Overseas Development Institute

Energy price shocks

Sweet and sour consequences for developing countries

Nicola Cantore with Alessandro Antimiani and Paulo Rui Anciaes

Working Paper 355

Results of ODI research presented in preliminary form for discussion and critical comment

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Acronyms

bbl/d	Billion Barrels a Day
BP	British Petroleum
CDE	Constant Difference of Elasticities
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
CPC	Central Product Classification
EEB	Extended Energy Balance
EIA	Energy Information Administration
ESMAP	Energy Sector Management Assistance Program
EU	European Union
FAO	Food and Agriculture Organization
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTAP	Global Trade Analysis Project
IEA	International Energy Agency
IMF	International Monetary Fund
I–O	Input–Output
IPCC	International Panel on Climate Change
ISIC	International Standard Industry Classification
LDC	Least-developed Country
Mtoe	Millions of Tons of Oil Equivalent
ODI	Overseas Development Institute
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization for the Petroleum-exporting Countries
SIDS	Small Island Developing State
UN	United Nations
UNCTAD	UN Conference on Trade and Development
UNDP	UN Development Programme
UNEP	UN Environment Programme
UNIDO	UN Industrial Development Organization
US	United States
WFP	World Food Programme
WTO	World Trade Organization

Abstract

This paper discusses the effects of recent energy price changes on developing countries. It reviews the transmission channels between energy prices and growth and distribution in developing countries based on the most recent literature; employs a Computable General Equilibrium (CGE) model to identify the most vulnerable countries; and presents three brief country case studies analysing policy responses to oil shocks in more detail (Nigeria, Malawi and Ghana).

The issue of energy shocks is crucial, as oil prices affect growth. Since Brent oil prices hit a 2011 high of $127 a barrel in April 2011, as the conflict in Libya shut down its supplies, the International Energy Agency (IEA) has repeatedly said that oil prices pose a threat to growth. In 2011, the IEA estimated nominal oil prices of $114 a barrel in 2015, revising its 2010 estimate of $104 a barrel upward.[1]

Oil prices and developing country growth

An increase in oil prices has a negative effect on oil-importing countries making their input costs are greater. Meanwhile, it is commonly thought that oil prices will benefit oil exporters through improved terms of trade, at least in the short run. However, if we take into account the decrease in world gross domestic product (GDP) induced by higher oil prices and the competitiveness (production costs) of non-oil sectors in oil-exporting country, higher oil prices may eventually lower incomes in all developing countries. We estimate that, in terms of real GDP, African countries may suffer up to a 3% loss from a doubling of oil prices.

Oil prices, poverty and distribution

Because of their effect on employment and on food and transport prices, oil price shocks also have important distributional impacts within each country. Evidence shows that recent energy price shocks have increased food insecurity and poverty levels in developing countries. Some population segments have a higher degree of vulnerability, including the poor, the landless, informal sector workers and female-headed households. Evidence from household surveys in several countries shows that oil price shocks tend to have a stronger effect on poorer households, as a higher proportion of their expenditure goes towards oil products.

Effects of recent oil price changes in selected case study countries

Reviewing the experience of Nigeria, we find that oil price increases can harm countries with abundant oil but low refinery capacity. In such cases, an oil price will lead to fuel price stabilisation policies such as fossil fuel subsidies, which affect the national budget negatively and generate adverse environmental effects. Countries with oil reserves such as Ghana may suffer 'Dutch disease', which may reduce long-term growth by making the national currency stronger and diverting resources from other exportable production to national consumption. In Malawi, physical fuel scarcity generated by a lack of foreign reserves has been exacerbated by economic scarcity deriving from fuel price increases.

Conclusions

Many developing countries are already putting in place policy responses to reduce their dependence on oil (e.g. energy conservation, diversification) but, as our case studies show, long-term commitment to such policies outside the political and/or electoral cycle, government effectiveness, real independence of regulatory bodies and technical skills of decision makers need to be in place for the successful implementation of appropriate actions to reduce vulnerability or cope with oil price increases. Policies to cope with oil price crises include the strengthening of refinery capacity for countries with oil endowments, interventions promoting a structural change towards green sources of energy, the creation of strategic petroleum reserves and hedging strategies.

1 http://www.reuters.com/article/2011/11/04/us-energy-iea-idUSTRE7A32A620111104

1. Introduction and overview

This paper discusses the effects of recent energy price changes on developing countries. Several studies highlight the vulnerability of developing countries to energy price shocks. For example, Kojima (2011) maps developing countries in terms of their vulnerability to higher oil prices, measured as the share of gross domestic product (GDP) spent on net oil imports, and finds that vulnerability increased in 82% of countries, especially in Africa over a five-year period ending in 2008. Africa had the highest share of countries in which rising oil intensity (oil consumed per unit of GDP) exacerbated rising vulnerability. Energy intensity is one of the main causes of oil price vulnerability because countries that have higher energy intensity – those that require more energy per unit of economic output – are more susceptible to price shocks.

On the other hand, developing countries may benefit from energy price increases when they are net exporters of energy sources and know how to invest the proceeds wisely. One of the main mechanisms of transmission of changes in international oil price changes to the oil-exporting countries' economies is through impacts on government revenue and expenditure, as, in many of these countries, oil revenues accrue to the government (Berument et al., 2010). Energy price shocks also have implications for distribution and sustainable development.

This study examines energy price shocks and focuses on:

1. The transmission channels linking energy prices to growth in developing countries based on the most recent literature;
2. A mapping exercise identifying the most vulnerable countries using a Computable General Equilibrium (CGE) model; and
3. Three brief country case studies analysing policy responses to oil shocks in more detail. The recent experience in Nigeria, where energy subsidies were removed, suggests it is important to examine individual cases in more depth, including the political incentives.

The structure of this paper is as follows. Section 2 reviews the determinants and impacts of oil price shocks based on the literature and recent evidence of oil price changes. Section 3 examines the possible effects in more detail using the GTAP E model. Section 4 includes a number of case studies with a focus on the impact of energy price shocks, policy responses and analysis of the facts in these countries. Section 5 concludes by drawing policy implications.

2. Determinants of recent energy price shocks and effects on developing countries

This section focuses on studies dealing with the period leading to the mid-2008 peak in oil prices, and developments since the end of 2008. Section 2.1 describes the recent dynamics of world oil prices focusing in more detail on the evolution over the past few months.

Section 2.2 reviews the main explanations offered for the recent evolution of energy prices, including disequilibrium between world supply and demand, macroeconomic instability and the role of speculation.

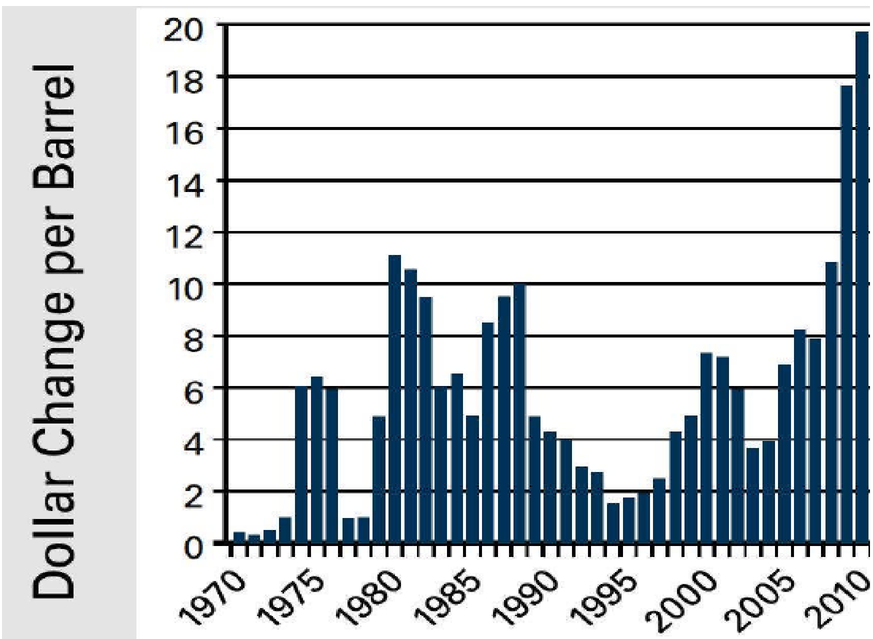
Section 2.3 and 2.4 discuss the effects of energy prices on developing countries, analysing separately the effects on net-exporting and net-importing countries. In both cases, the focus is on the main transmission mechanisms and on the effects on macroeconomic variables. In the case of net oil-importing countries, we also discuss the degree of vulnerability of different countries, the distributional effects on different social groups within each country and the effectiveness of the policies applied in response to the shocks.

Section 2.5 briefly describes the effect of energy prices on renewable energy production.

2.1Recent developments in oil prices and possible consequences

Empirical evidence shows that energy prices tend to be more volatile than prices of other commodities (Plourde and Watkins, 1998; Regnier, 2007). This may be explained by factors such as the short-term inelasticity of energy supply and demand or by the role of speculation in energy commodity markets (Baumeister and Peersman, 2009; Smith, 2009). The volatility of oil and other energy prices has also been following an upward trend since the mid-1950s, with particularly dramatic increases following the 1973 oil crisis, deregulation in 1981 and the 1991 Gulf War (Figure 1).

Figure 1: Crude oil three-year price volatility, measured as dollar change per barrel, 1970–2010

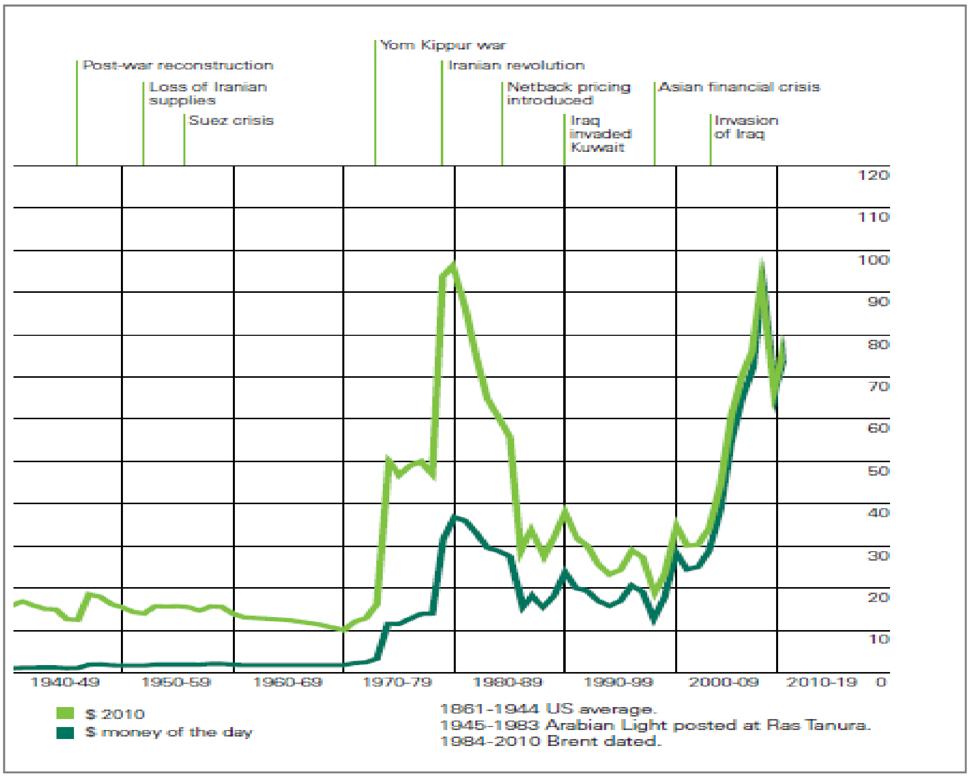


Source: US Chamber of Commerce (2012).

Fluctuations in oil prices have been particularly marked during recent years. Nominal prices increased steadily from 2001 to 2007, and then steeply from mid-2007, peaking at a historical maximum in mid-

2008 (Figure 2). This was followed by a fast decline at the end of 2008 and then by a renewed upward tendency since 2009.

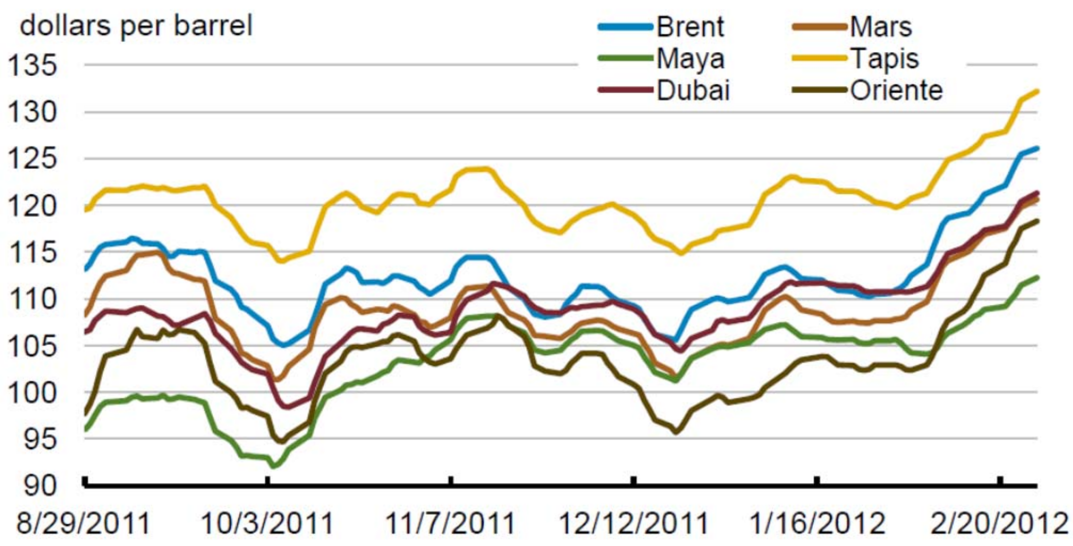
Figure 2: Crude oil prices, US$ per barrel, 1940–49 to 2010–19



Source: *BP (2011).*

Oil prices have increased over the past few months (Figure 3). The average price for Brent in March 2012 was the highest since July 2008.

