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

|by

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05 January 2012

Abstract

Instruments to regulate the consumption of oil in the transport sector include fuel taxes, biofuel requirements and fuel efficiency standards, though their impacts on oil consumption and price vary. 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 structure impacts not only the effectiveness of the policy instruments to reduce oil consumption, but also the terms of trade and carbon leakage. In particular, reduced oil consumption due to increased fuel efficiency standards will unambiguously *increase* the price of oil under monopoly.

JEL codes: D42; Q54; R48

Keywords: Policy instruments, oil consumption, monopoly, terms-of-trade, carbon leakage

***Acknowledgments:** This project is financed by the PETROSAM Program at the Research Council of Norway. Snorre Kverndokk is grateful for the hospitality from the University of Maryland and Resources for the Future (RFF), and Knut Einar Rosendahl to the RFF, while working on this paper. We are indebted to comments from Michael Anderson, Carolyn Fischer, Cathrine Hagem, Jon Strand, HaakonVennemo, two anonymous referees and editor Matti Liski, as well as to the seminar participants at RFF, the U.S. Environmental Protection Agency, the World Bank, the Fourth World Congress of Environmental and Resource Economists (Montreal), the IAEE European Conference in Vilnius and a PETROSAM conference. Both authors are associated with CREE – Oslo Centre for Research on Environmentally friendly Energy, which is supported by the Research Council of Norway.

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1 Introduction

Climate change is high on the global policy agenda, and studies such as IPCC (2007) and Stern (2007) have established the need for ambitious international climate agreements and strong domestic climate policies. Early steps include the EU Emission Trading System, the Kyoto Protocol and the Copenhagen Accord, and 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 are net oil importers, and the fact that one-third of global oil exports come from the Middle East brings forth concerns 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 become depleted (EIA, 2010), whereas the Organization of the Petroleum Exporting Countries (OPEC) may increase its market share and, consequently, its market power.[1]

Both climate change impacts and energy security call for policies to reduce the demand for oil in most oil-importing countries, which can be achieved through a number of different policies such as mandated biofuel shares, emissions standards, a quota system for carbon dioxide (CO_2) emissions, the taxation of CO_2 emissions or energy use, the supporting of renewable

[1] Canada has become a major oil supplier, and currently has the second largest oil reserves in the world after Saudi Arabia due to its large reserves of oil sands (EIA, 2010). However, the prospects of future oil sands production are somewhat limited by environmental concerns and investment restrictions. For more background on the oil market and future perspectives, see e.g. BP (2010) and EIA (2010).

energy production and standards for energy equipment.[2] Examples of policies that are rarely cost-effective with respect to climate change or energy security, yet often preferred by policymakers, are those that specifically 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), with all either being implemented or suggested in the European Union and the United States, although to different degrees. While the U.S. 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 has traditionally favored fuel economy standards, and aggressively tightened their standards in 2007 and 2009, [3] and biofuel requirements have been introduced in both the U.S. and the EU in recent years.[4]

The transport sector is essential when studying the demand for oil. According to the EIA (2010), transportation accounted for 53% of the total world liquids consumption in 2007, with that share expected to increase to 61% in 2035. In addition, the world's transportation systems are more than 90% dependent on oil and oil products, thus few alternatives can compete widely with oil in the transport market today. Biofuels are obviously candidates, but are mostly uncompetitive without regulations in favor of such fuels (with Brazilian ethanol being

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[2] 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.

[3] The new Corporate Average Fuel Economy (CAFE) standards for manufacturers (as of 2009) 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).

[4] All Member States in the EU are required to increase their share of biofuels in the transport sector to at least 10 percent in 2020 from a current share of about 3% (see e.g. http://ec.europa.eu/energy/renewables/doc/sec_2008_85-2_ia_annex.pdf). Additionally, 10 percent of U.S. gasoline now comes from corn ethanol, although the U.S. Renewable Fuel Standard mandates the minimum use of 36 billion gallons of ethanol by 2020, which is up from 11 billion gallons at present (Chakravorty et al., 2011)

one possible exception). Coal- and gas-to-liquids are other candidates, but are too expensive with the current prices of fossil fuels, and the same holds true for electric- and hydrogen cars. In the future, however, several of these technologies may become competitive versus oil, even without special treatment.

Policies to regulate transport may have different impacts in a competitive market, as well as a market with a dominant producer. The oil market can hardly be considered competitive, as OPEC exhibits at least some degree of market power (see e.g. Alhajii, 2004; Hansen and Lindholt, 2008). Thus, in this paper we study the impacts of different types of transportation regulations in the presence of market power, and compare them with the corresponding impacts in a competitive market. In particular, we compare three different types of policy instruments: a fuel tax, a required share of biofuels in the transport market and a fuel efficiency standard.

The choice of policy instrument may have major economic effects, although the impact on sectors and consumers will vary. There are a lot of studies that have focused on the effects of introducing carbon- or fuel taxes that could be part of a general carbon taxation policy, see e.g. Bye et al. (2003). A general carbon taxation policy will be cost-effective, but is mostly found to be regressive as low income households spend a larger budget share on carbon-intensive products than do high income households. The effects of biofuel standards may be quite different, and several papers have focused on the effects of food prices, as biofuel production requires land and may crowd out land for food production. Rosegrant et al. (2008) find that an aggressive expansion into biofuels will increase the prices of certain food commodities by up to 70% by 2020, while Chakravorty et al. (2011) find that only one-third of increases in food prices can be attributed to clean energy mandates. Additionally, crops for biofuels may be planted on pastureland and forests, and biofuel production may therefore increase the leakage of sequestered carbon into the atmosphere (see e.g. Searchinger et al., 2008). Finally, fuel efficiency standards may have less dramatic side effects, but can affect car sales and prices in addition to fuel consumption and emissions, see e.g. Goldberg (1998) and Fischer et al. (2007).

Our interest is on the effects on the price and quantity of oil consumption under different market structures, and we find that while a fuel tax and biofuel requirement will always reduce oil demand in a competitive market, a fuel efficiency standard may possibly increase consumption. This is due to the rebound effect, i.e. that the lower costs of driving a car may stimulate the demand for transport and thus counteract (at least part of) the direct drop in fuel consumption. The consumption effects also become ambiguous with a biofuel requirement when market power is present, but with more realistic demand functions, oil consumption will decrease for all policy instruments under both a competitive and monopoly market structure.

Price effects can be dramatically different, however, under market power compared to a competitive market, particularly if fuel efficiency standards are raised. Price effects are important, e.g. if 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 (carbon leakage; see Felder and Rutherford, 1993). It is also widely known that environmental regulations may affect the terms of trade (Krutilla, 1991), and oil-importing countries may worry about policy measures that can *increase* the price of oil. We find that while the producer price always falls when consumption is reduced in a competitive market, and most likely under a monopoly for fuel taxes and biofuel shares, a reduced oil consumption due to increased fuel efficiency standards will always increase the price of oil under a monopoly.

This also has distributional consequences. A monopolist receives reduced profits if oil consumption is reduced through a fuel tax or biofuel requirements, although its profit will increase if the consumption is reduced through fuel efficiency standards. While this paper studies the impacts of transport regulations, the theoretical model is general, and can be applied to the study of policy instruments under market power for a number of commodities.

The literature relevant to our study can be divided into two strands: one that studies regulations in the transport sector in more detail by primarily 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 oil market 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 the welfare effects of fuel economy regulations (e.g. Fischer et al., 2007) or calculate the 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 on reducing oil consumption and greenhouse gas emissions from the U.S. transportation sector but assume an exogenous oil price. The large literature on fuel-efficiency standards introduces market power in the supply of cars only, and not in the oil market (e.g. Goldberg, 1998; Plourde and Bardis, 1999). The economic literature on biofuels has also emerged over the last few years (see e.g. Rajagopal and Zilberman, 2007 for a survey), but competitive markets are usually assumed.

Even so, a recent paper on biofuels that makes a link to the second strand of literature is Hochman et al. (2010), which focuses on the impact of biofuels when OPEC acts as a cartel, as compared to a competitive market within a static model. Their results are consistent with our analysis of biofuel standards, though they do not make comparisons with other policy instruments to reduce oil consumption. Other studies focusing on the supply side of the oil market mainly analyze the impacts of introducing carbon taxes and tradable permits, with one example being Berger et al. (1992), who compare the producer price of fossil fuels when implementing the two policy instruments under different market structures. Some studies of carbon taxation also assume a intertemporal supply under different market structures (e.g. Berg et al., 1997b), while other studies analyze different policy measures from an intertemporal supply-side perspective under perfect competition (e.g. Sinn, 2008), but few studies compare policy instruments in an intertemporal setting when market power is taken into account.

