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National and EU-Level Estimates of Energy Supply Externalities

Steve Arnold & Alistair Hunt

Abstract

Energy security is a topic that is of increasing importance to policy-makers and yet is a relatively under-researched area. Although macroeconomists have noted that there may be external costs associated with energy security measures, there is no definitive methodology for calculating or assessing these externalities. This paper presents an overview of the theoretical externalities and develops estimates for the size of the external costs of energy arising from energy insecurity. In particular, the research centres on costs of electricity production and oil.

This paper presents an overview of how energy security is related to the external costs of electricity production. For European policy-makers, energy security is an important issue because private decisions about energy use may not fully take into account the costs of energy insecurity. Disruptions in supply and dramatic price increases have macroeconomic impacts that individual consumers and firms do not take into account. Furthermore, agents tend to underestimate the risks of disruption and subsequent price adjustments, and there are other less tangible effects, such as the psychological costs of people feeling insecure about their energy supplies. Therefore, it is important from a policy perspective to estimate the size of the external costs of energy arising from energy insecurity.

1. Macroeconomic External Costs

As noted in Hunt & Markandya (2004), there are three potential kinds of externality associated with energy security:

- *Monopsony wedge externality*. This occurs when the additional demand for imported oil from a country results in an increase in the world price of oil, thereby exerting an additional cost on other oil-importing countries. The importing country will – from an economically rational standpoint – ignore the additional cost to other countries and that constitutes an external cost. Note that there is no market failure in terms of global inefficiency, but the resulting financial transfers out of a country/region may be of concern.
- *Incomplete rent capture***.** The consumer surplus – here understood as economic rent – is the difference between the market price and the price the consumer would be willing to pay for a given fuel mix quantity. It exists because of the inability of the supplier to capture the full rent from consumers using differentiated pricing

This paper presents research carried out under the CASES project, a Co-ordination Action on "Cost Assessment for Sustainable Energy System" financed by the European Commission under the Sixth Framework Programme. CASES assessed internal and external costs of electricity generation from different energy sources in the EU and in selected third countries by the year 2030. It evaluated policy options for improving the efficiency of energy use and disseminated the related research findings to energy sector producers and users and to policy-makers. The project started in April 2006 and ended in September 2008. Information on the consortium, the findings and the meetings of CASES are available on the official website (http://www.feem-project.net/cases/index.php).

Steve Arnold and Alistair Hunt are Environmental Economists at the Department of Economics and International Development at the University of Bath.

strategies. Thus, an energy mix change within a country, e.g. as a consequence of a greater proportion of imported gas, will lead to a change in the level of this rent and so result in an externality.

- *Macroeconomic externalities*. These result from changes in the international energy markets, e.g. increases in the price of oil, that impact on an importing or exporting country differentially, and in markets other than the energy market. Such changes generate externalities only to the extent that they constitute impacts not accounted for in individual decisions.

There are major limitations in the techniques available for measuring in quantitative terms the first two types of externalities described above. Consequently, we focus our efforts on exploring the third type – the macroeconomic externalities.

Macroeconomic externalities are examples of pecuniary externalities where the action of one economic agent affects another through changes in price(s). This means the measurement of any externalities has to be done through economic means, either modelling the economy or through empirical estimation. Modelling allows specific changes to be assessed, but requires an accurately developed and calibrated model – this can be expensive and the information required can be hard to obtain. Empirical estimation, by contrast, benefits from being derived directly from real-world data but suffers from having to find a specific outcome (i.e. size of the externalities) from a general dataset (i.e. the economic data). In the subsequent analysis, we use evidence from both methods – modelled and empirical – and estimate the gross cost of fuel price uncertainty to find the upper bound of the energy security externalities.

Below, we report on a literature review of the impacts of energy insecurity relating to oil, gas and coal as it relates to electricity supply, with the focus on the EU region. On the basis of the findings of this review we make first estimates of the 'externality unit values' for energy insecurities. The majority of empirical work has been in relation to oil, and our work reflects this, focusing primarily on macroeconomic costs of oil market uncertainties, although also briefly discussing evidence relating to coal and gas.

The mechanisms through which pecuniary externalities arise are described in later paragraphs. However, the classification of all macroeconomic costs as externalities is not universally accepted and the identification of an externality effect is important in determining appropriate policy responses.