Figure 3: Global crude oil spot prices, US$ per barrel, August 2011–February 2012



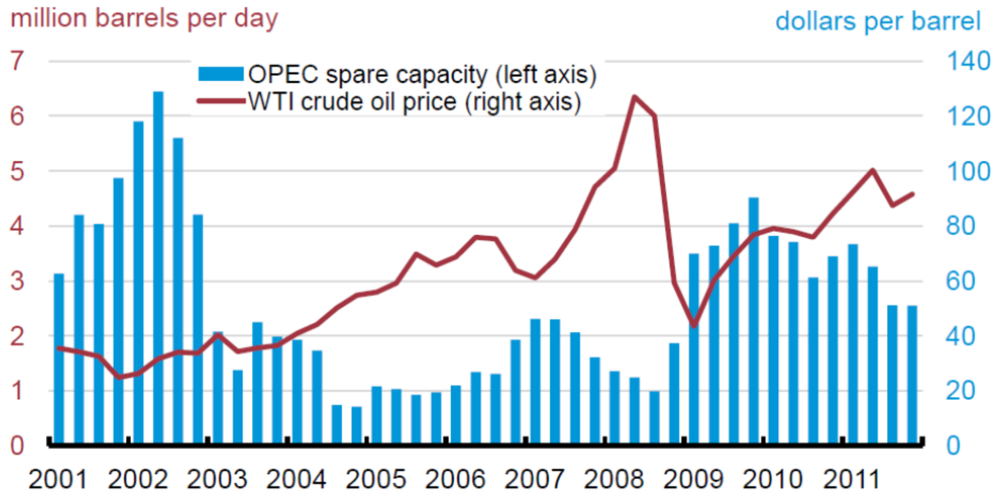
Source: *EIA (2012a).*

The Energy Information Administration (EIA) identifies supply and demand drivers of oil price changes. It estimates that spare production capacity averaged 2.6 million barrels per day in January and

February, less than 3% of global consumption and a decrease of 1.1 million barrels per day on one year ago. Most of the oil production from South Sudan, Syria and Yemen continues to be low and has contributed to the reduction in global spare production capacity.

The EIA defines spare crude oil production capacity as potential oil production that could be brought online within 30 days and sustained for at least 90 days, consistent with sound business practices. This does not include oil production increases that could not be sustained without degrading the future production capacity of a field. Currently, the world's only spare crude oil production capacity lies in the Organization for the Petroleum-exporting Countries (OPEC) countries in the Persian Gulf, largely in Saudi Arabia. Spare crude oil production capacity is an important indicator of the market's ability to respond to potential disruptions; consequently, low spare oil production capacity tends to be associated with high oil prices and price volatility, as small changes in demand or supply lead to large increases in oil prices. Figure 4 shows that spare crude oil production may have implications with regard to oil prices and vice versa.

Figure 4: World spare crude oil capacity, million barrels per day/US$ per barrel, 2001–2011



Source: EIA (2012b).

In terms of other supply sources, according to EIA (2012a), despite some notable reductions in refinery capacity and closures in the Caribbean, Europe and the US in 2011, total oil distillation capacity worldwide increased by 1.4% last year. Commercial oil inventories enable world liquids markets to ameliorate temporary imbalances between supply and demand. They constitute the first line of defence against a supply disruption, which makes inventory changes an important metric in assessing the tightness of world oil markets. World inventories over the past five years are estimated to have reduced by 0.20 million billion barrels a day (bbl/d). This could signal a tightening of the world liquid fuel supply and demand balance compared with the previous month.

In terms of demand during this same period, EIA (2012a) estimates that global liquid fuels consumption averaged 88.1 million bbl/d, 0.9 million bbl/d higher than the comparable period a year ago and 1.5 million bbl/d higher than its previous three-year annual average.

Summarising, the EIA finds that oil prices are increasingly being determined by a reduction of supply and an increase in demand. The reduction of supply is signalled mainly by the spare production oil capacity and a reduction of the inventories, whereas refinery capacity is growing. Dr Fatih Birol, Chief Economist and Director of Global Energy Economics at the International Energy Agency (IEA), recently commented on this upward trend, saying that the IEA estimates that the European Union (EU) will spend a record $502 billion this year on net imports of oil, up from $472 billion in 2011. This represents 2.8% of the bloc's GDP, whereas between 2000 and 2010 it was spending on average 1.7% of GDP on oil imports.

Table 1: Net imports of oil in selected countries

	2000 – 2010 ($ billions)	Share of GDP 2000 – 2010 (%)	2012 projection ($ billions)	Share of GDP 2012 (%)
EU	223	1.7	502	2.8
US	224	1.8	426	2.7
China	66	2.3	251	3.2
Japan	94	2.1	198	3.2

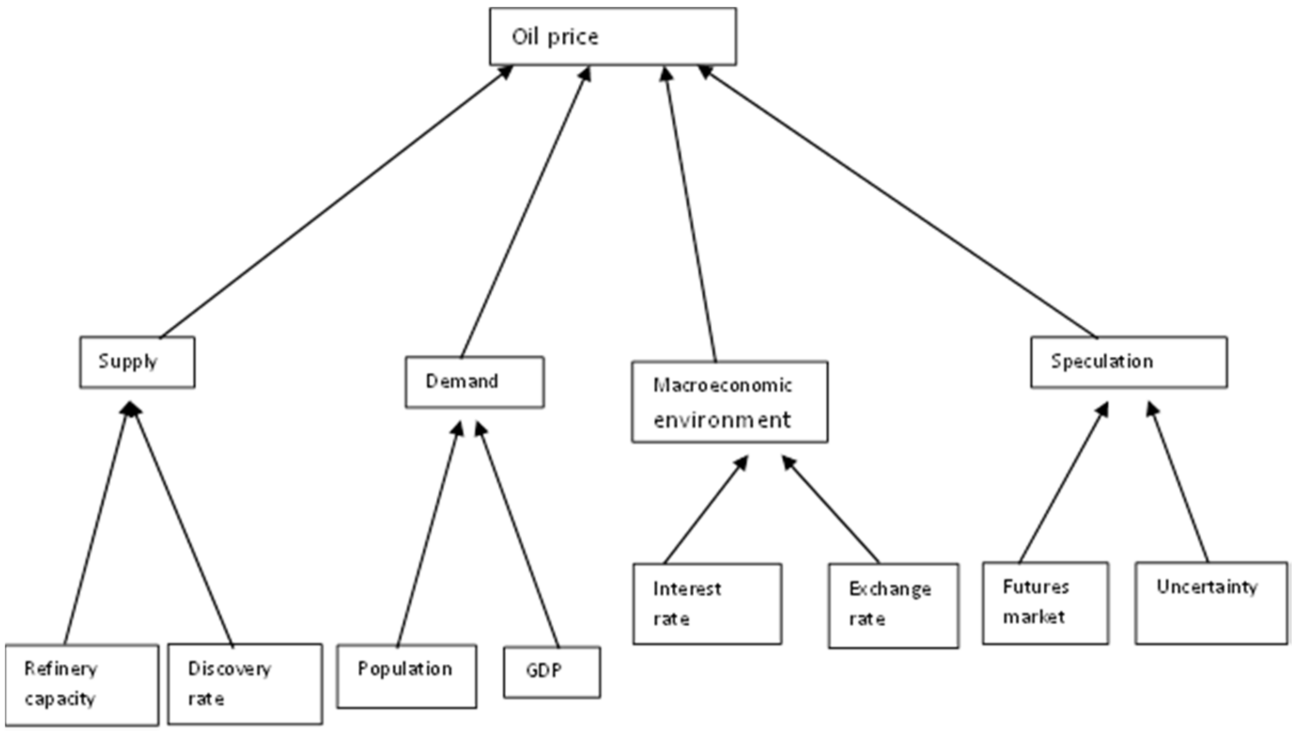
Source: http://www.ft.com/cms/s/0/ff0abf58-750d-11e1-a98b-00144feab49a.html

Birol warns that every recession in industrialised countries since World War II was preceded by an oil price spike. Saudi Arabia has pledged to increase production and exports to make up for the shortfall from Iran. But this will affect spare production capacity. After the global financial crisis recession, an energy market-driven recession could represent a dangerous risk for developing countries' economies.

2.2 Energy price shock determinants

Many factors explain energy price levels. In this work, we synthesise the main determinants on the basis of the scheme represented in Figure 5. We do not aim to present an exhaustive discussion of all oil price determinants but rather to provide an overview that is useful in understanding recent trends and possible future paths.

Figure 5: Synthesis of the main transmission channels from determinants to oil price levels



Note: This figure does not intend to discuss the causal relationship between energy prices and other macroeconomic variables but summarises oil price determinants as discussed in the next paragraphs.

2.2.1 Fundamentals

One of the most common explanations offered for the recent energy price increase is the disequilibrium between global oil supply and demand. According to Kilian (2009), the sharp price increase in 2007–8 can be explained by the combination of increased demand and stagnant supply. The increase in oil demand is linked mainly to the fast growth of emerging economies such as China and India. Although China has been growing at a fast rate for 25 years, only in the past decade has the size of the economy become large enough to influence the oil global market significantly. The relevance of changes in demand is thus particular to the 2007–8 shock, as previous oil shocks were caused mainly by physical disruptions of oil supply (Hamilton, 2009; Kesicki, 2010).

The main theoretical question underlying this explanation for the oil price shock is the relative sensitivity of oil demand to changes in income and in price. Several studies have pointed out that the main determinant of oil demand is income, and thus a rapid growth in income levels of very large countries would lead to a significant increase in global demand (Baumeister and Peersman, 2009; Kesicki, 2010; Smith, 2009). The change in the shares of each region in global income accelerates this effect, as oil demand shifts towards regions that are faster growing and less price responsive (Dargay and Gately, 2010).

The fast growth in global demand has not been met by an equivalent trend in global supply, as resource depletion has kept an upward pressure on costs and investment in supply has lagged behind. The disequilibrium between supply and demand leading to the 2007–8 shock can then be linked to short-run rigidities and stagnation in oil supply. Some authors also draw attention to the role of forecasting errors (Kilian and Hicks, 2009). The strength of economic growth in large emerging economies was to some extent unexpected and surprised the markets, leading to the 2008 oil price shock.

These hypotheses also apply to the steep decline in oil prices that followed the 2008 peak, which is linked to a substantial and unexpected decrease in demand following the global recession and the decline in economic growth in China and other emerging countries (Smith, 2009; Kilian and Hicks, 2009). In the same vein, the price rebound in 2009 is linked to the economic recovery of those countries.

However, this explanation is not universally accepted and does not provide a complete account. For example, Gallo et al. (2010) argue that oil consumption is growing in some countries but is stationary in others. The growth in demand from China and non-Organisation for Economic Co-operation and Development (OECD) countries is balanced partly by declines in demand from Europe, Japan and the US. The authors find that supply variables determine oil prices, which in turn determine oil demand.

Theories that focus on the effects of imbalances between supply and demand also fail to take into account the role inventories play. If short-term inventory stocks are low, shocks to demand or supply have a more dramatic effect on oil prices. In addition, if we assume that crude oil inventories are predetermined, then the demand for them also affects oil prices (Alquist and Lutz, 2010).

Drollas (2012) points out that, in the short term, the physical price of oil is explained mainly by stock disequilibrium. This is the disequilibrium between the stocks people want to hold and the stocks they are actually holding. In addition to the physical market, there is a financial market that buys and sells oil futures. The physical market is linked to the financial futures market, through expectations of prices. The forward curve affects the spot price through 'cash-and-carry' hedging. For example, a refinery looks at the spot price and the futures price and, if the futures price is higher than the spot price, this entices them to buy physical oil at the spot price and sell futures forward to lock in a margin.

Demand factors play a relevant role, especially in the medium to long term. As Stefanski (2011) and the last UN Industrial Development Organization (UNIDO) Industrial Development Report (2011) emphasise, low- and middle-income countries tend to spend a higher fraction of GDP and to be more oil intensive than rich countries. But when income grows, they tend to reduce energy intensity at a first stage by increasing energy efficiency; at higher levels of GDP, they go through structural transformation towards less energy-intensive sectors.

Finally, geopolitical events also have an influence on oil prices, owing to the effects on expectations of future disruption in oil supply. Uncertainty about these effects can also contribute to competition in financial markets, leading to further price increases. Overall, geopolitical tension in oil-producing countries may affect oil prices by a third for one to two years (te Velde, 2007). Speculation about a possible military action against Iran may have contributed to the oil price shocks in 2007–8.

2.2.2 Macroeconomic environment

An additional explanation for the recent oil shocks stresses the role of macroeconomic factors, such as variables related to the economies of the US or other key countries. Analysing the period 1990–2007, Akram (2009) found that shocks in oil prices relate to decreases in interest rates and in the value of the US dollar. This is based on the assumption that prices in commodity markets (such as oil) tend to be efficient. A decline in the nominal interest rate would increase the attractiveness of investments in the oil market, comparing with the financial market, and then increase demand. At the same time, it would lower supply as it becomes less profitable to extract exhaustible resources and invest the proceeds in financial markets. As crude oil is mainly priced in US dollars, a depreciation of this currency leads to lower prices in other currencies, increasing demand and decreasing supply.

These hypotheses are consistent with the results of Krichene (2008), who argues that there was no specific oil shock in the period 2003–7, but instead a simultaneous increase in all commodities prices, including oil. This is linked to an expansionary monetary policy in key developed countries and the depreciation of the US dollar.

However, the role of macroeconomic variables is not certain, and methodological caveats may apply. For example, Anzuini et al. (2010) found that the relationship between oil prices and US expansionary monetary policy becomes considerably less strong when including interest rates in a broader measure of monetary policy. Kilian and Vega (2011) also suggest that oil prices, unlike financial asset prices, do not respond instantaneously to news about US macroeconomic conditions.

