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# Energy security policies in EU-25—The expected cost of oil supply disruptions

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ABSTRACT

A framework for analyzing the impact on the expected cost of oil disruption by energy policies in EU-25 is developed. The framework takes into account how energy policies affect the oil market, the expected oil price increase, and the disruption costs. OPEC's strategic behavior is modelled as a dominant firm, and the model includes price interdependence between different energy commodities to better estimate the cost of an oil disruption. It is found that substituting pellets for oil in households and using imported sugar cane ethanol are cost-efficient policies if greenhouse gas benefits are included. Domestically produced wheat ethanol is not found to be cost-efficient even if both the expected cost of oil disruption and greenhouse gas benefits are included, the same also holds for hybrid vehicles. The gross expected economic gain of the policies is found to be between 9 and 22 €/bbl oil replaced.



## 1. Introduction

The two global oil crises of the 1970s put energy security at the top of the political agenda. These crises contributed to unemployment and inflation during this period. With the low oil prices of the 80s, concern for energy security almost disappeared. In the current decade, oil prices have increased once again. The US has invaded Iraq, Iran's nuclear program is disputed, and the EU is increasingly dependent on natural gas from Russia. All this has contributed to a renewed interest in energy security. In addition, energy security policies are often seen as a part of the strategy for combating climate change (EU Commission 2003, 2005).

Several approaches for studying energy security can be distinguished in the scientific literature. Some authors have used a country's *current* diversification of energy sources or import sources as a measure of energy security, see for instance Neff (1997); Jansen et al. (2004). Others have studied the *future* development of oil supply and imports using bottom-up energy systems models, e.g. Constantini et al. (2007); Turton and Barreto (2007).

Another approach to analyze energy security focuses on the externalities associated with oil imports, see for instance Broadman and Hogan (1988), Bohi and Toman (1993), Greene and Leiby (2006), Leiby et al. (1997), Leiby (2007), Nesbitt and Choi (1988), and Parry and Damstadter, (2003). These studies often try to find the optimal level of taxation on oil imports in order to compensate for the externalities associated with insecure supply. In general, they find quite low numbers, between 5 and15 USD/barrel of oil, some even argue that there is no need for policy intervention (Nesbitt and Choi, 1988). Typically, the policies suggested in these studies for addressing oil security are stockpiling oil and a consumer tax on oil.

In this paper, we develop an analytical framework to study one important aspect of energy security, the expected cost of an oil disruption. Our method builds on previous work in the economic literature on oil security, see e.g., Broadman and Hogan (1988), Greene and Leiby (2006), and Leiby et al. (1997). However, we add two aspects. We model OPEC as a rent maximizing strategic actor (in a way different from Leiby et al., 1997), and we model price interdependence between oil and other energy commodities, such as ethanol and natural gas.

The aim of this study is thus to:

(1) shape an analytical framework for analyzing the impact of energy polices on the expected cost of oil disruptions,
(2) use this framework to analyze how four energy policies affect the expected cost of an oil disruption for EU-25. The policies studied are: use of imported ethanol; domestically produced ethanol; more efficient cars; and use of pellets instead of oil for residential heating. These policies have both climate and energy security benefits.

Section 2 describes oil security and the oil market. In Section 3 we describe a model for calculating the effect on expected economic costs of oil disruptions of energy policies and the

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monopsony power gain. In Section 4 the policy scenarios considered are described, and in Section 5, parameters used in the model are presented and discussed. Results, discussion, and conclusion follow.

## 2. Oil security

Energy security is a vague concept that is hard to define properly. IEA defines energy security as adequate, affordable, and reliable energy supply, which does not offer very much guidance.

Energy security may be divided into demand and supply security. Supply security is the security problem of an energy consumer if energy supply is disrupted. Demand security on the other hand is the security problem for an energy supplier as uncertainty of future energy demand may lead to over-investment in supply capacity.

In this paper, we exclusively address supply security problems from the perspective of the EU. The main reason that there is a *security* problem with oil consumption lies in the combination of two factors: oil is a valuable and vital product that is difficult to substitute in the short run and most of the oil is extracted in politically instable regions. Oil disruptions – be they deliberate or not – may thus be costly. Supply of oil has several characteristics that are important to consider in this context.

First, the oil market is not a competitive market. Rather the Organization of the Petroleum Exporting Countries (OPEC), which supplies 41% of the global oil and holds more than 75% of the proven reserves (BP, 2005), exercises market power, see for instance Bohi and Toman (1993), Leiby et al. (1997), and Kaufman et al. (2004). It is quite clear that OPEC does not act as an optimally coordinated cartel; OPEC is often referred to as a clumsy cartel (Adelman, 2002). Nevertheless, the price of oil would likely have been significantly lower if the oil market were competitive. The oil price in a competitive market is estimated at 7–15 USD/bbl, see Greene and Leiby (2006) for an overview. Aguilera et al. (2009) estimate that there are reserves of 10 trillion barrels of conventional and non-conventional oil at a cost below 15 USD/bbl. An oil price that is higher than the competitive level (as in 2006–2007) implies that there is a dead weight loss for the global economy and that wealth is transferred from oil importers to oil exporters.

Second, oil is traded in a globally integrated market, which means that there is practically one uniform oil price in the whole world. Ninety percent of a price shock spreads instantaneously across the globe; the remaining 10% price difference disintegrates in 6–28 days (Bachmeier and Griffin, 2006). The well-integrated oil market implies that the price consumers face in one country is rather independent of where oil is imported from or how much oil is imported.

Third, the oil price affects other energy prices. The oil price correlates with European natural gas prices, with a time lag of around six months (Maisonnier, 2006; Villar and Joutz, 2006). In the European market, long-term contracts dominate the natural gas market. These contracts most often link the natural gas price to the price of crude oil or other petroleum products (Maisonnier, 2006). Therefore, there is a strong link between the oil and natural gas prices. The oil price affects the gas price, but not the other way around (at least not in the short to medium term). In the US, the natural gas market is deregulated. Still, there is a strong correlation between the natural gas and the lagged oil price (Villar and Joutz, 2006). The main reason for this price link is that there are short-term substitution possibilities between oil and natural gas in industry and in the power sector. The natural gas price does, however, not influence the crude oil price ,since each regional gas market is small in comparison with the oil market (Villar and Joutz, 2006). This may change and the natural gas market may become more globally integrated due to the expected expansion of the LNG market.

