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The Price of Oil – Will it Start Rising Again?

Jean-Marc Fournier, Isabell Koske, Isabelle Wanner, Vera Zipperer

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ABSTRACT/RESUMÉ

The price of oil – Will it start rising again?

Following a sharp drop amidst the global economic crisis and a subsequent recovery, the spot price of crude oil has been broadly stable for the past couple of years. This paper discusses the factors that drive oil demand and supply and, hence, the price of the resource. A set of oil demand equations is estimated for OECD and non-OECD countries, which is then combined with assumptions about the behaviour of supply to analyse the impact of a range of macroeconomic and policy scenarios on the future oil price path. The scenario analysis suggests that a return of world growth to slightly below pre-crisis rates would be consistent with an increase in the price of Brent crude to far above early-2012 levels by 2020. This increase would be mostly driven by higher demand from non-OECD economies – in particular China and India. The expected rise in the oil price is unlikely to be smooth. Sudden changes in the supply or demand of oil can have very large effects on the price in the short run.

JEL classification codes: Q41; Q43; Q47

Keywords: Oil price, Oil and the Macroeconomy, Oil Demand, Oil Price Projection

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Le prix du pétrole – va-t-il recommencer à augmenter ?

Après une forte baisse lors de la crise économique mondiale et une reprise ultérieure, le prix du pétrole brut est resté globalement stable depuis quelques années. Ce document examine les déterminants de la demande et de l'offre de pétrole et, par conséquent, du prix de cette ressource. Un ensemble d'équations de demande estimées pour les pays membres et non membres de l'OCDE est combiné à des hypothèses sur le comportement de l'offre pour analyser l'effet d'un éventail de scénarios macroéconomiques et politiques sur la tendance future du prix du pétrole. Cette analyse suggère que le retour de la croissance mondiale à un niveau légèrement inférieur au taux observé avant la crise pourraient entrainer le prix du baril de Brent d'ici 2020 bien au-dessus du niveau observé début 2012. Cette hausse principalement tirée par une demande soutenue des pays non membres de l'OCDE, notamment la Chine et l'Inde. Cette hausse du prix du pétrole a peu de chance d'être régulière. Des modifications soudaines de l'offre ou de la demande de pétrole peuvent avoir des effets importants sur les prix du pétrole à court terme.

Classification JEL : Q41 ; Q43 ; Q47

Mots clés : Prix du Pétrole, Pétrole et Macroéconomie, Demande de Pétrole, Projection du Prix du Pétrole

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THE PRICE OF OIL – WILL IT START RISING AGAIN?

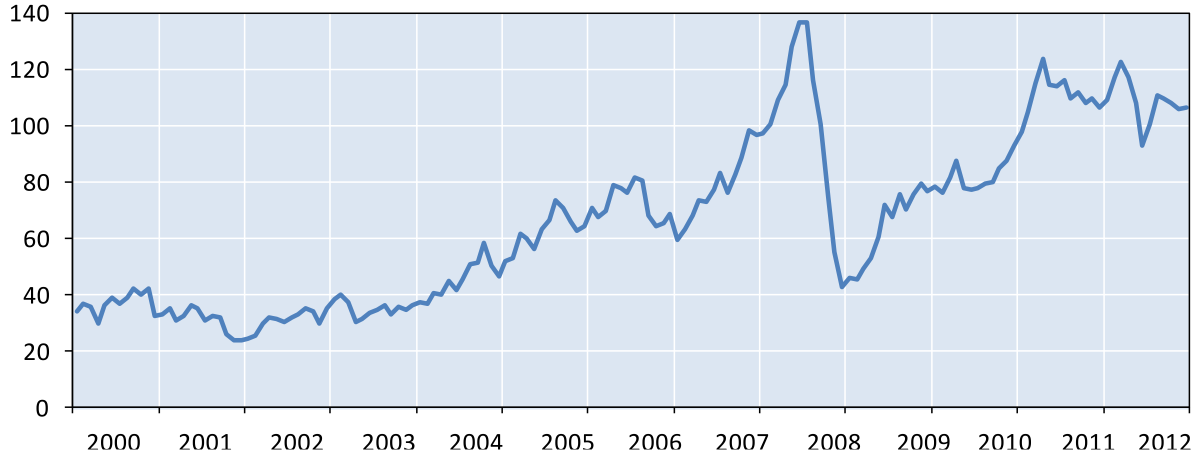
by Jean-Marc Fournier, Isabell Koske, Isabelle Wanner and Vera Zipperer[1]

1. Introduction

1. After the collapse in 2008 and the subsequent recovery in 2009-2010, the price of oil has hovered around 110 USD per barrel of crude Brent over the last two years (Figure 1). Were oil prices to start rising rapidly again, driven in particular by rising demand from emerging economies, they could dampen or even derail the prospects for recovery in the OECD. Against this background this paper discusses the factors that shape the oil price by impacting the demand for and the supply of the resource and, based on a newly estimated set of oil demand equations for OECD and non-OECD countries, analyses the impact of a range of economic and policy scenarios on the oil price path at the 2020 horizon.

Figure 1. **The oil price has stagnated in recent years**

Price of crude Brent in constant 2011 US dollars



Source: OECD Analytical Database and Reuters.

2. The following main conclusions emerge from the analysis:

- World oil demand rose markedly in the decade to 2010 as efficiency improvements could not offset the upward pressure from a growing world population and rising GDP per capita levels in non-OECD countries.

1. The authors are members of the Economics Department of the OECD. They would like to thank Jørgen Elmeskov, Jean-Luc Schneider, Romain Duval, Alain de Serres, Eckhard Wurzel and colleagues from the IEA, in particular Laura Cozzi, for their useful comments and suggestions and Celia Rutkoski for her excellent editorial support. The views expressed in this paper are those of the authors and do not necessarily reflect those of the OECD or its member countries.

- Upward pressure on prices also originated on the supply side. The costs of oil production, both to operate current capacity and develop new supply, rose strongly as new resources became more costly to access.

- Oil demand tends to respond very little to prices in the short run. In more than half of the countries and regions considered the short-run price elasticity is not significantly different from zero. Oil demand is somewhat more responsive to prices changes in the medium to long run. On average across countries, a one per cent rise in the price of oil is found to reduce demand by about one-fifth of a per cent over the medium to long run.

- Non-OECD countries are found to have a higher income elasticity of oil demand than OECD countries. On average across countries, a one per cent rise in real GDP pushes up oil demand by half a per cent in OECD countries over the medium to long run, whereas the figure is closer to unity for most non-OECD countries.

- Predictions of the future oil price are inherently difficult. Empirical estimates of key driving parameters are highly uncertain, resulting in a very wide range of plausible future oil price paths. Bearing this caveat in mind, this paper nonetheless suggests that risks are mainly on the upside. A return of world growth to slightly below pre-crisis rates would be consistent with an increase in the price of Brent crude far above early-2012 levels. Based on plausible demand and supply equations, there is a risk that prices could go up to anywhere between 150 and 270 US dollars per barrel in real terms by 2020, depending on the responsiveness of oil demand and supply and on the size of the temporary risk premium embedded in current prices due to fears about future supply shortages. These projections account for a negative feedback effect of higher oil prices on GDP.

- A price increase in the lower end of this range would require a gradual reversal of the risk premium as well as greater responsiveness of supply and demand to higher prices than witnessed in the past. Such greater responsiveness could materialise to the extent that the high and prospectively higher oil price led consumers to switch to alternative energy sources and producers to scale up supply of alternatives to conventional oil more strongly than in the past.

- The price increase would be associated with a rise in total oil supply by around 14 million barrels per day. The additional supply is likely to come from unconventional resources such as Canadian oil sands and US oil shale. If oil supply were to increase by respectively 1.3 and 2 million barrels per day less than in the baseline (which corresponds to the growth of the Canadian production of oil sands or the US production of shale oil between now and 2020), the oil price would increase by respectively 10 USD and 15 USD more.

- These projections abstract from potential nonlinearities in the impact of oil price changes on oil supply and demand. In practice, the impact of oil price changes may depend on the level of the price. If the price-sensitivity of oil demand and supply were to double at a price of 140 USD of Brent crude, the oil price would increase to slightly above 160 USD per barrel by 2020, which is markedly lower than the mid-range projection of 190 USD implied by a baseline scenario.

- A phasing out of fossil fuel subsidies to consumers in non-OECD countries would further reduce the projected price increase.

- The projected oil price paths are also sensitive to world economic growth prospects. For example, if both OECD and non-OECD economies grew each year one percentage point more (less) than in the baseline scenario, the analysis suggests that the oil price could end up about 40 USD higher (lower) in 2020.

- A trend increase in oil prices would not necessarily be smooth as sudden changes in the supply or demand of oil can have very large short-run effects on the price.

3. The remainder of this paper is structured as follows. Section 2 first discusses the drivers behind the oil price increase observed in the decade to 2010, looking at both demand- and supply-side factors. Section 3 then outlines a simple stylised framework of world oil demand which is used to motivate the empirical work. Section 4 presents an empirical analysis of oil demand, and Section 5 combines these estimation results with assumptions about the behaviour of oil supply to derive a set of scenarios for the future oil price path.

2. The factors behind the upward trend in the oil price

4. The oil price is determined by demand and supply, both of which depend on numerous factors including the expectations of developments in the oil price itself. In the short run, demand and supply hardly react to price changes. Adjustments on the demand side are hindered by the lack of readily available substitutes (for a recent meta-analysis of the literature on interfuel substitution see *e.g.* Stern, 2012). Switching from oil to alternative energy sources such as gas or coal requires investments, which take time to be put in place.[2] Especially in the transport sector, which accounts for half of world primary oil demand, substitution possibilities are limited in the short run (IEA, 2011).

5. Although inventory movements can largely balance changes in oil demand in the very short run, persistent changes in demand require an adjustment of production. Downward adjustments are technically fairly easy to implement (though the associated revenue losses may entail budgetary problems for the governments in producing countries), but upward adjustment of production are rather difficult due to small spare capacity combined with long lead times associated with the build-up of capacity to extract and refine oil. Lack of short-term adjustment on both the demand and supply side makes oil prices intrinsically volatile, over and above any possible role of speculation.[3] Changes in oil demand (*e.g.* the drop in 2008 caused by the global economic crisis) or supply (*e.g.* the fall caused by the Iraq war in 2003) led to sizable price reactions in the past.