There are also relevant aspects to notice regarding the role of the US dollar exchange rate. He et al. (2010) confirm the role of the exchange rate in the determination of oil prices, but place it alongside a more important explanatory variable measuring global economic activity. The exchange rate is also included in Zaklan et al.'s (2010) study of the dynamics of global crude oil production, which points to a considerable time lag between changes in the two variables.

2.2.3 Speculation

A more controversial aspect regards the role of speculation in the volatility of oil markets. A series of studies claims that speculation has amplified the price surge initiated by the disequilibrium between demand and supply. For example, Kaufmann and Ullman (2009) and Singleton (2010) tested causality between oil spot and futures market prices. The evidence of causality from futures to spot prices supports the hypothesis of speculation in the 2007–8 price surge. Kaufman (2001) also argues for the role of speculation based on the statistical and predictive failures of models of oil prices based on market fundamentals when analysing both the price spike and the subsequent collapse. Other authors argue that the role of speculation also derives from the climate of uncertainty regarding real levels of demand and supply in years before shocks. For example, Sornette et al. (2009) draw attention to the link between speculative behaviour and discrepancies in official figures on oil supply and demand issued by different governmental organisations.

The hypothesis of speculation does not always hold when we analyse the price surge alongside its subsequent decline. Einloth (2009) found that, while speculation played a role in the price increase up to mid-2008, the collapse owed mainly to an unanticipated decline in demand, with a less important role played by speculators unloading their positions. This suggests that the recovery of the global economy may have led to a second rise in oil prices. This hypothesis is confirmed by the evolution of prices post-2009. The role of speculation during the 2003–8 price surge can also be compared with previous oil shock episodes, in 1979, 1986 and 1990 (Kilian and Murphy 2010), where the evidence of speculative demand shifts is more significant.

Other arguments cast doubt on the validity of the theory of speculative behaviour. Irwin et al. (2009) show that the increase in oil prices was not created by a 'bubble' over fundamental prices, whereas Parsons (2010) argues that the oil price spike was a bubble created by the investors' rational beliefs and not by price manipulation strategies. Alquist and Gervais (2011) also state that, during the 2007–8 period, evidence shows that oil prices predict financial firms' positions and not the opposite

2.3 The impact of energy price on net oil-exporting countries

2.3.1 Economic growth versus fiscal policy

The volatility of oil prices affects the majority of the oil-producing developing economies, given their dependence on oil exports. Empirical studies of the causality mechanisms between oil prices and macroeconomic variables show that real GDP and unemployment rates tend to be linked to short-term changes in oil prices, with the increase in oil prices associated with a positive impact on the country's economy and the decrease with a decrease. These results have been obtained for a variety of countries, such as Nigeria (Umar and Abdulhakeem, 2010), Iran (Farzanegan and Markwardt, 2009), Malaysia and Indonesia (Chang et al., 2011), and net oil-exporting countries in the Middle East and North Africa (Berument et al., 2011).

The nature of the effects of oil price changes may be less clear in the case of small open oil-exporting countries, especially when considering longer periods. For example, testing the effects of oil price shocks on the economy of Trinidad and Tobago, Lorde et al. (2009) show that a positive oil price shock leads to a reduction in output within the first two years, followed by a an increase. The initial reduction is explained mainly by a short-term contractionary effect vis-à-vis the small economy's trading partners, whereas the increase is linked to increases in investment and government consumption. This study proves that, while output is related to price volatility, the nature of the relationship and the time lag between causes and effects are not easily predictable. The output of a small open oil-exporting economy can react positively or negatively to price increases and with various time lags. Shocks to price volatility may also have different macroeconomic impacts than shocks on prices themselves.

Collier and Goderis (2008) stress the necessity of distinguishing between the short- and long-term effects of oil price shocks. They suggest that high-rent, non-agricultural commodities (such as oil) have positive short-term effects on output, but adverse long-term effects. This pattern is known as the 'resource curse', and can be explained by real exchange rate appreciation ('Dutch disease'), public and private consumption and institutional failures.

One of the main mechanisms of transmission of changes in international oil price changes to net oil-exporting countries' economies is through impacts on government revenue and expenditure, as in many of these countries oil revenues accrue to the government. Villafuerte and Lopez-Murphy (2010) found that, in a group of net oil-exporting countries, government revenue and expenditure increased in 2003–8 and decreased when oil prices started declining in 2009. On average, government budgets in these countries improved significantly in the first period. However, low-income countries continued to run deficits. This result is not explained by different degrees of oil revenue dependency, but by differences in expenditure patterns, with low-income countries responding to oil price increases by increasing expenditure as a percentage of non-oil GDP. These trends were reversed during the 2009 downturn, with government budgets generally deteriorating, but much less dramatically in low-income countries. Fiscal policy has therefore been procyclical, intensifying the fluctuations in economic activity brought about by changes in oil prices. Furthermore, the degree of procyclicality is related negatively to countries' income levels. Procyclicality also seems to be a feature of net oil-exporting countries' economies when analysing longer periods of time, as confirmed by Sturm et al. (2009), who focused on the period 1965–2005.

Public policy may also be a mechanism of transmission of exogenous oil shocks to domestic economic performance when public investment crowds out private investment. In fact, oil price increases can lead to a reallocation of resources from the private to the public sector. According to Cologni and Manera (2011), market distortions created by this reallocation mean the negative effects of oil price increases on private sector output and employment levels are not compensated for by positive effects in the public sector.

Finally, fiscal policy is linked to asymmetry in the effects of oil price shocks. In a study of six major net oil-exporting developing countries, Moshiri and Banihashem (2011) show that a reduction in oil prices leads to economic stagnation in four countries, but that an increase does not lead to sustained economic growth in any country. In addition, the impacts of positive and negative oil shocks follow different paths of transmission. These results are explained not only by the procyclical character of fiscal policy but also by factors such as spending beyond the economy's absorption capacity, the impossibility of reverting some of the public expenditures made during the period of price increases and poor management and rent-seeking behaviour in the allocation of increased revenues. Government projects are therefore not sustainable in the long term and may be left unfinished when oil prices stabilise, failing to contribute to economic growth.

2.3.2 Inflation versus monetary policy

The increase in oil prices up to 2008 led to inflationary pressures in many developing economies. These pressures were especially severe in net oil-exporting countries. In the period 2003–7, the inflation rate in these countries was always higher and more volatile than in other countries, whereas in 2007–8, the growth in inflation was also considerably higher (Habermeier et al., 2009). However, this is not explained by a higher share of fuel in aggregate consumption in oil-exporting countries, but by the propensity of these countries to apply expansionary fiscal policies.

The sensitivity of each country to inflation pressures derived from the oil shock also depends on the exchange rate regime. Inflation pressures were particularly marked in countries with soft exchange pegs, where monetary policy was subject to the aim of maintaining the exchange rate target (Habermeier et al., 2009).

There are concerns over the suitability of developing countries' monetary policy to controlling inflationary pressures that derive from exogenous shocks. A study by Allegret and Benkhodjay (2011) for the period 1990–2010 in Algeria concludes that, in order to stabilise output and inflation, monetary policy should focus on a core inflation target. This implies structural changes to the financial sector and financial regulation institutions, in order to strengthen the role of the interest rate as a transmission channel for monetary policy.

2.4 The impact of energy price on net oil-importing countries

2.4.1 Economic growth

Oil price shocks tend to have significant effects on the macroeconomic variables of net oil-importing developing countries, including economic growth, employment, balance of payments and government accounts. However, the mechanisms of transmission differ from those in net oil-exporting countries. The empirical study of these mechanisms also points to the relevance of distinguishing between short- and long-term effects.

GDP growth decreased in most net oil-importing developing countries in 2008 and 2009 (Green et al., 2010), and recovered slightly after oil prices started to decrease. The fact that growth rates did not fully recover after the decrease is consistent with the hypothesis that energy price shocks usually have an asymmetric effect: the reduction in GDP when oil prices rise is higher than the increase in GDP when oil prices fall (Hamilton, 2003). This asymmetry is confirmed in a recent study of the Taiwanese economy (Yeh et al., in press).

The effects of oil price increases on economic growth reflect reductions in output in most economic activities. Manufacturing and transportation are especially affected by the increase in costs, and indirectly as a result of the reduction in and unreliability of energy supply. Empirical studies have confirmed the link between oil shocks and economic growth in many countries, although results are stronger for longer time horizons or when the oil price increases are permanent (Mohaddes and Raissi, 2011; Tang et al., 2010; Trung and Vinh, 2011; Twimukye and Matovu, 2009). The origin of the oil price shock may also be relevant for the significance or magnitude of the effect on oil-importing countries. Berument et al. (2010) show that, in some oil-importing countries, supply shocks lead to negative impacts on output, but demand shocks lead to positive impacts. This is explained by the fact that oil demand grows simultaneously with demand for other goods, including those exported by such countries.

The reduction in domestic output in net oil-importing countries also reflects the effects of lower purchasing power on domestic demand. However, we should notice that part of the greater revenue accruing to net oil-exporting countries may be recycled in the form of imports or other international flows, which contributes to keeping up demand in net oil-importing countries (Rasmussen and Roitman, 2011).

Energy shocks also have an impact on employment levels, as weaker economic growth decreases labour demand. However, employment can rise in the long term, if firms respond to energy price increases by substituting energy for labour as factors of production (Dogrul and Soytas 2010).

Oil price shocks also affect stock markets, given the reduction in profits of non-oil exporting firms. Ono (2011) shows that changes in oil prices have a significant impact on real stock returns of large emerging countries such as China, India and Russia. Ono also found evidence of asymmetric effects of oil price increases and decreases in India.

Finally, oil price shocks have an effect on the competitiveness of net oil-importing developing countries. Torres-Zorrilla and Guillén (2009) reveal that energy inputs are the most important cost for industries in three Latin American countries and that oil price increases lead to substantial increases in energy costs, with effects on the competitiveness of these countries. Alaimo and Lopes (2008) also found that the increase in oil prices led to a reduction in oil intensity in the economies of OECD countries but not in Latin American economies. These results have implications not only for competitiveness but also for the environmental sustainability of the latter countries, as they show that high-income countries are more successful in substituting oil from renewable energy sources.

2.4.2 Inflation

Oil price shocks also affect price and inflation in net oil-importing countries. Many developing countries have faced particularly strong inflation pressures since 2007, as a result of their large consumption shares of food and fuel products. Habermeier et al. (2009) report that inflation in developing countries is linked to a combination of international oil price increases and domestic demand pressures. The initial fuel and food price shock in 2008 was followed by second-round effects across the economy, although inflationary pressures eased when oil prices declined after mid-2008.

The impact on inflation depends on the degree of price transmission from energy to non-energy commodities. In an analysis of the 1960–2008 period using world data, Baffes (2009) found that transmission is higher for commodities related to primary activities such as fertilisers, precious metals, food and metals and minerals. There is also strong evidence of a link between energy and non-energy prices following the 2006–08 commodity price boom, especially in the case of food prices (Baffes and Haniotis, 2010). The transmission to food prices was especially marked in countries linked to world markets (Abbott and de Battisti 2009). This is the case for Thailand, for example, where the degree of transmission from international oil prices to domestic food prices was considerably higher than in neighbouring countries that apply stricter policies to control domestic prices (Downes, 2007; Keats et al., 2010).

Oil price shocks lead to increases in food prices resulting from effects on the costs of food production, such as oil-derived fertiliser and freight costs. However, the food industry also faces increased competition for inputs. This is because the increase in oil prices provides an incentive for agriculture and manufacturing to replace oil with biofuels, which use crops such as cereals and sugar cane (Mondi et al., 2011).

2.4.3 Balance of payments

Oil shocks affect the terms of trade, by changing the ratio between the value of imports and exports, with repercussions on countries' balance of payments. The rise in oil prices in 2007–8 indeed weakened the balance of payments of net oil-importing developing countries. One study (IMF, 2008) shows that the balance of payments impact of oil price increases in this period was four times as large as that of food prices, which reflects the higher share of fuel in total imports.

Deterioration in the balance of payments has effects on economic growth, although some countries are successful at absorbing shocks (Funke et al., 2008). These effects tend to be more acute in small countries dependent on oil imports and with a limited export base and low reserves, as the trade deficits linked to oil price increases have to be financed by foreign exchange reserves, which limits the scope for investment in machinery and equipment, thus affecting economic growth (Jayaraman and Lau, 2011). It should be noticed that the effects of oil shocks on the balance of payments of oil-importing countries are not necessarily negative. A study by Kilian et al. (2007) for the period 1975–2004 found that the transmission of oil shocks in middle-income economies in Latin America and Asia depended on the non-oil trade balance. While the oil trade balance falls after shocks that raise the price of oil, the non-oil trade balance may improve or deteriorate depending on the shock. The effect of an oil supply disruption tends to be negative, whereas the effect of a positive aggregate demand shock tends to be positive. The long-term effects of oil shocks may also follow a distinctive pattern. According to Schubert (2009), in small open economies, the negative effect of oil shocks in the balance of payments occurs only in the short term and owes to reluctance by consumers to reduce their expenditures. Over time, consumption falls and the economy may ultimately end up with a higher stock of foreign assets (the 'J curve' effect).