Ethanol is also substantially affected by the oil price, which is seen in both the Brazilian market (Goldemberg et al., 2004) and the US market (Coltrain et al., 2004). This is to be expected, since gasoline and ethanol are close substitutes in the transportation sector.

Fourth, there have been several supply disruptions in the oil market; these have increased the oil price and caused losses for the global economy. Most substantial disruptions in the past have occurred in the Middle East. A survey of US experts' views shows that the main risks of future disruptions are considered to lie in OPEC countries (Beccue and Huntington, 2005). Supply disruptions are expected to cause an oil price increase. However, historically, similar sizes of disruptions have caused quite different price changes.

The last five years have seen a substantial oil price increase while the global economic growth has still been very high. The question of whether oil has lost its capacity to shock the economy has been raised (Walton, 2006). There are probably several reasons why there have not been any major economic damages the last years. First, the price increase has been incremental, and the economic costs are estimated to be larger for sudden price increases (Huntington, 2004). Second, there has been a strong underlying growth and otherwise stable macroeconomic conditions which may hide or reduce the economic costs (Allsopp, 2006; Walton, 2006). Third, the economy today is less dependent on oil than in the 1970s and thereby less affected by oil price changes. It is, therefore, premature to argue that a sudden oil price increase, especially during time of weak macroeconomic conditions, cannot seriously harm the economy.

Fifth, after the oil crisis in the 1970s, oil and especially gasoline have been increasingly taxed in Europe. This is partly due to a political concern for energy security, but there are many other reasons as well, e.g., costs of road construction and maintenance, carbon dioxide emissions, local pollutants, accidents, and congestion. These taxes have hampered the growth of oil use quite significantly in the EU and thereby reduced carbon dioxide emissions (Sterner, 2007).

## 3. The model

In this paper, we first analyze how domestic energy policies can reduce the *expected economic cost of oil disruptions*, *ECD*. The fear of oil disruptions may also influence foreign policy – just think of the close relationship between the US and Saudi Arabia – which means that oil dependence has a political cost that is hard to assess in economic terms, see Klare (2004) for an analysis of the foreign policy implications of the oil market. The expected cost of an oil disruption in a base scenario is given by *ECD*, and in a policy scenario by *ECD*′. The *expected reduced economic loss of an oil disruption due to a policy*, Δ*ECD*, may then be computed as

$$\Delta ECD = ECD - ECD'. \quad (1)$$

In addition, energy policies that affect the oil market may also reduce the oil price, and the EU may thereby obtain a monopsony power gain, *MP*. We study the *gross expected economic gain*, *GEG*, of a policy, thus

$$GEG = \Delta ECD + MP. \quad (2)$$

To assess whether a policy is cost-efficient, we also compute the *net expected economic gain* of a policy, *NEG*, where *Z*, below, represents cost of the policy, thus

$$NEG = \Delta ECD + MP - Z. \quad (3)$$

### 3.1. Expected cost of oil disruptions

The short-term economic damage of an oil shock is usually divided into three parts, additional wealth transfer, social surplus loss, and macroeconomic adjustment cost.

Wealth is transferred to oil exporters as long as the oil price is higher than the extraction cost. An increased price due to an oil disruption implies an additional wealth transfer to oil exporters. This transfer is a pecuniary externality, which means that it doesn't amount to an efficiency loss for the global economy. Therefore, from the *global* perspective there are no efficiency reasons for introducing policy instruments in order to reduce the wealth transfer. From the perspective of an individual oil-importing country, wealth transfer is a cost; therefore, wealth transfer is often part of discussions considering oil imports (Leiby, 2007; Parry and Damstadter, 2003).

Econometric studies have found that the GDP growth often slows down when there is a sudden increase in the oil price. One part of this cost consists of a dead weight loss due to increased prices (the so-called social surplus loss) and can easily be computed. The total economic damages found in the econometric studies is, however, significantly higher. Those additional costs are attributed to macroeconomic adjustment costs.

The macroeconomic adjustment cost occurs in conjunction with sudden oil price increases, and stem from different factors such as shifted demand, decreased productivity in energy capital, balance of trade effects, and sticky wages.[1] Different from wealth transfer, the macroeconomic adjustment costs depend on the total use of oil in the economy rather than the amount of imported oil (Jones et al., 2004). Further, the macroeconomic adjustment cost is transitory, and seems to be independent of how long the oil price remains high. Also, the oil price has an asymmetrical impact on GDP: increased oil prices hamper GDP growth, but reduced oil prices do not boost the economy (Lardic and Mignon, 2006). The reason for this asymmetry is discussed in Huntington (1998) and Brown and Yücel (2002). Finally, the macroeconomic adjustment cost depends not only on the oil price increase but also on the macroeconomic conditions (both fiscal and monetary policies), see Barsky and Kilian (2004) and Huntington (2004).

There is a debate whether oil use is associated with an externality or not. On one hand, oil users may anticipated oil disruptions and thereby adjust their investments decisions so they are less vulnerable to the oil price increase. On the other hand, the macroeconomic adjustment costs tend to increase the more oil intensive the economy as the whole is. This effect is rather economy wide than firm specific and you may thereby argue that there are an externality associated with oil use. For a more thorough discussion on these issues, see Bohi and Toman (1993); Huntington, (2003); Parry and Damstadter (2003).

The expected economic cost of an oil disruption is determined by the probability of a disruption times the cost of the disruption. The damage in turn is a function of the price increase which is a function of the size of the disruption. The damage may also be reduced by insurances and release of stockpiled oil. The latter variables are not included in this analysis.

