sum up the quantity effects in competitive and monopoly markets (see Table 1), the effects of regulations become somewhat more ambiguous with market power. While both a fuel tax and an increased biofuel share will definitely reduce oil demand in a competitive market, the fuel tax is the only instrument studied that has an unambiguous negative effect on oil demand in a monopoly market. But in most realistic cases, the analysis suggests that oil consumption will fall irrespective of policy instrument and market setting studied above. Moreover, it is difficult to state in general terms whether the quantity reductions are largest in a competitive or a monopoly market. The brief discussion of the special linear case may indicate, however, that the relative output reduction may be biggest in the monopoly market except in the tax case, as the demand functions become more inelastic when introducing biofuel shares and fuel efficiency.

Figure 4. Impacts of Emissions Standards in the Oil Market

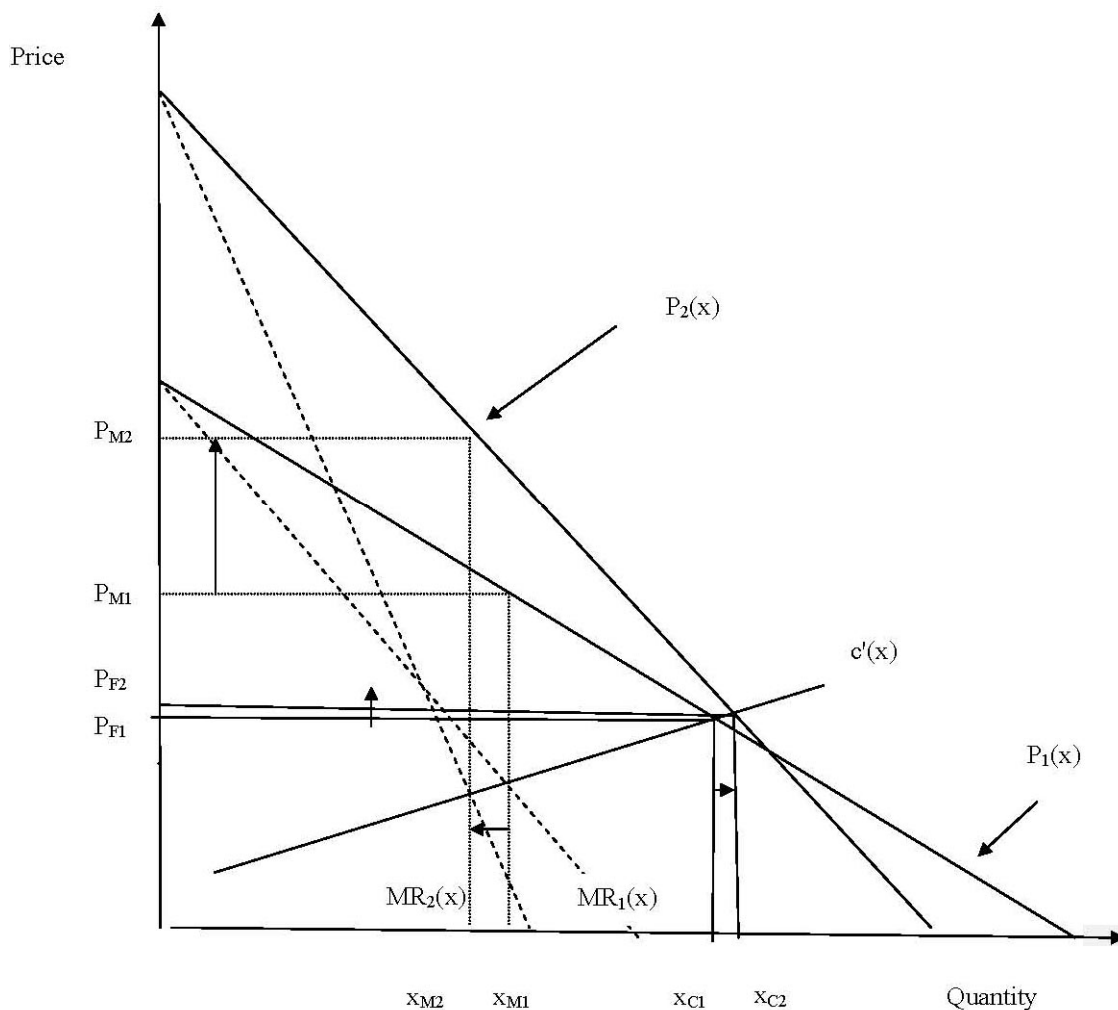


Table 1. Quantity Effects of Policy Instruments in Competitive (C) and Monopoly (M) Markets

	Fuel tax	Biofuel share	Efficiency standard
C	Negative	Negative	Negative if $\varepsilon(x^C) > -1$ Positive if $\varepsilon(x^C) < -1$
M	Negative	Negative if $\gamma(x^M) > -2$ Positive if $\gamma(x^M) < -2$	Negative if $\varepsilon(x^M) > -3 - \gamma(x^M)$ Positive if $\varepsilon(x^M) < -3 - \gamma(x^M)$

### 3.3 Price Effects

Let us now turn to the price effects of the different policy instruments in the two market settings. Figures 2–4 above partially indicate these effects, but we will discuss this more thoroughly by analyzing the effect on the producer price  $P$ —i.e., the price the oil producer(s) receive(s). In a closed market, price effects are of interest with respect to distributional issues—i.e., to what degree are monopolists able to charge a mark-up over marginal costs. Thus, the analysis may shed light on which policy instruments large oil producers would prefer and lobby for, given that oil consumption will have to come down.

If we think of the closed market as consisting of different countries agreeing on a common policy to reduce oil consumption, changes in  $P$  can be interpreted as terms-of-trade effects for the different countries. Thus, if a country is importing oil, it would like  $P$  to fall as much as possible when  $x$  is reduced to improve its terms of trade.

#### 3.3.1 Competitive Market

We will analyze the price effect by calculating the price change relative to the change in consumption. In a competitive market, it is obvious from the first-order condition (5) that we must have

$$(13) \quad \frac{dP^C}{dx^C} = c''(x),$$

irrespective of which policy instrument is used to reduce consumption of  $x$ . This gives the following proposition, which is useful as a reference for the analysis in the next subsection:

**Proposition 3:** *With standard assumptions under competitive markets ( $c''(x) > 0$ ), producer price and quantity always move in the same direction. Moreover, the relative price effect (i.e.,  $dP/dx$ ) is independent of instrument choice.*

*Proof:* This follows from equation (13).

Examples of this result are given in Figures 2, 3, and 4.