2.4.4 Vulnerability

Kojima (2011) calculates the vulnerability of world countries to oil price rises. The vulnerability index is expressed as the percentage of GDP used to purchase oil. Kojima finds that, from 2003 to 2008, the number of low-income countries more vulnerable to oil price increases shifted from 22 to 59; in Africa, the number went from 17 to 50. The top 10 most vulnerable countries belong to the low- and lower-middle-income category

Table 2: Oil Vulnerability index for world countries

	Region						Income			
	Africa	EAP	ECA	LAC	MNA	SAR	Low-	Lower-middle	Upper-middle	High-
No. of countries	42	17	17	28	9	7	32	43	41	42
V in 2003 >5%	17	18	18	21	22	14	22	16	20	0
V in 2008 >5%	50	59	47	64	33	57	59	53	54	7

Note: **158 countries, 109 oil producers.**

Source: *Kojima (2011).*

Table 3: The top 10 most vulnerable countries to oil price

Country	Income	Vulnerability index		
		2003	2008	Difference
Seychelles	Upper-middle	8.3	25.0	+ 17
Jamaica	Upper-middle	8.0	20.0	+12
Liberia	Low-	8.9	19.0	+10
Guyana	Lower-middle	16.0	18.0	+2.5
Nicaragua	Lower-middle	6.7	17.0	+10
Maldives	Lower-middle	11.0	16.0	+5.7
Fiji	Upper-middle	7.2	16.0	+8.7
Sierra Leone	Low-	7.0	15.0	+8.4
Jordan	Lower-middle	11.0	15.0	+3.8
Tonga	Lower-middle	4.0	13.0	+9.3

Source: *Kojima (2011).*

Guillaumont (2010) suggests that the vulnerability of developing countries to external shocks depends on factors such as population size, remoteness, export concentration and share taken up by the primary sector. The most vulnerable countries include least-developed countries (LDCs) and small island developing states (SIDS). In the case of oil price shocks, the Pacific island countries are in a particular vulnerable position because of their geographic location and economic structure (Levantis, 2008). The economy of these countries relies on fishing and tourism, which are fuel-intensive activities. The aggregate consumption of fuel is also high, owing to the need to transport commodities to the various internal markets.

More generally, open energy-importing developing economies are vulnerable to energy price shocks. Aydin and Acar (2010) study this hypothesis for Turkey, simulating the long-term effects of oil price shocks for different price scenarios. The results show there are substantial effects on several macroeconomic variables, including GDP, inflation, indirect tax revenues, the trade balance and carbon emissions.

In another simulation, Schubert and Turnovsky (2011) found that the impacts of oil price shocks on small net oil-importing developing economies depend mostly on the country's production structure and flexibility. The impacts are stronger in countries with a higher share of oil to labour in total output and with lower elasticity of substitution in production. These results are consistent with those of Alom (2011), who concludes that the effects of international oil price shocks tend to be higher in resource-poor countries that specialise in energy-intensive industries such as heavy manufacturing.

It should be noticed that, while smaller countries are more vulnerable to oil shocks, these shocks also affect larger countries. For example, Du et al. (2010) show that world oil prices affect economic growth and inflation in China, but even after the rapid increase in the share of China in global GDP in recent years, economic activity in China does not seem to affect oil prices[2].

The factors explaining China's vulnerability to disturbance in oil imports were the object of analysis by Gnansounou and Dong (2010) and Tang et al. (2010) and are linked to the structure of the economy and the energy profile of households and businesses. The effects of oil price fluctuations in large countries such as China and India are difficult to measure, however, and evidence on causality mechanisms should be approached with caution (Chang et al., 2011).

2.4.5 Distributional effects

Because of their effect on employment and on food and transport prices, oil price shocks also have important distributional impacts within each country. Estimates from several institutions show that the global Triple F (financial, food and fuel) crisis in 2008–9 is responsible for an increase of between 75 and 130 million in the world population under the extreme poverty line (FAO, 2008; World Bank, 2008; WFP, 2008). Evidence shows that the recent energy price shocks have increased food insecurity (Headey, 2009) and poverty levels in developing countries (Poveda and Martínez, 2011; Twimukye and Matovu, 2009). However, some segments of the population have a higher degree of vulnerability to these shocks, including the poor, the landless, informal sector workers and female-headed households.

Evidence from household surveys in several countries shows that oil price shocks tend to have a stronger effect on poorer households, as a higher proportion of their expenditure goes on oil products (te Velde, 2007). For example, in the case of Iran, Pakistan and Yemen, the impact of a fuel price increase was found to be higher for households in the poorest quartiles of income distribution (UNDP and ESMAP, 2005). That result is valid even for transport fuels, even though the poorest households do not own their own vehicles.

Baker (2008) and Cohen and Garrett (2010) argue that the urban poor are particularly exposed to price shocks given their greater reliance on cash income and jobs in the informal sector, limited access to agriculture and vulnerability to changes in the price of food and essential urban services such as transport. In peri-urban areas, higher fuel prices may also force poor households to increase the use of biomass, with consequences in terms of levels of indoor air pollution. Ruel et al. (2010) review studies of the effects of the 2007–8 crisis on poverty and food insecurity and conclude that, while the urban poor are clearly one of the most affected groups, the focus of public policies and international aid should be on the poorest of the poor, irrespective of country or the urban or rural area in which they live.

Hossain et al. (2009) and Heltberg et al. (2012) outline informal sector workers' sources of vulnerability of the 2008 crisis. Reports from several countries suggest that this sector has absorbed some of the impact of the crisis on unemployment, as a consequence of job losses in other sectors. However, increased competition within the informal sector has driven down profits. Workers moving to the

2 The conclusion of the Du et al. study seems to contradict the conclusion of Kilian (2009) mentioned in Section 2.2.1 claiming that China's market expansion influences oil prices.

informal sector have also met with problems such as a lack of capital, poor access to inputs and lack of support from government. In most cases, the shift has also implied a loss of income and reduced access to social protection measures.

Job losses linked to energy price increases may also have a disproportionate impact on women, given high rates of informal and casual employment. Miller-Dawkins et al. (2010) report on the case of Indonesia, where large number of women in the export-oriented industries have either lost their jobs or had their working hours reduced during the global economic crisis of 2008–9. Women-headed households also bore a disproportionate share of the effects of the food price crisis, both as producers and as consumers (Holmes et al., 2009). Jones et al. (2009) show that the Triple F crisis also had severe implications in terms of child mortality in the Middle East and North Africa region.

2.4.6 Policy responses

National governments reacted in varied ways to the energy price shock and the related food price and financial crises, including through fiscal policy to stimulate the economy or shield consumers from price increases, monetary policies and social policies. Kojima (2009) summarises a series of policies strictly related to energy sector management implemented by countries to reduce oil prices.

Table 4: Policy responses to oil price shocks

Energy conservation	The governments of Chile and the Philippines mandated energy use reduction with quantitative targets for government agencies. Ghana and Rwanda distributed compact fluorescent lamps to replace incandescent light bulbs.
Diversification	Efforts to diversify away from oil intensified when oil prices were rising. Argentina, Colombia, India, Indonesia, Peru and the Philippines introduced new biofuel blending mandates.
Strategic petroleum reserves	The Chinese government took advantage of low oil price periods to fill emergency oil tanks in four sites. India plans to establish reserves in three sites by 2012. Kenya, Rwanda, Tanzania, Uganda, Yemen and Zambia are all pursuing strategic oil stockpiling.
Hedging	Sri Lanka is the only country that has pursued hedging on a large scale. Hedging went well until oil prices began to collapse in September 2008, with Sri Lanka incurring very large losses.
Assistance from net oil exporters	Several governments obtained cash assistance from net oil exporters. Others managed to negotiate large discounts, such as Jordan with Iraq. The largest regional deal is managed by Venezuela, which sells oil and oil products under concessionary terms to 18 members of PetroCaribe.

Source: Kojima (2009).

Public spending increased in most developing countries following the initial energy price shocks. While expenditures in infrastructure and job creation aim to stimulate the economy, in some cases the investment has been large scale and not targeted at vulnerable groups or adjusted to local needs (Green et al., 2010).

There has also been a tendency to shield domestic consumers through oil subsidies, explicit or implicit in controls on retail prices or reductions in fuel taxes (Baig et al., 2007; Jha et al., 2009). While this strategy has reduced the transmission of international energy shocks to domestic prices, it has also contributed to the deterioration of fiscal deficits (IMF, 2008). The application of fuel price subsidies in developing countries also tends to distort prices and have a pro-rich bias, as higher-income households consume relatively more fuel than lower-income households (Coady et al., 2006; El Said and Leigh, 2006; Kpodar, 2006). Finally, in a scenario of long-term increase of international oil prices, oil subsidies will also undermine the sustainability of public debt, imply restrictions on other public expenditures (Jha et al., 2009) and undermine growth performance (Chitiga et al., 2012). This explains why in many countries the level of subsidies was reduced as oil prices continued to grow beyond what had initially been anticipated.

Most developing countries have also responded to inflationary pressures by tightening their monetary policy. In a review of several developing countries, Habermeier et al. (2009) found considerable variation in the timing and speed of this response. The tightening of monetary policy started earlier in countries exposed to world markets and highly dependent on oil, such as the Philippines, Singapore and Thailand (Downes, 2007). Transmission of monetary policy in developing countries is also constrained by a lack of development of financial markets and by rigid exchange rates. Exchange rate policy itself has also played a role in containing inflationary pressures: the nominal exchange rate appreciation in the set of countries analysed by Habermeier et al. correlates negatively with accumulated inflation in the period 2007–mid 2008.

Social policy has also faced a series of constraints. While governments in some countries, especially in South-East Asia, have made efforts to introduce new forms of social protection, in general the response in most countries has been to apply discretionary spending, given the inadequacy of existing social welfare systems. In general, the groups most affected by the crisis have relied on their families and social networks and not on formal institutions (Green et al., 2010). The range of government responses to food price increases has also been limited, as social protection policies in developing countries tend to be costly and are often poorly targeted (Ackello-Ogutu, 2011).

2.5 The impact of energy price changes on renewable energy

A change in the oil price will also affect the future path of renewable energy production and exports. As emphasised by the forthcoming European Report on Development, renewable energy is often not a cost-competitive option compared with fossil fuel sources of energy, even though the gap is shrinking over time and in some remote areas in developing countries decentralised grids for renewable energy are already cheaper than fossil fuels.

Some studies have also been able to quantify the impact of oil prices on renewable energy expansion. Timilsina et al. (2011) use a global CGE model to analyse the impact of oil prices on biofuel expansion. They show that a 65% increase in the oil price in 2020 on the 2009 level would increase global biofuels penetration to 5.4% in 2020, from 2.4% in 2009. A doubling of oil prices in 2020 from the baseline level, or a 230% increase on the 2009 level, would increase global biofuel penetration in 2020 to 12.6%.

Calculations on the penetration of biofuels depend strongly on the assumption of substitutability across fossil fuel sources of energy and oil. Timilsina et al. (2011) show that, assuming a doubling of the oil price, the penetration increase of biofuels may vary from 4% to 24% when changing assumptions about input substitutability.

Wiggins et al. (2011) show that, with an oil price of at least $90 a barrel, the production of sugar cane for biofuels would be the most profitable solution for East African countries as compared with other food crops. A lower oil price could reduce demand for biofuels, profitability of biofuel projects and participation of African farmers in this business.

The production costs of renewables also depend on learning by doing effects, by which early and massive production of alternative sources of energy help to reduce quickly production costs over time (van der Zwaan et al., 2002). Therefore, a positive consequence of high oil prices could be a rapid transition towards a decarbonised energy mix.

3. Modelling the impact of oil price changes on developing countries

3.1. Using the GTAP E model to analyse the impact of oil price changes

We use a CGE model to analyse the impact of an oil price doubling on developing country economies. The transmission mechanisms from oil price determinants to oil prices and finally to developing countries are complex. CGE models help to express such complex relationships in a stylised way.

For example, Aydin and Acar (2011) examine the impact of oil price changes on the Turkish economy using a CGE model. They find that high oil prices will have harmful effects through a reduction in output and consumption and by worsening Turkey's net foreign asset position. Cumulative output losses over the 10-year projection period resulting from a 121% increase in oil prices can be as large as 14%. Cumulative inflation (as measured by the consumer price index) may be nearly 5% under a fixed exchange rate regime.

Fan et al. (2007) implement a similar simulation for China. They simulate the impact on the Chinese economy of various oil price changes between 5% and 100%. The simulations identify the effects of low/medium/high technological advances in the crude oil mining, petroleum and chemical and transportation sectors in terms of addressing the risks of oil price shocks. The results indicate that an increase in the price of crude oil has negative effects on Chinese real GDP, investment, consumption, import and export, among a range of economic indices.

However, the literature lacks contributions with sufficient detail of impact on a range of developing countries. This paper helps policymakers understand vulnerability to price shocks. We use a new version of the established GTAP model, the GTAP E model. GTAP E enriches GTAP as it includes energy and environment equations. In particular, we adopt the version implemented by Antimiani et al. (2011), containing updated data.[3] This version is also further modified to incorporate major details on the regional aggregation with greater detail for African countries.[4]

3.2 Baseline scenario and the doubling of oil prices scenario

To prepare for the various model scenarios, we use an aggregation into 21 sectors and 34 regions. With regard to regional aggregation, we considered a 'Full Kyoto' framework, with 11 Annex I countries/regions plus a full disaggregation of Africa countries, in order to deal with the impact of crude oil price changes on developing countries[5] (see Table 5). In addition to the energy sectors, such as coal, crude oil, gas,[6] refined oil products and electricity, we singled out energy-intensive sectors (e.g. cement, paper, steel and aluminium). The model has been updated to incorporate 2012 data.[7]

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3 First of all, some substitution elasticities – namely, the substitution elasticity between the capital energy composite and other endowments and that between capital and energy in all the nests related to the energy composite – were replaced by those proposed by Beckman and Hertel (2010). Second, modellers updated the GTAP Database Version 7.1 (base year 2004) to calculate 2012 data.

4 For a description of the model, see the Appendix.

5 The calibration of GTAP E of the oil sector is not precise, as the model assumes oil endowments in some African countries where oil reserves do not exist. We correct this bias by assuming in the oil price doubling simulation the elimination of oil production for those African countries where the data calibration is wrong.

6 The gas sector in the present aggregation includes the natural gas extraction and gas manufacture and distribution sector.