The *expected economic cost of oil disruptions*, *ECD* is then calculated as

$$ECD = \sum_{k\varepsilon K} \delta_k(\Delta W(p(n_k), p_0) + M(p(n_k), p_0)). \tag{4}$$

There are $k = 1$ to $K$ events with the probability $\delta_k$ that an oil disruption occurs, reducing the supply by $n_k$. The supply disruption raises the oil price from $p_0$ to $p$, which in turn causes an economic cost equal to the sum of the additional wealth transfer, $\Delta W$, and the macroeconomic adjustment costs and the social surplus loss. The sum of the latter two terms is denoted by $M$.

We calculate *ECD* given the actual import, demand, and prices in 2004. We use 2004 as a base year, since there is good data availability for this year. We could have introduced future scenarios but would then add uncertainties of future demand and prices.

We therefore calculate the counter-factual $ECD'$ given that the policy was in place in 2004. In this case, we have a $\delta_k$ probability that there is a disruption $n'_k$ which raises the oil price from $p'_0$ to $p'$. Thus, we do not assume that domestic energy policies can affect the probability of disruptions; this issue is further discussed in Section 7. We calculate the *expected reduced economic loss of an oil disruption due to a policy*, $\Delta ECD$, by

$$\Delta ECD = \sum_{k\varepsilon K} \delta_k\big(\Delta W(p(n_k), p_0) + M(p(n_k), p_0) - \Delta W\big(p'(n'_k), p'_0\big) - M(p'(n'_k), p'_0\big). \tag{5}$$

#### 3.1.1. Wealth transfer

The price of many energy commodities $P^j$ depends on the price of oil, $p$. Thus, when calculating the additional wealth transfer one has to consider both the post-disruption price of oil and the other energy commodities, such as natural gas. The extra wealth transfer due to the disruption can be expressed as

$$\Delta W = \sum_{j\varepsilon J} (P^j(p)I^j - P^j_0 I^j_0). \tag{6}$$

$P^j_0$ is the pre-disruption price with the net import level of $I^j_0$, the post-disruption net import is given by $I^j$. The net import is dependent on demand for the energy carrier $j$, $D^j$, and the short-run demand elasticity $\varphi^j$ as well as the supply elasticity of the domestic production $\nu^j$ and the base level of the domestic production, $S^j_0$. The import level is thus given by

$$I^j = D^j_0\left(\frac{P^j(p)}{P^j_0}\right)^{\varphi^j} - S^j_0\left(\frac{P^j(p)}{P^j_0}\right)^{\nu^j}. \tag{7}$$

The change in wealth transfer is computed by inserting Eq. (7) into (6).

#### 3.1.2. Macroeconomic adjustment cost

Macroeconomic adjustment cost $M$ is calculated using the $\mu$, the oil-GDP elasticity, thus

$$M = Y_0 - Y_0\left(\frac{p}{p_0}\right)^{\mu}, \tag{8}$$

where $Y_0$ is the GDP in the absence of oil shocks, $p_0$ is the pre-disruption oil price and $p$ is the post-disruption oil price (Leiby et al., 1997; Greene and Leiby, 2006). Observe that by using this formula our expression for macroeconomic adjustment cost also captures the social surplus loss.

#### 3.1.3. Price response to the supply shock

*3.1.3.1. Oil price response.* To calculate the economic cost of the oil disruption, the post-disruption oil price, $p$, must be calculated. In the base scenario the pre-disruption price $p_0$ is at the actual level of 2004 (55 USD/bbl). The post-disruption price is determined by short-run demand and supply functions. Here, $\varphi$ is the short-term global demand elasticity for liquid fuels and $\nu_a$ the short-run supply elasticity for supplier $a$, which also includes OPEC's response to the higher prices followed by a supply shock. The loss of

[1] For more thorough discussion of these issues see Brown and Yücel (2002), Jones et al. (2004), Huntington (2003) and Toman (1993).

supply is denoted as $\Delta q$, and $p$ is obtained by solving

$$D\left(\frac{p}{p_0}\right)^{\varphi}=\sum_{a\varepsilon A}q_0^a\left(\frac{p}{p_0}\right)^{\nu^a}-\Delta q. \tag{9}$$

*3.1.3.2. Price interdependence.* We use regression analysis based on minimization of ordinary least squares to estimate the price interdependence between crude oil and the price of other energy commodities. The model used to estimate the relation is given by

$$\ln\left(\frac{P_t}{P_{t-1}}\right)=\sum_{i=0}^{I}\alpha_i\ln\left(\frac{p_{t-i}}{p_{t-i-1}}\right)+\beta. \tag{10}$$

$P_t$ is the price of the energy commodity studied at time $t$, and $p_t$ is the crude oil price at time $t$. We assume $P$ is dependent on $p$ with time lag $i=0$ to $I$, and estimate the impact on the price for time lag $k$ with parameter $\alpha_i$. The constant is denoted as $\beta$.

Price interdependence is seldom included in estimates of cost of oil disruption. Still, the price increase of other energy commodities is important for calculating the wealth transfer Eq. (6) as well as for the oil-GDP elasticity, see Eq. (12).

## 3.2. Policy scenarios

We compare the expected cost of an oil disruption between a base scenario and a counter-factual policy scenario using Eq. (5). In the policy scenarios wealth transfer is calculated as in Eq. (6) and the macroeconomic adjustment cost as in Eq. (8); the oil price-GDP elasticity may also be affected according to Eq. (12). Further, the post-disruption price is determined by Eq. (10).

### 3.2.1. Pre-disruption price

The pre-disruption oil price in a policy scenario, $p'_0$, is, however, not the same as in the base scenario. Policies implemented in the EU may influence the global liquid fuel market since the EU is a large oil consumer. The EU may influence the global liquid market by either reducing the demand for liquid fuels (through energy savings, energy efficiency or fuel shifts away from liquid fuels) or by increasing the supply of liquid fuels, such as ethanol or domestic oil.