#### 3.3.2 Monopoly Market

In a monopoly market, however, the price effect depends highly on the instrument choice. It is straightforward to show (by total differentiation of (3) and inserting from (12)) that we get the following price effects:

$$(14) \quad \begin{aligned} \text{i)} \quad \left. \frac{dP^M}{dx^M} \right|_{dt>0} &= c''(x) - P'(x)(1 + \gamma(x)), \\ \text{ii)} \quad \left. \frac{dP^M}{dx^M} \right|_{da>0} &= \frac{c''(x)}{2 + \gamma(x)}, \text{ and} \\ \text{iii)} \quad \left. \frac{dP^M}{dx^M} \right|_{dm>0} &= \frac{c''(x)(1 + \varepsilon(x)) + P'(x)[1 - \varepsilon(x)(1 + \gamma(x))]}{3 + \varepsilon(x) + \gamma(x)}, \end{aligned}$$

where we know that  $\varepsilon(x^M) \leq -1$  in a monopoly market.

We immediately see that the value of  $\gamma$  is crucial for the comparisons of the price effects, but so is the third derivative of the cost function. Note that  $x$  will always be higher in a competitive market than with monopoly. Thus, the sign of  $c'''(x)$  for  $x \in [x^M, x^C]$  determines whether  $c''(x)$  will be higher or lower with monopoly compared to a competitive market.

Let us first look at the tax case. We notice that the price reduction (relative to the output reduction) can be either bigger (e.g., if  $\gamma > -1$  and  $c'''(x) \leq 0$ ) or smaller (e.g., if  $\gamma < -1$  and  $c'''(x) \geq 0$ ) in a monopoly market than in a competitive market. In the special linear case ( $\gamma = 0$ ), the price reduction will be biggest in a monopoly market. On the other hand, if  $\gamma < -1$ , it is possible that the producer price increases if the inverse demand function is sufficiently steep compared to the marginal cost function. The explanation is that the fuel tax moves consumption toward a more inelastic part of the demand function, making it profitable for the monopolist to decrease production more substantially.

Consider now an increase in the biofuel share. Again we see that the relative price reduction can be either bigger (e.g., if  $-2 < \gamma < -1$  and  $c'''(x) \leq 0$ ) or smaller (e.g., if  $\gamma > -1$  and  $c'''(x) \geq 0$ ) in a monopoly market than in a competitive market. However, as we see, the conditions on  $\gamma$  for whether the price effect is bigger or smaller is completely turned around compared to the tax case. Thus, in the special linear case ( $\gamma = 0$ ), the price reduction will be smallest in a monopoly market. It also follows that the price reduction in a monopoly market will be smaller with a biofuels share than with a tax. As explained above, the demand curve facing the monopolist becomes steeper (more inelastic) only in the former case, and thus it becomes more profitable to withhold production. If the inverse demand function is very convex ( $\gamma < -2$ ), we know from the discussion in Section 2.2.2 that oil consumption will increase when a biofuels share is imposed. Equation (14) ii) shows that the price will decrease also in this case. Thus, the

price will unambiguously fall if a biofuels share is introduced. The intuition is that the new demand function will always be below the old one.

Last but not least, if fuel efficiency is increased, it can be shown that the price of oil will always increase as long as oil consumption decreases.<sup>14</sup> This is completely opposite of the price effect in a competitive market, where the price and quantity always move in the same direction (see equation (13)). If increased fuel efficiency stimulates oil consumption, the price effect is ambiguous and depends on the marginal cost and inverse demand functions.

We can summarize the conclusions in the following proposition:

**Proposition 4:** *With a monopoly supplying oil,*

- *introducing fuel taxes will reduce the producer price if  $\gamma > -1$  but possibly increase the producer price if  $\gamma < -1$  and the inverse demand function is sufficiently steep compared to the marginal cost function;*
- *introducing a biofuel requirement will always reduce the producer price; and*
- *increasing fuel efficiency will increase the producer price if oil consumption decreases but may either increase or decrease price if oil consumption increases.*

*Proof:* This follows from equation (14) and the discussion above.

There are several policy implications when a monopoly supplies oil, based on the price effects. A country may prefer the oil price decrease or increase depending on its situation. We will return to this after discussing the open economy because price effects are particularly important in such an economy due to terms-of-trade effects and carbon leakage.

Table 2 sums up the price effects of the three policy instruments for the different assumptions about the market, showing that the direction of change depends significantly on the market setting.

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<sup>14</sup> Note that  $x^M$  decreases if  $3 + \varepsilon + \gamma > 0$ ; see (12) iii). Thus, the denominator in (14) iii) is positive. The first term in the numerator is negative since  $\varepsilon \leq -1$ , and the second term is also negative when  $3 + \gamma + \varepsilon > 0$ .

**Table 2. Price Effects of Policy Instruments in Competitive (C) and Monopoly (M) Markets**

		Fuel tax	Biofuel share	Efficiency standard
<i>C</i>	$dx^C < 0$	Negative	Negative	Negative
	$dx^C > 0$	N/A	N/A	Positive
<i>M</i>	$dx^M < 0$	?	Negative	Positive
	$dx^M > 0$	N/A	Negative	?

#### 4. Transport Regulations in an Open Economy

In the preceding section, we learned that the price effect of reducing oil consumption is independent of the policy instrument in a competitive market but highly dependent on the instrument choice in a monopoly market. In particular, whereas a biofuel share and, most likely, a fuel tax will reduce the producer price of oil in a monopoly market, increased efficiency will increase the price, given that the instrument leads to lower oil consumption. In this section, we will explore this issue further in an open economy with either a monopolist or a dominant firm with a competitive fringe. As the analysis becomes more complicated in an open economy, we will make a number of simplifying assumptions and also present some numerical illustrations.

Assume now that two regions in the world are consuming oil: Region *A* and *B*. Region *A* imports oil from Region *B*. Both regions are assumed to have linear transport demand functions. Moreover, we disregard transport regulations in Region *B*, so that  $q_B = x_B$ . Consequently, using equation (3), the consuming regions have the following inverse demand functions for oil, where  $\alpha_1 > 0$ ,  $\alpha_2 > 0$ ,  $\beta_1 > 0$ ,  $\beta_2 > 0$  and subscript  $i = A, B$  represents the variable of region *i*:

$$(15) \quad P(x_A) = m(\alpha_1 - \alpha_2 m(1+a)x_A) - t \text{ and}$$

$$(16) \quad P(x_B) = \beta_1 - \beta_2 x_B.$$

Here  $P$  denotes the world market price of oil. We normalize price and quantity units so that  $\alpha_1 = \alpha_2 = 1$ . Moreover, we assume that  $\beta_1 = 1$ —i.e., the choke price is identical in the two regions at  $m = 1$ .

Region  $B$  has a dominant firm ( $D$ ) and a competitive fringe ( $F$ ).<sup>15</sup> The marginal costs of producer  $j$  is specified as

$$(17) \quad c_j'(x_j) = c_{j1} + c_{j2} \cdot x_j.$$

We assume that  $c_{j1} < 1$  to ensure positive production of oil. The fringe has the same first-order condition as in a competitive market; see equation (5). Note that a monopoly market emerges as a special case if  $c_{F2} \rightarrow \infty$ .