7 Further details are contained in the Appendix.

Table 5: Sectors and regions in the GTAP E version used in this report

	Regions		Sectors
1	EU	1	Agriculture
2	Croatia	2	Coal
3	USA	3	Oil
4	Canada	4	Gas
5	Japan	5	Oil_pcts
6	Australia	6	Electricity
7	NewZealand	7	Min_Pcts
8	Swiss	8	Che_Rub_Pla
9	Norway	9	Electr_equip
10	FSU	10	Transp_equip
11	Belarus	11	Machinery_eq
12	RESTofEUROPE	12	Motorvehicl
13	ENEEXP (energy exporter)	13	Met_Pcts
14	SouthAfrica	14	Food_ind
15	Mexico	15	Pap_Pcts
16	Brazil	16	Text_Leather
17	China	17	Oth_Manufact
18	India	18	Transport
19	RestofASIA	19	Sea_Transp
20	Morocco	20	Air_Transp
21	Tunisia	21	Services
22	Senegal		
23	Ethiopia		Endowments
24	Madagascar	1	Land
25	Malawi	2	Lab
26	Mauritius	3	Capital
27	Mozambique	4	NatRes
28	Tanzania		
29	Uganda		
30	Zambia		
31	Zimbabwe		
32	Botswana		
33	RestofAFRICA		
34	RestofAMERICA		

We simulate the economic impact of a doubling of the crude oil price in 2012 and assess short-term economic consequences that are coherent with the static GTAP E model framework. Since GTAP E is a CGE model, where prices are relative, we do not simulate a specific level change (i.e. we do not know the 'level' price in 2012), but a change in the relative 'terms'. In other words, we shock the crude oil price by 100%, which means the opportunity cost of crude oil is worsened compared with other inputs (and vice versa for the crude oil seller). The model also does not capture dynamic effects such as the budget-sharing decision between consumption and investment, and does not incorporate expectations.

3.3 The results

This section presents the main results of the analysis. For reasons of brevity we focus on just three main impact areas:

1) Consequences of the oil price shock on welfare and real GDP, to identify the countries most vulnerable to oil price shocks;
2) The components of welfare changes on the basis of welfare decomposition techniques;
3) These effects in relation to African economies.

Table 6: Impact of a doubling of the oil price on countries and regions

	Total welfare (US$ million)	Allocative efficiency (US$ million)	Financial component (US$ million)	Terms of trade (US$ million)	% of oil imports
EU	-204,915	-125,267	-7,995	-71,653	87.9
Croatia	-2,199	-1,221	-408	-570	85.19
US	-148,184	-38,868	-39,274	-70,042	66.33
Canada	-585	-4,788	873	3,330	29.7
Japan	-58,090	-20,199	4993	-42,884	99.59
Australia	-6,435	-3,237	-1,187	-2,011	41.45
New Zealand	-1,634	-428	165	-1,371	80.81
Switzerland	-3,767	-2,188	1040	-2,619	99.66
Norway	21,180	-1,157	431	21,906	0.37
Former Soviet Union	43,873	-9,327	4,136	49,064	12.12
Belarus	-2,491	-125	-389	-1,977	92.01
Rest of Europe	-13,984	-5,012	-3114	-5,858	88.19
ENEXP*	218,366	-14,219	12,411	220,174	4.69
South Africa	-5,142	-994	126	-4,274	99.66
Mexico	1,610	-11,109	665	12,054	0.01
Brazil	-6,887	-4,351	2,705	-5,241	24.96
China	-13,704	-1,733	21,955	-33,926	40.68
India	-19,620	-6,252	-3,130	-10,238	80.07
Rest of Asia	-62,314	-17,815	9,702	-54,201	95.5
Morocco	-1,605	-183	-292	-1,130	99.68
Tunisia	-253	-113	-211	71	27.78
Senegal	-562	-124	-256	-182	99.55
Ethiopia	-577	-94	-208	-275	0
Madagascar	228	-1	13	216	0
Malawi	-66	-10	-38	-18	0
Mauritius	-121	-30	-5	-86	0
Mozambique	-134	-24	-21	-89	0
Tanzania	-265	-18	-90	-157	0
Uganda	-142	-9	-12	-121	6.67
Zambia	-167	-46	-12	-109	100
Zimbabwe	-92	2	-23	-71	0
Botswana	-54	-1	40	-93	0
Rest of Africa	2,038	-314	-1,081	3,433	25.17
Rest of America	-12,442	-4,541	-1,784	-6,117	68.07

Note: * The energy exporters group includes Indonesia, Malaysia, Argentina, Bolivia, Colombia, Ecuador, Venezuela, Kazakhstan, Other Former Soviet Union countries, Azerbaijan, Iran, Rest of Western Asia, Egypt, Rest of North Africa, Nigeria, Central Africa and South Central Africa.

Welfare effects are decomposed into a terms of trade effect, an allocative efficiency effect and a financial component.[8] The terms of trade effect is represented by the difference export/import values, whereas the allocative efficiency effect represents those variations determined by a shift of resources towards more productive sectors as a consequence of oil price doubling. Under an oil price increase, those countries that have a productive structure where cheaper inputs can substitute for oil are those facing allocative efficiency gains. The financial terms expresses the gain/losses from changes in the relative prices of savings and investments.

8 A technological effect would also be part of this decomposition because we need to change the countries' technology parameters to keep the original calibration. As this effect is introduced only for calibration reasons we present only results concerning the allocative, financial and terms of trade effect.

Table 6 shows, unsurprisingly, a positive welfare impact in the ENEXP region (energy exporters including African countries such as Algeria, Libya and Nigeria) induced by the highest terms of trade effect in the list of 34 regions. The terms of trade gain is caused by the oil price increase, which boosts the value of exports and improves the terms of trade. The gainers from a doubling of the oil price are especially those with a low percentage of oil imports. Norway (0.37%), Former Soviet Union (12.12%), ENEXP (4.69%) and Mexico (0.01%) belong to this category, together with Madagascar (0%) and Rest of Africa (about 25%).[9] In Africa, Morocco, with a 99.68% share of imported oil consumption and a related size of oil consumption spending, is highly penalised, whereas Madagascar, which does not import oil, enjoys welfare gains. However, African countries that do not import oil, such as Tanzania, Zimbabwe and Ethiopia, suffer welfare losses because of terms of trade losses in the oil products sector, including refinery activities.

In an aggregated sense, the terms of trade effect explains more than 65% of total welfare variations[10] and is the predominant effect in the majority of African countries (with a few exceptions, such as Malawi, Senegal and Tunisia, where the financial or allocative terms are predominant, as shown in Figure 6). Some 28 world regions/countries show negative welfare effects from a doubling of the world oil price. In Africa, all countries except Madagascar, Rest of Africa and the big oil exporters included in the ENEXP group suffer negative consequences.

Not surprisingly, the oil and oil products terms of trade effects are those generating the highest amount of welfare variations[11] (about 40%). The oil sector contributes with a positive sign to the terms of trade effect for net oil exporters. The oil products sector responds negatively to higher prices for net oil exporters such as Madagascar (a $54 million loss). Countries such as Tunisia enjoy gains from the export of oil ($177 million), but also register losses in the oil products sector. Overall, Tunisia suffers welfare losses (Table 7). Countries with oil availability but which are net oil importers, such as Morocco, may experience a terms of trade loss in the oil sector ($707 million).

Table 7: Trade balance of African countries in the doubling scenario for the oil and oil products sectors (US$ million)

	Morocco	Tunisia	Senegal	Ethiopia	Madagascar	Malawi	Mauritius
Oil & oil products	-908	-95	-191	-215	127	-19	-63
	Mozambique	Tanzania	Uganda	Zambia	Zimbabwe	Botswana	Rest of Africa
Oil & oil products	-69	-137	-62	-80	-15	-77	1,552

If, in addition to welfare changes, we consider an indicator expressing the real economy, such as real GDP (i.e. with value of goods and services expressed by holding constant prices), we notice that almost all African countries suffer GDP losses (Table 8). In the oil sector, oil exporters suffer a loss of real GDP, as the global demand for oil decreases as a result of higher oil prices. This explains real GDP losses in the ENEXP region (-8.54%), Madagascar (-2.98%) and Rest of Africa (-1.96%).

On top of this mechanism, higher oil prices decrease production in non-oil sectors of the economy for many oil exporters and importers. Oil-importing African countries where oil and oil products terms of trade losses represent a significant share of GDP are heavily penalised by the oil price doubling as inputs are more expensive and their economies are less competitive (Figure 7). These results are consistent with those presented in a recent International Monetary Fund (IMF) Sub-Saharan African Regional Outlook (IMF, 2012), claiming that a 50-60% increase of oil prices generates 'large real income shocks in oil importing countries and a decline of non-oil exports in all countries' (20).

9 The Rest of Africa group includes West and East African countries and SACU countries excluding South Africa.
10 This calculation is obtained by considering only the absolute values of the welfare total variations and its components.
11 We calculate this percentage by considering only the absolute values of all the welfare variations.

Figure 5: Summary of the welfare effects of a doubling of oil prices for African economies

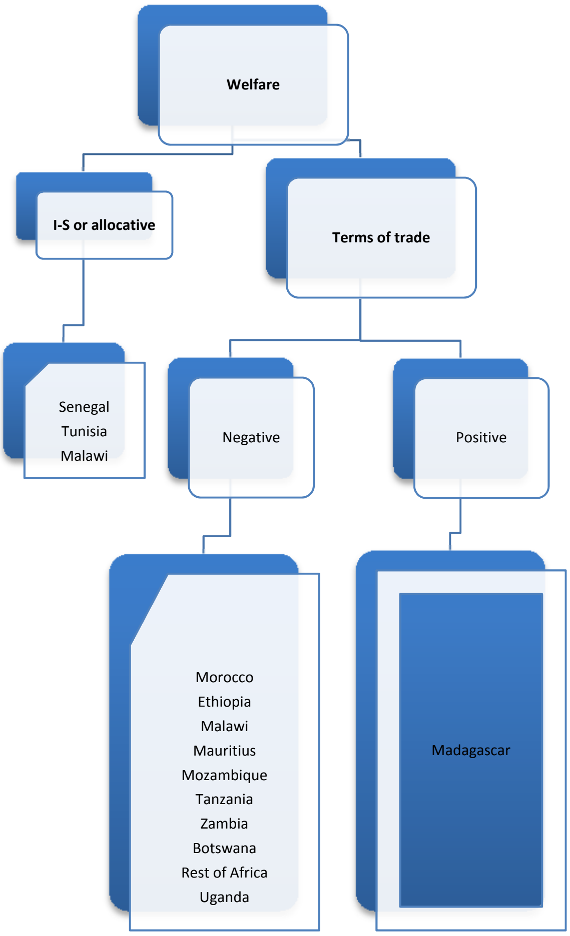
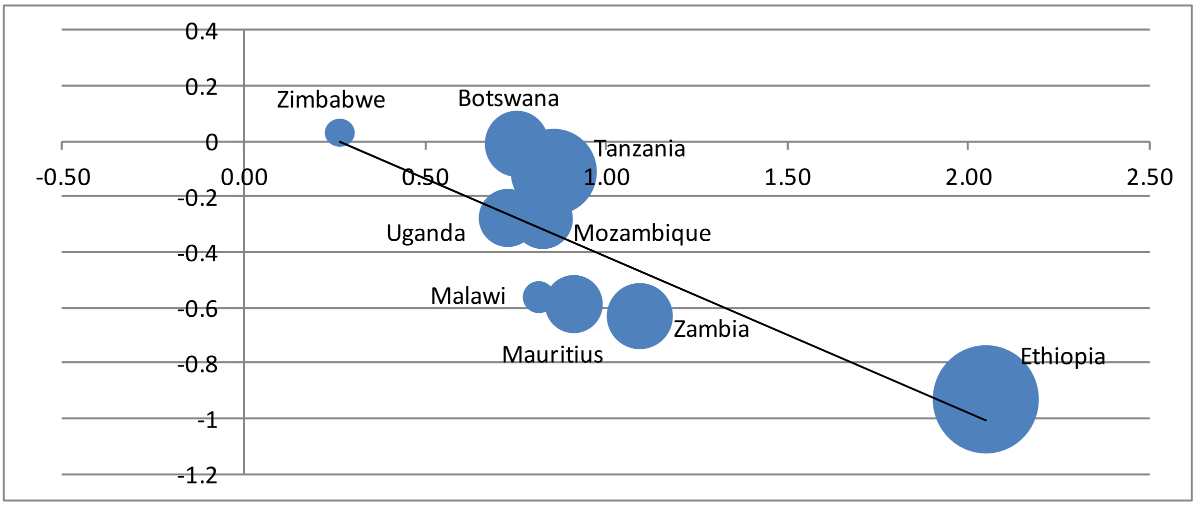


Table 8: Real GDP losses in African countries as a result of a doubling of oil prices

Country	% of GDP
Madagascar	-2.98
Rest of Africa	-1.96
Senegal	-1.16
Tunisia	-1.05
Ethiopia	-0.93
Zambia	-0.63
Mauritius	-0.59
Malawi	-0.56
Morocco	-0.29
Mozambique	-0.28
Uganda	-0.28
Tanzania	-0.11
Botswana	-0.01
Zimbabwe	0.03

Figure 6: Doubling of oil prices: terms of trade changes in the oil and oil products sectors at % of GDP (horizontal axis) vs. real GDP changes (%) in oil importing African countries



Note: Bubbles represent the size of the terms of trade losses.

4. Country experiences of energy price shocks

This section discusses three country experiences of rising energy prices. These case studies, of Nigeria, Malawi and Ghana, help us to understand how high energy prices affect economies and how countries respond. Nigeria captured the attention of international media because of the turmoil after the government decided to remove fossil fuel subsidies, which increased energy prices. Malawi is an interesting case as it has recently undergone a fuel availability and price crisis. Ghana is an example of a country performing very well in terms of GDP and with abundant new oil reserve, as we can investigate whether high prices in a context of natural resource availability may harm a poor country. The choice of these countries was also made to incorporate the perspectives of both energy exporters and importers.

4.1 The removal of fossil fuel subsidies in Nigeria

Background

In 2011, the contribution of oil to the government budget was about 70%,[12] and oil represented the main means of implementing public policy. In spite of this huge oil availability, Nigeria still imports 80% of refined oil, because it lacks refinement capacity. As a result, the country is vulnerable to oil price shocks. Even though recent evidence shows that many important macroeconomic variables in Nigeria, such as real GDP and inflation, are not strongly correlated with oil price shocks (Iwayemi and Fowowe, 2011), the oil price and in particular the fuel price are important variables for poor segments of the population. Government policy in the 1980s to subsidise fuel was justified by the need to protect the poorest people.