We consider OPEC a rent maximizing dominant firm, whereas the remaining liquid fuel producers ($a=2$ to $A$) adjust their supply as given by their supply elasticity, $\varepsilon^a$, and base supply, $q_0^a$ (Greene, 1991). The total liquid fuel supply of the fringe is denoted as $q$. OPEC's supply is given by $Q(p)$, and the cost of producing oil in OPEC is $c(Q)$ with a supply elasticity of $\sigma$. The global demand response is determined by the global demand, $D_0$, in the base scenario and demand elasticity $\gamma$. EU may either reduce global liquid fuel demand by $d$, or add supply of $q_0^1$. OPEC's optimization problem can then be expressed as

$$\max(p-c(Q))Q(p). \tag{11}$$

Subject to

$$Q(p)=(D_0-d)\left(\frac{p'_0}{p_0}\right)^{\gamma}-\sum_{a\varepsilon A}q_0^a\left(\frac{p'_0}{p_0}\right)^{\varepsilon^a}.$$

$$c(Q)=c_0\left(\frac{Q}{Q_0}\right)^{-\sigma}.$$

We solve the problem numerically to find the pre-disruption oil price that optimizes OPEC's profit. Furthermore, the OPEC market share of the liquid fuel market is affected which in turn affects the size of disruption $n'_k$ for some $k$, see Section 5.1.

### 3.2.2. Macroeconomic adjustment cost

The mechanisms behind the macroeconomic adjustment costs are poorly understood; therefore, it is difficult to estimate how energy policies affect the macroeconomic adjustment cost. Huntington (2004) estimated in an econometric analysis that the oil-GDP elasticity was proportional to the oil expenditure per GDP. Policies that reduce oil consumption may therefore decrease the macroeconomic adjustment cost. However, substitution of oil for energy commodities that have a strong price link to the oil price would probably not have this effect.

Ethanol has a strong price link to the oil price; therefore, substituting ethanol for gasoline would probably not reduce the macroeconomic adjustment cost as much as substituting a fuel with a weaker link to the oil price. Including ethanol expenditures in addition to the oil expenditure when estimating the oil price-GDP elasticity would increase the estimated value of the elasticity since ethanol is more expensive than oil. On the other hand ethanol is a substitute for gasoline rather than crude oil so it would be strange to add crude oil and ethanol expenditures.

One way in which ethanol use may reduce macroeconomic adjustment costs is that its price lags the oil price. Macroeconomic adjustment cost occurs for sudden price increases, a lagged price response would therefore imply reduced cost.

It is thus unclear how to incorporate ethanol use in a reasonable way, and the effect on the results is significant. Here, we assume that the oil-GDP elasticity in the policy case $\mu'$ is dependent on the pre-disruption price of gasoline and ethanol, $p_0^g$ and $p_0^e$ and the consumption of oil products and ethanol $q_0^g$ and $q_0^e$. Primes indicate prices and consumption in the policy case, and $Y$ the GDP, thus

$$\mu'=\mu\frac{p'^g_0q'^g_0+(\alpha_0+\alpha_1)p'^e_0q'^e_0/Y}{p^g_0q^g_0+(\alpha_0+\alpha_1)p^e_0q^e_0/Y}=\mu\frac{p'^g_0q'^g_0+(\alpha_0+\alpha_1)p'^e_0q'^e_0}{p^g_0q^g_0+(\alpha_0+\alpha_1)p^e_0q^e_0}. \tag{12}$$

To account for the delay in the price response, the ethanol price is weighted by the oil–ethanol price elasticities for the immediate response and the first lag, thus $\alpha_0$ and $\alpha_1$.

### 3.2.3. Monopsony power

The policies we study in this paper do not only affect the expected economic gain, $\Delta ECD$, but they have other benefits too. Energy policies aiming at reducing oil use also affects the monopsony power of the importing region. Monopsony power is the consumer side of market power (Dasgupta and Heal, 1979; Leiby, 2007). A large consumer may reduce import and thereby reduce the global oil price. That way, all consumers may buy the same commodity to a lower price. In a competitive market this makes the market as a whole less efficient. Still, for the individual country exercising its monopsony power, it would be beneficial. But, if there is a monopolist on the supply side, using the monopsony power may reduce the market price, so it is closer to the competitive level; this omits some dead weight loss (and decreases the wealth transfer to the monopolist). Hence, in this case the market as a whole would be become more efficient. Under such circumstances it is considered justified from an efficiency point of view to use the monopsony power (Leiby et al., 1997).

The monopsony power gain depends on the perturbation in the oil market calculated in Eq. (11). However, there is also a monopsony power gain from energy commodities whose prices are linked to the oil price. An approximation to calculating the monopsony power gain, $MP$, is

$$MP=\sum_{j\varepsilon J}(P_0^j-p'^j_0(p'_0))I'^j, \tag{13}$$

where the pre-disruption energy price in the base scenario is $P_0^j$, and in the policy scenario $p'^j_0$, the import level in the policy scenario is given by $I'^j$ (Leiby et al., 1997).

## 4. Scenarios

We simulate four counter-factual policy scenarios, and compare these to the base scenario, the actual situation in 2004. In the policy scenarios, the EU applies a policy that impacts the global liquid fuel market. OPEC and the rest of the market adjust their production according to Eq. (11).

The four policy scenarios studied are:

1. *Imported ethanol*: 1.6 EJ gasoline (corresponding to 10% of the energy in the road transportation sector) is replaced by imported ethanol.
2. *Domestic ethanol*: 1.6 EJ gasoline is replaced by domestic ethanol.
3. *More efficient cars*: 1.6 EJ less oil is used in the road transportation sector.
4. *Biomass in households*: 1.6 EJ oil is replaced by domestic solid biomass in the household sector.

We have chosen these four scenarios since they (a) represent policies that are discussed or even ongoing in the EU or in the member states and (b) they represent different mechanisms by which EU-25 can gain energy security benefits.

The first two scenarios increase the supply to the liquid fuels market. Efficient cars on the other hand reduce the demand for liquid fuels. The biomass in the household sector scenario also reduces demand for liquid fuels, since oil is replaced by solid biomass whose price is not currently linked to the prices in the liquid fuel markets, see below. The latter two scenarios are, therefore, referred to as demand-reduction scenarios, whereas the first two are called ethanol scenarios.