To date, the macroeconomic consequences of energy market changes have largely been the result of activities in the world oil market, but if there were to be a similar dependence on other imported fuels in the energy mix, in principle the mechanisms would also apply to these other fuel sources. Thus, whilst the following section identifies empirically observed mechanisms by which oil price increases bring about macroeconomic changes, these may be seen to be based on generic macroeconomic principles.

Following the majority of economic modelling of energy prices and their macroeconomic linkages, a clear line of causation exists from oil price increase to macroeconomic impact:

1. Payment for oil imports results in a worsening trade balance for an importing country (since higher fuel prices result in an increase in total payments – assuming fuel price inelasticity).
2. The consequent current account and balance-of-payments deficits, and associated depreciation of the exchange rate, result in other more costly imports from outside the EU.
3. Higher import costs – of oil and other commodities – may lead to higher price levels and inflation. Higher unemployment may result from the transfer of resources needed to pay for the oil imports and lower GDP may result.

This is a simplification of the central mechanism. There is considerable discussion about a number of complicating factors in the operation of such a mechanism (Bohi & Toman, 1996). For example, the terms of trade effects may be positive or negative. Additionally, whilst it is acknowledged that higher oil prices raise prices, unless these prices continue to rise there will not be on-going inflation. Thus, whilst energy price increases may aggravate existing inflationary processes, they should not be seen as the cause of continuing inflation.

There also appears to be the threat of government – rather than market – failure that contributes to the macroeconomic impacts of energy price increases (Bohi & Toman, 1996). Because of regulation, e.g., an increase in oil prices will not lead to efficient adjustments in gas and electricity prices. These price rigidities may cause adjustment problems throughout the economy where regulation cannot simultaneously constrain market power and allow regulated prices to adjust to market conditions.

The externality estimates are based on total macro-economic costs associated with given changes in energy markets. They are derived directly from a review of the historically observed macroeconomic effects of these changes, as well as changes that are simulated in macroeconomic models.

In the following analysis we look principally at the impact of sudden, but sustained, increases in price on the macro-economy.

2. Modelling the Macroeconomic Impacts of Oil Price Increases

A number of general equilibrium macroeconomic models have been developed to simulate the impact of energy price increases and/or supply disruptions on the macro-economy and these have largely focused on the impacts of oil supply shocks that last for a year or more. Note that whilst price volatility in itself has potential macroeconomic consequences, they are not regarded as being as significant as the sustained price rises resulting from medium-term oil price shocks and are not studied separately here.

The outputs of such models are helpful in isolating these impacts from other macroeconomic trends – something that a reliance on untreated observational data is unable to do. This section therefore briefly reviews the output of a number of these models in terms of their EU-wide macroeconomic costs of energy price rises. Hunt & Markandya (2004) reviewed the published results produced by these models up to 2004, shown in Table 1. The results reviewed after 2004 that are most pertinent are reported in Table 2. In general, the differences between the two sets of results are small; we therefore conclude that the same input values used to produce the Hunt & Markandya (2004) external cost estimates are valid to apply in our updated calculations.

Roeger (2005) used the DSGE model to estimate the effects of a 50% oil price rise on the euro area's macro-economy. The paper does not give the baseline price. After 4 quarters, GDP is 0.5% lower than the baseline case, and falls further to 0.6% after 2 years and 0.9% after 5 years. Other studies that have presented results of this kind include World Bank (2005).

The summary results do not reflect the complexity of the models and the variety of their outputs for world regions. Nevertheless, despite the models' differences, there is some consistency in the pattern and extent of GDP changes. The models show that even when the oil price increase is assumed to be permanent, GDP impacts are likely to be greatest in the first four years of the price increase, and decline subsequently, suggesting that economic agents adapt their expectations to the new price level so that factor and product markets move to new equilibria over this time period. Surprisingly, there is also a degree of consistency in the scale of annual GDP losses associated with specific oil price increases. Thus for the industrialised countries a $10 price increase per barrel gives rise to a 0.5% loss of GDP (European Commission, 2002) or a proportionate linear scaling of that, on average (IMF, 2000). For the eurozone countries, there is a similar consistency in the results although here it appears that GDP is more sensitive to oil price increases than for the industrialised countries as a whole. For eurozone countries, as presented in Table 2, a 50% increase in oil prices results in a 0.4% decline in annual GDP for the first year, simply taking the arithmetic mean of these results, with a range of 0.1% to 0.8%.