In December 2011, the government considered removing the large subsidy on end user fuel, which accounted for roughly 30% of the entire Nigerian spending budget and amounted to an estimated $8 billion in 2011.[13] Many economists warned that the subsidy might not be sustainable and in the end might end up being anti-poor, but some Nigerian people were against removing it because they thought it would hit them very hard through increased pump prices (Center for Public Policies Alternatives, 2011).

Initially, President Jonathan considered a gradual decrease in subsidies, but he abandoned this plan in favour of a single shock approach. Minister of Finance Dr Ngozi Okonjo-Iweala laid out a plan whereby she intended to use to the extra revenue from removing oil subsidies to pay for infrastructure improvements and more broad-sweeping projects like education and vocational schools to help combat youth unemployment. She also said the move would shore up Nigerian capital market confidence and attract more investment to the country.

Once the announcement to end subsidies was made, on 1 January 2012, the price of gasoline at the pump in Nigeria essentially doubled overnight, sparking huge protests and discontent nationwide, as citizens who relied on cars or fuel for their livelihood found themselves paying twice as much per gallon for fuel.

The vast majority of citizens in Nigeria are very price sensitive, and the rise in gas from $1.70 to $3.50 a gallon had major effects. After protests and turmoil following the decision, the president announced that the government would subsidise gasoline prices to a lesser extent, which immediately reduced the price to around $2.27 a gallon.

12 http://www.vanguardngr.com/2012/04/nigeria-should-look-beyond-oil-revenue-now-world-bank-country-director/
13 http://www.brookings.edu/research/opinions/2012/01/10-fuel-subsidies-nigeria-songwe

Analysis

From a theoretical point of view, the removal of fossil fuel subsidies is an appropriate policy tool. A subsidy distorts the market and a country could better spend the money on growth-enhancing measures, including for the poorest (this was promised in Nigeria, of course, but people doubted the intent). Subsidy removal is also better for the environment. But the reality is much more complex than this. The European Report on Development 2012 focuses on different circumstances under which fossil fuel subsidies can be removed successfully:

1) The removal of fossil fuel subsidies must be credible and must be grounded in a long-term commitment delinked to the political debate and the electoral cycle.
2) Ideally, specific independent authorities must be created to manage the energy sector and prices. As emphasised by the UNIDO Industrial Development Report 2011, these agencies need a well-defined mandate, strong technical skills and a secure source of funding. Their role would cover information dissemination, implementing technical and policy measures, coordinating engagement of players in policy formulation and implementation and serving as a focal point for economic actors.
3) Awareness campaigns are crucial to explain to the public the advantages of removing fossil fuel subsidies, such as the ability to use the funds to implement alternative pro-poor policies.
4) The credibility and anti-corruption policies of the government are key to convince the public that savings from fossil fuel subsidies will be used to combat poverty and fight social exclusion. According to the Center for Public Policies Alternatives (2011), the cost of corruption to the Nigerian government is $75 billion, about 40% of GDP a year.
5) Removing subsidies gradually may help to increase acceptance.

For Nigeria, many of these points are of crucial importance. The removal of fossil fuel subsidies was announced suddenly, with no attempt to introduce change gradually. It seems that government policy was motivated overnight, by panic over the budget rather than by a real commitment to channel funds towards pro-poor policies (if the latter were the case, pro-poor spending needed to precede subsidy removal). People were not adequately prepared for the removal of fossil fuel subsidies through appropriate awareness campaigns.

Moreover, it is important that policies that intend to remove fossil fuel subsidies in the short term are accompanied by a long-term vision. For example, in Nigeria the strengthening of refining capacity to decrease dependency on oil imports could represent a useful mitigation instrument against energy price shocks. However, there is insufficient capital for this. Appropriate policies are needed to encourage initial investments and to make convenient long-term investments (e.g. concessional finance or green bonds) (see UNEP, 2012).

Nigeria could learn from other experiences of policies that have aimed to remove fossil fuel subsidies. Bacon et al. (2010) show Jordan as a country that has successfully removed fossil fuel subsidies. Jordan subsidised petroleum products for many years, but the system came under pressure at the beginning of 2003 when it lost preferential fuel supply from Iraq. The government then implemented a series of price increases to limit the budgetary effect. In 2008 the subsidy bill for energy amounted to about 5% of GDP. The government, to eliminate the negative effects on the population, announced that it would remove fuel subsidies, while adopting mitigating measures, including increases in the salaries of state employees, an increase in food subsidies, a reduction in certain import duties and the introduction of projects to combat unemployment and poverty. The compensation package was estimated to be equivalent to 7% of GDP. The compensation package was thought to address a share of the budgetary savings to benefit low- and middle-income households directly. Household expenditure survey data were used for in-depth analysis of middle-class risks in setting the limits for support. Before the scheme became operational, an effective media campaign was launched to inform and prepare the public. Despite the very large international oil price increase that followed immediately after the government's decision to liberalise prices, the policy has been successful and domestic prices have continued to follow international levels.

The Nigeria case is an important lesson for the whole African continent, as many countries have in place fossil fuel subsidies whose funds could be used more efficiently for different purposes. In 2010–11, over half of all African countries had some kind of subsidy in place for fuel products, and these subsidies consumed, on average, 1.4% of GDP in public resources. Of the 25 countries with fuel subsidies, the fiscal cost of subsidies in six countries – primarily oil exporters – was at or above 2% of GDP in 2011[14]. The fiscal cost in oil exporters was almost two-and-a-half times the levels observed for oil importers. With oil prices likely to remain elevated, fuel subsidies will continue to weigh on government budgets.

4.2 The fuel crisis in Malawi

Background

In contrast with Nigeria, Malawi is a net oil-importing country whose economy depends mainly on agriculture and commodities such as tea, coffee and tobacco exported in international markets. These key exporting sectors faced low international prices, resulting in worsened terms of trade; in 2010, the main driver of economic growth was strong performance in mining and quarrying, construction, financial and insurance services and information and technology.[15]

Malawi suffered fuel shortages in 2011. Prices rose on the black market, to $4.5 a litre, almost twice the regular price of $2.3 a litre.[16] This shortage owed mainly to a lack of foreign exchange. Malawi derives much of its foreign exchange earnings from tobacco. The Malawi Tobacco Control Commission reported low output in tobacco production in 2012, dropping about 40% to 151 million kg compared with 237 million kg in 2011.[17]

This coincided with a drop in aid decided on by donors as a result of concerns over governance. For example, in July 2011, the UK suspended part of its aid programme, worth £19 million, because of the country's repeated failure to address concerns over economic management and governance,[18] although following the recent death of the president changes to this are expected. In October 2011, US President Obama was also asked to suspend the US Malawi programme.[19] To tackle the emergency, the government implemented some short-term policies aimed at reducing fuel demand:[20]

- Introduction of a 20% excise duty on big buses (over 45 seats);
- Introduction of an additional 20% excise duty on passenger-carrying motor vehicles aged over 8 years but not exceeding 12 years of age;
- Introduction of an additional 50% excise duty on passenger-carrying motor vehicles exceeding 12 years of age;
- Introduction of a 20% excise duty on goods-carrying motor vehicles aged 15 years and over (applicable to vehicles carrying 10 tonnes and above);
- Introduction of a 20% excise duty on vehicles imported by car hire operators (applied on the existing rate of 10% import duty and 16.5% value-added tax).

14 http://siteresources.worldbank.org/INTAFRICA/Resources/Africas-Pulse-brochure_Vol5-Section_2.pdf
15 http://www.africaneconomicoutlook.org/en/countries/southern-africa/malawi/
16 http://www.ips.org/africa/2012/02/malawi8217s-consumers-have-a-right-to-fuel-and-forex-black-market/
17 http://www.bloomberg.com/news/2012-05-01/malawi-sells-tobacco-at-32-below-government-mandated-price.html
18 http://www.guardian.co.uk/global-development/2011/jul/14/britain-suspends-aid-to-malawi
19 http://www.malawidemocrat.com/politics/obama-asked-to-drop-malawi-from-us-aid/
20 http://www.mra.mw/customs_tariff_amendments.php

In November 2011, Malawi increased fuel prices by an average 27%, a move likely to trigger broader inflation in a country that has already seen violent protests. The Malawi Energy Regulatory Authority said the pump price of petrol had increased by 31%, diesel by 38% and paraffin by 10% to reflect higher world commodity prices and the national currency kwacha devaluation since its last revision in January.[21]

Analysis

The fuel policy of the Malawi government was dictated mainly by the short-term need to tackle the emergency rather than to provide a solution to a structural problem. The government focused more on the short-term fuel demand angle of the problem without giving full consideration to the fact that the crisis derived from the structure of the economy rather than just that of the energy sector. The decision to introduce a 10% devaluation of the kwacha in August 2011 to counter a chronic lack of dollars in the domestic economy was not fully successful, and it is not immediately clear why a large devaluation was not pursued. In addition, demand-side interventions may guarantee a quick intervention, but they should be implemented together with a broad range of medium- to long-term policies, such as:

1) Promoting economic diversification: The Malawian economy should be able to collect foreign currency on the basis of a more diversified structure of exports, which should not depend only on the tobacco industry. As reported by Chirwa (2011), the tobacco industry now represents almost 60% of Malawi's exports (although this has declined from 79% in 1990).
2) Limiting oil dependency: As the European Report on Development 2012 shows, the highest potential in terms of renewable energy lies in Sub-Saharan African countries, especially if we consider solar power.
3) Governance issues are further reducing Malawi's capacity to receive aid from international donors and to accumulate foreign exchange reserves. The fight against corruption and pro-democracy policies may also represent indirect ways to counter the fuel crisis situation in the country.

Analysts[22] also argue that the significant fuel price hike in Malawi was a result not of the increase in global oil prices or the devaluation of the kwacha but of a need to support the cost of borrowing funds from offshore sources to purchase fuel products. The policy to reduce fuel demand and increase fuel prices could be very harmful to the overall economy, as it could increase firms' production costs, affect the competitiveness of industry and add an economic dimension (beyond a physical dimension) of fuel scarcity as fuel may become unaffordable for the poorest segments of the population.

4.3 A positive energy shock: oil discoveries in Ghana

Background

According to the African Economic Outlook 2011,[23] economic growth in Ghana has been strong, with real GDP growth reaching an estimated 5.9% in 2010 and growth prospects even brighter, as real GDP growth projections came in at over 10% for 2011 and 2012. In addition, the country's growing democratic and social stability has served to boost confidence, leading to rising investment.

21 http://af.reuters.com/article/investingNews/idAFJOE7A70DG20111108
22 http://ssrn.com/abstract=2038110
23 http://www.africaneconomicoutlook.org/en/countries/west-africa/ghana/

Figure 7: Real GDP growth in Ghana

Source: http://www.africaneconomicoutlook.org/en/countries/west-africa/ghana/

Ghana also appears to be taking advantage of the growing engagement of emerging economies in Africa, and new partnerships between Ghana and emerging economies such as China are providing additional sources of financing and expertise for development. Ghana recorded 95 new foreign direct investment (FDI) projects, with an estimated value of $1.18 billion, in the first three months of 2012. This represents an increase of 68% over the value recorded in the same period in 2011. The US, with an FDI value of $407.21 million, ranks first, and China takes the top spot for the number of projects within the period.[24] One very recent report elaborates an index expressing ability of developing countries to manage change and cultivate opportunities and finds that Ghana is among the top positions among African countries[25].

Gold, timber, cocoa, diamond, bauxite and manganese exports are major sources of foreign exchange, and Ghana has also recently started producing oil from the offshore Jubilee field, which straddles two licenses: Deepwater Tano and West Cape Three Points, off Ghana's western coast. Ghana's oil reserves are relatively small on a global scale: its potential 4 billion barrels is significantly below the production of Saudi Arabia (265 billion), Canada (175 billion), Venezuela (98 billion) and Nigeria (38 billion). However, van der Ploeg et al. (2012) estimate that Ghana is approximately 15th in the world in terms of barrels of oil per dollar of GDP, roughly on a par with Angola and Nigeria. Moreover, they estimate that, when considered as a proportion of the Ghanaian government's annual income, production from the Jubilee field at its peak will generate up to 30% of government income.

Analysis

Many resource-abundant countries have experienced the so-called 'Dutch disease'. This refers to the problem of a temporary increase in revenues from natural resources (or aid or any other foreign exchange flow) that may reduce long-term growth because it makes the national currency stronger and diverts resources from other exportable production to national consumption. As Ghana has seen strong growth, it seems that the country has not been affected by Dutch disease. However, there are some early warning signals:[26]

1) A 20% appreciation of the Ghana national currency (cedi) over the period 2009–11;
2) A reduction in non-oil export growth over 2009–11; and
3) An increase in the contribution of the oil subsector relative to manufacturing and agriculture. The oil subsector share in GDP increased from 1.8% in 2009 to 8.7% in 2011.

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24 http://www.ghanaweb.com/GhanaHomePage/NewsArchive/artikel.php?ID=238570

25http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/change-readiness/Documents/change-readiness-index.pdf

26 http://danquahinstitute.org/news/1553-oil-and-the-2012-budget-statement-reflections-on-the-ghanaian-economy.html

Table 9: Growth in exports in Ghana, 2009–10 to 2010–11, %

	2009–10	2010–11
Cocoa	**18.9**	18.0
Gold	49.0	39.5
Others	36.1	21.6

Source: http://danquahinstitute.org/news/1553-oil-and-the-2012-budget-statement-reflections-on-the-ghanaian-economy.html

Such symptoms of Dutch disease could undermine the growth and long-term development of the country. Van der Ploeg et al. (2012) indicate some remedies that could help Ghana prevent itself from falling victim to Dutch disease:

1) Ghana can repay foreign debt, reducing credit spreads and in turn stimulating private and public investment and raising wages. The stock of debt affects the perceived creditworthiness of a country, which increases its costs of borrowing.
2) Ghana can invest in foreign assets. The sovereign wealth fund acts as a store of wealth to be consumed across generations. This approach basically dictates replacing subsoil assets with foreign assets and consuming only the interest income. Second wealth funds are useful to save income when oil prices are above a benchmark, to be used when they fall below it, and can reduce the pass-through of income volatility to the economy. They are also useful to neutralise Dutch disease by reducing the increase in consumption in non-oil sectors, which is the main cause of the real exchange rate appreciation.
3) Finally, during oil price shocks, Ghana can use the increase in proceeds to accumulate physical capital, before slowly returning to the non-oil growth path once the shock has finished.