## 5. Parameters

### 5.1. Risk of disruption

The risk and size of disruptions are estimated from historical data between 1960 and 2003, compiled in Beccue and Huntington (2005). We divide the probability into three discrete cases, see Table 1. In the first case, we place large disruptions that are dependent on OPEC's production share, such as disruptions due to wars and internal unrests in OPEC countries. In the second case, we have smaller disruptions of the same kind. In the third category we include accidents and deliberate disruptions like the Saudi embargo against the US and the Netherlands during the Yom-Kippur war in 1973. We place the Norwegian strike in 1996 in this category, too.

**Table 1**
Probability, size, and duration of oil supply disruptions.

| $k$ | Probability per year $\delta_k$ (%) | Size $n_k$ | Duration (months) |
|---|---|---|---|
| 1 | 11 | 13% of OPEC[a] | 7 |
| 2 | 23 | 2.7% of OPEC[b] | 5 |
| 3 | 18 | 0.7 million bbl/day | 4 |

[a] In the base scenario this corresponds to a disruption of 3.8 bbl/day.
[b] In the base scenario this corresponds to a disruption of 0.8 bbl/day.

### 5.2. Oil price-GDP elasticity

The oil price-GDP elasticity for EU is set to −0.04 in the base case, but is altered in the sensitivity analysis. This is within the range −0.02 to −0.06 reported in an overview by Leiby et al. (1997). Jones et al. (2004) report the oil price-GDP elasticity to be −0.055 as a best estimate in a later overview.

### 5.3. Oil price parameters

The energy use, import, domestic supply and import prices for EU-25 are obtained from IEA (2007a) and the global demand and supply data from BP (2005). We assume that OPEC nations have optimized their supply according to Eq. (9).

Greene (1991) shows that if OPEC acts as a dominant firm, they have adjusted their production to long-term demand elasticities and supply elasticities for the fringe when the oil price has been low and to short-term elasticities (for demand and for supply from the fringe) when the price has been high. The long-run demand and supply elasticities have been estimated to about −0.65 and 0.46, respectively, while the short-run demand and supply elasticities have been estimated to −0.07 and 0.07, respectively (Greene and Leiby, 2006). For the situation in 2004, a medium-run elasticity is suitable since 2004 falls in the middle of an oil price increase, the price was 55 USD/bbl. We set the supply and demand elasticities to 0.3 and −0.33, respectively. These values give a good fit with the actual production and price for 2004.

### 5.4. Price interdependence

We estimate the price interdependence between oil and other energy commodities using Eq. (10). We use quarterly price data for oil and natural gas obtained from IEA (2007a) and ethanol price data from Brazil (Walter, 2007). A series of pellets prices in EU is constructed as a weighted price average for the major pellets consumers in Europe (European Pellets Center, 2007; Pro Pellets Austria, 2007; and ÄFAB, 2007).

Our regression analysis shows that there is a lagged relationship between the oil price and the European natural gas prices, and the same holds for ethanol, even though the relation is stronger, as shown in Table 2. We use the Durbin–Watson test and do not find autocorrelation. There is no statistically significant relation between the pellet prices and the oil prices, even though there is some co-movement in 2006 and 2007.

We also test the relation between oil and coal prices and between natural gas and oil, but do not find any significant coefficients. Further we tried to explain the variation in ethanol price as dependent on the sugar price, but do not find significant coefficients.

**Table 2**
Estimated coefficients for price interdependence between oil and natural gas prices and oil and ethanol prices.

| | Natural gas | Standard error | Ethanol | Standard error |
|---|---|---|---|---|
| $B$ | 0.0034 | 0.0068 | −0.034 | 0.036 |
| $\alpha_1$ | 0.25*** | 0.059 | 0.60*** | 0.24 |
| $\alpha_2$ | 0.20*** | 0.062 | 0.46** | 0.26 |
| $\alpha_3$ | 0.25*** | 0.060 | 0.41* | 0.25 |
| Adjusted $R2$ | 0.50 | | 0.27 | |

*** Significant at the 97.5% level.
** Significant at the 95% level.
* Significant at the 90% level.

### 5.5. Scenario costs and greenhouse gas emissions

We estimate the cost of the four different policies by calculating the annualized investment cost and fuel costs for consumers without taxes. In the ethanol scenarios, we assume that the ethanol is blended into the gasoline; therefore, there are no extra costs for the vehicles. The more efficient cars scenario may be obtained if consumers choose to buy smaller cars; however, it is hard to estimate the cost of this change. In the efficiency scenario, we assume that hybrid cars are introduced at a large-scale, which reduces fuel consumption. For the fourth scenario, we assume pellets are used for residential heating instead of oil. For all cost calculations, a discount rate of 5%/year is used. Greenhouse gas emissions are based on life-cycle emissions and converted into $CO_2$ equivalents using global warming potentials calculated over a 100-year time horizon. The basis for the cost estimates and greenhouse gas emissions is found in Table 3.

## 6. Results

### 6.1. Expected cost of oil disruptions

The expected cost of oil disruption in our base and policy scenarios is 0.27–0.29% of the GDP of EU-25 or between 29.5 and 31.6 billion Euros a year, as shown in Fig. 1. The largest cost is the macroeconomic adjustment cost, which constitutes around 85% of the expected economic cost of oil disruption. In the imported ethanol scenario, the expected cost of oil disruption is slightly higher, whereas the opposite holds in the other policy scenarios. The efficient cars and biomass in households have the largest reduction in the expected cost among the policy scenarios. The reasons for this are given in the subsequent section.

### 6.2. Gross expected economic gain of policies

In the imported ethanol scenario there is an increased wealth transfer compared to the base scenario, see Fig. 2. The reason is that the ethanol price increases even more and remains high for a longer period of time than the oil price (according to our regression analysis). Since ethanol is imported, wealth is transferred to the ethanol exporter instead of the oil exporter. The post-disruption oil price is in this scenario lower than in the base scenario (this tends to reduce the additional wealth transfer but not enough to compensate for the increased ethanol price). The lower oil price increase (in relative terms) reduces the macroeconomic adjustment cost. In addition, the macroeconomic adjustment cost is lowered since the oil price-GDP elasticity is reduced (see Eq. (12)). The latter effect is small, however, since the ethanol price is highly linked with the oil price.