A number of strong assumptions are adopted in order to derive these values and these are explained in detail below. In addition, the macroeconomic cost estimates only allow us to include the effect of a sustained price increase. No separate estimates based on price volatility are made since there are – as yet – no good studies of sectoral or macroeconomic costs resulting from price volatility (Sauter & Awerbuch, 2003). We therefore assume that the unit value estimates derived here are minimal. We assume for simplicity that the time period considered is only one year. The greater uncertainty for impacts in subsequent periods suggests that at the very least this gives rise to a plausible minimum estimate.

In order to estimate the external effects of energy insecurity in terms of cost per kilowatt hour, we follow the same methodology as Hunt & Markandya (2004). As with the earlier work, we assume that the main externality is the set of macroeconomic effects and that these can be classified as externalities.

We make the conversion from gross macroeconomic costs to costs per kilowatt hour via a series of steps. The first step is to identify a benchmark for the world oil price against which deviations in price – and therefore GDP – can be measured as a reference value in the event of an oil price change, for instance. However, the predictive models reviewed do not make this assumption explicit. We are therefore obliged to simply adopt the outputs from these models in our analysis. Similarly, whilst we would like to make explicit a second step to apportion a price increase that can be seen as typical for a given oil supply reduction – and thus to allow us to relate a GDP change resulting from a price change to the energy production from a given volume of oil – we have to assume that a 50% price increase (most frequently used in the models) is appropriate. Total GDP for the EU27 in 2005 equalled €10.9 trillion. Therefore, a 0.4% fall in GDP – identified from Table 3 – equates to €43.8 billion p.a. or €175.2 billion over a four-year period. For the world as a whole, the equivalent figures are €142.7 billion p.a. and €570 billion over the four-year period.

Table 1. Macroeconomic cost estimates of oil price increases

Source	Driver	Estimate	Units	Country/Region
EC (2002)	Sustained $10 increase in price of crude oil (per barrel)	- 0.5%	GDP growth rate	Industrialised countries
IEA (2004)	Sustained increase $25-$35 i.e. $10 per barrel crude oil	- 0.5%	GDP growth rate	Eurozone
		0.5%	Inflation	Eurozone
IMF (2000)	Sustained increase of $5 per barrel of crude oil (20% increase)	- 0.25% (over first four years, then fades to negligible)	GDP growth rate	World
		- 0.4% (percentage deviation from baseline after one year)	GDP growth rate	Euro area
		0.5% (percentage deviation from baseline after one year)	Inflation	Euro Area
		- 7.8 ($ billion)	Trade balance	Euro area
IMF (2004)	Sustained increase of $5 per barrel of crude oil (20% increase)	- 0.4% (after one year)	GDP growth rate	Euro zone
Jones et al. (2002)	Price change exceeding a three year high	- 0.05 to - 0.06	Elasticity GDP to oil price shocks	US
Sauter & Awerbuch (2003)	Sustained 10% rise in oil price	- 1.5% (for 3-6 months)	GDP growth rate	Eurozone
		- EURO 35 to 70 billion	GDP	Eurozone
World Bank (2000) in IMF (2000)	50% increase in price in first year, then decline back to original level by the third year.	- 0.25% (over first two years)	GDP growth rate	Industrial countries
		0.2%	Inflation	Industrial countries
Huntington (2004)	Doubling of oil price	-3.7%	GDP	US and eurozone
IEA (2001)	Price level: 1% increase	0.44%	% change in investment	IEA member countries
	Price volatility: 1% increase	- 0.11%	% change in investment	IEA member countries

Source: Hunt & Markandya (2004).

Table 2. Impact on eurozone GDP from a 50% increase in oil prices (deviation from baseline GDP after 1 yr)

Source	Year	Driver	Estimate (%)	Country/Region
Barell & Pomerantz	2004	50% increase in oil prices	-0.8	Eurozone
EU Commission	2004	50% increase in oil prices	-0.5	Eurozone
Dalsgaard et al.	2001	50% increase in oil prices	-0.4	Eurozone
World Bank	2000	50% increase in oil prices	-0.3	World
Hunt et al.	2001	50% increase of oil prices	-0.1	Eurozone
Dieppe & Henry	2004	50% increase of oil prices	-0.1	Eurozone

In order to express the estimated welfare cost of the oil price change in the same terms as the rest of the externalities considered by CASES, it must be decided whether the loss is expressed per barrel of oil consumed or per barrel of oil foregone. We consider that it is correct to assign the cost across the barrels consumed as this can be taken to be the cost per kilowatt hour of electricity generated. This will give the average cost.