As reported in IMF (2012), Ghana has already started following this policy direction. As a new oil-producing country, it has put in place a legal framework governing the collection, allocation and management of petroleum revenue, with 70% of resource revenues allocated to the budget and the rest split between a stabilisation fund and a heritage fund to neutralise oil price volatility and cater to the needs of future generations.

5. Conclusions

This study has reviewed the impact of energy price changes on developing countries in three parts. In the second section, we analysed the determinants of energy price shocks and the consequences for energy exporters and importers. In the third, we used a CGE model to analyse vulnerability to energy price increases in different types of countries. In the fourth, we discussed policy responses, with a particular focus on fossil fuel subsidies.

There are a number of broad conclusions:

1) The determinants of energy prices include supply and demand factors, speculation and geopolitical concerns.
2) The consequences of energy price shocks are particularly negative for energy importers, as they may suffer losses because of the higher price of inputs. Energy exporters may experience some gains and budget revenue increases but also suffer inflation.
3) CGE analysis shows which regions are particularly vulnerable to energy price shocks. African countries are particularly vulnerable, but some countries may capture welfare benefits from improved terms of trade. As a consequence of an oil price doubling, almost all African countries will experience a reduction in real GDP because of higher input costs to the economy and lower oil demand (as world GDP decreases as well), which could hamper growth of energy exporters in the medium term.
4) A typical government response to energy price increases is to increase fossil fuel subsidies to keep domestic prices low. The removal of fossil fuel subsidies may not be accepted by parts of the population because it may affect the budget of the poorest people, even though it would be justified under normal economic considerations and in efforts to lower government deficits. This suggests that subsidy removal needs to coincide with a well-targeted and communicated complementary programme of investment that helps the poorest (e.g. in Nigeria). Meanwhile, specific energy price impacts require appropriate policy responses. Whereas the Malawi fuel and price rise crisis calls for the diversification of the national economy to increase foreign exchange, in Ghana early Dutch disease warnings deriving from oil discoveries require a set of policies including wealth funds, debt repayment and physical capital accumulation.

The following policy implications have emerged:

1) There needs to be more attention to developing new and innovative solutions to pursue oil price stability. These solutions could involve global coordinating mechanisms that would be able to facilitate efforts at international level to avoid sudden oil price spikes and reduce oil price volatility. China is calling for an international body to govern energy markets and is suggesting that developed nations take action to address issues of energy and resource inequality in impoverished states. Chinese Premier Wen Jiabao proposed at the World Future Energy Summit in Abu Dhabi that a G20-like body be assembled to establish ‘fair, reasonable and binding’ global rules to stabilise supplies of natural gas and oil. Stakeholders from consumers, suppliers and transit countries should all be involved, he said27.
2) Policies to cope with oil price crises include the strengthening of refinery capacity for countries with oil endowments, interventions promoting a structural change towards green sources of energy, the creation of strategic petroleum reserves and hedging strategies.
3) Increases in oil prices are particularly harmful for some countries, and for some groups within countries. The CGE modelling exercise suggests that energy price increases may generate winners

27 http://www.chinadaily.com.cn/cndy/2012-01/17/content_14457637.htm

> and losers in terms of welfare, but only losers among African countries in terms of real GDP. It is important that policies for poverty reduction and social programmes are addressed towards the most vulnerable low-income countries by setting policies to address short-term impacts where necessary, but also to avoid long-term negative consequences.

Many countries use fossil fuel subsidies to reduce the domestic cost of living for poor people and to alleviate the effects of high energy prices on poor people (although energy price subsidies are often regressive). The removal of fossil fuel subsidies would represent a step forward towards an economically more efficient economy and a more environmentally friendly world, and could incentivise investment in alternative energy sources, which could help countries to become more resilient to shocks. However, national governments need to plan the removal of fossil fuel subsidies properly. Removal should not be sudden but gradual, because people could perceive such policies themselves as an energy price shock. Governments must be credible and not waste resources, and must convince people of the advantage for pro-poor policies, by committing immediately to these. Long-term policies in terms of renewable energy adoption and the strengthening of refining capacity could help to orient a transition towards a green economy without affecting social targets.

Fossil fuel energy and oil will remain important for growth for a long time, and it is reasonable to think that the transition towards renewable energy will take a long time.[28] In the meantime, many policy improvements can be adopted to reconcile economic, environmental and social targets.

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28 See the recent IPCC report on renewable energy (IPCC, 2011).

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Appendix I. Description of GTAP E model version

The GTAP model

Overview

A CGE model that has recently shown outstanding growth is the GTAP model. This is part of the Global Trade Analysis Project (GTAP),[29] a global network of researchers and policymakers conducting quantitative analysis of international policy issues. The core feature of GTAP is a global database including input–output (I–O) tables on bilateral trade flows, production, consumption and intermediate use of commodities and services, as well as transport costs and tax and tariff information. Our decision to use the GTAP model was also driven by its updated and detailed database.

The GTAP model is a multiregional applied general equilibrium model, representing the global economy. In each region, a representative agent maximises utility, and private demand and production are modelled using different functional forms. Some of the most important features that distinguish the GTAP model from other CGE models are the explicit treatment of international trade and transport margins and a global banking sector that intermediates between global savings and consumption. Moreover, the model incorporates a constant difference of elasticity (CDE) utility function in private household preferences; this non-homothetic functional form, unlike the usual homothetic constant elasticity of substitution (CES) function, allows for the analysis of simulations with a large income effect.

The GTAP Database

The GTAP 7 Database represents the world economy, with 2004 as the reference year. All values are expressed in 2004 US dollars and it covers 57 sectors in 113 regions.[30] The 57 sectors are defined according to the International Standard Industry Classification (ISIC), except for the agriculture and food processing sectors, which refer to the Central Product Classification (CPC).[31]

The 113 regions (single countries or groups of countries) are defined as aggregates of 226 countries for which contributors to the GTAP Database provide domestic data. The table below synthesises the main sources of the GTAP Database version 7.

29 Developed by the Center for Global Trade Analysis in Purdue University's Department of Agricultural Economics, West Lafayette, Indiana, US. For more information, see https://www.gtap.agecon.purdue.edu/

30 The new GTAP 8 version will be available in 2012 and will allow for the comparison of 2004 and 2007 data.

31 CPC was developed by the Statistical Office of the UN to serve as a bridge between ISIC and other sectoral classifications.

Data source	Description of data taken from source
World Bank	Macroeconomic aggregates (GDP, private consumption, government consumption and investment)
UN Comtrade	Trade data
OECD Producer and Consumer Support Estimates	Macroeconomic data (output subsidies, land-based payments, labour- and capital-based payments)
World Trade Organization (WTO) 'Financial Report on European Agricultural Guidance and Guarantee Fund'	Macroeconomic data (agricultural export subsidies)
Market Access Maps (MAcMaps), developed by the International Trade Centre (UN Conference on Trade and Development (UNCTAD)/WTO	Macroeconomic data (import tariffs)
IMF	Macroeconomic data (income and factors taxes)
Calibrated from other data sources	Behavioural information (behavioural parameters such as demand and trade elasticities)
IEA database	Model Input Energy (primary energy consumption for all 113 regions and 57 sectors included in GTAP 7 Database

In the GTAP Database, I-O data may be processed in several ways and, if necessary, disaggregated as described in the GTAP Database Documentation.

Energy is represented by a special set of data, prepared not only to supplement data from sector generic sources but also to 'correct' I–O tables. Such an approach has been developed to fix divergences of energy data in earlier GTAP releases from IEA data (see, among others, Babiker and Rutherford, 1997). With regard to energy flows, the GTAP Database includes not only money value but also volume data, referring to I–O tables and international trade flows measured in millions of tons of oil equivalent (Mtoe). In particular, the energy data file contains three arrays that report the volume of energy commodities (namely, coal, natural gas, oil, oil products and electricity) purchased by firms and households and also the volume of bilateral trade in energy commodities.

The main source of energy data is the IEA Extended Energy Balances (IEA EEBs onward) for 2004. The energy balance constitute a large array of energy flows, built using a different sectoral classification; in order to be used in the GTAP model, the energy data should be aggregated and harmonised with the rest of the database. Although the EEBs' classification of energy flows and products is much more detailed than that in the GTAP model, the classification of non-energy sectors is less detailed in EEBs. Furthermore, unlike in the GTAP model, IEA EEBs do not recognise gas distribution as a separate activity. For the most part, IEA EEB sectoral classifications are treated as a disaggregation of the GTAP sectoral classifications. The exceptions fall into three classes. First, some of the IEA EEB sectors are discarded; these include sectors such as 'statistical differences' that represent nothing in the real world, but are items of accounting convenience. Second, some of the EEB flows are coherent with GTAP classifications but not in the intermediate usage block: this is true for production, exports and imports.

Third, some EEB flows combine uses that must be separated in the GTAP model, such as gas and crude oil industries, the transport industry and private consumption.

Model structure

The GTAP model includes two different kinds of relationships: accounting and behavioural equations. While the first ensures the balance of receipts and expenditures for every agent in the economy, behavioural equations specify the behaviour of optimising agents (production and demand functions). Given the large number of equations in the GTAP model, providing a synthesis of the theory behind the model is not an easy task. The basic accounting relationships can be better understood with a flow chart.[32] The graphical illustration provided in the first figure below explains the basic structure of the GTAP model by focusing on the accounting relationships in a multiregional open economy.

First of all, the regional household collects all income that is generated in the closed economy by each region or composite region which derives from ownership and sales of primary factors of production – capital, skilled and unskilled labour, land and natural resources. According to a Cobb Douglas utility function, regional income is allocated across three forms of final demand (see the first figure below): private household expenditures (PRIVEXP), government expenditures (GOVEXP) and savings (SAVE). The flow associated with savings constitutes the input for the production sector. This formulation in terms of regional household preferences is well suited to computing regional equivalent variation as an indicator of the welfare changes caused by different policy scenarios.

The GTAP production structure distinguishes between primary and intermediate factors. Five primary factors are considered, namely, land, skilled and unskilled labour, capital and natural resources. Among these, the GTAP model additionally distinguishes between endowment commodities that are perfectly mobile and those that are sluggish to adjust (land and natural resources).

The production function of each sector is modelled through a 'technology tree' that contains different levels. At the top level, we find a final production nest in which primary factors and intermediate factors are combined, and at the bottom level a value-added nest and an intermediate nest where the producer chooses the optimal mix of primary factors and intermediate inputs, respectively. It is worth mentioning that imported intermediate inputs are assumed to be separable from domestically produced intermediate inputs, following the Armington assumption (Armington, 1969). Under this approach, imported intermediates are separable from domestically produced intermediate inputs: firms first decide on the sourcing of their inputs and then, according to the resulting composite import price, determine the optimal mix of imported and domestic goods. The way the firm combines production factors to produce its output depends on the assumptions made on separability in the production function. Production technology is assumed to be weakly separable between primary factors of production and intermediate inputs, meaning that the elasticity of substitution among any individual primary factor and intermediate input is equivalent. It is assuming this kind of separability that enables the production function to be represented as a multi-level production function (technology tree): indeed, the above-mentioned CES enters the fork in the inverted tree at which the primary and intermediate factors are joined.

At the top level of the technology tree, a Leontief production function operates: namely, the elasticity between value-added and intermediate factors is zero, and they are combined in fixed proportions that are different for each sector. Hertel and Tsigas (1997) highlighted that the Leontief production function and the hypothesis of constant return of scale make the mix of intermediate factors independent of their prices. The technology tree is further simplified by employing the CES functional form in the value-added and intermediate nests (bottom level). Value added is then produced through a CES function of primary factors of production. Each intermediate input is in turn produced using domestic and imported

32 Hertel and Tsigas (1997) offers a detailed explanation of the theory behind the model, especially with regard to the derivation of the behavioural equations.

components (following the Armington assumption), with the technical process described by a CES function. Finally, imported components are a mix of imports from the other regions in the global model, with the technical process again described by a CES. Under the CES functional form, the substitution possibilities within each nest are restricted to a parameter that changes from one sector to another. It should be mentioned that this CES assumption is fairly general in sectors that employ only two inputs, but when assuming that all pair-wise elasticities of substitution are equal, it represents quite a simplification.

Private consumer optimising behaviour is represented in the GTAP model by the CDE expenditure function, first proposed by Hanoch (1975). This formulation can be considered more flexible than the commonly used CES/Linear Expenditure System demand functions. Indeed, the CDE function has the desirable property that the resulting preferences are non-homothetic; they also allow for possible differences in income effects since marginal budget shares of individual goods can vary with income levels. CDE functions are more facilitated in their parameter requirements than functional flexible forms. Moreover, parameters of CDE demand functions can be easily calibrated using historical data on income and own price elasticities, even though, with the exception of some special cases of the CDE (e.g. Cobb Douglas functions), elasticities are not constant. On the contrary, they vary according to expenditure shares and relative prices. For this reason, elasticities are updated with iterations given by the non-linear solution procedure; such an approach also allows a mix of composite consumption of tradable commodities included in the model to be obtained, based on domestic and composite imported goods.

The static version of the GTAP model computes a linearised representation of the accounting relations described; in this form, the equations are implemented in GEMPACK language (Harrison and Pearson, 2002), which solves non-linear equilibrium problems via iterations and re-linearisation. The model also provides a wide range of closure options, namely, choosing which variables are exogenous; different closures are associated with different policy experiments, exogenously imposed as shocks. Moreover, partial equilibrium closures are possible, facilitating comparisons with studies developed on partial equilibrium models.