We will refer to demand in Region  $B$  minus fringe production as the residual demand in region  $B$  ( $x_B^D$ ). From equations (5), (16), and (3), we have that  $x_B^D$  is given by

$$(18) \quad P(x_B^D) = \beta_1^D - \beta_2^D x_B^D,$$

where 
$$\beta_1^D = \frac{c_{F2} + \beta_2 c_{F1}}{\beta_2 + c_{F2}} \quad \text{and} \quad \beta_2^D = \frac{\beta_2 c_{F2}}{\beta_2 + c_{F2}}.$$

The total residual demand facing the dominant firm ( $x^D$ ) consists of  $x_B^D$  and  $x_A$ . From equation (18) and (15) we find that

$$(19) \quad P(x^D) = \frac{1}{\phi_3(m, a)} \left[ \phi_1(m, a, t) - \phi_2(m, a) x^D \right],$$

where 
$$\phi_1(m, a, t) = \beta_1^D m^2 (1+a) + \beta_2^D m - \beta_2^D t, \quad \phi_2(m, a) = \beta_2^D m^2 (1+a) \quad \text{and} \\ \phi_3(m, a) = \beta_2^D + m^2 (1+a).$$

By using the first-order condition of a dominant firm, which is the same as for a monopolist (equation (8)), we can derive the following expressions for the equilibrium price and residual demand in this market as functions of the policy instruments:

$$(20) \quad P = \frac{\phi_1(m, a, t) \phi_2(m, a) + \phi_1(m, a, t) \phi_3(m, a) c_{D2} + \phi_2(m, a) \phi_3(m, a) c_{D1}}{2\phi_2(m, a) \phi_3(m, a) + \phi_3(m, a)^2 c_{D2}} \quad \text{and}$$

$$(21) \quad x^D = \frac{\phi_1(m, a, t) - \phi_3(m, a) c_{D1}}{2\phi_2(m, a) + \phi_3(m, a) c_{D2}}.$$

<sup>15</sup> Conclusions regarding prices and consumption will not change if we have a competitive fringe in region  $A$  instead of region  $B$ .

Equilibrium consumption in the two regions and fringe production then follows from the equations above.

We are now ready to investigate the effects of the different policy instruments. It turns out, however, that is difficult to derive analytical and interpretable expressions in the case of a dominant firm with a competitive fringe (except in the tax case). Thus, in the first subsection below we consider a monopoly market and examine the effects of the policy instruments in this market setting. We also present some numerical illustrations. Then, in Subsection 3.2, we present some numerical illustrations showing how the existence of a competitive fringe affects the results.

#### 4.1 Monopoly Market

In a monopoly market, we have that  $\beta_1^D = 1$  and  $\beta_2^D = \beta_2$ . This is easily seen by letting  $c_{F2} \rightarrow \infty$  in the expressions for  $\beta_1^D$  and  $\beta_2^D$ . The steepness of the inverse aggregate demand curve is then given by  $\beta_2 / (1 + \beta_2)$ . We make a final simplification by assuming that  $c_{D1} = 0$ .<sup>16</sup>

We find that the three different policy instruments affect consumption and producer price in the following way:

$$(22) \quad \begin{aligned} \text{i)} \quad & \frac{dx_A}{dt} = -\frac{\beta_2^2 + 2\beta_2 + \beta_2 c_{D2} + c_{D2}}{(\beta_2 + 1)(2\beta_2 + c_{D2}\beta_2 + c_{D2})} < 0, \\ \text{ii)} \quad & \frac{dx_A}{da} = -\frac{\beta_2(2\beta_2 + c_{D2})}{(2\beta_2 + c_{D2}\beta_2 + c_{D2})^2} < 0, \text{ and} \\ \text{iii)} \quad & \frac{dx_A}{dm} = \frac{2\beta_2 c_{D2}^2 + 3\beta_2^2 c_{D2} + \beta_2^3 c_{D2} + 2\beta_2 c_{D2} + c_{D2}^2 + \beta_2^2 c_{D2}^2 - 2\beta_2^3}{(\beta_2 + 1)(2\beta_2 + c_{D2}\beta_2 + c_{D2})^2}. \end{aligned}$$

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<sup>16</sup> This can also be viewed as a normalization, if we first subtract  $c_{D1}$  from  $\alpha_1$  and  $\beta_1$  and then normalize prices and quantities so that  $\alpha_1 - c_{D1} = 1$ ,  $\beta_1 - c_{D1} = 1$  (and  $\alpha_2 = 1$ ).



$$\begin{aligned}
& \text{i) } \frac{dx_B}{dt} = -\frac{1}{\beta_2} \frac{dP}{dt} = \frac{\beta_2 + \beta_2 c_{D2} + c_{D2}}{(\beta_2 + 1)(2\beta_2 + c_{D2}\beta_2 + c_{D2})} > 0, \\
(23) \quad & \text{ii) } \frac{dx_B}{da} = -\frac{1}{\beta_2} \frac{dP}{da} = \frac{\beta_2 c_{D2}}{(2\beta_2 + c_{D2}\beta_2 + c_{D2})^2} > 0, \text{ and} \\
& \text{iii) } \frac{dx_B}{dm} = -\frac{1}{\beta_2} \frac{dP}{dm} = -\frac{\beta_2 c_{D2} + 2\beta_2^2 + c_{D2}^2 + 2\beta_2 c_{D2}^2 + \beta_2^2 c_{D2} + \beta_2^2 c_{D2}^2}{(\beta_2 + 1)(2\beta_2 + c_{D2}\beta_2 + c_{D2})^2} < 0.
\end{aligned}$$

$$\begin{aligned}
& \text{i) } \left. \frac{dP}{dx_A} \right|_{dt>0} = \frac{\beta_2^2 + \beta_2^2 c_{D2} + \beta_2 c_{D2}}{\beta_2^2 + 2\beta_2 + \beta_2 c_{D2} + c_{D2}} > 0, \\
(24) \quad & \text{ii) } \left. \frac{dP}{dx_A} \right|_{da>0} = \frac{\beta_2 c_{D2}}{2\beta_2 + c_{D2}} > 0, \text{ and} \\
& \text{iii) } \left. \frac{dP}{dx_A} \right|_{dm>0} = \frac{\beta_2 (\beta_2 c_{D2} + 2\beta_2^2 + c_{D2}^2 + 2\beta_2 c_{D2}^2 + \beta_2^2 c_{D2} + \beta_2^2 c_{D2}^2)}{2\beta_2 c_{D2}^2 + 3\beta_2^2 c_{D2} + \beta_2^3 c_{D2} + 2\beta_2 c_{D2} + c_{D2}^2 + \beta_2^2 c_{D2}^2 - 2\beta_2^3}.
\end{aligned}$$