6. In the medium to long run, demand and supply are more flexible. To understand the factors that drive oil demand at these horizons, it is useful to think of it as the product of three components: (*i*) the GDP per capita level of the economy considered; (*ii*) the size of its population; and (*iii*) its oil

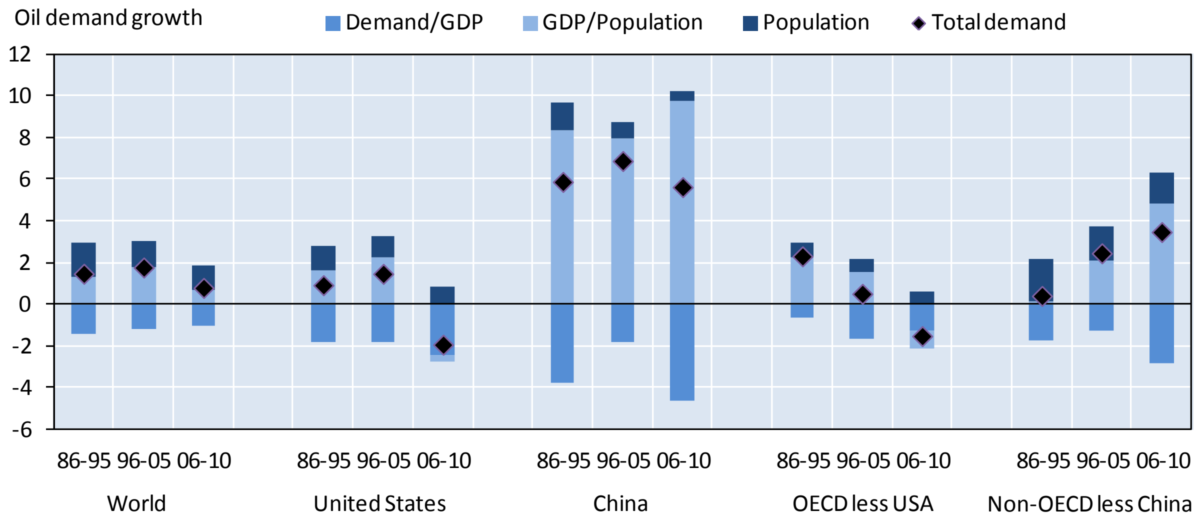
2. For example, switching from oil to another source of energy may involve building new plants for electricity generation, replacing durable consumer goods (*e.g.* moving towards electric or hybrid cars), and adapting networks (*e.g.* developing gas pipelines).

3. Most studies in fact conclude that speculation neither raises the volatility of the oil price nor creates oil price bubbles (*e.g.* Irwin and Sanders, 2010; Iwarson 2012). Also the literature reviews by Fattouh *et al*. (2012) and IMF (2011*a*) argue that the evidence does not point to an important role of speculation in driving the price of oil.

intensity, *i.e.* the volume of oil consumed for each dollar of GDP (Figure 2).[4] Fast growing GDP per capita in some of the emerging economies have been the single main driver of rising oil demand over recent decades. Demographics also pushed up world oil demand, owing largely to strong population growth in the developing and emerging world. The effects of rising living standards and demographics were only partly offset by a fall in oil intensity, which was particularly rapid in several emerging and developing economies. Overall, world demand for oil rose by around 14% over the decade to 2010, with non-OECD countries fully accounting for this increase as demand in OECD countries actually fell (Figure 3).

Figure 2. **Improvements in world living standards have been the main driver of rising oil demand**

So-called Kaya decomposition of annual oil demand growth (in per cent)



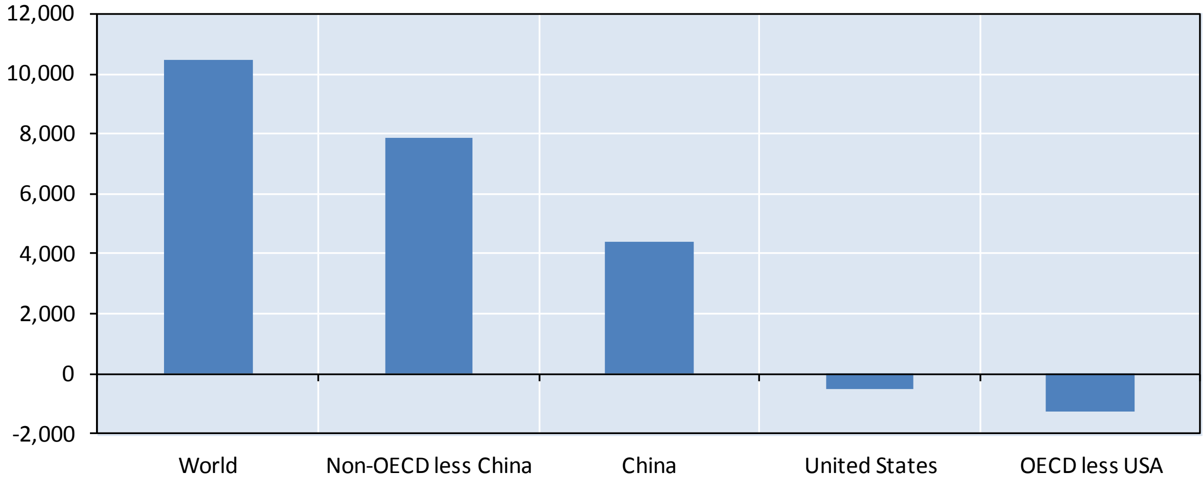
Note: The decomposition is based on the following relationship: oil demand = oil demand/GDP * GDP/population * population. The contribution of the cross terms that emerge when looking at growth rates is not shown in the chart, but as a result of these cross terms the three bars do not sum exactly to total oil demand growth.

Source: IEA World Energy Statistics and World Development Indicators database.

4. For a further discussion of the drivers of oil price movements over the past decade, see Wurzel *et al.* (2009).

Figure 3. **Emerging economies fully account for the trend rise in world oil demand**

Change in oil demand in thousand barrels per day, 2001-2010



Source: IEA World Energy Statistics.

7. The fall in oil intensity reflected a combination of different factors:

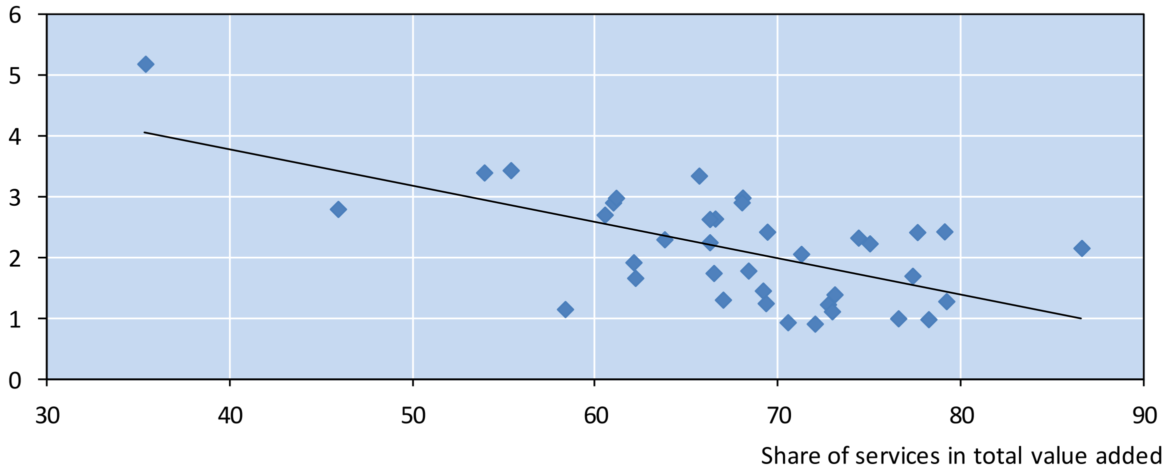
- Amidst energy security and environmental concerns, governments strengthened their efforts to curb oil demand through fuel efficiency standards, removal of end-user subsidies, higher energy taxes and support for alternative energy sources such as biofuels and renewable-based electricity. This contributed to lowering the oil intensity of production.

- High (and rising) oil prices encouraged consumers and companies to gradually move towards alternative energy sources and to implement technological improvements that reduced their reliance on oil.

- A shift of world output away from manufacturing and towards services may also have reduced the demand for oil (Figure 4). A major exception was transport services, which are very oil-intensive and for which demand rose due to greater demand for personal mobility and freight services.

Figure 4. **A country's oil intensity depends on the sector composition of its economy**

Oil demand (in thousand barrels per day) per unit of GDP (in 2011 USD), 2010 or latest available year

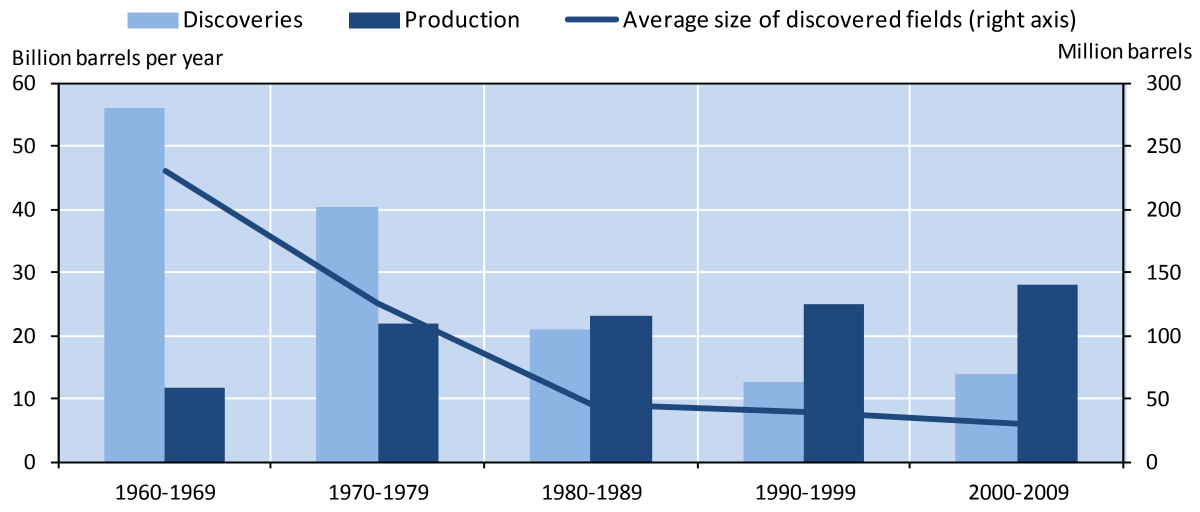


Source: IEA World Energy Statistics and World Development Indicators database.