The GTAP E model

Recently, growing research demands for integrated assessment of climate change issues have motivated the construction of different versions of the GTAP model and databases related to, for instance, greenhouse gas (GHG) emissions, land use and biofuels.

The GTAP E (Burniaux and Truong, 2002) is an energy-environmental version of the standard GTAP model that allows for inter-fuel and inter-factor substitution in the production structure of firms and in the consumption behaviour of private households and the government sector. In addition to standard macroeconomic results, GTAP E captures the effects arising from changes in energy-environmental policy strategies, in terms of both economic and environmental indicators.

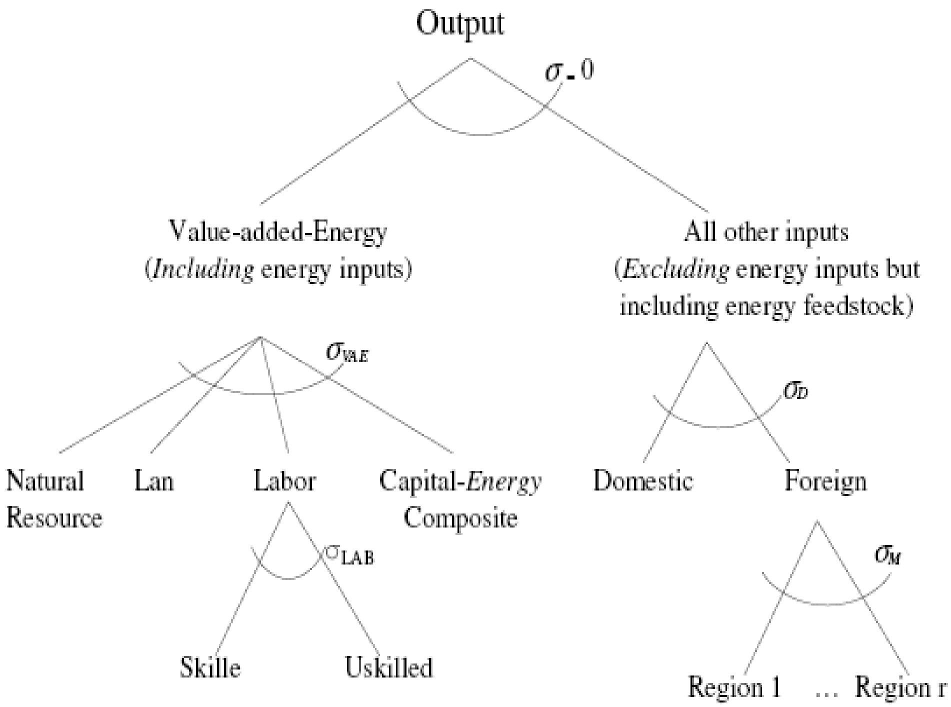
The GTAP E model includes modified treatment of energy demand energy-capital and inter-fuel substitution, carbon dioxide accounting, taxation and emission trading, since it has been specifically designed to be used in the context of GHG mitigation policies. The potential of the GTAP E model in existing debate on climate change is illustrated by some simulations of the implementation of the Kyoto Protocol (see among others, Burniaux and Truong, 2002). It represents a top-down approach of energy policy simulation since it estimates the demand of energy inputs in terms of sectoral demand producing detailed macroeconomic projections.

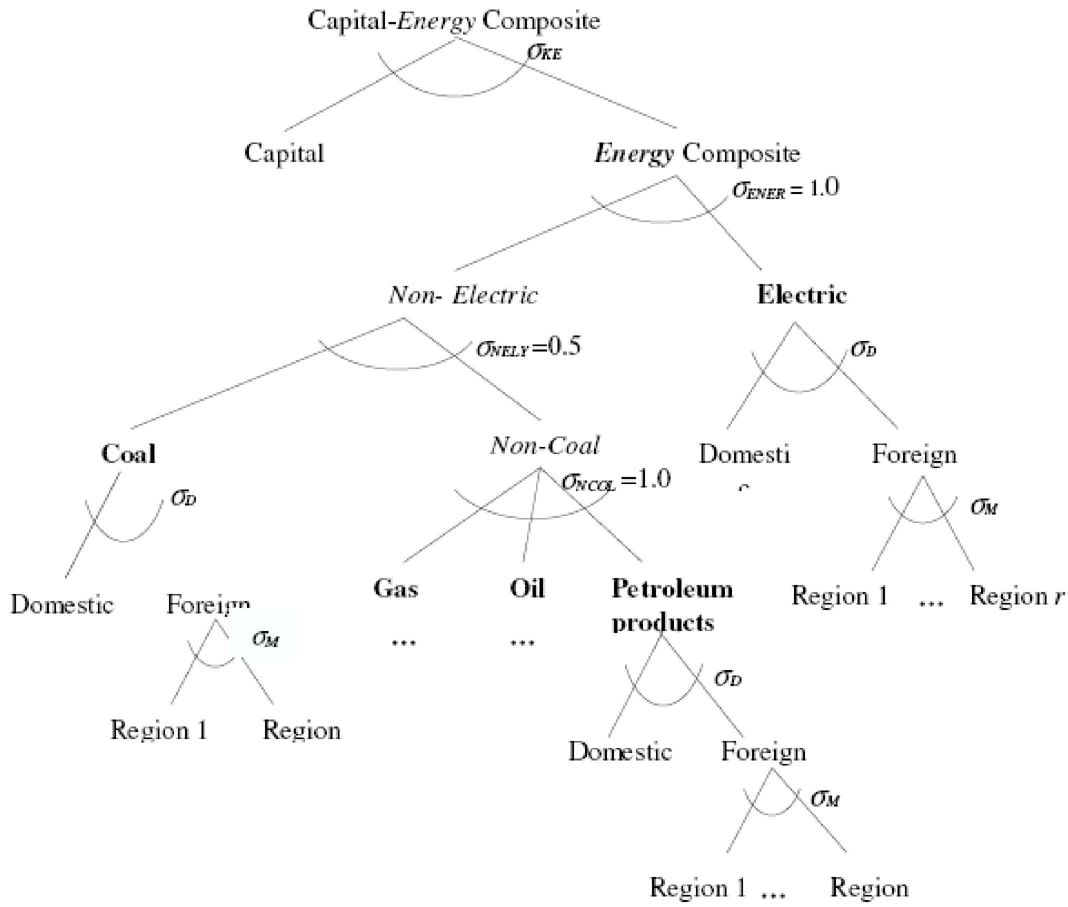
The main change in the GTAP E compared with the traditional GTAP model is the inclusion of the possibility of energy input substitution in production and consumption, allowing for a more detailed description of substitution possibilities in different energy sources. Energy substitution is incorporated in the GTAP E model in both the production and the consumption structure. The important issue of capital-energy substitutability versus complementarity is also explicitly considered.

Production structure
In the standard GTAP model, energy inputs are treated as intermediate inputs (outside the value-added nest); the GTAP E model incorporates energy directly in the value-added nest. In this case, energy inputs are combined with capital to produce an energy-capital composite; the latter is combined with other primary inputs in a value-added energy nest using a CES function (the second figure below).

The GTAP E model incorporates energy in the value-added nest in two different steps. First, energy commodities are separated into 'electricity' and 'non-electricity' groups, where a substitution elasticity ($\sigma ENER$) operates. The following nest separates non-electric into coal and non-coal, with a specific substitution elasticity ($\sigma NELY$), and non-coal into gas, oil and oil refined products, with a specific substitution elasticity ($\sigma NCOL$).

Second, energy composite is combined with capital to produce energy-capital composite to be incorporated in the value-added nest. This production structure can be further enriched to include biofuel production (Taheripour et al., 2007) or clean energy technologies as in the Intertemporal Computable Equilibrium System model (Bosello et al., 2011). According to this approach, energy inputs are part of the endowment commodities owned by producers. Capital and energy use depends mainly on the model parameters (elasticity values) and the policy simulated.





Consumption structure

As far as consumption is concerned, the GTAP E model modifies both private and government consumption. In the standard GTAP model, private and government consumption are separated from private savings.

Government consumption has a Cobb-Douglas structure (with a substitution elasticity equal to one), where energy commodities are separated from non-energy commodities by a nested CES structure. Household private consumption follows the standard GTAP model, using the CDE functional form previously described, but in the second-level nest the GTAP E model further specifies the energy composite using a CES functional form. Another significant change in the consumption structure is the possibility of adding carbon tax to private expenditure, as well as to public (government) expenditure, for goods that emit carbon dioxide when used.

CO_2 emissions and related parameters

The GTAP E model modifies the standard GTAP Database to incorporate CO_2 emissions from fossil fuel combustion, which are incorporated by region, commodity and use in million tons of carbon. Energy commodities include coal extraction (coa), crude oil (oil) extraction, natural gas extraction (gas), petroleum products (pc), electricity (ely) and gas manufacture and distribution (gdt). CO_2 emissions for electricity are equal to zero, as well as for all other non-energy commodities.

CO_2 emissions data are based on estimates from Lee (2008), properly adjusted to fit with the compatible GTAP format. They contain CO_2 combustion-based emissions values from intermediate use, government and private consumption, and also play a key role in describing the behaviour of energy consumers in facing higher energy prices. As an example, taxes on CO_2 emissions would require energy consumers to use less polluting energy such as natural gas instead of coal. In addition, by using detailed and reliable emissions data at regional level, analyses of potential carbon leakage effects can be performed.

A GTAP E revised version

A recent revision of the energy environmental extension of the GTAP E by Burniaux and Truong (2002) can be found in McDougall and Golub (2007). This is adapted to a wider range of energy-environmental policy scenarios. In particular, improvements are related to different issues: emissions data, emission trading, carbon taxation, revenue from emissions trading, production structure and welfare decomposition.

First, new arrays are added to the data file, showing CO_2 emissions by region, commodity and use. This represents another way of using the information that in the standard GTAP E model is represented as energy volume data. In particular, the database contains emissions from firms' usage of domestic and imported intermediate goods, emissions from households and government consumption of domestic and imported products.

Moreover, in order to model an emission trading system, blocs of regions' trading permits among themselves are identified; a non-trading region is simply a one-region bloc. Considering the Kyoto Protocol framework where Annex I countries may operate in an emissions trading scheme, Annex I regions constitute one single bloc whereas the remaining non-Annex regions are considered individual blocs. To impose or relax emission constraints, a bloc-level power-of-purchases variable is defined, relating regional quota to actual emissions; when emissions constraints are in force, this variable is endogenous (whereas emission quotas are exogenous), so that regional emissions and emission quotas are decoupled. When not in force, emissions quotas are endogenous (whereas power-of-purchases variable is exogenous), so that regional quotas follow emissions.

An economic environment without emission constraints can be simulated by making the power of emissions purchases endogenous and the real carbon tax rate exogenous.[33] In this case, there are two options for market and agents' prices, *ad valorem* tax and carbon tax. To distinguish them, a new computational level is added, including only non-carbon tax for each usage (referring to firms, private and government consumption of energy goods, domestic and imported). The model also enables carbon tax and emission trading revenues to be computed by region from all sources.

Many more intermediate levels of nesting are added in the production system, combining capital with energy at the top level. To implement this system, a new set of sub-products is defined which includes value-added-energy composite, capital-energy composite, energy composite, non-electric energy commodities and non-coal energy commodities. Such a production system enables technological change to be simulated at every level in the nest structure. Furthermore, the set of inputs and substitution elasticities is specified with a high level of detail. A similar approach is adopted for all the other nests in the production system, whether the inputs are tradable, endowments, sub-products or any combination thereof. Given the previous changes, welfare decomposition is subject to a double modification. First, net emission trading revenues are taken into account, and these contribute to welfare changes. Second, welfare contributions of all forms of input-saving technological changes are summed up in a single variable, including technological changes associated with the energy nests of production function.

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33 The real carbon tax rate is defined as the nominal tax rate deflated by the income disposition price index.

It is worth mentioning that, although the GTAP E model has been designed specifically to be used in the context of GHG mitigation policies, its uses include biofuels (Banse et al., 2008; Hertel et al., 2008; Taheripour et al., 2010), induced tourism demand changes in climate change setting (Berrittella et al., 2007a) and the costs of climate mitigation policies (Kemfert et al., 2005; Nijkamp et al., 2005). The framework has also been used to examine water scarcity (Berrittella et al., 2007b), as well as the economic impacts of a rise in sea levels (Bosello et al., 2007). Lastly, Gan and Smith (2005) utilised the GTAP E model to investigate the cost competitiveness of woody biomass for electricity production in the US under alternative CO_2 emission targets.

Updates of the GTAP E model implemented for this report

Using 2004 data, a 2012 baseline was created based on the GTAP 7.1 Database. We built a business as usual scenario for emissions data, assuming slow adoption of clean technologies and economic projections to 2012 based on IMF and World Bank data on actual growth rates after the financial and economic crisis. Several steps were necessary to obtain a consistent 2012 baseline. We first updated the database to 2008, assuming population and GDP as reported by the World Bank and the IMF,[34] and calibrating the emissions to the most recent IEA CO_2 data. The same procedure was adopted to bring the model to 2012. In both cases, while the emissions level in aggregate was correct, its distribution in terms of emissions quota among regions was not satisfactory. Consequently, in the 2008 baseline, we corrected CO_2 emissions to fit the IEA data, whereas in the 2012 baseline we calibrated the CO_2 emissions to the IEA projections.[35]

In a CGE model,[36] prices are usually endogenous because they are the result of a ‘change’ in the economy, then together with an oil price increase we assume a simultaneous output productivity of crude oil (i.e. an increase of price is linked to an output productivity worsening in the oil sector).

34 In order to treat regional GDP as an exogenous variable and to shock it, regional technological progress was taken as an endogenous variable.
35 Emissions were swapped with technical progress using a specific closure (Altertax) which allows some data to be changed but preserves the overall consistency of the model calibration.
36 The GTAP E model is a pure economic model, so we do not have ‘political’ or similar variables.

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