In addition to changes in the expected cost of oil disruption, energy policies yield a monopsony power gain for the EU-25 in all

**Table 3**
Cost estimates and greenhouse gas emissions for energy technologies used in the policy scenarios.

| Cost estimate based on | Vehicle cost (€) | Inv. cost (€/kW) | Fuel price (€/GJ) | Total cost | Greenhouse gas emissions (kg $CO_2$-eq/GJ) |
|---|---|---|---|---|---|
| Gasoline | 21,500 | | 9.3[a] | 0.14 €/km | 95[b] |
| Sugar cane ethanol | 21,500 | | 13.3[c] | 0.15 €/km | 20[b] |
| Wheat ethanol | 21,500 | | 25.8[c] | 0.19 €/km | 50[b] |
| Hybrid car | 25,400[d] | | 9.3[a] | 0.16 €/km | 95[b] |
| Oil heater | | 15[e] | 7.0[a] | 7.9 €/GJ | 90[f] |
| Pellets boiler | | 50[e] | 10[g] | 14.4 €/GJ | 12[f] |

[a] EUROSTAT (2007).
[b] Edwards and Larivé (2006).
[c] Hammerlink (2004).
[d] OECD/IEA (2006).
[e] STEM/KO (2006).
[f] Dones et al (2003).
[g] European Pellets Center (2007).

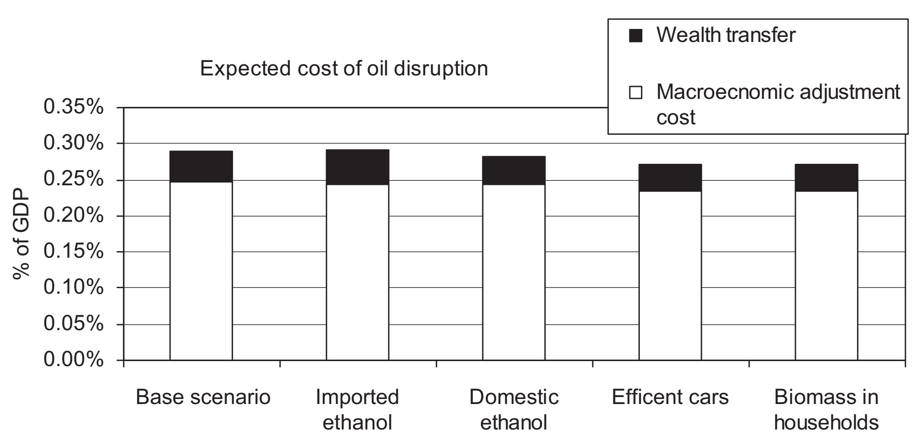


**Fig. 1.** Expected economic cost of oil disruption for the different scenarios.

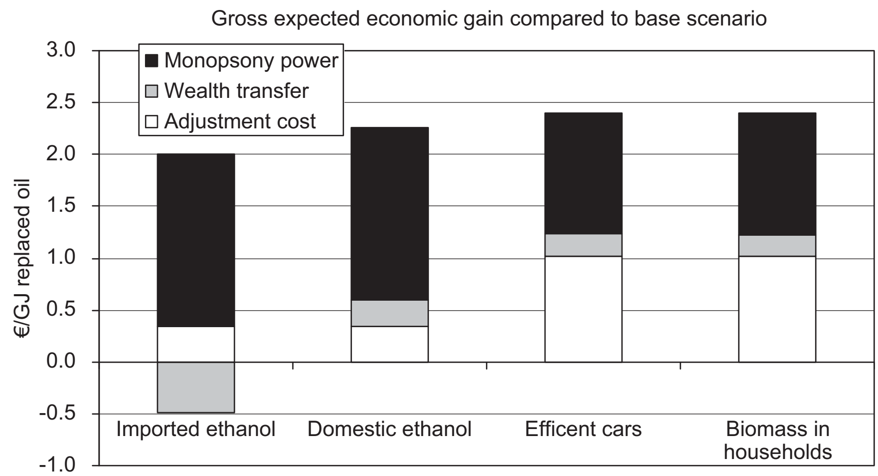


**Fig. 2.** Gross expected economic gain for different policy scenarios.

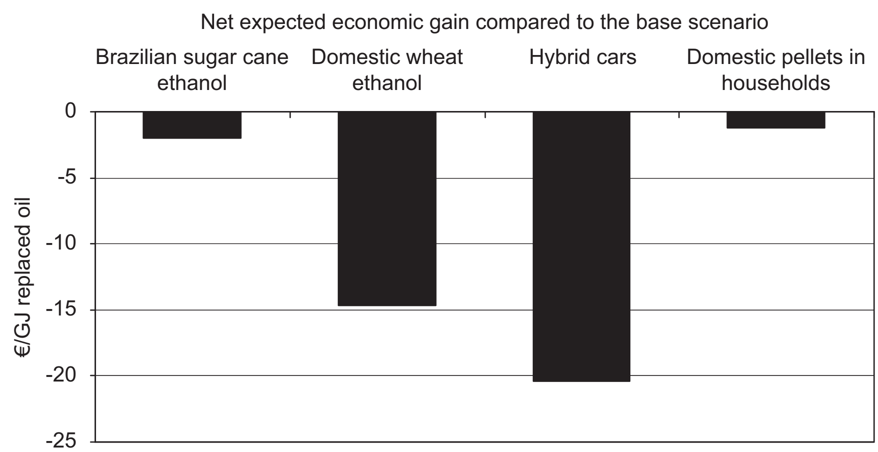


**Fig. 3.** Net expected economic gains for the different policy scenarios.

scenarios. The monopsony gain is largest in the ethanol scenarios (see Fig. 2), since OPEC's market share is reduced more in the scenarios in which liquid fuel is added to the market compared to scenarios which reduce demand. This is in line with the study by Hoftyzer et al. (1989) who analyze how the market share of the dominant firm is affected by changes in base demand. The lower the market share, the more difficult it is for OPEC to maintain a high price. Therefore, the monopsony power gain is higher in the ethanol scenarios.