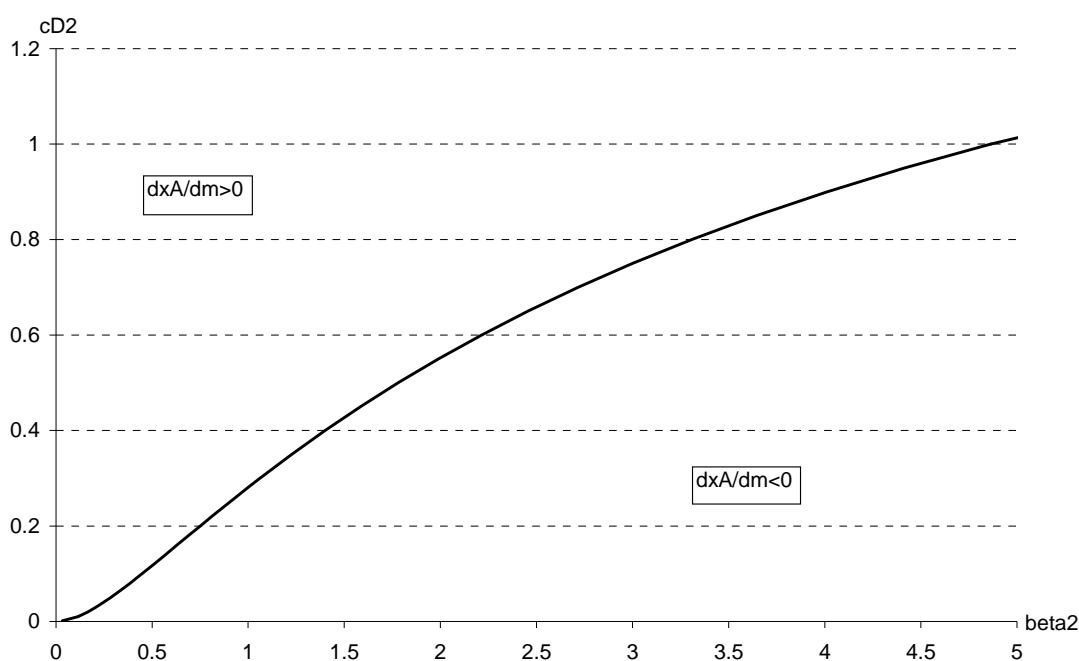
Notice that a fuel tax and a biofuel share will unambiguously reduce the producer price of oil and consumption in Region *A* as it increases consumption in Region *B*, causing carbon leakage. Increased fuel efficiency, however, will unambiguously increase the producer price of oil and hence reduce consumption in Region *B*. The effects on consumption in Region *A* are ambiguous and depend on the steepness of the demand curve in Region *B* as well as the marginal costs of the monopolist. These results are consistent with the results found in Section 2 in the case of a closed market.<sup>17</sup>

Let us first examine in which cases increased fuel efficiency will reduce fuel consumption in Region *A*. Figure 5 shows what combinations of  $\beta_2$  and  $c_{D2}$  make  $dx_A/dm$  negative. Define Region *B* to be large compared to Region *A* when it comes to oil consumption if  $\beta_2$  is smaller than  $\alpha_2 \equiv 1$ —i.e., the oil demand is higher in region *B* than *A*. Thus, although  $c_{D2}$

<sup>17</sup> A closed market can be seen as a special case of an open market with  $\beta_2 \rightarrow \infty$ .

typically will be small when  $\beta_2$  is small because of the normalization, equation (22) iii) shows that the sign of  $dx_A/dm$  more likely will be positive when Region  $A$  is small compared to Region  $B$ .<sup>18</sup> Thus, a small country facing a monopolist on the world market should not introduce fuel-efficiency standards if it aims to reduce domestic consumption (given the simple model framework outlined above). The explanation is that the equilibrium price in a monopoly market with linear demand functions will be above the intersection between the old and new demand curve shown in Figure 1. As  $\beta_2$  is small, the demand curve in Region  $B$  will be relatively flat; thus the small region has little influence on the price, and consumption will increase.

**Figure 5. Combinations of  $\beta_2$  and  $c_{D2}$  That Give Respectively Increased and Decreased Domestic Oil Consumption when Fuel Efficiency Is Increased in a Monopoly Market**



If the two regions are equally large ( $\beta_2 = 1$ ), increased fuel efficiency will reduce oil consumption in Region  $A$  if and only if  $c_{D2} < (17^{0.5} - 3) / 4 \approx 0.28$ ; see equation (22) iii) and Figure 5. Thus, the demand curve must be much steeper than the marginal cost function if we want to reduce consumption by increasing fuel efficiency. We further see that consumption in Region  $A$  will always increase if  $c_{D2} \geq 2$ , irrespective of the size of  $\beta_2$ . The intuition is that high

<sup>18</sup> Assume for instance that  $c_{D2}$  is proportional by a factor  $l$  to  $\beta_2 / (1 + \beta_2)$ , i.e., the steepness of the inverse aggregate demand curve. Then, for any  $l > 0$  we can always find a  $\beta_2^*$  so that  $dx_A/dm > 0$  for all  $\beta_2 < \beta_2^*$ .

marginal costs move the equilibrium price above the intersection between the old and new demand curve. Moreover, if Region  $B$  is small compared to Region  $A$  (i.e.,  $\beta_2 \gg 1$ ), consumption will decrease in the latter region if the value of  $c_{D2}$  is sufficiently below 2. In the limit, when  $\beta_2 \rightarrow \infty$ , we are in a closed market, and we notice that the result is consistent with the findings in Section 2.

The results can be summarized in the following proposition:

**Proposition 5:** *In a world consisting of two regions (A and B), with a monopoly in Region B supplying oil, increased fuel-efficiency standards in Region A will increase oil consumption in this region if*

- *Region A is sufficiently small compared to Region B ( $\beta_2$  is small); or*
- *marginal costs of the oil producer are sufficiently high.*

*Proof:* This follows from the discussion above.

Now focus on the situations where the policy instruments lead to reduced oil consumption in Region  $A$ . How will the producer price of oil change relative to the consumption reduction in Region  $A$  (see equation (24))? We already know that the fuel tax and the biofuel share will reduce the price, whereas fuel efficiency will increase the price. In Figure 6, we keep  $\beta_2 = 1$  and vary  $c_{D2}$ . In Figure 7, we keep  $c_{D2} = \beta_2 / (1 + \beta_2)$ , and vary  $\beta_2$ .