8. The responsiveness of supply to price changes should also rise with the length of the time horizon as it takes time for producers to put more oil on the market. Although conventional oil discoveries picked up recently amidst persistently high oil prices, they fell short of production by a considerable amount. During 2000-09, only one out of every two barrels produced was replaced by new discoveries (Figure 5). Development of new production capacity has become more costly over time – according to the International Energy Agency, worldwide costs have doubled over the past decade (IEA, 2011) – as easily accessible resources have been depleted and development has moved to resources with less favourable geology or in more remote locations (*e.g.* offshore oil fields). The average size of conventional discoveries has been on a trend decline for several decades, even though some larger fields have recently been found in deepwater locations. Unconventional supply has surged in recent years – mainly from light tight oil in the United States and oil sands in Canada, natural gas liquids, and deepwater production in Brazil – and now accounts for almost 5% of total oil production.

9. A complicating factor on the supply side is the absence of a perfectly competitive market. Strategic behaviour by the Organisation of Petroleum Exporting Countries (OPEC) – which accounts for about 40% of current oil production and about 70% of proven reserves – plays a complex role. If the group were to maximise its profit, production should be set such that the marginal revenue of the group equals its marginal cost. However, as each member is just a small fraction of the group this would imply that the marginal revenue of each member would be higher than its marginal cost. Each member thus has an incentive to cheat and, as demonstrated by Hamilton (2009), the link between quotas and actual production is indeed far from perfect in practice. More generally the empirical literature provides little evidence for the cartel hypothesis (see Alhajji and Huettner, 2000, for an overview) while at the same time rejecting the hypothesis of a competitive market as well (*e.g.* Smith, 2005). Overall, OPEC thus seems to be an imperfect cartel that achieves its goals only partially, but which has proven to be a key actor in particular circumstances. Besides, production levels in exporting countries may not only be determined by price-cost considerations but also by the desire to address government spending concerns (*e.g.* Jadwa Investment, 2011).

Figure 5. **Conventional oil discoveries are falling short of production**



Source: IEA (2010), *World Energy Outlook 2010*, OECD/IEA, Paris.

10. Another important consideration on the supply side is a segmentation of the oil market that has become visible since the end of 2010, with the price for WTI persistently undercutting the price of crude Brent. High stocks at the WTI delivery point are the main driver of the gap, with limited pipeline capacity preventing larger outgoing deliveries. Refiners with pipeline access to WTI crude in the US Midwest thus enjoy discounts, unlike refiners in Europe and elsewhere.

11. The total volume of oil that will eventually become available for production is crucial to long-run oil prices but also highly uncertain. *First*, the volume of oil that is still in the ground is known only vaguely. *Second*, how much of that volume will eventually prove to be commercially producible is unclear; it depends on technology, which will improve, and the price of oil, which will most likely rise. The International Energy Agency estimates remaining recoverable conventional resources (*i.e.* crude oil and natural gas liquids that are likely to be commercially producible at some point in the future) at 2.7 trillion barrels worldwide, or about 80 years of current production. The size of unconventional recoverable resources may amount to another 3.2 trillion barrels (IEA, 2012a). These include extra-heavy oil and bitumen from oil sands (59% of all unconventional recoverable resources), kerogen oil produced by industrial heat treatment of shale (34%) and light tight oil produced from shale or other very low permeability rocks through hydraulic fracturing (7%).

12. While resource depletion does not seem to have been a major factor behind oil price movements in the past, this may be about to change as argued by Hamilton (2009). In this sense the Hotelling rule (Hotelling, 1931), according to which the price of an exhaustible resource should exceed marginal cost even if the market is perfectly competitive, may become relevant. Since the price of an exhaustible resource should increase over time, producers have an incentive to produce less today in order to produce more tomorrow when it can be sold at a higher price.[5] Hamilton (2009) argues that the pressure to preserve resources for the future has started to increase in some countries

5. Specifically, the Hotelling rule establishes that the price p of the resource grows at the rate $r(1 - c/p)$ where r denotes the real interest rate and c the marginal cost. As c/p decreases with the rise in p, the growth rate of the price of the resource is rising towards the level of the real interest rate. This implication is inconsistent with the recent history when pricing were growing at rates above the real rate of interest.

such as Kuwait. If such behaviour is shared by a large proportion of producers, the current price of oil may already reflect a rising scarcity rent.

3. A stylised framework of world oil demand

13. This section provides a simple theoretical framework of the demand side of the oil market, which forms the basis for the empirical approach taken later on.[6] The framework is static in nature and relies on the assumption that oil is used both as a production factor and for final consumption. For simplicity, oil is assumed to be the unique source of energy in a set up where the world consists of a large number of small open economies that take the oil price as given.

2.1.1. Oil as a factor of production

14. In each country c, companies produce a final good Y_c with a technology that makes use of three complementary production factors: oil, capital and labor. Specifically, production is modeled by a two-level nested Constant Elasticity of Substitution (CES) production function. The first level is defined as follows:

$$(1) \qquad Y_c = A_c \left[\alpha_{KE,c} (KE)_c^{\frac{\sigma_{Y,c}-1}{\sigma_{Y,c}}} + (1 - \alpha_{KE,c}) L_c^{\frac{\sigma_{Y,c}-1}{\sigma_{Y,c}}} \right]^{\frac{\sigma_{Y,c}}{\sigma_{Y,c}-1}}$$

where A_c is a uniform technology shifter, $(KE)_c$ is a bundle of capital and energy – which here includes only oil – and which is defined below by the second stage of the CES production function, and $\alpha_{KE,c}$ its share in the production function, L_c is the exogenous supply of labor, and $\sigma_{Y,c}$ is the elasticity of substitution between the capital-energy bundle and labour.

15. At the second level, the $(KE)_c$ bundle itself is modeled as a CES function of capital and oil:

$$(2) \qquad (KE)_c = \left[\alpha_{E,c} E_c^{\frac{\sigma_{KE,c}-1}{\sigma_{KE,c}}} + (1 - \alpha_{E,c}) K_c^{\frac{\sigma_{KE,c}-1}{\sigma_{KE,c}}} \right]^{\frac{\sigma_{KE,c}}{\sigma_{KE,c}-1}}$$

where E_c is oil, $\alpha_{E,c}$ its share in the bundle, K_c capital, and $\sigma_{KE,c}$ the elasticity of substitution between energy and capital. To the extent that labour and energy are complementary $\sigma_{KE,c}$ will be smaller than unity. The parameters $\alpha_{E,c}$ and $\alpha_{KE,c}$ reflect the economy's oil intensity, which is likely to decline over time as the technology improves.

16. The profit of firms is defined as follows:

$$(3) \qquad \pi_c = Y_c - rK_c - P_{oil} E_c - w_c L_c$$

where P_{oil} is the price of oil in domestic currency, r is the interest rate and w_c is the wage. The final good is used as the numeraire.

17. Assuming that firms take all relative prices as given, profit maximisation determines a first equation for the price of energy that can be computed in two steps:

6. The framework presented in this section draws on a (substantially) simplified version of the comprehensive LINKAGE model outlined in Van der Mensbrugghe (2005) and Burniaux and Chateau (2008).

$$(4)\qquad E_c = \alpha_{E,c}^{\sigma_{KE,c}} (KE)_c \left(\frac{P_{KE,c}}{P_{oil}}\right)^{\sigma_{KE,c}} = \alpha_{E,c}^{\sigma_{KE,c}} \alpha_{KE,c}^{\sigma_{Y,c}} A_c^{-1} Y_c \left(\frac{1}{P_{KE,c}}\right)^{\sigma_{Y,c}} \left(\frac{P_{KE,c}}{P_{oil}}\right)^{\sigma_{KE,c}}$$

where the price of the bundle is defined by $P_{KE,c}(KE)_c = rK_c + P_{oil}E_c$. The first line of equation (4) reflects the optimisation of the use of oil within the capital-oil bundle and the second line the optimisation of the use of the capital-oil bundle within the whole range of production factors. The demand for oil as a factor of production is thus a decreasing function of the oil price. The slope of this relationship depends on the elasticities of substitution between the production factors, while output and technology (where technology depends on overall productivity A_c and energy efficiency, which is captured by $\alpha_{E,c}$ and $\alpha_{KE,c}$) shift it.

2.1.2. Oil as a consumption good

18. Household consumption is determined by a representative consumer who maximises his utility, which is a weighted average of the consumption of oil $C_{oil,c}$, the consumption of the final good $C_{f,c}$, and real saving S_c/P_c^S (the treatment of saving as a good in itself follows the extended linear expenditure system developed by Lluch, 1973):[7]

$$(5)\qquad \max U = \mu_{oil,c} \ln C_{oil,c} + \mu_{f,c} \ln C_{f,c} + \mu_s \ln\left(\frac{S_c}{P_c^S}\right)$$

where $\mu_{oil,c}$, $\mu_{f,c}$ and $\mu_{s,c}$ are preference parameters which are assumed to sum to unity. Maximisation of equation (5) is subject to the following budget constraint where the final good serves as numeraire:

$$(6)\qquad P_{oil}C_{oil,c} + C_{f,c} + S_c = Y_{d,c}$$

where $Y_{d,c}$ denotes the consumer's nominal disposable income.

19. Solving this maximisation problem yields the following expression for the demand of oil as consumption good:

$$(7)\qquad C_{oil,c} = \frac{\mu_{oil,c}}{P_{oil}} Y_{d,c}$$

The demand for oil thus depends on the real price of oil, the level of national disposable income, and the preferences of the consumer as measured by the share $\mu_{oil,c}$. While not shown in this simplified framework, the price elasticity of oil demand depends on the elasticities of substitution between oil and other sources of energy so that the latter are implicitly included in the framework.