Given that we have now derived a macroeconomic cost per barrel of oil not supplied to the market, i.e. its opportunity cost, we need to make the final conversion to the energy provided by one barrel of oil. The conversion factor for changing barrels per day into kilowatt hours is shown in Table 3. A conversion factor of 40% to estimate total electricity production per possible kWh output was used to reflect the energy-generating capabilities of oil-fired power plants in the EU.

Table 3. Summary of cost estimation process: Oil security externality

	EU27
GDP loss over 1 year (€bn)	43.8
GDP loss over 4 years (€bn)	175.1
Original oil consumption (mb/day)	82.5
Fall in oil consumption (mb/day)	3
New oil consumption (mb/day)	79.5
Change in GDP per barrel consumed (1-year loss) (€)	1.5
Change in GDP per barrel consumed (4-year loss) (€)	6.0
Electricity generation per barrel (kWh)	1648.8
Thermal efficiency	40%
Likelihood of shock	0.2
Cost estimate per kWh – 1-year loss (€)	0.002289
Cost estimate per kWh – 4-year loss (€)	0.009154
Cost (€/kWh) 1-year loss	0.000458
Cost (€/kWh) 4-year loss	0.001831
Cost proportional to electricity generation (€/kWh)	0.000004

Since the project is focused on the external costs of electricity generation, the costs from the model so far need to be apportioned to the level of oil being used in electricity. Thus, we estimate the proportion of oil that is used for electricity generation and the proportion of electricity generation that arises from oil-fired power plants. At this stage, aggregated figures for the whole EU will suffice, but disaggregated data could highlight interesting facets of the scenario.

In 2004, 4% of EU25 electricity production came from oil[1] and the proportion of oil used in the EU for electricity generation was 5%.[2] Thus, the proportion of oil price variation that can be apportioned to electricity generation is 0.04*0.05 = 0.00002.

Since we want an annual equivalent, these figures need to be multiplied by the probability of the event occurring in any given year to give us expected values. As an indication the current probability of a price increase of this magnitude occurring can be approximated on the basis of historical data. Harks (2003) estimates that a 3 million barrel shortfall event may be expected to occur at present on a 1 in 5 year frequency, based on historical events. Adopting this probability, the resulting expected value for the EU27 – assuming a 0.4% annual loss in GDP – is €0.000004 per kWh within a range of €0.000001 - €0.000008 for a 0.1% and 0.8% annual GDP loss. The breakdown of this model is shown in Table 3.

The model presented above is a simplified model of the economy that asks 'what is the cost of this event happening, and what is the likelihood of the event?'

It estimates an upper bound to the external pecuniary effects of a fall in supply of oil to the EU's electricity generating sector.

3. Gas and Coal

The above section has looked at the energy security externalities related to the macroeconomic effects of oil price rises. It found that the small levels of electricity generation from the use of oil in the EU imply that these externalities are very small. Gas, coal and nuclear power have much larger shares of the electricity generation so that price volatility of these may have significant effects.

Russia, Algeria and Norway were the three largest suppliers of natural gas imports to the EU27 from 1999-2006, with Nigeria significantly smaller, whilst Russia, Australia and South Africa were the largest source of coal imports to the EU. However, whilst energy security risks from these fuels are well known, see Stern (2004) for example on possible causes of gas insecurity, to our knowledge, no quantitative analysis has been undertaken on the macroeconomic – or other – sources of possible external costs from such risks. We highlight this as a research gap.

4. Overall Conclusions

The measurement of energy security externalities remains a complex and difficult exercise. Problems of definition as to what constitutes these externalities make agreement on the policy implications hazardous. Additionally, the range of assumptions that need to be made in order to calculate quantitative estimates of the size of these externalities means that these estimates should be viewed as indicative only. There are also a range of gaps in the coverage of the analysis, notably the exclusion of oil price volatility impacts, and the potential macroeconomic costs of gas and coal supply disruption, which suggests that the negligible values (around 0.000004 €/kWh) currently estimated are much lower than the true costs, whether categorised as external or not.

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