**Figure 6. Effects on the Producer Price of Oil ( $dP/dx_A$ ) under Different Policy Instruments when  $\beta_2 = 1$  in a Monopoly Market**

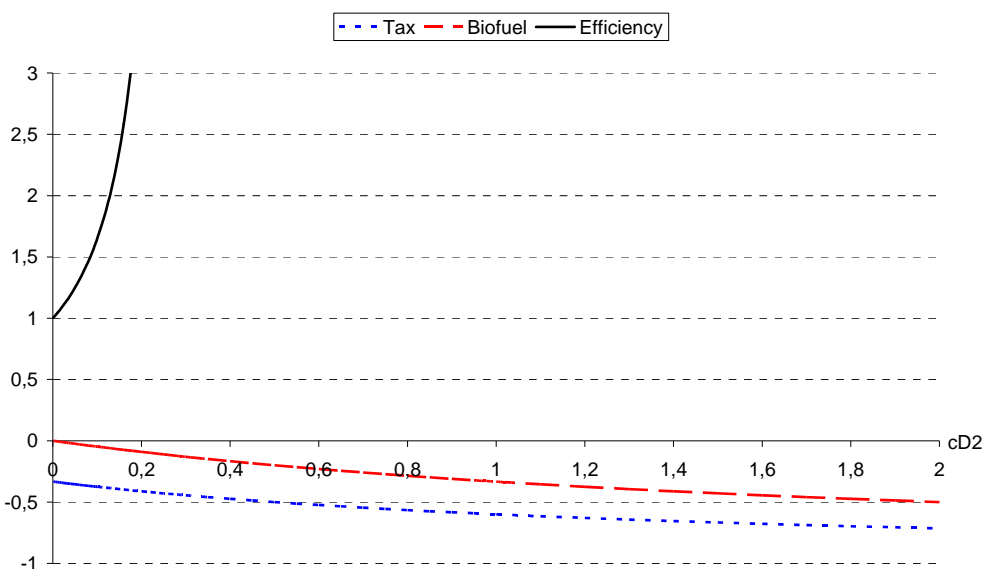
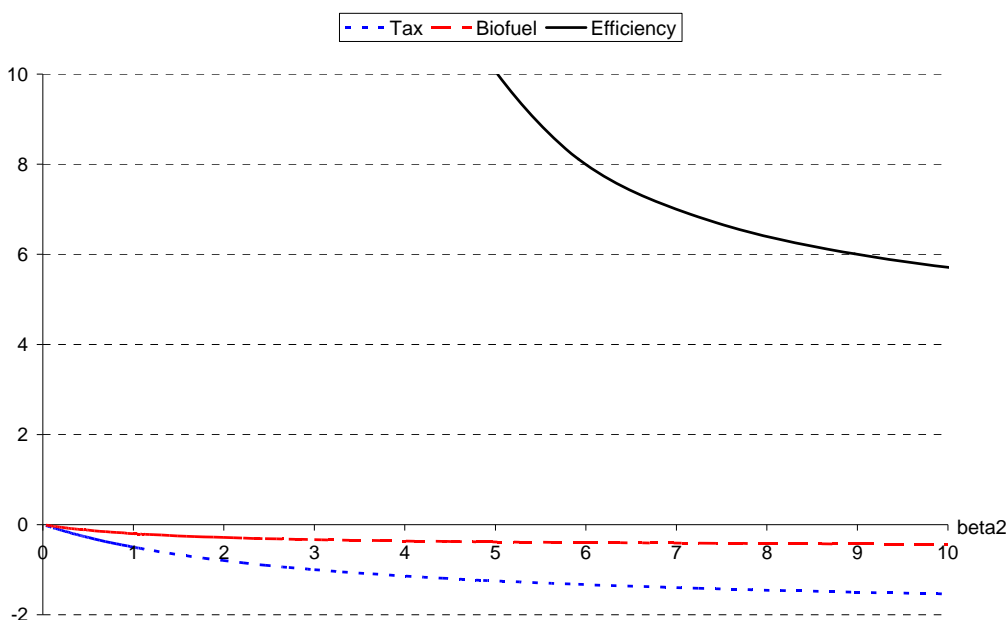


Figure 6 shows that the price reduction will be consistently and significantly larger if a tax is imposed than if a biofuels share is imposed. Comparing equations (24) i)–ii) shows that this holds more generally, unless  $c_{D2} \geq 7$  and  $\beta_2$  is sufficiently above one and sufficiently below  $c_{D2}$ . In other words, unless the marginal cost function is several times steeper than the aggregate demand curve (which we find highly unlikely), a fuel tax will lead to larger price reductions than a biofuels share. In line with Section 2, this is due to steeper demand functions with biofuels shares than with a tax. The figure further demonstrates that the steeper the monopolist’s marginal costs are, the more the price drops when consumption is reduced by a fuel tax or a biofuels share.

The figure also shows that the price effect is much bigger when fuel efficiency is enhanced and can be very big relative to the consumption reduction when  $c_{D2}$  approaches 0.28. This is because the efficiency standard hardly reduces consumption when  $c_{D2}$  is above 0.25.

Figure 7 illustrates that the price reduction under a tax or a biofuels share increases with the relative size of Region A. For instance, if Region A is two times bigger than Region B ( $\beta_2 = 2$ ), the price reduction is 50–60 percent higher than if the regions are equally big ( $\beta_2 = 1$ ). Moreover, when Region A is very small compared to the rest of the world ( $\beta_2 \rightarrow 0$ ), we see that the price reduction is negligible. These results follow the discussion above, where a flatter demand curve in Region B (i.e., high  $\beta_2$ ) gives small price reductions.

**Figure 7. Effects on the Producer Price of Oil ( $dP/dx_A$ ) under Different Policy Instruments when  $c_{D2} = \beta_2 / (1 + \beta_2)$  in a Monopoly Market**



On the other hand, if fuel efficiency is increased, Region *A* must be at least three times bigger than Region *B* to achieve reduced consumption, assuming the same steepness of marginal costs and aggregate demand. Again, the price increase relative to the consumption reduction can be very big but decreases further as we increase the relative size of Region *A*. This is because the policy instrument becomes more effective in reducing consumption when the region is large, so the relative price increase falls.