In the domestic ethanol scenario the gross benefit is larger than in the imported ethanol scenario since the wealth transfer is reduced compared to the base scenario. The reason for this is that the wealth is transferred to domestic producers and therefore not considered a cost.

In the biomass in households scenario, there is an increased use of pellets. Since pellets do not have a price correlation to the oil price in the short term, there is a reduced wealth transfer in this scenario. In the more efficient cars scenario the same holds since less oil is imported.

In the demand-reduction scenarios the relative price increase after a disruption is slightly higher than in the base scenario. This would have led to a slightly higher macroeconomic adjustment cost if not it was taken into account that the liquid fuel intensity is reduced due to this policy measures. The combined effects of these two changes results in a reduction in the macroeconomic costs; hence the reduction in the liquid fuel intensity more than offset the relatively higher price increase.

### 6.3. *Net expected economic benefits*

We calculate the net expected economic benefits in the policy scenarios, see Eq. (3). In all scenarios, the cost of the policy outweighs the expected economic benefits (Fig. 3). The pellets scenarios is the closest to being cost-efficient. Pellet prices in the EU vary significantly between countries; therefore, this policy may be cost-efficient in some EU countries where the pellet price is low.

The cost of implementing a scenario with imported sugarcane-based ethanol is significantly lower than the cost of all other transportation scenarios. Therefore, among the transportation scenario, the imported ethanol scenario gains the largest net benefits even if the gross benefit was the lowest among all the scenarios. The more efficient cars scenario showed quite high gross expected economic gain. But when implemented with hybrid cars, the cost by far exceeds the benefits. More efficient cars may, however, be obtained at a lower cost if consumer preferences regarding passenger vehicles change. In addition, important cost reductions for hybrid systems can be expected in the future if these are deployed large-scale, due to economies-of-scale and learning-by-doing.

### 6.4. Sensitivity analysis

We perform a sensitivity analysis of the *gross expected economic gain* with respect to the short-run supply and demand elasticities, the oil-GDP elasticity, and the OPEC response to the EU energy policy.

Increasing the short-term supply and demand elasticities by 50% results in lower post-disruption oil price. This reduces the benefit of energy policies in all scenarios except the imported ethanol scenario. The opposite result holds if the elasticities are lowered by 50% (see Fig. 4). The reason why imported ethanol stands out is that a higher post-disruption oil price increases the wealth transfer, which is a negative term in this scenario. Therefore, the gross economic gain is reduced compared to the base case and vice versa when the elasticities were 50% higher.

If the oil-GDP elasticity increases, the benefits of energy policies increase in all scenarios (and vice versa).

In the non-OPEC response case, OPEC does not adjust production when the EU implements its energy policy; rather, the oil supply is kept constant at its original level, $Q$. The new supply and demand are given by

$$(D^0 - d)\left(\frac{p}{p^0}\right)^{-\gamma} = \sum_{a \varepsilon A} q_a^0 \left(\frac{p}{p^0}\right)^{\varepsilon_a} + Q. \tag{14}$$

This affects the demand-reduction scenarios the most. Recall that in the demand-reduction scenario OPEC's market power was less reduced due to the policy than in the ethanol scenarios. If OPEC is not using its market power, the benefits of this will be higher in the demand-reduction scenarios than in the ethanol scenarios.

Even though there are some changes in the gross economic gain in the sensitivity analysis, none of the policies become cost-efficient.

All policy scenarios studied also reduce greenhouse gas emissions. We, therefore, also add a greenhouse gas benefit to the gross economic gain. We study two cases, a carbon price of (a) 20 and (b) 100 €/ton $CO_2$-eq in the EU. In this case, we find that pellets in households and import of Brazilian ethanol reaches break-even at a carbon price of around 20 €/ton $CO_2$-eq, whereas for a carbon price of 100 €/ton $CO_2$-eq both scenarios are clearly cost-efficient, see Fig. 5. Hybrid cars and domestic wheat ethanol do not yield net benefits even in these cases.

The results on macroeconomic costs are based on the assumption that oil price-GDP elasticity is proportionate to liquid fuel expenditure per GDP. There are theoretical reasons for this assumption and also some empirical support, but the exact relation is of course uncertain (Huntington, 2003). As we described in Section 3.2.2, it is unclear how to incorporate ethanol use in this framework. If only the instant price correlation is considered, the effect on macroeconomic adjustment cost is roughly the same as for the demand-reduction scenarios. If on the other hand, we compare the crude oil expenditure (instead of gasoline) in the base scenario to the crude oil and ethanol expenditure in the ethanol scenarios this increases macroeconomic adjustment costs. Domestic ethanol is not cost-efficient either way, whereas the case is ambiguous for the imported ethanol scenario.