2.1.3. World oil demand

20. World oil demand is obtained by first aggregating at the country and then at the world level. The total demand for oil D_c in country *c* is the sum of the demand for oil as a production factor and the demand for oil as consumption good:

$$(8)\qquad D_c = E_c + C_{oil,c} = \alpha_{E,c}^{\sigma_{KE,c}} \alpha_{KE,c}^{\sigma_{Y,c}} A_c^{-1} Y_c \left(\frac{1}{P_{KE,c}}\right)^{\sigma_{Y,c}} \left(\frac{P_{KE,c}}{P_{oil}}\right)^{\sigma_{KE,c}} + \frac{\mu_{oil,c}}{P_{oil}} Y_{d,c}$$

7. The minimum consumption level is set to zero for simplicity.

Aggregating across countries yields the following expression for world oil demand:

$$(9) \qquad D = \sum_c \left(E_c + C_{oil,c}\right) = \sum_c \left(\alpha_{E,c}^{\sigma_{KE,c}} \alpha_{KE,c}^{\sigma_{Y,c}} A_c{}^{-1} Y_c \left(\frac{1}{P_{KE,c}}\right)^{\sigma_{Y,c}} \left(\frac{P_{KE,c}}{P_{oil}}\right)^{\sigma_{KE,c}} + \frac{\mu_{oil,c}}{P_{oil}} Y_{d,c}\right)$$

21. While equation (9) provides a simple representation of world oil demand, long-run price and income elasticities are not explicit. To obtain a simple and explicit expression for these long-run elasticities, aggregation is alternatively done in first differences. *First*, at the country level, the growth rate of aggregate oil demand is expressed as a weighted sum of the growth rates of oil demand for production and consumption purposes:

$$(10) \qquad \frac{\Delta D_c}{D_c} = \frac{E_c}{D_c} . \frac{\Delta E_c}{E_c} + \frac{C_{oil,c}}{D_c} . \frac{\Delta C_{oil,c}}{C_{oil,c}} \quad \text{or} \quad \Delta \log(D_c) \approx \frac{E_c}{D_c} . \Delta \log(E_c) + \frac{C_{oil,c}}{D_c} . \Delta \log\left(C_{oil,c}\right)$$

22. Using equations (4) and (7), the growth rate of oil demand in country c is then given by:

$$(11) \qquad \Delta \log(D_c) \approx \underbrace{\frac{E_c}{D_c} . \Delta \log\left(\alpha_{E,c}^{\sigma_{KE,c}} \alpha_{KE,c}^{\sigma_{Y,c}} A_c{}^{\sigma_{Y,c}-1} \left(\frac{1}{P_{KE,c}}\right)^{\sigma_{Y,c}} P_{KE,c}{}^{\sigma_{KE,c}}\right) + \frac{C_{oil,c}}{D_c} . \Delta \log\left(\mu_{oil,c}\right)}_{\alpha_c}$$

$$\underbrace{-\left(\frac{E_c}{D_c}\sigma_{KE,c} + \frac{C_{oil,c}}{D_c}\right)}_{\beta_c} . \Delta \log(P_{oil}) + \frac{E_c}{D_c} . \Delta \log(Y_c) + \frac{C_{oil,c}}{D_c} . \Delta \log\left(Y_{d,c}\right)$$

23. The long-run price elasticity of the country's demand for oil, denoted β_c, depends on the shares of oil in total demand, *i.e.* E_c/D_c and $C_{oil,c}/D_c$, and the elasticity of substitution between energy and capital, *i.e.* $\sigma_{KE,c}$. The long-run income elasticity of oil demand is equal to unity, provided the share of consumption in production does not change over time so that the output of the final good Y_c and disposable income $Y_{d,c}$ grow at the same rate. This result reflects the assumption of constant returns to scale in the CES production function. Relaxing this assumption and allowing returns to scale to rise in output would reduce the long-run income elasticity to below unity. In this simplified framework, the economy's level of technology A_c and its energy efficiency (captured by the terms $\alpha_{E,c}$ and $\alpha_{KE,c}$) are included in the constant α_c.

24. World oil demand growth is obtained by aggregating all country-specific equations, similarly to the aggregation used to derive equation (10):

$$(12) \qquad \frac{\Delta D}{D} \approx \sum_c \alpha_c \frac{D_c}{D} + \sum_c \beta_c \frac{D_c}{D} \frac{\Delta P_{oil}}{P_{oil}} + \sum_c \frac{E_c}{D} \Delta \log(Y_c) + \sum_c \frac{C_{oil,c}}{D} \Delta \log\left(Y_{d,c}\right)$$

The long-run income and price elasticities of world demand are thus weighted averages of all country-specific elasticities under the first-order approximation $\frac{\Delta D}{D} \approx \Delta \log(D)$.

4. Empirical analysis of the determinants of oil demand

4.1. Methodology

25. The specification that underlies the empirical analysis of oil demand is motivated by the theoretical framework described in Section 4, more precisely by equation (11). The specification links the demand for oil in a given country or region to the price of oil and the country's or region's real GDP. In addition to this long-run relationship, the empirical setup accounts for short-run rigidities and

adjustment costs (which are ignored in the theoretical framework presented in Section 4 for reasons of simplicity) by including short-run dynamic terms in the specification. The resulting error correction model has the additional advantage of accounting for the unit-root properties of the time series (as shown in Tables A.1 to A.4 in the Annex the overwhelming majority of the time series have a unit root). Specifically, the estimated specification takes the following form:

$$\Delta D_{i,t} = \alpha_i\left(D_{i,t-1} - \beta_{i,P}P_{t-1} - \beta_{i,Y}Y_{i,t-1} - \beta_{i,0}\right) + \sum_{j=1}^{k}\gamma_{i,D}^{j}\Delta D_{i,t-j} + \sum_{j=0}^{k}\gamma_{i,P}^{j}\Delta P_{t-j} + \sum_{j=0}^{k}\gamma_{i,Y}^{j}\Delta Y_{i,t-j} + \varepsilon_{i,t} \quad (13)$$

where D is logarithm of total oil demand in thousand barrels per day, P is the logarithm of the real price of Brent crude, measured in 2005 US dollars (the US CPI is used as a deflator), Y is the logarithm of real GDP in 2005 PPP US dollars and the subscripts i and t denote country/region and time. The number of short-run lags included in the specification depends on the frequency of the data used in the estimation. When estimating equation (11) with annual data, a maximum of two short-run lags is included; for quarterly estimations the maximum number of lags is four. Insignificant short-run terms are deleted in a stepwise procedure, starting with the least significant term and continuing until all terms are significant at the 10% level. To account for the endogeneity of the oil price in the demand equation, estimation is done with instrumental variables, using a two-stage least squares (TSLS) estimator. Total proven world oil reserves, the US producer price index for oil and gas field machinery/ equipment and the US producer price index for drilling oil and gas (all in logarithms) are used as instruments for the price of Brent crude.[8,9] OLS regressions are also run for means of comparison.

26. Equation (13) is estimated for five countries (the United States, Japan, China, India, and Indonesia) and three regions of the world (the European Union, other OECD countries, and the rest of the world).[10] Aggregates for the three groups are calculated by chain-linking growth rates using countries' GDP shares as weights.[11] Since the aggregation of countries into groups requires a common currency denomination, the estimation relies on the real Brent price in US dollars instead of local currency units as would be suggested by the model presented in the previous section. Expressing the real oil price in US dollars instead of national currency units would not be problematic in so far as purchasing power parity held, which is more likely to be the case in the medium to long-run. The equation is estimated both on a quarterly and an annual basis. The exact sample periods vary by country/region; the maximum time span covered is 1983 to 2011 for the annual estimations (all OECD countries and India) and 1987 to 2011 for the quarterly ones (United States, Japan, and the European Union).

8. The annual specifications only include total world oil reserves and cost data on oil field machinery as instruments, and not, as in the quarterly specifications, cost data on oil drilling, as this series is not available for a long time period.

9. The number of instruments exceeds the number of endogenous regressors. However, the Hanson J-statistic for overidentifying restrictions generally indicates that the estimated models are valid.

10. The group of EU countries includes Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. The group of other OECD countries includes Australia, Canada, Chile, Island, Israel, Korea, Mexico, New Zealand, Norway, Switzerland, Turkey and the rest of the world includes all countries which are not included in any other group and for which all necessary data are available.

11. Due to differences in data availability across countries, a specific aggregate is not computed when available country coverage falls below 2/3 for the zone in terms of 2005 GDP.

27. Estimating equation (13) on a country-by-country basis poses problems in the case of areas. In particular, it is not possible to express the price of oil in local currency units and to account for cross-country heterogeneity in the constant. To overcome these deficiencies, equation (13) is also estimated for three panels of countries (OECD countries, the BRIICS and the rest of the world), varying the currency in which the price variable is denominated. In each of the three panel estimations, the slope coefficients are constrained to be identical across countries. A two-stage-least squares estimator is then applied, using the same set of instruments as discussed above.

28. Data on total oil demand are taken from the *World Energy Statistics Database* of the IEA and represent the sum of several oil products, including both conventional and non-conventional oil.[12] The price of crude Brent is taken from the *Energy Prices and Taxes Statistics Database* of the IEA, total world oil reserves from the *Energy Database* of the Oil & Gas Journal, and the US producer price indices for oil and gas field machinery/equipment as well as for drilling oil and gas from the Bureau of Labor Statistics of the United States Department of Labor. Data on real GDP, CPI inflation and exchange rates are taken from the autumn-2011 edition of the *OECD Economic Outlook* for OECD and BRIICS countries and from the *World Development Indicators Database* of the World Bank for all other countries.[13]

4.2. Estimation results

29. Tables 1 and 2 provide an overview of the short and long-run price and income elasticities implied by the various estimations.[14,15] The error correction coefficient is not significant at conventional significance levels in most specifications when applying the critical values by Banerjee *et al.* (1998), meaning that the variables of interest are not cointegrated. However, this type of test is known to suffer from low power and indeed, several other tests point towards a cointegrating relationship (see Table A.7 in the Annex). Therefore, one can still conclude that the estimated equations can be interpreted in a meaningful way.

30. Oil demand is found to be more responsive to GDP in emerging than in OECD countries (Table 4), meaning that oil intensity is falling faster in the former group of countries. The long-run income elasticities obtained for China, India and Indonesia are not significantly different from unity, while OECD countries tend to have elasticities closer to one-half. Comparing these elasticities with existing evidence suggests that the elasticities found for OECD countries are roughly in line with the literature, while the elasticities found for non-OECD countries are in the upper range of the values

12. Specifically, total oil demand is defined as sum of natural gas liquids, liquefied petroleum gas, naphtha, motor gasoline, aviation fuels, other kerosene, gas/diesel oil, fuel oil, and other products such as bitumen.

13. Non-OECD non-BRIICS countries for which not all necessary data are available are ignored in the analysis.

14. Tables A.5 and A.6 in the Annex give further details on the annual and quarterly TSLS regressions obtained at the region/country level and Figures A.1 and A.2 in the Annex show the goodness of fit of these regressions.

15. While the lag deletion process varies considerably across countries and regions, all but one regressions have in common that the highest lag is insignificant, supporting the choice to initially include with a maximum of four lags in the quarterly specifications and a maximum of two lags in the annual specifications. Short-run elasticities are calculated as $\varepsilon_{i,Y} = \left(\sum_{j=0}^{k} \gamma_{i,Y}^{j}\right) / \left(1 - \sum_{j=1}^{k} \gamma_{i,D}^{j}\right)$ and $\varepsilon_{i,P} = \left(\sum_{j=0}^{k} \gamma_{i,P}^{j}\right) / \left(1 - \sum_{j=1}^{k} \gamma_{i,D}^{j}\right)$.

reported by other studies (Table 3).[16] For the short-run elasticities the estimation results reported in Tables 1 and 2 reveal a high degree of cross-country heterogeneity. For some countries, the short-run income elasticity is not statistically different from zero, while for others it is significantly positive and often much higher than the corresponding long-run elasticity.