Our paper is connected to both these strands of literature. Instead of focusing on the preferences of consumers, we study the importance of the supply-side structure in a market reaction to transport regulations. We do not consider intertemporal optimization on the supply side, but instead focus on market power in a static setting. Limited resources are certainly a characteristic of fossil fuel markets, and early literature (Stiglitz, 1976; Lewis et al., 1979) demonstrated that the nature of resource monopoly distortion may differ from that of static monopoly distortion, as it is difficult to manipulate quantities when total resources are given. Thus, an oil monopoly may behave exactly as a competitive sector, or could even extract the resource faster (depending on e.g. the demand function). However, this early literature generally assumed that the resource stock is exogenous with constant unit extraction costs, thereby implying that the resource is fully depleted over time. More recent studies have made the more realistic assumption that different stocks have different extraction costs, meaning that the ultimate extraction is endogenous. For instance, Gaudet and Lasserre (1988) showed that when reserves need to be discovered and the costs of discovery are convex, a resource monopoly will restrict supply compared to a competitive outcome. Hence, monopolistic behavior in the dynamic setting will be more similar to the static setting. The new literature on the "green paradox", which emphasizes the role of intertemporal optimization on the effects of climate policies, also reveals that when we abstract from simple assumptions such as constant extraction costs and perfect energy substitutes, the qualitative results get closer to those of static optimization, i.e. the green paradox may erode (see e.g. Gerlagh, 2010). Nevertheless, we should add that the policy effects we derive in the static setting are more robust if we consider permanent policy changes – to a larger degree, temporary policies may lead to the intertemporal reallocation of resource extraction.

The paper is organized as follows: In the next section, we use a static model for a closed economy to study the impacts of various policy instruments in a competitive- 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. Here, we also introduce the dominant firm and competitive fringe model. The final section concludes.

2 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 and a natural interpretation is to think of this as the global oil market. Nevertheless, we will also discuss the implications for a single oil-importing country, and will explicitly model an open market in Section 3. Since the substitution possibilities are small in the transport market, we implicitly keep the prices of other energy goods constant.[5]

We study different transport regulations to reduce fossil fuel consumption and hence CO_2 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. Thus far, it seems more realistic to consider such regulations within a single country or group of countries than the entire world, as not all countries are likely to sign a climate agreement, which is why we examine an open economy in the next section. The analysis of a closed market will still provide useful insight into a situation in which a large part of the oil market becomes regulated.

The demand-side regulations we consider are the following:

- A *fuel tax* interpreted as a tax t per unit of oil consumed.

- A required *share of biofuels* such that for each unit of oil that is sold, one also needs to sell a units of biofuel (e.g. gasoline mixed with ethanol).[6]

- An *efficiency standard* interpreted as a binding minimum average vehicle efficiency m, measured as miles per gallon (mileage).

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[5] In the future, given the significant progress for alternative transportation technologies, this assumption may become less valid. To simplify the analysis throughout the paper, we further ignore oil consumption outside the transport sector.

[6] Alternatively, there is a required share of biofuels interpreted as a fraction $\hat{a}$ of total transport fuel consumption, where $a = \hat{a}/(1-\hat{a})$. Ideally, a should relate to the energy content and not a gallon, as one gallon of biofuel generally has less energy content than one gallon of gasoline.

We will compare the effects of these policy instruments in a competitive market (C) and a monopoly market (M), and will also consider a market with a dominant producer and competitive fringe in the next section.

2.1 The Demand for Oil

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

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

To drive a certain distance, one can use oil and/or biofuels as the fuel source.[7] Since oil is measured in gallons, $m \cdot x$ is the number of miles driven on oil and $m \cdot a \cdot x$ is the number of miles driven on biofuels. Alternatively, $(1+a)x$ is the blended fuel. We see that for a given consumption of transport services q, the increased mileage or share of biofuels means that the consumption of oil is reduced accordingly.

Stricter fuel efficiency standards will presumably lead to higher production costs for car companies, and therefore higher car prices. This could lead some consumers to drop out of the car market or buy fewer cars. On the other hand, consumers' valuation of a given car becomes higher when its fuel efficiency increases because it becomes cheaper to use. Consequently, if a stricter standard leads to only a modest price increase for cars, the demand for cars could possibly expand instead of shrink. Hence, the new demand function could shift either

[7] We disregard other alternative transport technologies such as electricity and hydrogen, as they currently have much smaller market shares, and are usually not regulated through the policy measures studied here.

downwards or upwards compared to equation (1), although this possibility is disregarded in our analysis.

Furthermore, biofuels are currently more expensive than gasoline (otherwise the requirement would presumably be superfluous). To simplify the analysis, we assume that the government covers the extra costs of supplying biofuels, i.e. the difference between the wholesale price of biofuels and the wholesale price of gasoline. For this reason, we assume that the consumer price of both fuels (either blended or distributed separately) equals the price of oil (gasoline), with a similar assumption used by Hochman et al. (2010). If we instead assumed that the oil producer has to buy biofuels at a price above its own marginal costs and then supply the blend in the market, an increase in the blending requirement, *a*, would also increase the marginal cost of the blended fuel, which would tend to decrease consumption as well as the price of oil compared to the results we present below.

Next, let us turn to the demand for oil. 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 relative effect on the demand function for all quantities of oil. 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 the amount of miles driven. Moreover, $P_x(x)$ 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. Consequently, we have:

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

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

where we assume that $P(q)$ is twice differentiable, and that $P_q'(q) < 0$ and thus $P_x'(x) < 0$.

Equation (3) shows quite clearly that the three different policy instruments affect the inverse demand function for oil very differently. This is illustrated for a linear demand function in Figure 1, where P_x^i are the new demand functions under the various regulation schemes ($i=a,m,t$). A fuel tax, t, shifts the inverse demand function downward, while a higher 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. Moreover, if the choke (maximum) price is finite, it increases because it becomes cheaper to drive a mile if prices are unchanged, and so the initial and new demand curves must cross. As a result, as opposed to the two other instruments, increased efficiency *may possibly increase* oil demand for some (high) price levels. If the demand curve does not have a finite choke price, the new demand curve may or may not lie above the initial demand curve for some or all price levels.[8]

To see why the two demand curves may cross, first note that with higher mileage one does not need as much gasoline to drive the same distance as before, thus lowering the demand for oil. This is particularly relevant when consumers' price responsiveness is low (e.g. at low prices),

[8] 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 in which 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. the price elasticity below one in absolute value).

though by contrast, if consumers are price responsive, the lower cost of driving a mile will stimulate demand for transport, which is called the *rebound effect* in the literature (see e.g. Portney et al., 2003; Small and Van Dender, 2007; Frondel et al., 2008; Frondel and Vance, 2009).[9] If the rebound effect is very strong, which would be the case if consumers are very price responsive (see the next subsection), transport volumes could be stimulated to such a degree that even the demand for gasoline increases. However, the cited studies suggest that the rebound effect in the transport market may be close to, but not above, 100% (some of the studies find very small rebound effects). Note that all our results apply whether or not the two demand curves cross each other.

< Insert Figure 1 >

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

2.2.1 Competitive Oil Market

Assume that a representative, profit-maximizing producer faces a cost function $c(x)$, with the standard properties: $c'(x) > 0$ and $c''(x) \geq 0$. As shown in the Appendix (equation (A4)), we obtain the following effects of the different instruments in a competitive market:

[9] 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 with everything else given. As $P'_q(q) < 0$, we see that $P_x(x)$ may either increase or decrease for an increase in m.

$$\text{i)}\quad \frac{dx^C}{dt} = -\frac{1}{c''(x) - P'(x)} < 0,$$

$$(4)\quad \text{ii)}\quad \frac{dx^C}{da} = \frac{xP'(x)}{c''(x) - P'(x)} < 0, \text{ and}$$

$$\text{iii)}\quad \frac{dx^C}{dm} = \frac{P(x)\left(1 + \frac{1}{\varepsilon(x)}\right)}{c''(x) - P'(x)},$$

where $\varepsilon(x) = \frac{P(x)}{xP'(x)}$ is the price elasticity of demand.[10]

Not surprisingly, and as also shown in previous studies, oil consumption drops if either a tax or a required share of biofuels is introduced. On the other hand, we notice from (4) iii) that the effect of an increased mileage on oil consumption is ambiguous, and depends on the size of the price elasticity of the demand. If the marginal cost function crosses above the possible intersection of the P_x- and the P_x^m-curves, oil consumption increases when the mileage is raised, otherwise it will fall (cf. Figure 1).

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

Proposition 1: *In a competitive oil market, introducing fuel taxes or biofuel requirements will reduce oil consumption. Increased fuel efficiency standards 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 (4) i)–iii).

[10] Note that $x(P)$ is the demand function for oil, which is the inverse of $P(x)$.

Most recent empirical analyses seem to conclude that price elasticities are rather low in absolute value and are quite 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 the total consumption of oil in the short run. This is also the empirical conclusion for the U.S. by Small and Van Dender (2007) (see also the discussion about the rebound effect above). In the long run, the price elasticity is higher, although even then we believe the elasticity is mostly below one (see e.g. Sterner, 2007).[11]

2.2.2 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 confine our discussion to linear demand and marginal cost functions in Section 3, we will also briefly report the results for such functions here.