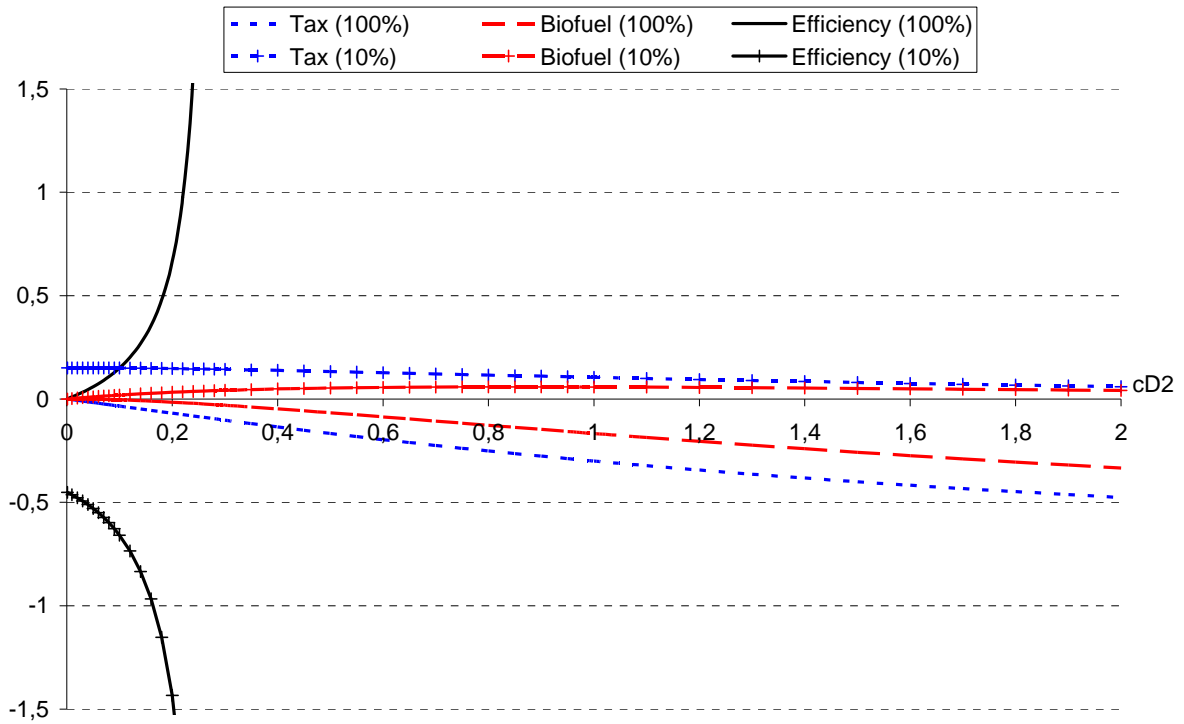
In what way do these findings influence the optimal choice of policy instrument in Region *A*? As mentioned in Section 2, policymakers in the region may be concerned about both terms-of-trade effects and carbon leakage in Region *B*. The costs of the different policies obviously matter as well, but this is not the topic of this analysis. We also disregard distributional aspects. The international (net) benefits ( $d\Omega$ ) for Region *A* of policy instrument *i* can then be expressed as:

$$(25) \quad \left. \frac{d\Omega}{dx_A} \right|_{di>0} = x_A \left. \frac{dP}{dx_A} \right|_{di>0} + \tau \left. \frac{dx_B}{dx_A} \right|_{di>0},$$

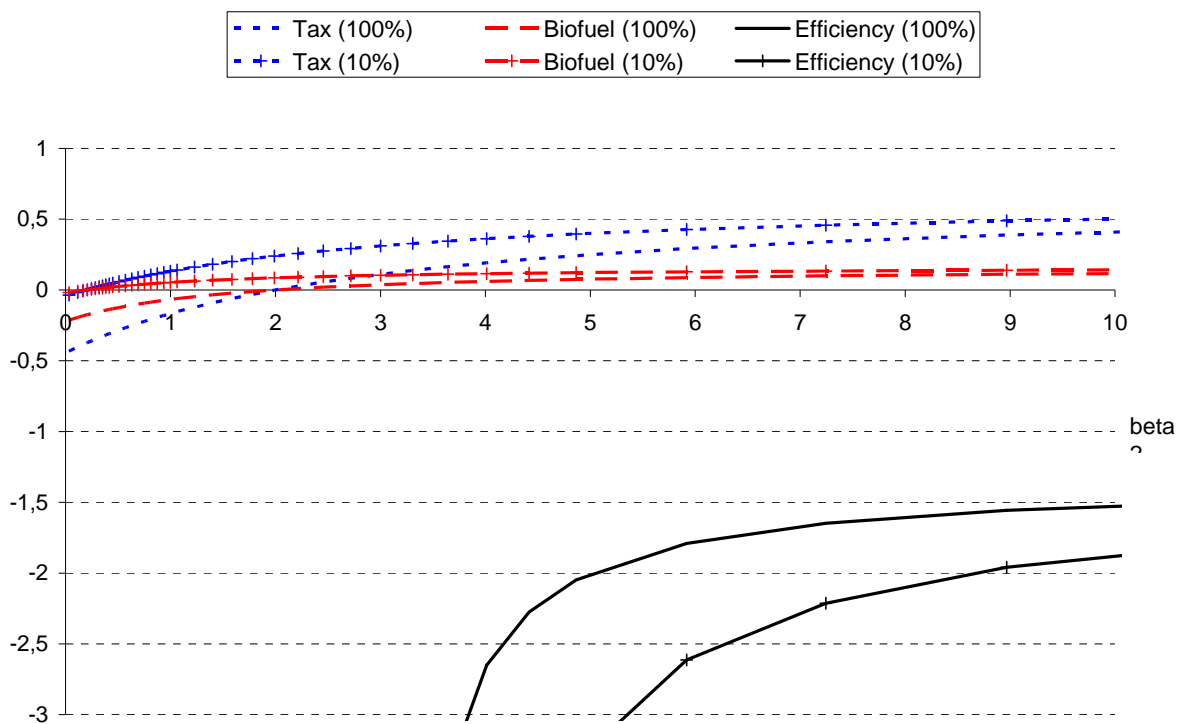
where  $\tau$  denotes the shadow price of increased consumption abroad.

If carbon leakage is not important, we are left with  $x_A dP/dx_A$ , the latter part of which we have discussed above. But what if  $\tau > 0$ ? Figures 8 and 9 correspond to Figures 6 and 7, and show how the international benefits depend on the relative sizes of the two regions as well as the steepness of the marginal cost curve relative to the aggregate demand curve. Note that we only concentrate on the cases where fuel efficiency reduces demand in Region *A* ( $dx_A/dm < 0$ ). The shadow price  $\tau$  has been set to respectively 10 percent or 100 percent of the producer price in the figures.

**Figure 8. Effects on International (Net) Benefits ( $d\Omega/dx_A$ ) under Different Policy Instruments when  $\beta_2 = 1$  in a Monopoly Market**



**Figure 9. Effects on International (Net) Benefits ( $d\Omega/dx_A$ ) under Different Policy Instruments when  $c_{D2} = \beta_2 / (1 + \beta_2)$  in a Monopoly Market**



The figures indicate that the total international benefits are very dependent on  $\tau$ , which denotes the shadow price of increased consumption abroad—i.e., how much we value carbon leakage. This is particularly important for the benefits of fuel efficiency, as shown later in Figure 11. With fuel efficiency, the carbon leakages are negative, and a higher  $\tau$  gives more credit to this effect. A fuel tax fares best when the shadow price of foreign emissions is not too high. Then the terms-of-trade benefits from reduced oil price dominate over the leakage effect.