31. While demand is very price-inelastic in the short run – in the majority of countries the short-run elasticity is not significantly different from zero – demand tends to fall in response to a higher oil price in the medium to long run. The only exception is the rest-of-world group, for which neither the quarterly nor the annual specification yields a negative price elasticity. Potential reasons for this include poor data quality for most of the countries in this group and the inclusion of oil-exporters. On average across OECD and BRIICS countries, a one percent rise in the price of Brent crude is found to reduce demand by one-fifth of a per cent in the medium to long run according to the TSLS estimates on annual data.[17] This figure is in line with – although in the bottom half of – the existing empirical evidence as most studies report long-run price elasticities between zero and -0.6 (Table 3).[18] Studies that report the largest elasticities generally include the 1970s in the sample period, suggesting that price elasticities have declined over time. In fact, when extending the sample period for OECD countries to the 1970s in the panel estimation approach, the price elasticity rises considerably. A recent study by the IMF also suggests that the price elasticity was higher during the 1960s and 1970s than in later decades (IMF, 2011*b*).[19] In light of this, the elasticities estimated here can be considered as falling roughly in the middle of the range of estimates when excluding the 1960s-1970s.[20] For the short-run elasticities, almost all studies conclude that they are small, but many of them find that they are nonetheless significantly negative. This stands in contrast to the present study and suggests that the results reported here may understate the dynamics at work and therefore need to be interpreted with caution.

32. Contrasting the OLS results (specifications I and III in Tables 1 and 2) to those obtained with the TSLS estimator (specifications II and IV) shows that dealing with the endogeneity of the Brent crude price leads, as expected, to higher price elasticities. The difference is fairly small, however. While this may mean that the bias is small in practice, it could also be due to the fact that the chosen instruments are fairly weak as indicated by the Cragg-Donald F-statistic for the first-stage regression.

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16. This comparison with the literature needs to be taken with care as most papers specify the oil demand equation in per capita terms.

17. For China, Indonesia and the group of other OECD countries only the regressions at annual frequency yield a price elasticity that is significant at conventional significance levels.

18. To make the comparison meaningful, only studies that use the price of crude oil are considered. The reaction of consumers and companies to changes in the price of crude oil is smaller than their reaction to changes in the prices of oil products due to taxes as well as refining and trade costs. Studies that build on the prices of oil products thus mechanically yield higher price elasticities.

19. Interestingly, this study provides some evidence that demand may have become almost inelastic to the oil price in the long run in non-OECD countries. This is also confirmed by Dargay and Gately (2010) for China or Russia. While this may reflect subsidies in these countries that distort the price signal, it should be noted that China largely abandoned its end-user subsidies in 2008.

20. The sensitivity of the price elasticity to the sample period might be due to a non-linear reaction of demand. The efficiency gains that are associated with the technological improvements triggered by higher oil prices largely remain in place even after oil prices fall from their peak. Oil demand may thus not only depend on the current price level, but also on the level of the latest price peak as argued for instance by Gately and Huntington (2002) and Dargay and Gately (2010). Furthermore, the development of more oil-efficient technologies may not to be triggered by small price shifts due to the substantial fixed costs involved.

However, the chosen instruments still seem to be the best available, and in fact that OLS estimates fall somewhat below the IV estimates as expected is reassuring.[21]

33. Detailed results for the panel estimations are shown in Tables A.8 and A.9 in the Annex. While the long-run income elasticity for the BRIICS panel is near the average elasticity obtained for India, China and Indonesia in the country/region-level regressions, the elasticities obtained for the OECD and the rest-of-world panels are higher and in fact very similar to that of the BRIICS panel. For the OECD panel, the price elasticity of oil demand is very close to the average across all OECD countries and regions obtained in the TSLS times-series regressions (specifications II and IV in Table 1), irrespective of the frequency of the data and of whether the oil price is specified in US dollar or local currency units. For the other two panels, the long-run price elasticity is not statistically significant with the exception of the specification using annual data and the price in US dollars. This weak estimated link between oil price and oil demand might be due in part to the importance of oil subsidies in many emerging countries. As for the insignificance of the local-currency price of oil, while it is surprising at first glance, a lower sensitivity of oil demand to the local-currency price rather than to the US-dollar price of oil might make sense to the extent that oil is heavily used in export sectors.

21. Lin (2011), who also employs an instrumental variable approach to estimate the price elasticity of oil demand, instruments the oil price with the total world rig count and world oil reserves, but obtains insignificant or wrongly signed coefficients.

Table 1. Overview of price elasticities

		USA		Japan		European Union		Other OECD		China		India		Indonesia		Rest of World	
		SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
I	OLS	-0.019***	-0.084*	0.021*	-0.213***	-0.018*	-0.088**	0.004	-0.079	0.062***	-0.053	0	-0.236***	0.132***	-0.183	-0.04***	-0.447
	quarterly	(0.006)	(0.042)	(0.012)	(0.031)	(0.01)	(0.039)	(0.011)	(0.285)	(0.022)	(0.066)		(0.069)	(0.038)	(0.112)	(0.014)	(1.697)
II	TSLS	-0.023*	-0.115**	0	-0.248***	0.006	-0.095***	0	-0.061	0.083**	-0.127	0	-0.255***	0.13**	-0.199	-0.001	0.266
	quarterly	(0.013)	(0.058)		(0.037)	(0.032)	(0.033)		(0.241)	(0.036)	(0.082)		(0.069)	(0.065)	(0.15)	(0.024)	(0.178)
III	OLS	-0.024**	-0.09**	0	-0.208***	-0.03**	-0.112**	0	-0.205***	0	-0.148*	0	-0.199***	0	-0.356**	0	0.098
	annually	(0.011)	(0.036)		(0.041)	(0.011)	(0.042)		(0.049)		(0.083)		(0.036)		(0.15)		(0.072)
IV	TSLS	-0.056**	-0.118*	0	-0.229***	-0.102*	-0.103**	0	-0.205***	0	-0.238*	0	-0.171**	0.086*	-0.383***	0	0.13**
	annually	(0.026)	(0.064)		(0.043)	(0.058)	(0.042)		(0.048)		(0.118)		(0.067)	(0.048)	(0.121)		(0.054)

		OECD		BRIICS		ROW	
		SR	LR	SR	LR	SR	LR
V	FE, USD	-0.051***	-0.197***	0	-0.051	-	-
	quarterly	(0.012)	(0.03)		(0.059)		
VI	FE, LC	-0.054***	-0.253***	0	-0.086	-	-
	quarterly	(0.012)	(0.033)		(0.108)		
VII	FE, USD	-0.065***	-0.216***	0	-0.132***	0.044***	-0.141***
	annually	(0.023)	(0.031)		(0.061)	(0.017)	(0.064)
VIII	FE, LC	-0.063***	-0.215***	0	-0.203	0.159***	0.033
	annually	(-0.019)	(0.036)		(0.134)	(0.042)	(0.072)

Note: Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficient. Standard errors are in parentheses. OLS = ordinary least squares estimator, TSLS = two-stage least squares estimator, FE = fixed effects estimator (panel), USD = oil price specified in US dollars, LC = oil price specified in local currency units.

Table 2. Overview of income elasticities

		USA		Japan		European Union		Other OECD		China		India		Indonesia		Rest of World	
		SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
I	OLS	0.803***	0.416***	0.986***	0.447***	0.481***	0.255*	0.346*	-0.556	1.061*	0.737***	0	0.977***	0	1.054***	1.353***	1.457
	quarterly	(0.193)	(0.071)	(0.209)	(0.121)	(0.171)	(0.151)	(0.198)	(2.597)	(0.586)	(0.063)		(0.084)		(0.234)	(0.363)	(3.746)
II	TSLS	0.868***	0.502***	1.279***	0.603***	0	0.344***	0	-0.218	1.885***	0.806***	0	1.014***	0	1.083***	1.053**	0.022
	quarterly	(0.217)	(0.095)	(0.271)	(0.163)		(0.118)		(1.526)	(0.705)	(0.072)		(0.084)		(0.297)	(0.453)	(0.367)
III	OLS	0.921***	0.467***	0	0.018	0.592***	0.362***	0	0.632***	1.384**	0.828***	0	0.902***	0.394**	1.253***	0.911***	0.359**
	annually	(0.159)	(0.065)		(0.122)	(0.185)	(0.069)		(0.07)	(0.57)	(0.076)		(0.035)	(0.154)	(0.234)	(0.253)	(0.145)
IV	TSLS	1.078***	0.58***	0	0.029	1.073**	0.502***	0	0.644***	1.98**	0.903***	0	0.865***	0.406**	1.284***	0.914***	0.304***
	annually	(0.232)	(0.171)		(0.116)	(0.508)	(0.148)		(0.069)	(0.704)	(0.101)		(0.097)	(0.169)	(0.18)	(0.272)	(0.095)

		OECD		BRIICS		ROW	
		SR	LR	SR	LR	SR	LR
V	FE, USD	0.765***	0.745***	0.372***	0.733***	-	-
	quarterly	(0.069)	(0.065)	-0.114	-0.089		
VI	FE, LC	0.721***	0.797***	0.387***	0.752***	-	-
	quarterly	(0.062)	(0.063)	-0.118	-0.118		
VII	FE, USD	0.803***	0.802***	0.419***	0.822***	0.308***	0.806***
	annually	(0.085)	(0.089)	(0.09)	(0.082)	(0.048)	(0.085)
VIII	FE, LC	0.743***	0.703***	0.454***	0.856***	0.469***	0.619***
	annually	(0.068)	(0.084)	(0.103)	(0.148)	(0.099)	(0.096)

Note: Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficient. Standard errors are in parentheses. OLS = ordinary least squares estimator, TSLS = two-stage least squares estimator, FE = fixed effects estimator (panel), USD = oil price specified in US dollars, LC = oil price specified in local currency units.