As shown in the Appendix (equations (A9)), the quantity effects of the various policy instruments are as follows in a monopoly market:

i) $$\frac{dx^M}{dt} = -\frac{1}{c''(x) - 2P'(x) - xP''(x)} = -\frac{1}{\Gamma(x)} < 0,$$

(5) ii) $$\frac{dx^M}{da} = \frac{2xP'(x) + x^2 P''(x)}{c''(x) - 2P'(x) - xP''(x)} = \frac{xP'(x)\left(2 + \gamma(x)\right)}{\Gamma(x)}, \text{ and}$$

[11] If the price elasticity is above unity at high prices (e.g. as with 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.

iii) $$\frac{dx^M}{dm} = \frac{P(x) + 3xP'(x) + x^2P''(x)}{c''(x) - 2P'(x) - xP''(x)} = \frac{xP'(x)\left(3 + \varepsilon(x) + \gamma(x)\right)}{\Gamma(x)},$$

where $\gamma(x) = x\frac{P''(x)}{P'(x)}$, and $\Gamma(x) = c''(x) - 2P'(x) - xP''(x) > 0$ (by the second order condition). In a monopoly market, we recall that $\varepsilon(x^M) \leq -1$ for the marginal revenue (*MR*) to be positive.[12]

We notice that the value of $\gamma(x)$ is crucial for the impact of two 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 quickly when x changes; ii) $-2 < \gamma < -1$, 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."[13]

[12] As mentioned above, most empirical studies find the 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 below one. 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.

[13] Note that γ is a function of x — i.e., it is not necessarily constant. We have disregarded $\gamma = -1$ and $\gamma = -2$. For $\gamma = -2$, dP/dx is not defined for $da>0$; see equation (7) below. For $\gamma = -1$, we see from (6) and (7) below that dP/dx is similar in a monopoly and a competitive market for both $dt>0$ and $da>0$.

From equations (5), we first observe that a tax will unambiguously reduce the consumption of oil, just as in the competitive market. In the linear case of $P''(x) = 0$, we can easily show that the relative output reduction will be the same under the two market structures.

Further, a required biofuel share will reduce oil consumption if and only if the inverse demand function is not very convex ($\gamma > -2$). In the linear case, the relative output reduction will be bigger in a monopoly- than a competitive market (unless marginal costs are constant). The reason for this is that the demand function becomes steeper, and thus the monopolist finds it profitable to reduce output relatively more than in the tax case. Nevertheless, for very convex inverse demand functions ($\gamma < -2$), oil consumption will actually increase. 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 will typically (but not necessarily) lead to negative marginal revenue even for low values of x, which makes this outcome (i.e. increased oil consumption) rather unlikely.[14]

As for the competitive market, the effect of increased fuel efficiency standards on oil consumption is generally ambiguous in a monopoly market. The sign of the numerator in (5) iii) depends on the sum of γ and the price elasticity ε. 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 standards are increased.[15] Oil consumption can also increase with $\gamma \geq -2$

[14] One example is $P(x) = x^{-2}$, in which $\gamma = -3$ and $MR = -x^{-2}$. On the other hand, a demand function where we obtain higher oil consumption by introducing biofuel requirements is $P(x) = \text{Min}\ (3\ ;\ 2 + x^{-2})$. The intuition here is that marginal revenue increases in x. An interior solution, however, requires that $c'(x)$ increases faster than $MR(x)$.

[15] The reason is the same as for biofuels; the marginal revenue will increase in x in this case.

if $\varepsilon + \gamma < -3$. Nonetheless, a more realistic scenario may be that $-2 < \varepsilon < -1$ and $\gamma > -1$, so that the numerator in (5) iii) is negative, in which case oil consumption decreases.

The conclusions 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 otherwise increases consumption ($\gamma < -2$); and*
- *increasing fuel efficiency standards will reduce oil consumption if the inverse demand function is not very convex and not very price elastic ($\varepsilon + \gamma > -3$), but otherwise increases consumption ($\varepsilon + \gamma < -3$).*

Proof: See equation (5) and the text above.

An example of increased fuel efficiency standards in the oil market is shown in Figure 2. Here, 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 under this market structure (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, which is not accidental. In the special linear case, we can show that we will never obtain higher x^{M} and lower x^{C} for the same set of demand and cost functions. Again, the reason is that the demand function becomes more inelastic with increased fuel-efficiency standards, making it more profitable for the monopolist to reduce supply. If we instead assumed a 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. By contrast, if the marginal cost curve were lying above the crossing point for the two *MR* curves, we would receive a higher demand in both cases.

< Insert Figure 2 >

To sum up the quantity effects in competitive- and monopoly markets, the effects of regulations become ambiguous under more policy instruments with market power. Still, in most realistic cases, the analysis suggests that oil consumption will fall irrespective of the policy instrument and market structure studied above. Moreover, it is difficult to state in general terms whether the quantity reductions are largest in a competitive- or monopoly market. Even so, the brief discussions of the special linear case may indicate 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 standards.

2.3 Price Effects

Let us now turn to the price effects of the various policy instruments under the two market structures. 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. Hence, 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.

2.3.1 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:

$$\text{(6)} \qquad \frac{dP^C}{dx^C} = c''(x) \,,$$

irrespective of which policy instrument is used. 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 when one of the policy instruments is used. Moreover, the relative price effect (i.e. dP/dx) is independent of the instrument choice.*

Proof: This follows from equation (6).

2.3.2 Monopoly Market

In a monopoly market, however, the price effect depends highly on the instrument choice. It is straightforward to show (by a total differentiation of (3) and inserting from (5)) that we get the following price effects:

$$\text{i)} \qquad \left.\frac{dP^M}{dx^M}\right|_{dt>0} = c''(x) - P'(x)\big(1+\gamma(x)\big) \,,$$

$$(7) \quad \text{ii)} \quad \left.\frac{dP^M}{dx^M}\right|_{da>0} = \frac{c''(x)}{2+\gamma(x)}, \text{ and}$$

$$\text{iii)} \quad \left.\frac{dP^M}{dx^M}\right|_{dm>0} = \frac{c''(x)\big(1+\varepsilon(x)\big)+P'(x)\big[1-\varepsilon(x)\big(1+\gamma(x)\big)\big]}{3+\varepsilon(x)+\gamma(x)},$$

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

We immediately see that the value of $\gamma(x)$ is crucial for the comparisons of the price effects, as is the third derivative of the cost function as well. Note that x will always be higher in a competitive market than with a monopoly. Therefore, 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 larger (e.g. if $\gamma > -1$ and $c'''(x) \le 0$) or smaller (e.g. if $\gamma < -1$ and $c'''(x) \ge 0$) in a monopoly- than in a competitive market. In the special linear case ($\gamma = 0$), the price reduction will be greatest 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, thereby 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 larger (e.g. if $-2 < \gamma < -1$ and $c'''(x) \le 0$) or smaller (e.g. if $\gamma > -1$ and $c'''(x) \ge 0$) in a monopoly- than in a competitive market. However, as we see, the conditions on γ for whether the price effect is larger or smaller is completely turned around compared to the tax case. In the special linear case ($\gamma = 0$), the price reduction will therefore be smallest in a monopoly market. It also follows that the price reduction in a monopoly market will be smaller with a biofuel share than with a tax. As explained above, the demand curve facing the monopolist becomes steeper (more inelastic) only in the former case; 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 biofuel share is imposed. Equation (7) ii) reveals that the price will also decrease in this case. Hence, the price will unambiguously fall if a biofuel share is introduced.

Last but not least, if fuel efficiency standards are increased, it can be documented that the price of oil will always increase as long as oil consumption decreases.[16] This effect, which is shown in Figure 2 in the linear demand case, is completely opposite of the price effect in a competitive market, in which the price and quantity always move in the same direction (see equation (6)). If increased fuel efficiency standards stimulate 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 $\gamma > -1$, though 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*

[16] Note that x^M decreases if $3 + \varepsilon + \gamma > 0$; see (5) iii). Thus, the denominator in (7) iii) is positive. The first term in the numerator is negative since $\varepsilon \leq -1$, and the second term is also negative when $3 + \gamma + \varepsilon > 0$.

- *increasing fuel efficiency standards will increase the producer price if oil consumption decreases, although it may either increase or decrease the price if oil consumption increases.*

Proof: This follows from equation (7) and the discussion above.

Given a monopoly market, there are several policy implications to be drawn from the price effects in Proposition 4. A government may prefer the oil price to decrease or increase depending on the country's situation, and we will return to this after discussing the open economy with a dominant producer, as this is a more relevant market situation, and because price effects are particularly important in an open economy due to terms-of-trade effects and carbon leakage.