How large are the net benefits shown in Figures 8 and 9 compared to the benefits of reduced domestic consumption, disregarding costs? The answer to this depends on the valuation of domestic reductions. If, for instance, we assume that Region *A* values domestic and foreign consumption reductions equally much (e.g., due to greenhouse gas emissions), the domestic benefits will be in the range 0.05–0.08 (10 percent) and 0.5–0.8 (100 percent) in Figure 8 and equal 0.067 (10 percent) and 0.67 (100 percent) in Figure 9. Thus, we see that the international (net) benefits are at least comparable with the domestic benefits and possibly much more important (at least if the region is not too small).

## 4.2 Dominant Firm with Competitive Fringe

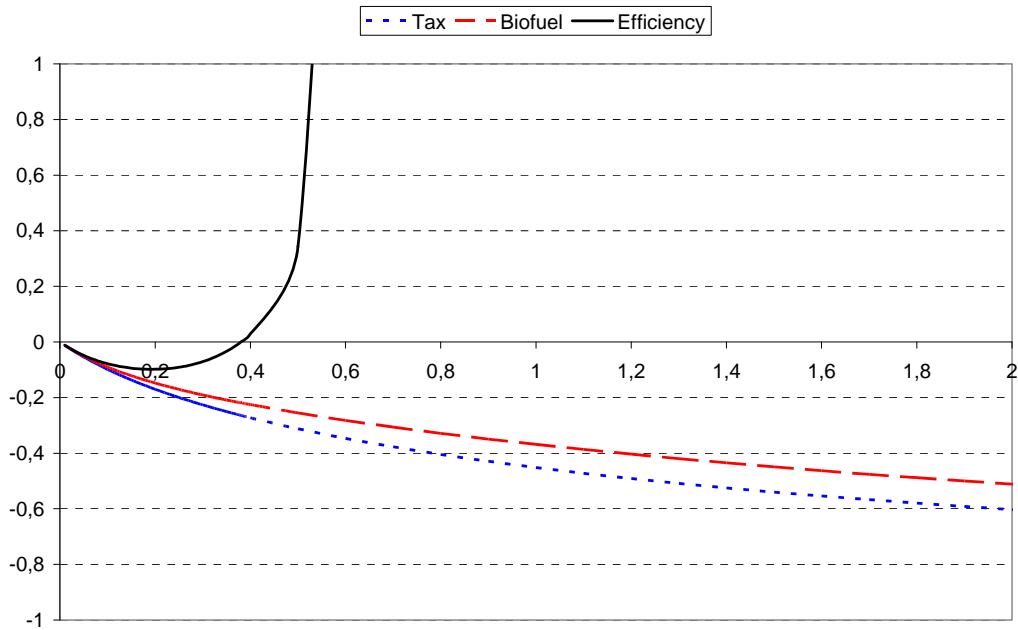
As explained above, it is difficult to derive interpretable expressions similar to equations (22)–(24) in the case with a dominant firm and competitive fringe. Thus, in this subsection we will present only some numerical illustrations that show how the existence of the fringe can influence on the results discussed above. To simplify the comparison with the preceding subsection, we assume that  $c_{F1} = c_{D1} = 0$ .

In the figures below, we have assumed that the fringe can produce half as much as the dominant firm at a given marginal cost level (i.e.,  $c_{F2} = 2c_{D2}$ ). In the market equilibrium, however, it will supply more than one-third of the market, and possibly more than 50 percent, depending on the values of  $c_{D2}$  and  $\beta_2$ . The existence of the fringe increases the likelihood that increased fuel efficiency in Region *A* will reduce consumption in that region. On the other hand, it is now possible that the price of oil can fall.

Figures 10 and 11 correspond to Figures 6 and 8, where  $\beta_2 = 1$ . Figure 10 shows that the existence of the fringe significantly changes the terms-of-trade effect for Region *A* if fuel efficiency is increased. If the marginal cost curves are rather flat—i.e.,  $c_{D2}$  is low—higher fuel efficiency will *decrease* the price of oil because the fringe will react quite significantly to a change in the price. If the curves are steeper (but not too steep), we get the same qualitative result as in the monopoly case. In the tax case, the price reduction is much smaller than in Figure 6 if the marginal cost curves are flat, which again is explained by the fringe's responsiveness.



**Figure 10. Effects on the Producer Price of Oil ( $dP/dx_A$ ) under Different Policy Instruments when  $\beta_2 = 1$  in a Dominant Firm Model**



**Figure 11: Effects on International (Net) Benefits ( $d\Omega/dx_A$ ) under Different Policy Instruments when  $\beta_2 = 1$  in a Dominant Firm Model**

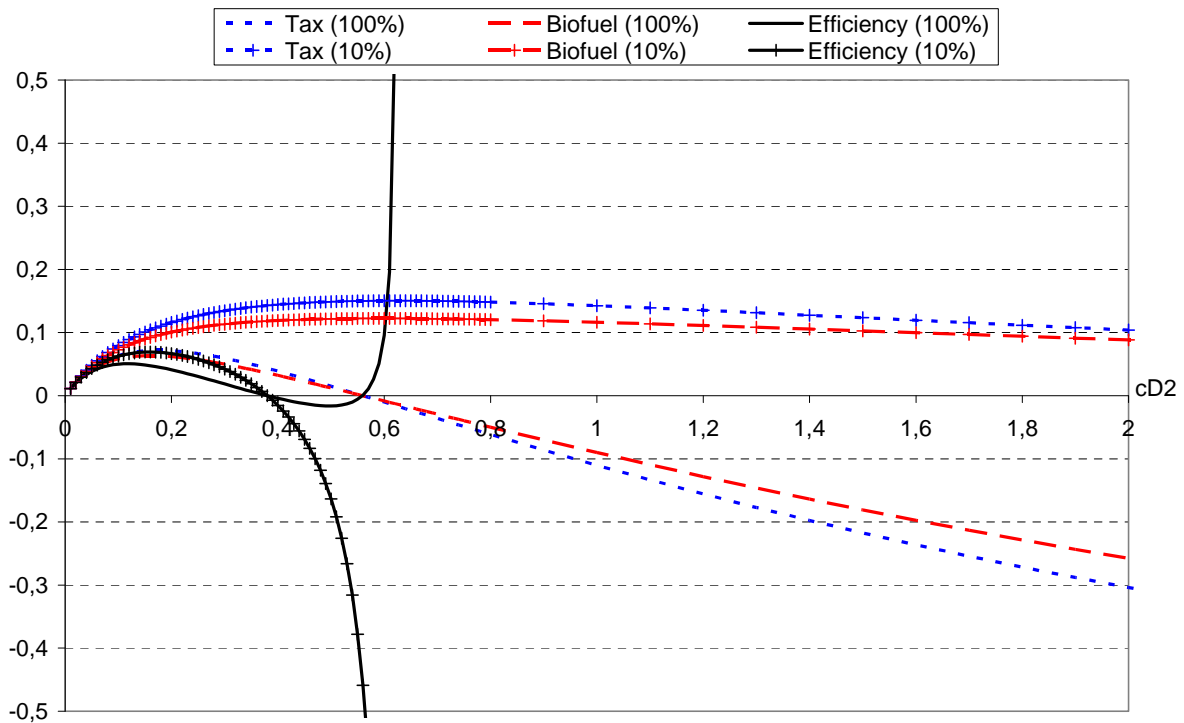


Figure 11 shows that if marginal costs are rather flat (and small), the different policy instruments fare quite similarly.<sup>19</sup> The reason is again that the fringe responds significantly to any price changes, and hence the dominant firm has little room to maneuver. When marginal costs are steeper, the results are more similar to the ones in Figure 8. We notice, however, that the difference between the fuel tax and the biofuels share is much smaller when the fringe exists. This is because the price reduction under a tax is smaller than under a monopoly market.