Table 3. Overview of selected empirical studies of the price and income elasticities of oil demand

	Income elasticity		Oil price elasticity		Source
	Short-run	Long-run	Short-run	Long-run	
United States	0.12^{s}	0.17^{u}	-0.09^{s}	-0.13^{u}	Haas and Schipper (1998), OLS, 1970-1993
	0.77^{s}	0.98^{s}	-0.02^{s}		Dees *et al*. (2007), ECM with time trend, 1984-2002
	0.04^{u}	0.22^{u}	-0.02^{u}	-0.12^{u}	IEA (2006), p.c., 1979-2005, North America
Japan	0.53^{s}	1.02^{u}	-0.10^{s}	-0.19^{u}	Haas, Schipper (1998), OLS, 1970-1993,
	0.69^{s}	0.89^{s}	-0.03^{s}		Dées et al (2007), ECM with time trend, 1984-2002
European Union	0.36^{s}	0.35^{u}	-0.15^{s}	-0.14^{u}	Haas, Schipper (1998), OLS, 1970-1993, simple average over AUT, DNK, FRA, DEU, ITA, SWE, GBR
	0.45^{s}	0.57^{s}	-0.03^{s}		Dees et al (2007), ECM, Euro area, 1984-2002
	0.14^{u}	0.49^{u}	-0.03^{u}	-0.11^{u}	IEA (2006), p.c., 1979 - 2005, OECD Europe
Other OECD countries		-0.18^{s}		-0.59^{s}	Gately and Huntington (2002), OLS, p.c., 1971-1997, OECD
	0.67^{s}	0.24^{s}	-0.03^{s}	-0.10^{s}	IMF (2011*b*), p.c., 1990-2009, OECD panel
	0.70^{s}	-0.39^{s}	-0.04^{s}	-0.58^{s}	IMF (2011*b*), p.c., 1965-2009, OECD panel
	0.00^{ns}	0.39^{s}	-0.01^{ns}		Dées *et al*. (2007), ECM, other developed countries, 1993-2002
	0.08^{u}	0.39^{u}	-0.05^{u}	-0.25^{u}	IEA (2006), p.c., 1979 - 2005, OECD Pacific
		0.80^{s}			Dargay and Gately (2010), OLS, p.c., 1971-2007, OECD
China		0.62^{u}		-0.29^{u}	Gately and Streifel (1997), OLS, 1971-1993
		0.74^{s}		0.00^{ns}	Dargay and Gately (2010), OLS, p.c., 1980-2007
Other non-OECD countries	0.42^{u}	1.10^{u}	-0.07^{u}	-0.16^{u}	Dahl (1993) median elasticities for developing countries (literature review).
		1.16^{u}		0.11^{u}	Gately and Streifel (1997), OLS, 1971-1993, Asia excl. CHN
		0.94^{s}		-0.10^{s}	Gately and Huntington (2002), OLS, p.c., 1971-1997, non-OECD income-growers (excl. CHN and IDN)
	0.09^{u}	0.73^{u}	-0.03^{u}	-0.21^{u}	IEA (2006), p.c., 1979-2005, developing Asia
		0.87^{s}		-0.07^{s}	Dargay and Gately (2010), OLS, p.c., 1971-2007, Income Growers'
		0.84^{s}		-0.16^{s}	Gately and Huntington (2002), OLS, 1971-1997, non-OECD
	0.71^{s}	0.39^{s}	-0.01^{ns}	-0.04^{ns}	IMF (2011*b*), p.c., 1990-2009, non-OECD panel
	0.74^{s}	0.59^{s}	-0.01^{s}	-0.13^{s}	IMF (2011*b*), p.c., 1965-2009, non-OECD panel
	0.00^{ns}	0.51^{s}	-0.02^{s}		Dées *et al*. (2007), ECM with time trend, transition economies, 1995-2002
	0.82^{s}	0.85^{s}	-0.00^{ns}		Dées *et al*. (2007), ECM, Latin America, 1993-2002
	0.44^{u}	0.58^{u}			Dées *et al*. (2007), ECM, rest of world, 1991-2002
		0.43^{s}		0.00^{ns}	Dargay and Gately (2010), OLS, p.c., 1996-2007, Soviet Union.
	0.14^{u}	0.65^{u}	-0.02^{u}	-0.12^{u}	IEA (2006), p.c., 1979-2005, simple average over three groups (Middle East, Latin America, Africa)
		0.24^{s}		-0.25^{s}	Gately and Huntington (2002), OLS, p.c., 1971-1997, non-OECD non-oil exporters non-income-growers
World	0.09^{u}	0.48^{u}	-0.03^{u}	-0.15^{u}	IEA (2006), p.c., 1979-2005

Note: Superscript s denotes statistical significance (threshold set by the authors), superscript ns denotes statistical insignificance, and superscript u denotes unknown significance. p.c. means that the demand equation is specified in per capita terms.

5. Scenario analysis

5.1. Methodology

34. To explore future oil market prospects a scenario analysis is conducted that dynamically simulates the demand for and supply of oil as well as its price up to 2020.[22] On the demand side, the

22. Several papers argue that a simple random walk or a random walk with drift is statistically the best model to project future oil price movements (*e.g.* Hamilton, 2009; Alquist and Kilian, 2010). While such simple models are appealing a priori, macroeconomic analysis that is built on an exogenous oil price might be

simulation makes use of the income and price elasticities presented in the previous section. The long-run elasticities and error correction parameters are taken from the quarterly specification for the United States, Japan, the European Union and India (specification II in Tables 1 and 2) and from the annual specification for China, India and the group of other OECD countries, for which the quarterly specification did not yield significant long-run elasticities (specification IV in Tables 1 and 2).[23] The short-run elasticities are taken from the quarterly specification for all of these regions/countries.[24] As neither the quarterly nor the annual specification yielded usable results for the ROW group, the long-run elasticities are taken from Gately and Huntington (2002), while the short-run elasticities are assumed to be equal to zero and the error correction coefficient is assumed to be equal to the average of the other seven countries/regions.[25] A summary of the demand-side coefficients used in the simulation is provided in Table 4.

Table 4. Key demand-side parameters used in the baseline simulation

	United States	Japan	European Union	Other OECD	China	India	Indonesia	Rest of World
Constant	-0.574	-1.559	-0.084	-0.570	-3.127	-3.007	-3.053	-2.209
EC-term	-0.118	-0.194	-0.179	-0.064	-0.184	-0.151	-0.116	-0.150
Long-run price elasticity	-0.115	-0.248	-0.095	-0.205	-0.238	-0.255	-0.383	-0.160
Long-run income elasticity	0.502	0.603	0.344	0.644	0.903	1.014	1.284	0.840
Short-run price elasticity	-0.023	0.000	0.006	0.000	0.083	0.000	0.130	-0.001
Short-run income elasticity	0.868	1.279	0.000	0.000	1.885	0.000	0.000	1.053

35. For the supply side, a simple error correction framework is imposed with a long-run supply elasticity of 0.2 and a short-run elasticity of 0.05, where supply is defined as including both production and stock variations. Attempts to estimate oil supply equations for different groups of countries did not produce meaningful results and also the literature does not provide any clear guidance on the price elasticity of supply as only few studies exist and those few typically obtain mixed results (*e.g.* Lin, 2011). These difficulties might be related to the existence of a large number of structural breaks in the relationship linked to the discovery of new fields (some of which may involve entirely new types of oil), improvements in extraction techniques and also poor quality of key data such as reserves (Watkins and Streifel, 1998). To overcome this problem some papers (*e.g.* Dées *et al.*, 2007) model the supply of oil using curve-fitting technique along the lines of Hubbert (1962). However, such techniques are inherently difficult and tend to be consistent with a wide range of possible supply paths, particularly if peak production is unknown. In light of these problems, the price elasticity of supply was calibrated so as to obtain a supply/price path that

misleading as argued by Kilian (2009). For example, having an endogenous oil price allows conducting scenario analysis to investigate the impact of changes in the macroeconomic situation or policies.

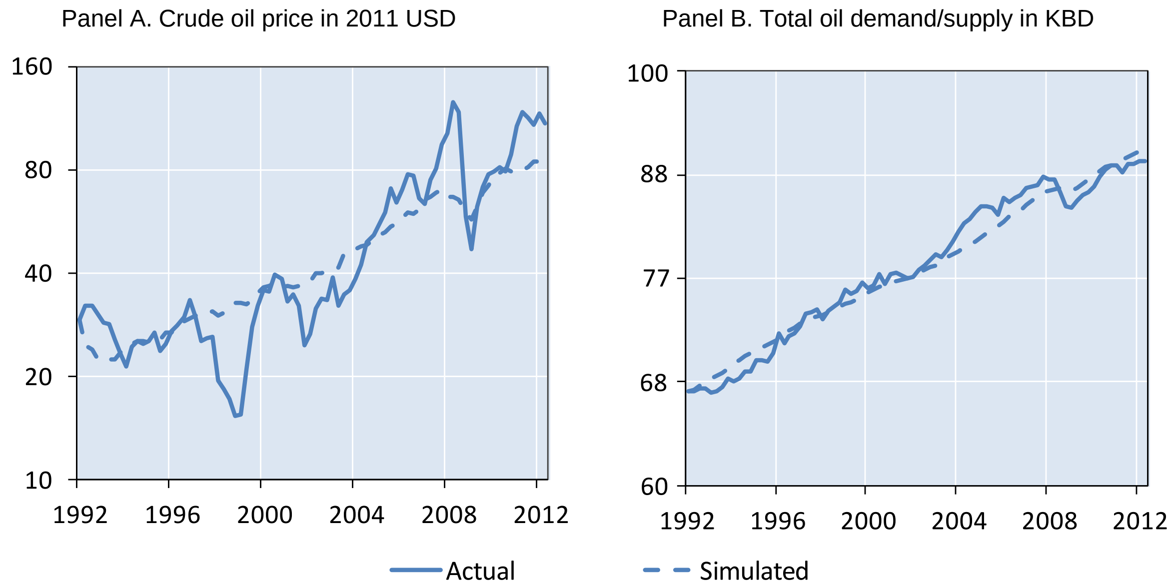
23. When relying on the error correction coefficients of the annual specification these coefficients are adjusted so that the half-life of demand shocks in the quarterly simulation matches the half-life implied by the original annual estimates.

24. Wrongly-signed short-run elasticities are set equal to zero in the simulation.

25. Specifically, the elasticities are taken from the ordinary least square estimates of the specification that includes lagged demand, covers transport oil only and was estimated over the 1971-97.

is broadly in line with history and with what is currently known about investment activity.[26] Following Brook *et al*. (2004) it is implicitly assumed that OPEC countries maintain their market share at current levels.

Figure 6. Dynamic simulation of the oil market model



Note: Logarithmic scaling on the vertical axis.

36. Oil demand, oil supply and the oil price are jointly simulated in a dynamic framework. Starting from the earliest possible quarter given data availability constraints, namely the second quarter of 1992, the model is solved for each quarter of the simulation period using a linearisation which assumes that the variation in oil demand/supply is small relative to its level.[27, 28] The dynamic simulation underestimates oil prices in the second quarter of 2012 (Figure 6).[29] It is assumed that half of this gap reflected a risk premium due to fears of more severe supply shocks in the future.[30] This risk premium (which is assumed equal to about 9% of the price in the second quarter of 2012) is gradually reversed over the simulation period. Any further role of spare capacity shortages and speculative behaviour is ignored in the analysis due to its medium-term focus. The impact of monetary policy is ignored for the same reason. A potential phasing out of fossil fuel subsidies is also not taken into account in these projections but this issue is picked up below.