To sum up, the discussion above illustrates quite clearly that the price effects of the various policy instruments depend significantly on the market structure, not least in the case with increased fuel efficiency standards. Policymakers may also be interested in the profits of oil producers. In a competitive market, it is straightforward to show that all of the three policy instruments lead to lower profits (unless marginal costs are constant, in which case profits are zero), assuming that higher fuel efficiency standards will also lead to lower consumption. In a monopoly market, we can show the following proposition:

Proposition 5. *With a monopoly supplying oil,*

- *the monopolist will obtain reduced profits if oil consumption is reduced through either a fuel tax or biofuel requirements, given that the demand function is not very convex ($\gamma > -2$); and*
- *the monopolist will receive increased profits if oil consumption is reduced through an increase in fuel efficiency standards.*

Proof: See the Appendix.

In other words, reduced consumption due to increased fuel efficiency standards leads to a higher price *and* higher profits for the monopolist, despite lower sales.

3 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 nevertheless is 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 as long as it leads to lower oil consumption.

In this section, we will further explore this issue in an open economy with either a monopolist or a dominant producer with a competitive fringe.[17] The dominant producer model has been empirically tested with respect to the oil market, and with OPEC or a subgroup of OPEC being the dominant producer. The results are somewhat mixed (see e.g. Hansen and Lindholt 2008; Alhajji and Huettner 2000), except that a competitive market structure is generally rejected.[18] As the analysis becomes more complicated in an open economy, we will make a number of simplifying assumptions, in addition to presenting some numerical illustrations. The analytical derivations and expressions are left to the Appendix, whereas their implications are discussed in the main text below.

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[17] There is also quite a bit of literature dealing with the effects of policy instruments in two-country Hotelling models. On the dominant producer and the competitive fringe model, see, e.g. Salant (1976, 1982) and Berg et al. (1997a,b).

[18] Alternative model formulations have also been proposed and tested such as Cournot games, target revenue models, property rights models and models focusing on OPEC's spare capacity (cf. e.g. Alhajii, 2004). The latter can be an important factor influencing the price of oil in the short run, but less so in the medium- and long run.

Consider now that the world is divided into two oil consuming regions: Region *A* and *B*. Moreover, there is a dominant producer (*D*) and (possibly) a competitive fringe (*F*) in the market, while transport demand functions and marginal cost functions are assumed to be linear. We focus on transport regulations in Region *A*, and disregard any regulations in Region *B*.[19]

In the first subsection below, we consider a monopoly market and examine the effects of the policy instruments under this market structure, while also presenting some numerical illustrations. Next, in Subsection 3.2 we examine how the existence of a competitive fringe affects the results. As it is difficult to derive analytical and interpretable expressions in this case (except with a fuel tax), we confine ourselves to numerical illustrations.

3.1 Monopoly Market

As shown in the Appendix (equations (A19)-(A21)), a fuel tax and a biofuel share will unambiguously reduce the producer price of oil and consumption in Region *A*, thereby increasing consumption in Region *B*, which causes carbon leakage. Increased fuel efficiency standards, however, will unambiguously increase the producer price of oil and hence reduce the consumption in Region *B*. The effects of an increased efficiency on consumption in Region *A* are ambiguous and depend on the steepness of the demand curve in Region *B* as well as on the marginal costs of the monopolist, which is consistent with the results found in Section 2 in the case of a closed market.[20]

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[19] It seems natural to think of Region *A* as the import region, although this is not decisive for the analysis, before we discuss welfare effects at the end of Section 3.

[20] A closed market can be seen as a special case of an open market, with Region *B* becoming infinitely small.

Let us examine more closely in which cases increased fuel efficiency standards will reduce fuel consumption in Region *A*. Define Region *B* to be large compared to Region *A* when oil demand is higher in Region *B* than *A*. The sign of dx_A/dm will more likely be positive when Region *A* is small compared to Region *B* (see equation (A19) in the appendix with $\beta_2 \rightarrow 0$, where β_2 is the slope of the demand function in Region *B*). Consequently, a small country facing a monopolist on the world market should not introduce fuel-efficiency standards if it aims to reduce its consumption (given the simple model framework used here). 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 2. If Region *A* is small, the demand curve in Region *B* will be relatively flat in comparison; thus the small region has little influence on the price, and consumption will increase.

If the two regions are equally large, increased fuel efficiency standards will increase oil consumption in Region *A* if, though if and only if each of the two demand curves is less than 3.6 times steeper than the marginal cost function of the monopolist. Furthermore, irrespective of the size of Region *B*, consumption in Region *A* will unambiguously increase if the marginal cost function is at least twice as steep as the demand function in Region *A*. The intuition is that the marginal cost curve then crosses above the intersection between the old and new marginal revenue curve (see Figure 2). On the other hand, if Region *B* is small compared to Region *A*, consumption will decrease in the latter region if the marginal cost curve is not too steep in comparison to the demand curve in Region *A*. In the limit, when Region *B* is infinitely small, we notice that the results are consistent with the findings for a closed market in Section 2.

The main results can be summarized in the following proposition:

Proposition 6: *Consider a world consisting of two regions (A and B), with a monopoly in Region B supplying oil, linear demand and marginal cost functions. Increased fuel-efficiency standards in Region A will then;*

- *increase the producer price of oil; and*
- *increase oil consumption in Region A if the region is sufficiently small compared to Region B, or if the marginal costs of the oil producer are sufficiently steep.*

Proof: This follows from the discussion above.

Now, let us focus on situations in which the policy instruments lead to reduced oil consumption in Region *A*. We know from above that the fuel tax and biofuel share will reduce the producer price of oil, whereas fuel efficiency standards will increase the price. But how much will it change relative to the consumption reduction, and how does this depend on the steepness of demand versus marginal cost functions? In Figure 3, we assume that the two regions are of the same size, and vary the steepness of the marginal cost function (denoted c_{D2}, cf. the Appendix).[21] In the next subsection, we consider the effects of different sizes of the two regions.

< Insert Figure 3>

Figure 3 shows that the price reduction will be consistently and significantly larger if a tax is imposed than if a biofuel share is imposed. This holds more generally, i.e. with the different sizes of the two regions. In accordance with Section 2, this is due to steeper demand functions

[21] When c_{D2} = 0.5, the marginal cost curve of the monopolist (dominant producer in Figures 4 and 6) and the global demand curve have the same steepness.

with biofuel shares than with a tax. The figure further demonstrates that the steeper the monopolist's marginal costs, the more the price drops when consumption is reduced by a fuel tax or a biofuel share. This is intuitive, as it is less profitable for the monopolist to reduce its supply if its marginal costs drop significantly. The figure also confirms what we found in Proposition 6, i.e. that the oil price increases when fuel efficiency standards are enhanced. Moreover, the figure shows that the price effects, relative to the volume effects in Region *A* (dP/dx_A), are more pronounced when this instrument is chosen, which is partly, though not entirely, due to the fact that consumption reductions in Region *A* are relatively small when dP/dx_A is large.[22]

3.2 Dominant Producer with Competitive Fringe

As it is difficult to derive interpretable expressions in the case with a dominant producer and competitive fringe, we will present numerical illustrations in this subsection to demonstrate how the existence of the fringe can exert an influence on the results discussed above.

First, it is important to note that the monopoly- and competitive models are special cases of the model with a dominant producer and competitive fringe. In other words, if the fringe is very small compared to the dominant producer, we are close to a monopoly situation, and vice versa if the fringe is very large. From the previous discussions, we therefore conclude that the existence of the fringe increases the likelihood (vis-à-vis the monopoly situation) that increased fuel efficiency standards in Region *A* will reduce consumption in that region. By contrast,, it is now possible that the price of oil can fall (as in the competitive model).

[22] To illustrate, with c_{D2} =0.15, a 10% increase in *m* reduces consumption by 4.5%, whereas a tax that amounts to 10% of the price reduces consumption by 7% (in this simple model).

Figure 4 corresponds to Figure 3, in which the regions are of the same size. Here, we have assumed that the fringe can produce half as much as the dominant producer at a given marginal cost level, although in the market equilibrium, it will supply more than one-third of the market. The figure shows that the existence of the fringe may significantly alter the price effects when fuel efficiency standards are increased. If the marginal cost curves are rather flat (low c_{D2}), higher fuel efficiency standards will *decrease* the price of oil because the fringe will react quite significantly to a change in the price, and therefore the dominant producer will not reduce its supply that much. If the curves are steeper (though not too steep), we obtain the same qualitative result as in the monopoly case, i.e. a higher oil price. We also see that in the tax case, the price reduction is much smaller than in Figure 3 if the marginal cost curves are flat, which again is explained by the fringe's responsiveness.

< Insert Figure 4 >

Let us calibrate this simple, linear model to the current oil market, assuming that a common policy instrument is introduced in both the United States and the European Union, which together comprises approximately 40% of global oil consumption (BP, 2010). OPEC currently has a market share of about 40% of the global supply. We assume that non-OPEC and OPEC unit production costs amount to 40–100% and 20–40% of the oil price, respectively, which then leads to obtaining the effects shown in Table 1 of the three policy instruments.[23]

Table 1. Simulated Effects of Policy Instruments in the Current Oil Market when Joint Consumption in the United States and the European Union Is Reduced by 5%

[23] The parameter values of this model are $c_{D1} = 0.1$, $c_{F1} = 0.2$, $c_{D2} = 0.3$, $c_{F2} = 0.6$, and $\beta_2 = 0.7$ (cf. the Appendix).