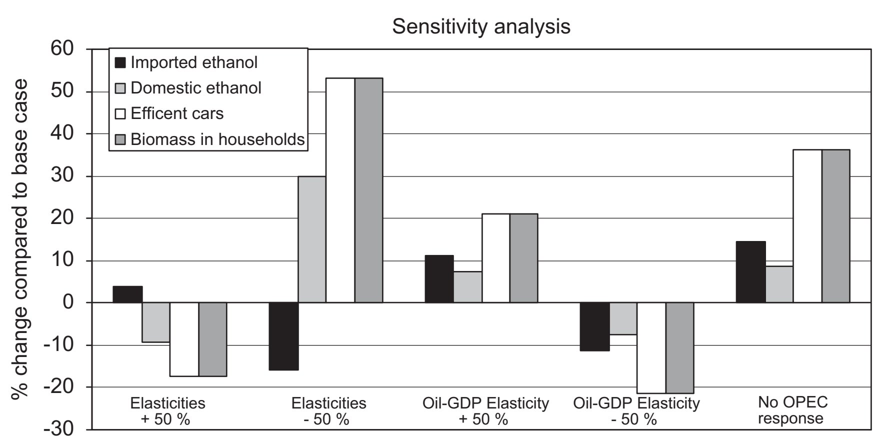


**Fig. 4.** Influence on the gross expected economic gain due to energy policies by adjusting some parameters.

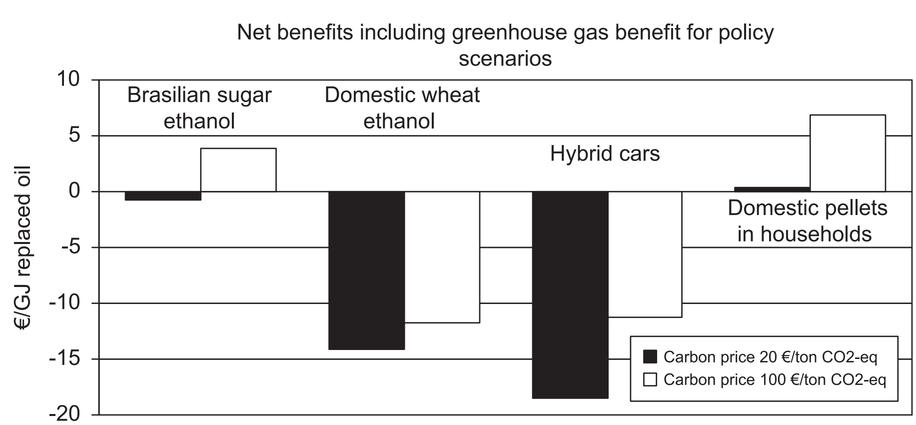


**Fig. 5.** Net benefits including greenhouse gas benefits.

### 6.5. Mechanisms behind the results

The ethanol scenarios and the demand-reduction scenarios act mainly through different mechanism.

Increased liquid fuel supply has a stronger effect on the OPEC's market power, and thereby the pre-disruption oil price, than a corresponding reduction in demand of liquid fuels. This means that the monopsony power gain is larger in the ethanol scenarios than in the demand-reduction scenarios. Furthermore the relative price increase after the oil shock is smaller when there is more liquid fuel supply at the market. This means reduced macro-economic adjustment cost and wealth transfer if the new fuel is produced domestically.

In the demand-reduction scenarios the relative price increase is larger than in the base scenario. Still, the macroeconomic adjustment cost is lower in the demand-reduction scenarios than in the ethanol scenarios since the oil price-GDP elasticity is reduced due to lower oil expenditure. The ethanol price is strongly linked to the oil price; therefore, there is only a small reduction in the oil price-GDP elasticity in the ethanol scenarios.

The ethanol scenarios mainly yield benefits through reduced pre- and post-disruption oil price, whereas the demand-reduction scenarios mainly gain benefits through reduced oil price-GDP elasticity. Our analysis show that the gross benefits are larger if demand is reduced rather than if additional supply is added.

## 7. Limitations of the model

There are some aspects that we have not captured in the model that may have altered the results; these are discussed below.

First, the probability of a disruption is assumed to be independent of OPEC's market share and EU's consumption. It may be argued that if the EU is less dependent on oil, OPEC will be less willing to use "the oil weapon", since it will be less effective. This could possibly translate into a somewhat lower supply disruption probability. It is, however, very hard to quantify this effect if at all it exists; also, historically, the oil weapon has only been used once by OPEC, whereas disruptions due to other factors have been much more common.

Second, we have assumed that the most of the risk depends on OPEC's market share. A more rigorous analysis should assess the market share of each individuals oil exporting country. A promising way of in detail assessing the stability of the oil market is found in IEA (2007b), where both diversification of suppliers and political stability are taken into consideration.

Third, there is a long-term aspects of energy security that is related to these more short-term aspects of which we have studied here. The major difference that is to be expected in the coming decades, independent of the stringent climate policies or not, is that there is likely to be diversification of the global liquid fuel supply. Conventional oil will probably to a larger extent be complemented by natural gas liquids, coal to liquids and ethanol from sugar cane. Even due to this likely diversification it most likely that OPEC will take gradually a larger and larger share of the global liquid supply. Also, on the demand side one should expect a very high growth of liquid fuel demand in fast growing countries such as China and India.

To better understand how this development will impact on future energy security issues, EU supply diversification and demand-reductions needs to be studied in a dynamic setting. Here, crucial issues include potential supply and location of oil reserves and future substitutes, and how this is linked to the strategic behavior of the major oil market actors, hence OPEC, and potentially also the strategic behavior of major importers. See for instance Johansson et al. (2009) for a study of the long-term liquid fuel market where OPEC's market power is taken into account.

Fourth, we have only been concerned with oil security in this paper. Since oil and natural gas prices are linked one might suspect that the natural gas intensity in the economy also affects the macroeconomic adjustment cost. Due to lack of data we have not included that aspect here. Moreover, there is a risk of natural gas disruption. This might affect the EU in a similar way to an oil shock. However, there have not been any major natural gas disruptions; the probability of a disruption is therefore hard to estimate. Still, the framework used in this paper could be used to assess the natural gas market.

## 8. Conclusion

In this paper we have studied the impact on the expected economic cost of an oil disruption and monopsony power for four different energy policies. We have found that the gross expected economic gain of the policies lies in the range 9–22 €/bbl reduced oil consumption, depending on the parameters chosen. This corresponds to roughly 6–14 c/l of gasoline. The gasoline taxes in Europe are substantially higher than that but also account for externalities such as accidents, local pollutants congestions, carbon dioxide emissions, etc. and are assumed to cover road construction and maintenance costs.

None of the policies studied were cost-efficient when only considering expected cost of oil disruption and monopsony power. When we also include greenhouse gas benefits of 20 €/ton $CO_2$-eq it becomes cost-efficient to substitute oil for pellets in the household sector.

Including both oil markets benefits and greenhouse gas benefit does not make domestic ethanol cost-efficient in our analysis. Therefore, to justify subsidies of domestic wheat ethanol production in economic terms, additional reasons must be given.

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