26. The assumed price elasticities are broadly in line with other studies. For example, the long-run elasticity falls in the lower range of the price elasticities chosen by Gately (2004) (he uses elasticities between 0.15 and 0.58), while the short-run elasticity falls in the upper range (he uses elasticities between 0.03 and 0.05).

27. The error introduced by this approximation proves to be very small.

28. Starting the dynamic simulation already in 1992 (instead of the third quarter of 2012) ensures that recent short-term changes in fundamentals do not influence the medium-run oil price path.

29. In the dynamic simulation, the constants in all demand equations are adjusted so that the residuals from a static simulation over the period 1992Q2 to 2012Q2 sum to zero. This technical fix is needed for all countries/groups for which the simulation relies on coefficients from the annual estimation and is also applied to the other countries/regions for reasons of consistency (though for them, the effect on the simulation results is negligible).

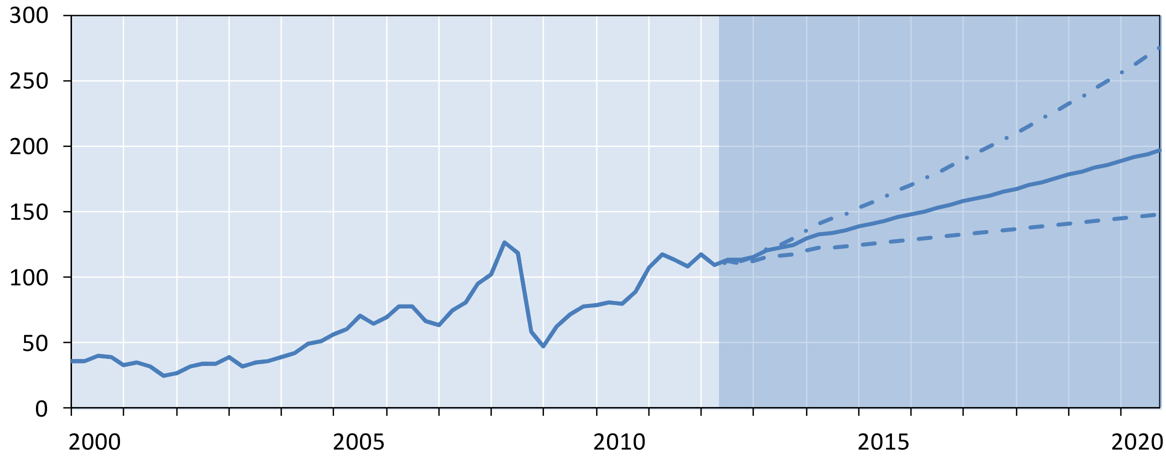
30. Since this assumption is arbitrary, sensitivity analysis is carried out to investigate its importance for the projected oil price path (see below).

5.2. Baseline scenario

37. The analysis suggests that a gradual recovery of world growth would be associated with an increase in the price of crude oil to 190 USD per barrel by 2020, measured in 2011 prices (Figure 7, panel A). This is an increase of about 7% per year. The GDP growth rates that underlie this baseline scenario are taken from the long-term economic scenario of the spring-2012 OECD Economic Outlook. These projections assume the real oil price to increase by 5% per year, which is slightly less than implied by the baseline. To account for this small difference and its implications on potential output, GDP growth rates are adjusted downwards using a production-function framework (Cournède, 2010).[31] Overall, this means that over the period 2011-20 all countries would grow at rates slightly below those of 1998-2007. In 2020, US potential output would be 2.1% lower than under a constant oil price (Table 5). For Japan and Europe the negative feedback effect would be slightly lower, at respectively -1.4% and -1.6%. Reflecting their higher oil intensity of production, emerging countries would suffer more from the oil price increase.[32] The potential output of China, for instance, would be lowered by 3.5% over the projection period. The adjustment is rather crude in that redistributive effects via countries' external positions and exchange rates are disregarded for reasons of simplicity. However, the goal here is not to estimate the GDP impact of higher oil prices but rather, more modestly, to fine-tune the oil price projection by factoring in some GDP feedback effect. The calculations further assume that the downward trend in world oil intensity would continue throughout the simulation period (Figure 8). While this downward trend would materialise even under constant prices, it is slightly exacerbated by the endogenous reaction of oil demand to the price increase.

Figure 7. The projected oil price path is sensitive to underlying elasticities

Panel A. Price of crude oil in 2011 USD



31. The approach by Cournède (2010) is based on a Cobb-Douglas production function so that potential output responds to a change in the real price of oil with the elasticity $\theta/(\theta - 1)$, where θ is the share of oil in production.

32. Note that the feedback effect for the ROW group is calculated on a very small set of countries and might therefore not be representative of the group as a whole. In particular, it does not take into account positive GDP effects that might occur in oil producing countries.

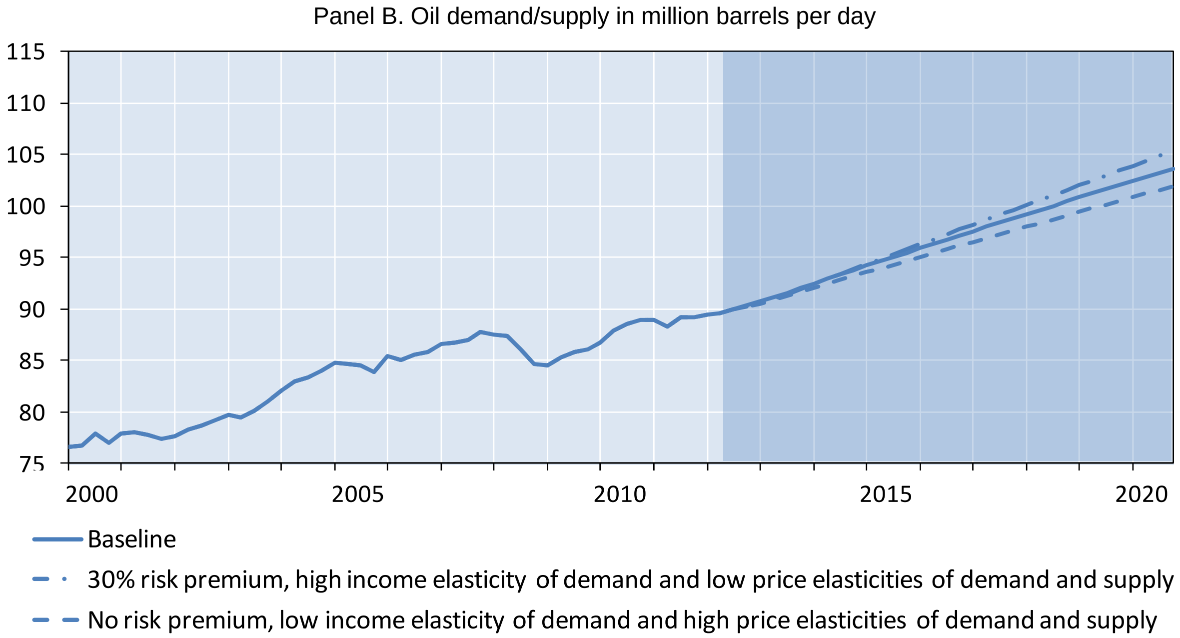


Figure 8. The downward trend in oil intensity is projected to continue

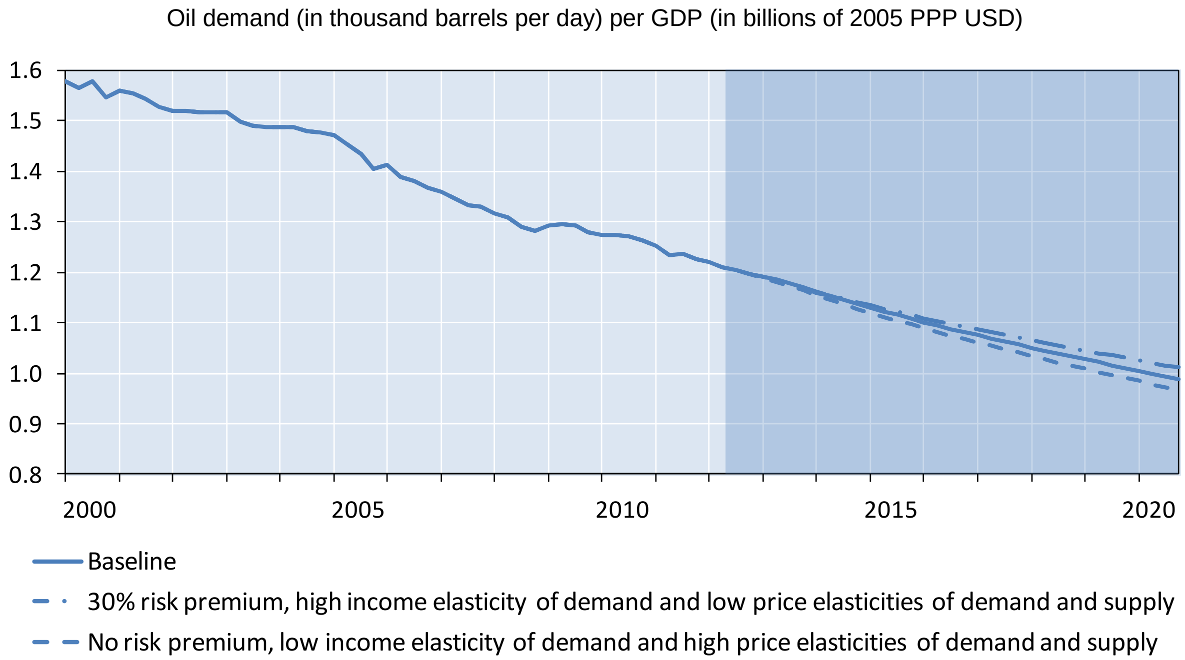


Table 5. Feedback effects of higher oil prices on GDP

Cumulative effect over the period 2011-2020 in per cent

	United States	Japan	European Union	Other OECD	China	India	Indonesia	Rest of World
Baseline	-2.1%	-1.4%	-1.6%	-2.2%	-3.5%	-4.2%	-3.9%	-2.8%
Upper bound	-2.7%	-2.0%	-2.2%	-2.8%	-4.0%	-4.7%	-4.5%	-3.4%
Lower bound	-1.6%	-0.8%	-1.1%	-1.7%	-2.9%	-3.6%	-3.4%	-2.3%