	Fuel tax	Biofuel share	Efficiency standard
Oil price	-1.0%	-0.8%	+3.9%
Oil consumption, rest of the world	+1.0%	+0.8%	-3.7%
Oil production, OPEC	-1.9%	-2.4%	-17%
Oil production, non-OPEC	-1.1%	-0.9%	+4.4%

We notice that a fuel tax and biofuel requirement have quite similar effects, with a somewhat stronger price reduction in the former case. The results imply that the joint oil import supply elasticity for the EU and the U.S. are 5 and 6%, respectively, when consumption is reduced through fuel taxation or a biofuel standard. This is consistent with simulated estimates in Leiby (2007) for the U.S., which ranged from 1.3 to above 15%.

The effects of increased fuel efficiency standards are quite different and sizeable, with a substantial reduction in OPEC supply and a significant *increase* in the price of oil. This result, however, is very sensitive to small variations in the parameters of the model and reflects the fact that increased fuel efficiency standards have small effects on U.S. and EU oil consumption in this model, such that a 5% reduction in consumption requires a large efficiency increase. Hence, the results of increased fuel efficiency standards should be interpreted with particular caution, as they suggest that it could be very difficult to predict the market outcome of raising fuel efficiency standards in some major oil-consuming countries. Nevertheless, we should expect higher oil prices and/or very limited reductions in fuel consumption.

Figure 5 shows how the results in Table 1 change if the relative size of the regulating region (Region *A*) changes from 0 to 100%, and the results in Table 1 are highlighted with asterisks (i.e. at 41%). We assume that the policy instruments (i.e., the values of *t*, *a* or *m*) remain fixed as we extend or reduce the relative size of Region *A*. We first notice that the price increase or price reduction is proportional to the size of Region *A,* and that *t*he more countries that impose similar transport regulations, the more pronounced the price change will be. This linearity is due to the assumed linearity of demand and marginal cost functions in this simple model.

Next, we see that the relative consumption effects diminish somewhat under a fuel tax or a biofuel share when Region *A* expands. The explanation for this is of course that the oil price decreases, thus dampening the consumption reduction. Global oil consumption drops, though, as more countries impose the tax or the biofuel requirement. The effects of expanding Region *A* are different under fuel efficiency standards – as Figure 5 shows the relative consumption reduction increases as Region *A* expands. Again, this is due to the price effects, which go in the opposite direction under this policy instrument.

< Insert Figure 5 >

Finally, in what way do these findings influence the optimal choice of policy instrument in Region *A*? As mentioned before, policymakers in the region may be concerned about both their own terms-of-trade effects and carbon leakage in other regions. The costs of the different policies obviously matter as well, although this is not the topic of this analysis. Also disregarding domestic distributional aspects, the “international (net) benefits” ($d\Omega$) for Region

A of policy instrument i can then be expressed as:

(8) $$\left.\frac{d\Omega}{dx_A}\right|_{di>0} = (x_A - \hat{x}_A)\left.\frac{dP}{dx_A}\right|_{di>0} + \tau\left.\frac{dx_B}{dx_A}\right|_{di>0},$$

where τ denotes the shadow price of increased consumption abroad (i.e. carbon leakage), and $\hat{x}_A$ denotes production in Region A.

If carbon leakage is not important, we are left with $(x_A - \hat{x}_A)\,{dP}/{dx_A}$, the latter part of which we have discussed above. But what if $\tau > 0$? Assuming $\hat{x}_A = 0$, Figure 6 shows how the international benefits depend on the steepness of the marginal cost curves relative to the aggregate demand curve. Note that we only show the outcome of cases in which the demand in Region A is reduced. The shadow price τ has been set, in a somewhat ad hoc manner, to 10% or 100%, respectively, of the producer price in the figure.[24]

The figure shows that if the marginal costs are rather flat, the different policy instruments fare quite similarly. The reason for this again is that the fringe responds significantly to any price changes, hence the dominant producer has little room to maneuver. When marginal costs are steeper, we see that the total international benefits are very dependent on τ, i.e. how much we value carbon leakage, which is particularly important for the benefits of increased fuel efficiency standards. Remember that this policy reduces the price of oil if the marginal cost curves are flat, but increases the price if the curves are moderately steep (while increasing consumption for even steeper curves). Thus, the carbon leakages are positive and negative,

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[24] As a comparison, the average EU ETS price in 2009 amounted to approximately $8 per barrel of oil, i.e., about 13% of the world oil market price that year.

respectively.[25] A fuel tax fares best when the shadow price of foreign emissions is not too high, as the terms-of-trade benefits from a reduced oil price dominate over the leakage effect, with similar effects being seen for biofuel requirements.

How large are the net benefits shown in Figure 6 compared to the benefits of reduced domestic consumption, disregarding the costs of the policy? 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 as much (e.g. due to greenhouse gas emissions), the domestic benefits will be at most 0.07% (if τ is 10% of the price) and 0.7 (100%) in the figure. As a result, we see that the international (net) benefits are at least comparable with the domestic benefits and possibly more important.

< Insert Figure 6 >

4. Conclusions

This paper has shown that the effects of different policy measures on reducing oil demand in the transport sector depend significantly on the market structure. In a competitive market, a fuel tax and biofuel requirement will always reduce oil demand, whereas the outcome of a higher fuel-efficiency standard is more ambiguous due to the well-known rebound effect (though empirical studies suggest a reduced oil consumption). If a monopoly supplies the oil market, the consumption effects also become ambiguous under a biofuel requirement. Nevertheless, in most realistic cases, oil consumption will decrease under all these policy

[25] This explains why the fuel-efficiency curves intersect around c_{D2} = 0.35, with the international benefits being equal to 0.

instruments, and most likely even more than in a competitive market if the biofuel requirements or increased fuel efficiency standards are implemented.

More interestingly, the price effects depend significantly on the market structure, particularly if the fuel efficiency standards are increased. 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 always goes along with a lower producer price. Additionally, the price effects are independent of the policy instrument as long as the instruments are fine-tuned to produce the same reduction in oil consumption. However, with a monopoly on the supply side, the price effects highly depend on the choice of policy instrument, as well as on the curvature of the demand and cost functions. In particular, and rather counter intuitively, an increased fuel-efficiency standard will unambiguously *increase* the price of oil as long as the consumption is decreased. This result, which holds for any downward-sloping demand and upward-sloping marginal cost functions, is quite opposite to the effect with perfect competition. The reason for this is that a higher fuel efficiency makes the demand curve steeper, thereby giving the monopolist more incentives to cut back on its supply while increasing profits.

In an open economy, we show that (now assuming linear demand and marginal cost functions) with a monopoly on the supply side, the price of oil will still increase if one region increases its fuel efficiency standards. If this region is relatively small, it will most likely experience an increased oil consumption in this case.

Price effects are important for a number of reasons. For instance, a regulating body may care about the 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. Hence, the signatory countries may favor instruments that increase the price of oil.

It is hard to make policy recommendations based on the analysis, as policymakers' preferences with regard to consumption and price effects may contrast. Moreover, other (potentially more important) issues also come into play when choosing between policy instruments, such as cost-effectiveness, which is not considered in this paper. If we assume that the regulator only cares about a reduced oil consumption, a fuel tax is the safest alternative because it will always decrease consumption. Increased fuel efficiency standards are the most uncertain instrument, especially if the region in question is small and there is market power on the supply side.

If the regulator cares about price effects, we have seen that in a competitive market, lower oil consumption always goes hand-in-hand with a lower oil price. This gives preferred terms-of-trade effects for an oil-importing country, while inducing carbon leakage and undermining attempts to reduce global carbon emissions. If there is market power on the supply side and the policymakers are concerned about a too high profit for big oil producers or their oil import bill, they should avoid fuel-efficiency standards since this policy will quite possibly increase the price of oil. Instead, they should choose a fuel tax, or if the inverse demand function is quite convex, a biofuel standard. If policymakers prefer high prices, e.g. due to concerns about carbon leakage, the conclusions naturally become completely turned around. The same reasoning can also be applied to big oil producers, who would find it in their interest to lobby for fuel-efficiency standards rather than fuel taxes and biofuel shares.

In this paper we have analyzed three policy instruments to regulate oil consumption in the transport sector. Other policy instruments are of course also possible such as oil price floors, feebates and an ad valorem fuel tax. If effective, oil price floors may reduce the price difference between a monopoly and a competitive market. Feebates are usually used for car purchases and not in the fuel market as analyzed here, while an ad valorem fuel tax is interesting as it causes a change in the slope of the inverse demand curve. However, while the slope becomes steeper for biofuel shares and fuel efficiency standards, it becomes flatter with an ad valorem tax. Thus, the possibility to increase prices for a monopoly or cartel will be reduced.