Finally, let us calibrate this simple, linear model to the current oil market, assuming that a common policy instrument is introduced in the United States and the European Union, which together has about 40 percent of global oil consumption (BP 2010). OPEC currently has a market share around 40 percent of global supply. We assume that non-OPEC and OPEC unit production costs amount to 40–100 and 20–40 percent of the oil price, respectively. Then we obtain the effects shown in Table 3 of the three policy instruments.<sup>20</sup>

**Table 3. Simulated Effects of Policy Instruments in the Current Oil Market, when Joint Consumption in the United States and the European Union Is Reduced by 10 Percent**

	Fuel tax	Biofuel share	Efficiency standard
Oil price	-2.0%	-1.7%	+8%
Oil consumption, rest of world	+1.9%	+1.6%	-7%
Oil production, OPEC	-3.7%	-4.9%	-34%
Oil production, non-OPEC	-2.3	-1.8%	+9%

We notice that a fuel tax and a biofuel requirement have similar effects, with somewhat stronger price reduction in the former case. The effects of increased fuel efficiency are strong, with substantial reduction in OPEC supply and a significant increase in the oil price. This result,

<sup>19</sup> Note that the fuel-efficiency curves intersect for  $c_{D2} = 0.35$ . The reason is that the price effect changes at this value. For lower values of  $c_{D2}$ , the price effect is negative, while it is positive for higher values.

<sup>20</sup> The parameter values of this model are  $c_{D1} = 0.1$ ,  $c_{F1} = 0.2$ ,  $c_{D2} = 0.3$ ,  $c_{F2} = 0.6$ , and  $\beta_2 = 0.7$ .

however, is very sensitive to small variations in the parameters of the model and reflects that increased fuel efficiency has small effects on U.S. and EU oil consumption in this model, such that a 10 percent reduction in consumption requires a major increase in efficiency. Thus, the results of increased fuel efficiency should be interpreted with particular caution; they suggest that it might be extra difficult to predict the market outcome of raising fuel efficiency in some major oil-consuming countries.

## 5. Conclusions

This paper has shown that the effects of different policy measures to regulate the transport sector depend on the market structure in the oil market. In a competitive market, a fuel tax and a biofuels requirement will always reduce oil demand. A fuel-efficiency standard, on the other hand, will have ambiguous effects on oil demand as it lowers the price and increases demand for transport services, while reducing the oil consumption needed to produce a certain level of transport services. As long as the price elasticity of demand is below one in absolute value, increased fuel efficiency will decrease oil consumption.

If a monopoly supplies the oil market, the effects of transport regulations become more ambiguous. While a fuel tax will definitely reduce oil consumption, a required share of biofuels may actually increase oil consumption with a monopoly if the inverse demand function is very convex. Fuel-efficiency standards also have uncertain impacts on oil consumption, just as in a competitive market. Again, the more convex the inverse demand function is, the more likely oil consumption increases with increased fuel efficiency. In most realistic cases, however, oil consumption will decrease under all these policy instruments. Moreover, the reduction in oil consumption will most likely be largest under a monopoly if biofuel requirements or increased fuel efficiency are implemented.

A regulating body may also care about the effects on the oil price, for instance due to distribution effects between oil producers and consumers. In addition, an oil-importing country may worsen its terms of trade if the oil price rises, and vice versa for an oil-exporting country. The effects on the oil price may also be important if an international climate treaty is in place. If not all countries have signed the treaty, a lower oil price may increase oil demand in non-signatory countries and lead to carbon leakages. Thus, countries signing a carbon treaty may favor instruments that increase the oil price.

The price effects depend on the market setting. In a closed economy, the producer price always move in the same direction as the consumption if the market is competitive, so a lower

consumption level also gives a lower producer price. Moreover, the price effects are identical as long as the policy instruments lead to the same reduction in oil consumption. However, with a monopoly on the supply side, the effects are more ambiguous and depend on the curvature of the inverse demand function and the cost function. A fuel tax possibly could increase the producer price of oil if the inverse demand function is sufficiently steep compared to the marginal cost function. With a biofuels requirement, the producer price will decrease, while with a fuel-efficiency standard, the price of oil will always increase if oil consumption decreases, a result that is quite opposite to the effect with perfect competition.

In an open economy with an oil-producing region as well as an oil-importing region, we show that under reasonable assumptions, both taxes and biofuels shares will reduce oil consumption if they are introduced in the oil-importing region. Again, the effects of increased fuel efficiency are ambiguous. With monopoly on the supply side, oil consumption in the importing region is more likely to increase if it is small compared to the exporting region (measured in oil consumption). Existence of a competitive fringe producing oil increases the likelihood of reduced oil consumption in the case of increased fuel-efficiency standards.

It is hard to make policy recommendations based on this analysis because policymakers' preferences for the effects on their oil consumption and the producer price of oil may contrast. If we assume that the main objective of transport regulations is to reduce oil consumption, a fuel tax is the safest alternative because it will always reduce oil consumption. Because the producer price moves in the same direction as the consumption in a competitive market, lower oil consumption always goes hand-in-hand with a lower oil price. This may give preferred terms-of-trade effects for an oil-importing country but will induce carbon leakage and undermine attempts to reduce global carbon emissions.

The effects on oil prices in the closed market resemble the effects in the open market. There are several policy implications when a monopoly supplies the oil market. For instance, if policymakers are concerned about the mark-up for big oil producers (or the terms-of-trade effects), they should avoid fuel-efficiency standards as the main policy instrument to reduce oil consumption because this policy will increase the producer price of oil. If the inverse demand function is not too convex, they rather should choose a fuel tax. Alternatively, if the inverse demand function is quite convex, a biofuels standard is most advantageous in this respect. However, if the function is very convex, a biofuels standard will not reduce oil consumption.

If policymakers prefer high prices (e.g., due to concern about carbon leakage), the conclusions naturally become completely turned around.<sup>21</sup> The same reasoning can be applied to big oil producers, who would find it in their interest to lobby for fuel-efficiency standards rather than fuel taxes and biofuels shares.

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<sup>21</sup> Other (potentially more important) issues come into play when choosing between policy instruments, such as cost-effectiveness. Such issues are not the topic of this paper, however.

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