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Appendix

Closed, competitive market

The outcome of a closed, competitive market is derived by considering the oil producers' maximization problem when the price is taken as given:

(A1) $$Max\left[P(x)x - c(x)\right].$$

This gives the well-known first-order condition,

(A2) $$P = c'(x).$$

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

(A3) $$\left(c''(x) - P'(x)\right)dx = \left(P(x) + xP'(x)\right)dm + xP'(x)da - dt.$$

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

i) $$\frac{dx^C}{dt} = -\frac{1}{c''(x) - P'(x)} < 0,$$

(A4) ii) $$\frac{dx^C}{da} = \frac{xP'(x)}{c''(x) - P'(x)} < 0, \text{ and}$$

iii) $$\frac{dx^C}{dm} = \frac{P(x)\left(1 + \frac{1}{\varepsilon(x)}\right)}{c''(x) - P'(x)},$$

where $\varepsilon(x)=\dfrac{P(x)}{xP'(x)}$ (price elasticity of demand).

Closed, monopoly market

A monopolist also considers the maximization problem in (A1), but does not take the price as given. This gives the standard first-order condition,

(A5) $$MR(x)=xP'(x)+P(x)=c'(x),$$

and the second-order condition,

(A6) $$\Gamma(x)=c''(x)-2P'(x)-xP''(x)>0.$$

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

(A7) $$dP'=(1+a)\left[2mP_q'dm+m^2P_q''\big((1+a)xdm+mxda+m(1+a)dx\big)\right]+m^2P_q'da.$$

Inserting from (3) in (A5) and then differentiating, using (A7), $a=t=0$, $m=1$, $P'=P_q'$, and $P''=P_q''$ (see equation (2) for a = t = 0 and m = 1), gives the following expression:

(A8) $$\begin{aligned}&\big(c''(x)-2P'(x)-xP''(x)\big)dx=\\&\big(P(x)+3xP'(x)+x^2P''(x)\big)dm+\big(2xP'(x)+x^2P''(x)\big)da-dt.\end{aligned}$$

Thus,

i) $$\frac{dx^M}{dt} = -\frac{1}{c''(x) - 2P'(x) - xP''(x)} = -\frac{1}{\Gamma(x)} < 0,$$

(A9) ii) $$\frac{dx^M}{da} = \frac{2xP'(x) + x^2 P''(x)}{c''(x) - 2P'(x) - xP''(x)} = \frac{xP'(x)\left(2 + \gamma(x)\right)}{\Gamma(x)}, \text{ and}$$

iii) $$\frac{dx^M}{dm} = \frac{P(x) + 3xP'(x) + x^2 P''(x)}{c''(x) - 2P'(x) - xP''(x)} = \frac{xP'(x)\left(3 + \varepsilon(x) + \gamma(x)\right)}{\Gamma(x)},$$

where $\gamma(x) = x\frac{P''(x)}{P'(x)}$, and $\Gamma(x) > 0$ is given from (A6).

Proof of Proposition 5

The profits of the monopolist are given by $\pi(x) = P(x)x - c(x)$, and thus the change in profits is:

(A10) $$d\pi = xdP + Pdx - c'dx = \left[P + x\frac{dP}{dx} - c'\right]dx$$

From (7) we then have:

i) $$d\pi = \left[P + x\left(c'' - P'(1+\gamma\right) - c'\right]dx = \left[c'' - P'(2+\gamma)\right]xdx \qquad \text{(tax)}$$

(A11) ii) $$d\pi = \left[P + x\frac{c''}{2+\gamma} - c'\right]dx = \left[\frac{c''}{2+\gamma} - P'\right]xdx \qquad \text{(biofuel)}$$

$$d\pi = \left[P + x\frac{c''(1+\varepsilon) + P'\left[1-\varepsilon(1+\gamma)\right]}{3+\varepsilon+\gamma} - c' \right] dx$$

iii) $$= \left[\frac{3P + \varepsilon P + \gamma P + xc''(1+\varepsilon) + xP' - \varepsilon xP' - \varepsilon\gamma xP'}{3+\varepsilon+\gamma} - c' \right] dx \quad \text{(fuel efficiency)}$$

$$= \left[\frac{P\left(2+\varepsilon+\frac{1}{\varepsilon}\right) + xc''(1+\varepsilon)}{3+\varepsilon+\gamma} - c' \right] dx$$

We see that, if $dx < 0$, $d\pi < 0$ if $\gamma > -2$ in the tax and the biofuel cases. In the fuel efficiency case, $d\pi > 0$ if $dx < 0$ (remember that $\varepsilon < -1$ in the monopoly case, and $3+\varepsilon+\gamma > 0$ when $dx < 0$).

Open market with monopolist or dominant producer and competitive fringe

Given the open market described in Section 3, and 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:

(A12) $P(x_A) = m(\alpha_1 - \alpha_2 m(1+a)x_A) - t$ and

(A13) $P(x_B) = \beta_1 - \beta_2 x_B$.

Here P denotes the world market price of oil. Moreover, we have used that $q_B = x_B$ (as we disregard transport regulations in Region B). 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 $m = 1$.

The marginal costs of producer j is specified as

(A14) $c_j'(x_j) = c_{j1} + c_{j2} \cdot x_j$.

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 (A2). Note that a monopoly market emerges as a special case if $c_{F2} \to \infty$.

We will refer to demand in Region *B* minus fringe production as the residual demand in region *B* (x_B^D). From equations (A2), (A13), and (3), we have that x_B^D is given by:

(A15) $P(x_B^D) = \beta_1^D - \beta_2^D x_B^D$,

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

The total residual demand facing the dominant producer (x^D) consists of x_B^D and x_A. From equation (A15) and (A12) we find that:

(A16) $$P(x^D) = \frac{1}{\phi_3(m,a)}\left[\phi_1(m,a,t) - \phi_2(m,a)x^D\right],$$

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

By using the first-order condition of a dominant producer, which is the same as for a monopolist (equation (A5)), we can derive the following expressions for the equilibrium price and residual demand in this market as functions of the policy instruments:

(A17) $$P = \frac{\phi_1(m,a,t)\phi_2(m,a) + \phi_1(m,a,t)\phi_3(m,a)c_{D2} + \phi_2(m,a)\phi_3(m,a)c_{D1}}{2\phi_2(m,a)\phi_3(m,a) + \phi_3(m,a)^2 c_{D2}}$$, and

(A18) $$x^D = \frac{\phi_1(m,a,t) - \phi_3(m,a)c_{D1}}{2\phi_2(m,a) + \phi_3(m,a)c_{D2}}.$$

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

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 $c_{D1} = 0$.[26]

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

i) $$\frac{dx_A}{dt} = -\frac{\beta_2{}^2 + 2\beta_2 + \beta_2 c_{D2} + c_{D2}}{(\beta_2 + 1)(2\beta_2 + c_{D2}\beta_2 + c_{D2})} < 0,$$

(A19) ii) $$\frac{dx_A}{da} = -\frac{\beta_2(2\beta_2 + c_{D2})}{(2\beta_2 + c_{D2}\beta_2 + c_{D2})^2} < 0$$, and

iii) $$\frac{dx_A}{dm} = \frac{2\beta_2 c_{D2}{}^2 + 3\beta_2{}^2 c_{D2} + \beta_2{}^3 c_{D2} + 2\beta_2 c_{D2} + c_{D2}{}^2 + \beta_2{}^2 c_{D2}{}^2 - 2\beta_2{}^3}{(\beta_2 + 1)(2\beta_2 + c_{D2}\beta_2 + c_{D2})^2}.$$

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[26] This can also be viewed as a normalization, if we first subtract c_{D1} from α_1 and β_1 and then normalize prices and quantities so that $\alpha_1 - c_{D1} = 1$, $\beta_1 - c_{D1} = 1$ (and $\alpha_2 = 1$). In Figures 5-6 we have assumed that $c_{F1} = c_{D1} = 0$, which is not merely a normalization, but simplifies the comparison with Figure 4.

i) $$\frac{dx_B}{dt} = -\frac{1}{\beta_2}\frac{dP}{dt} = \frac{\beta_2 + \beta_2 c_{D2} + c_{D2}}{(\beta_2 + 1)(2\beta_2 + c_{D2}\beta_2 + c_{D2})} > 0,$$

(A20) ii) $$\frac{dx_B}{da} = -\frac{1}{\beta_2}\frac{dP}{da} = \frac{\beta_2 c_{D2}}{(2\beta_2 + c_{D2}\beta_2 + c_{D2})^2} > 0, \text{ and}$$

iii) $$\frac{dx_B}{dm} = -\frac{1}{\beta_2}\frac{dP}{dm} = -\frac{\beta_2 c_{D2} + 2\beta_2^2 + c_{D2}^2 + 2\beta_2 c_{D2}^2 + \beta_2^2 c_{D2} + \beta_2^2 c_{D2}^2}{(\beta_2 + 1)(2\beta_2 + c_{D2}\beta_2 + c_{D2})^2} < 0.$$

i) $$\left.\frac{dP}{dx_A}\right|_{dt>0} = \frac{\beta_2^2 + \beta_2^2 c_{D2} + \beta_2 c_{D2}}{\beta_2^2 + 2\beta_2 + \beta_2 c_{D2} + c_{D2}} > 0,$$

(A21) ii) $$\left.\frac{dP}{dx_A}\right|_{da>0} = \frac{\beta_2 c_{D2}}{2\beta_2 + c_{D2}} > 0, \text{ and}$$

iii) $$\left.\frac{dP}{dx_A}\right|_{dm>0} = \frac{\beta_2\left(\beta_2 c_{D2} + 2\beta_2^2 + c_{D2}^2 + 2\beta_2 c_{D2}^2 + \beta_2^2 c_{D2} + \beta_2^2 c_{D2}^2\right)}{2\beta_2 c_{D2}^2 + 3\beta_2^2 c_{D2} + \beta_2^3 c_{D2} + 2\beta_2 c_{D2} + c_{D2}^2 + \beta_2^2 c_{D2}^2 - 2\beta_2^3}.$$

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

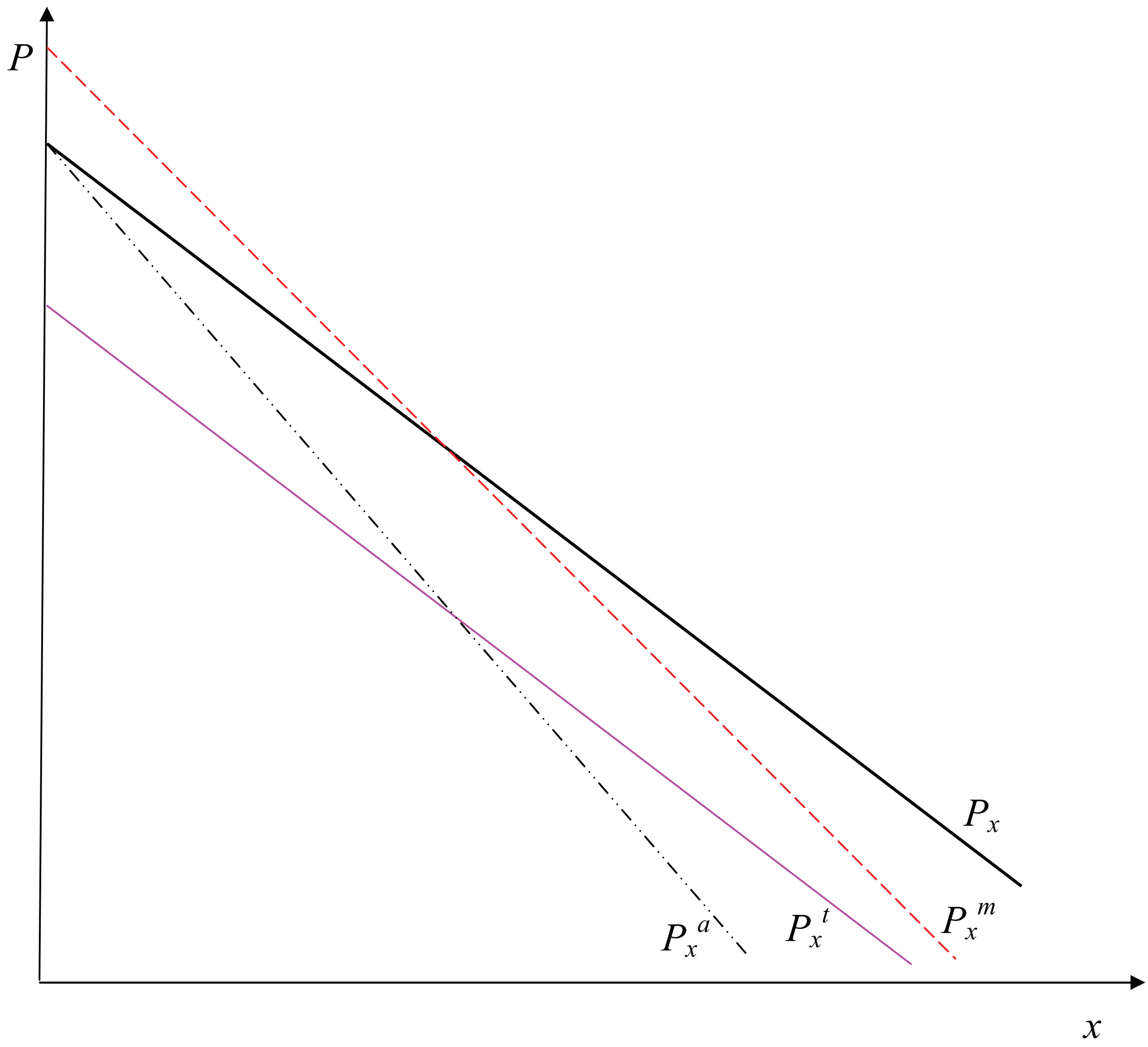

Figure 2. Impacts of Fuel Efficiency Standards in the Oil Market

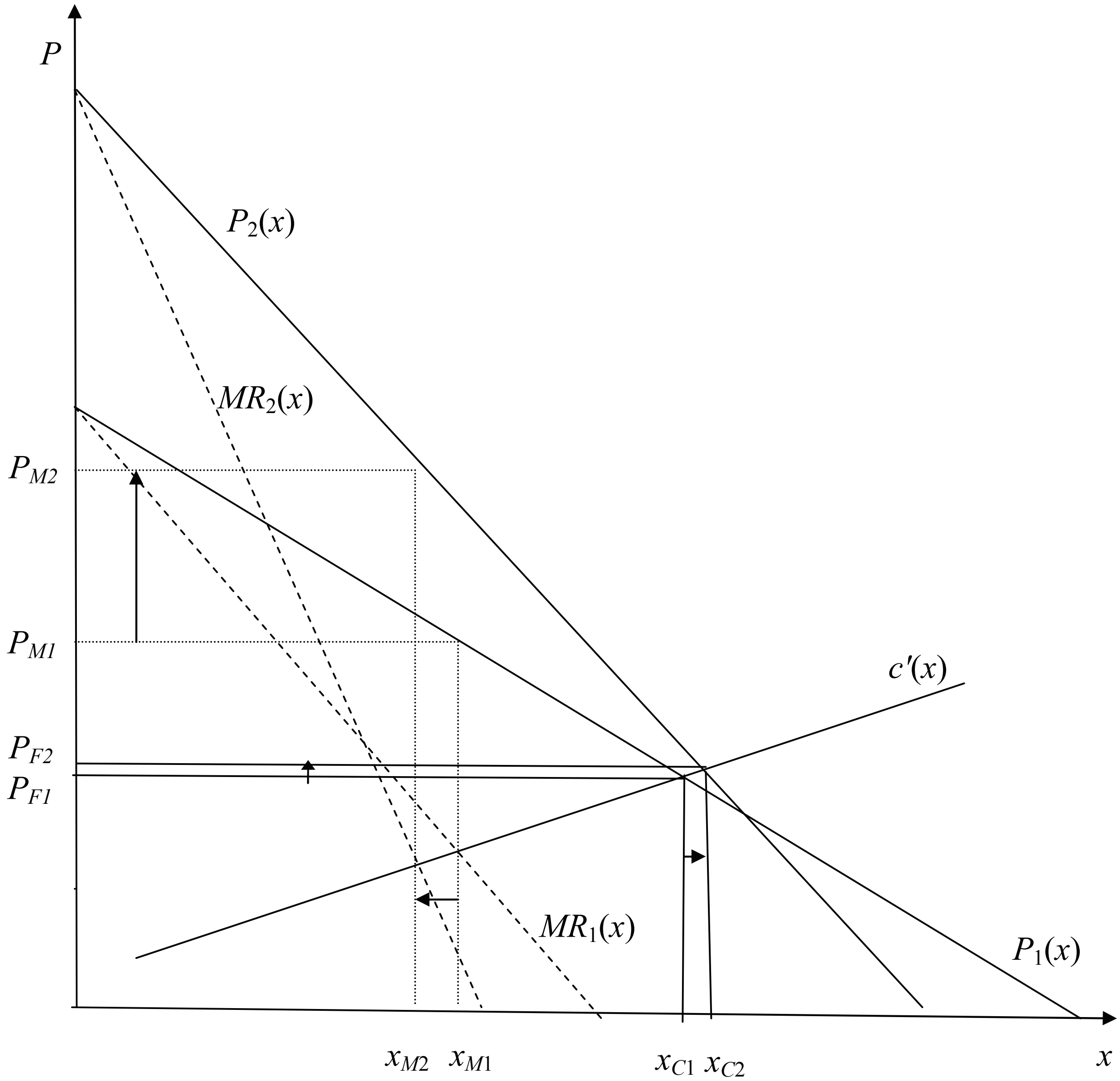

Figure 3. Effects on the Producer Price of Oil (dP/dx_A) under Different Policy Instruments when $\beta_2 = 1$ in a Monopoly Market

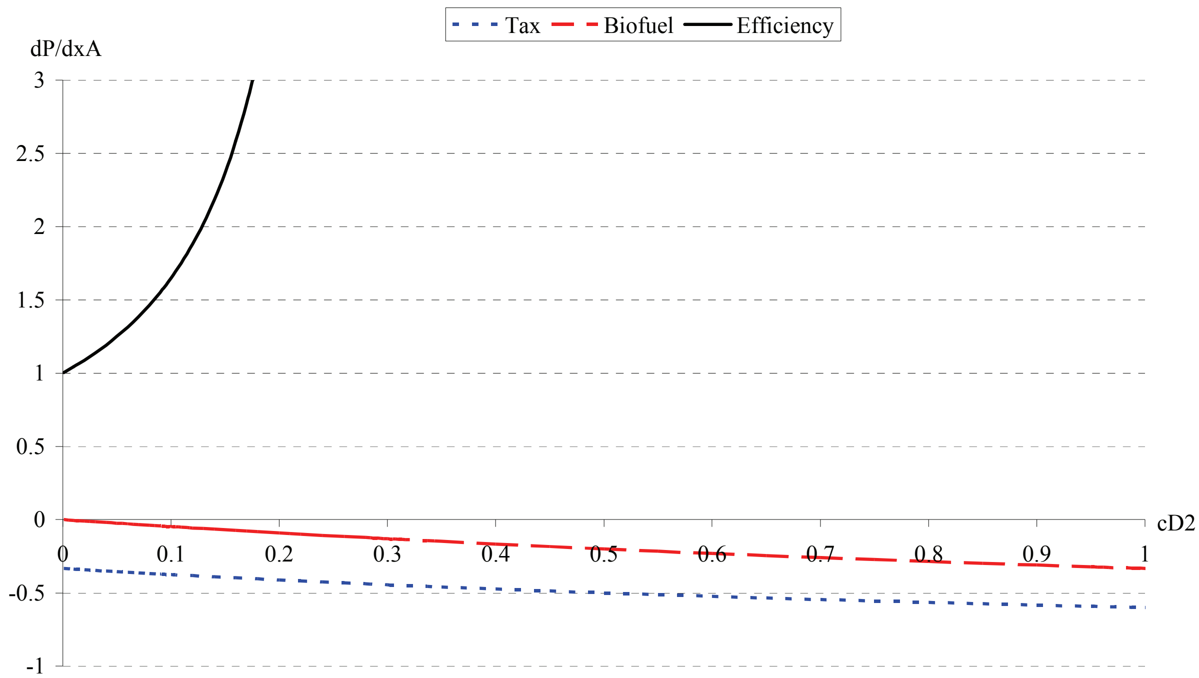

Figure 4. Effects on the Producer Price of Oil (dP/dx_A) under Different Policy Instruments when $\beta_2 = 1$ in a Dominant Producer Model

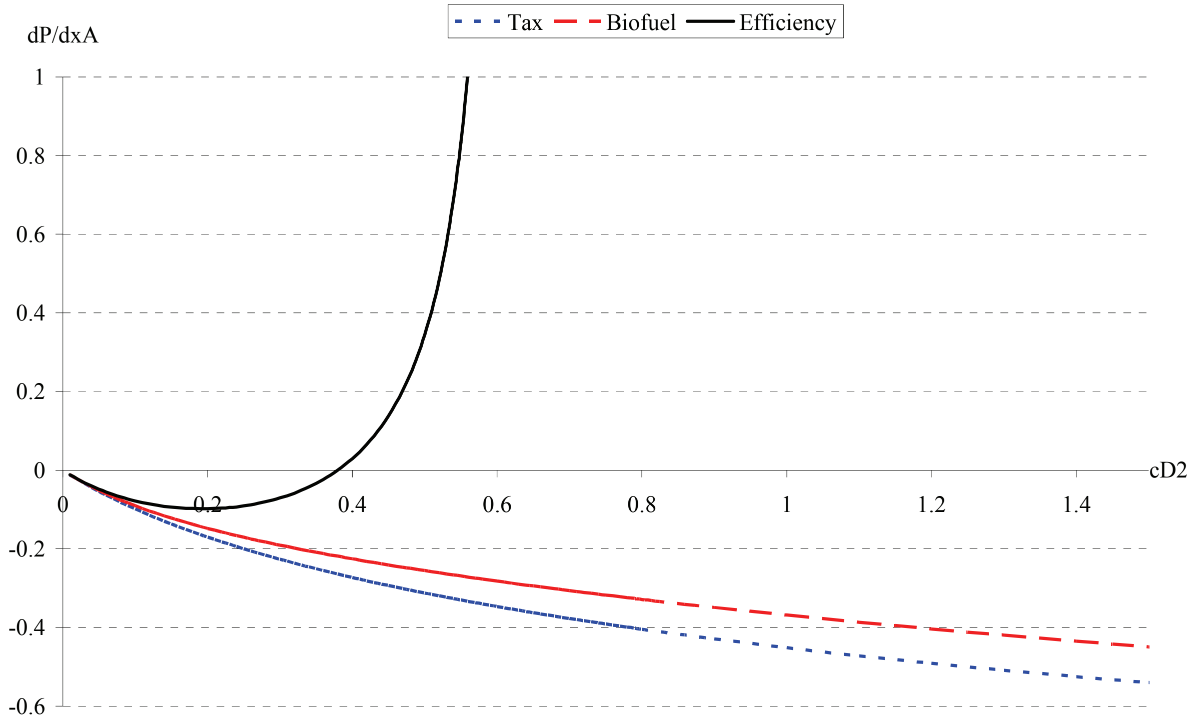

Figure 5: Effects on the Producer Price of Oil and Oil Consumption in Region *A* of changing the relative size of Region *A*, while keeping the level of *t*, *a* or *m* fixed. Percentage changes compared to the case with no policy

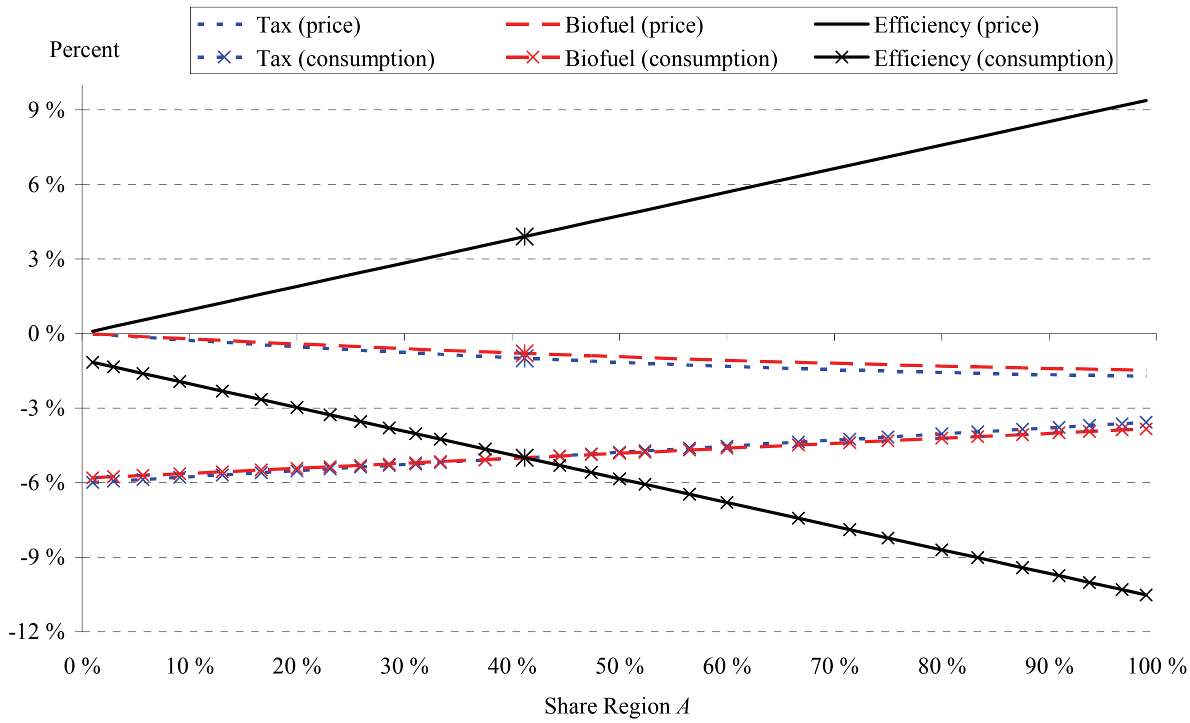

Figure 6: Effects on International (Net) Benefits ($d\Omega/dx_A$) under Different Policy Instruments when $\beta_2 = 1$ in a Dominant Producer Model