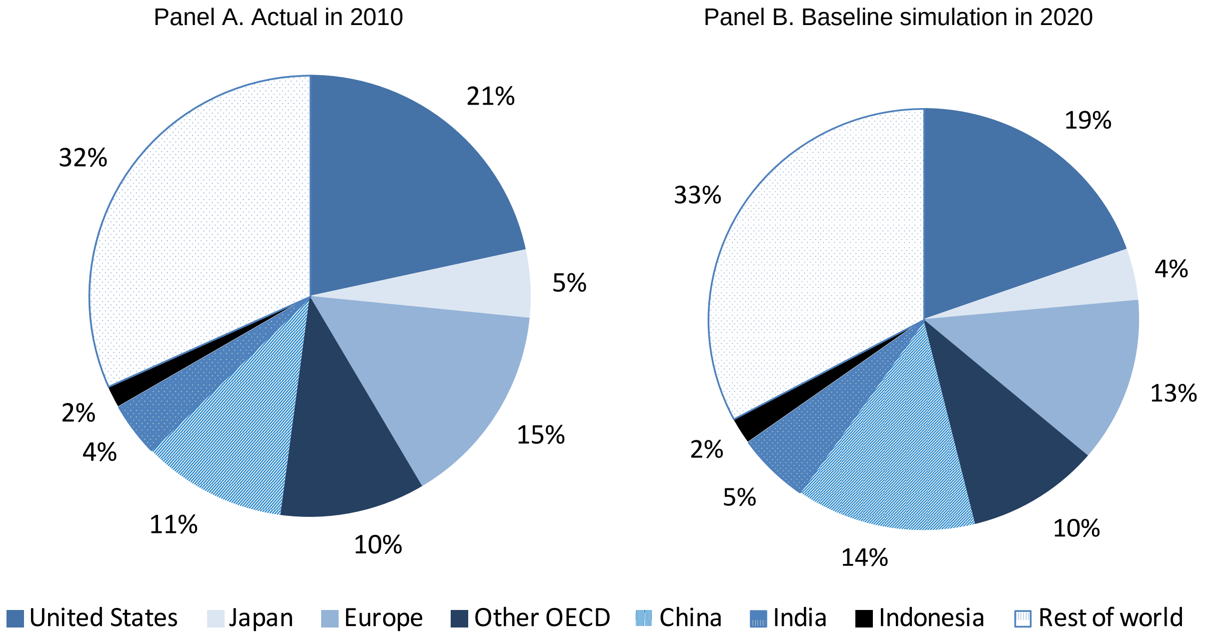
38. In line with recent trends, oil demand would only grow in non-OECD economies, but remain flat in the OECD where efficiency gains roughly offset the GDP growth effect. Oil demand growth would be particularly high in China and India (Table 6). They would account for about half of the rise in world demand – so that their share of world oil demand would reach about one-fifth by 2020 (Figure 9) – and for about two-fifths of the oil price increase. If price and income elasticities of oil demand in the two countries were equal to the OECD average, the latter contribution would be halved, suggesting that the high contribution is equally due to their strong GDP growth and to the high (though declining) oil intensity of that growth. At a global level, the baseline scenario entails a further fall in the oil intensity of output, at roughly the same pace as over the past decades.

39. The rise in the oil price would be expected to trigger an increase in total oil supply by around 16% over the period 2011-20, which is somewhat above the growth rate observed over the past decade (Figure 7, panel B). Still, the need to bring new production capacity on stream would be much greater than the simulated supply increase due to the need to compensate for the fall in production from currently producing fields. According to the International Energy Agency, crude oil production from fields that were producing in 2011 will drop by around 15% by 2020 (IEA, 2012a). Moreover, since – at least in the absence of decisive worldwide action to curb carbon emissions – the production mix is likely to move towards a higher share of light tight oil, natural gas liquids, extra-heavy oil and natural bitumen, major investment in processing facilities for the lighter fluids and upgrading facilities for the heavier ones would be required (for details see IEA, 2010, Chapter 3).

Table 6. Projected average annual change in oil demand over the period 2011-20

	United States	Japan	European Union	Other OECD	China	India	Indonesia	Rest of World
Oil demand (%)	0.5%	-1.0%	-0.1%	0.7%	4.7%	5.2%	4.0%	2.1%
Oil demand (KBD)	97	-44	-11	68	531	224	70	630

Figure 9. Composition of world oil demand



40. The oil price increase implied by the baseline scenario is surrounded by a high degree of uncertainty. This is because (*i*) the elasticities that underlie the scenario exercise are highly uncertain due to both the inherent uncertainty surrounding estimations of past elasticities and structural changes that may alter such parameters during going forward; and (*ii*) the size of the risk premium that was embedded in 2012 prices is uncertain. A sensitivity analysis that varies these elasticities and the risk premium suggests that the price of crude oil may rise to anywhere between 150 and 270 USD per barrel by 2020 (Figure 7, panel A), again taking into account negative feedback effects of the higher oil price on GDP (Table 5). The confidence band is derived by varying the risk premium from 0% to 18% and all estimated long-run income and price elasticities by one standard deviation and all imposed long-run elasticities by 10%.[33] The upside risk could materialise if the oil price in 2012 were in line with fundamentals, thus not embedding any risk premium, and if demand and supply turned out to be less responsive to prices than in the baseline scenario. The latter is not unrealistic, because oil demand in particular seems to have become less responsive to price changes over time (*e.g.* IMF, 2011*b*), which may not be fully reflected in the baseline parameters which are derived from estimates over more than two decades for most countries. The downside risk could materialise if the risk premium embedded in 2012 prices turned out to be higher than assumed in the baseline scenario and if the rise in oil prices would trigger efforts from consumers and companies to substitute alternative energy sources such as gas, coal, nuclear or renewable energy for oil (*e.g.* Deutsche Bank, 2009) and from suppliers to exploit new unconventional sources of oil that would become profitable at such high prices.[34] Since the elasticities employed in the central scenario account for historically observed behavioural responses to price changes, the changes in behaviour required to reach

33. For example, the upper band is derived by simultaneously: (*i*) raising the income elasticity of demand for all OECD countries, China, India and Indonesia by one standard deviation and that of the ROW group by 10%; (*ii*) lowering the price elasticity of demand for all OECD countries, China, India and Indonesia by one standard deviation and that of the ROW group by 10%; and (*iii*) lowering the price elasticity of oil supply by 10%. Evidently, the likelihood of *all* these changes occurring simultaneously is small.

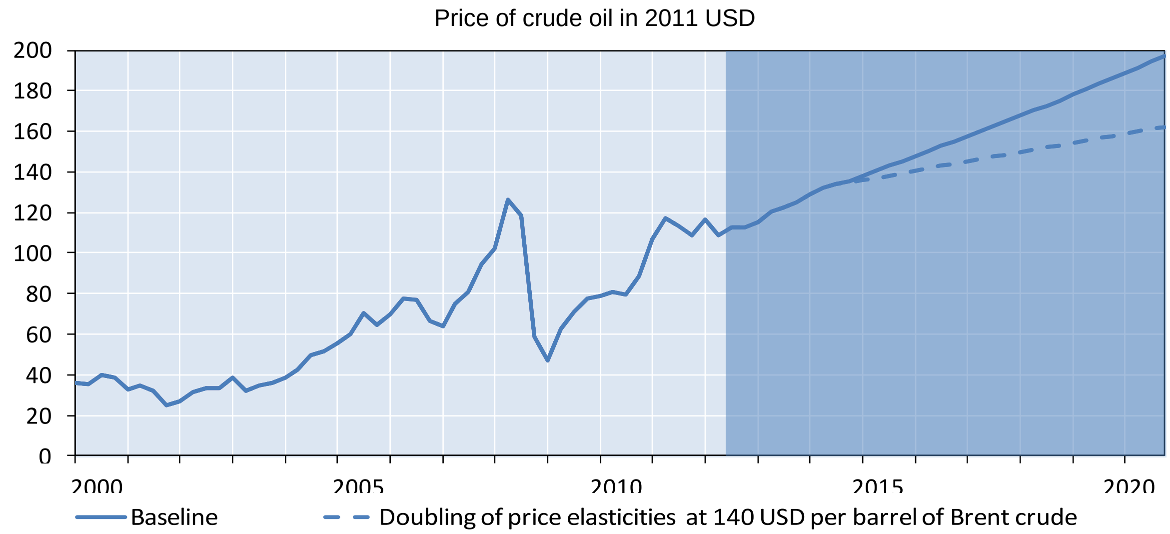
34. The extent of substitution will also depend on other factors, such as whether countries strengthen security standards for nuclear plants as a reaction to the Fukushima event, which would raise the cost of nuclear energy, all else equal.

the lower bound would need go beyond the response to oil price increase in the past.[35] Such behavioural changes are plausible but would take time to occur.

41. The lower-bound scenario shown in Figure 7 assumes that supply and demand are more sensitive to oil price changes, with the additional sensitivity constant throughout the projection period. Changes in behaviour may also follow a non-linear pattern whereby demand and supply become more responsive to oil price changes, once the price reaches a certain level (*e.g.* because certain production technologies become profitable at that price). This alternative hypothesis is explored in Figure 10, which assumes that the responsiveness of oil demand and supply to prices doubles at 140 USD per barrel of Brent crude. The price of crude oil would reach a bit more than 160 USD by 2020, which is markedly less than the 190 USD implied by the baseline scenario.

42. Futures prices do not currently reflect such a strong price increase – in early 2013 future contracts for 2020 even traded below the spot price. While Pagano and Pisani (2006) argue that future prices adjusted for a time-varying risk premium can help predicting future spot prices, others are less optimistic. For example, Alquist and Kilian (2010) show that oil futures contain little information about future spot prices over and above the current price level and conclude that the current price is actually a better predictor. The usefulness of futures prices may be particularly limited at longer horizons due to the limited liquidity of longer-term futures markets. This points to the relevance of model-based projections, which also have the advantage of ensuring consistency with projections of other economic variables such as GDP.

Figure 10. The oil price implications of nonlinearities in the price-sensitivity of oil demand and supply



Source: OECD estimates.

43. Comparing the baseline oil price path with that of other models shows that it is steeper than that projected for instance by the International Energy Agency in its World Energy Outlook or by the US Energy Information Administration in its 2012 Annual Energy Outlook. In its most recent 'current policies scenario' the International Energy Agency expects the average oil import price to rise to around 130 USD per barrel by 2020 in 2011 prices (IEA, 2012a), taking into account the development of non-conventional

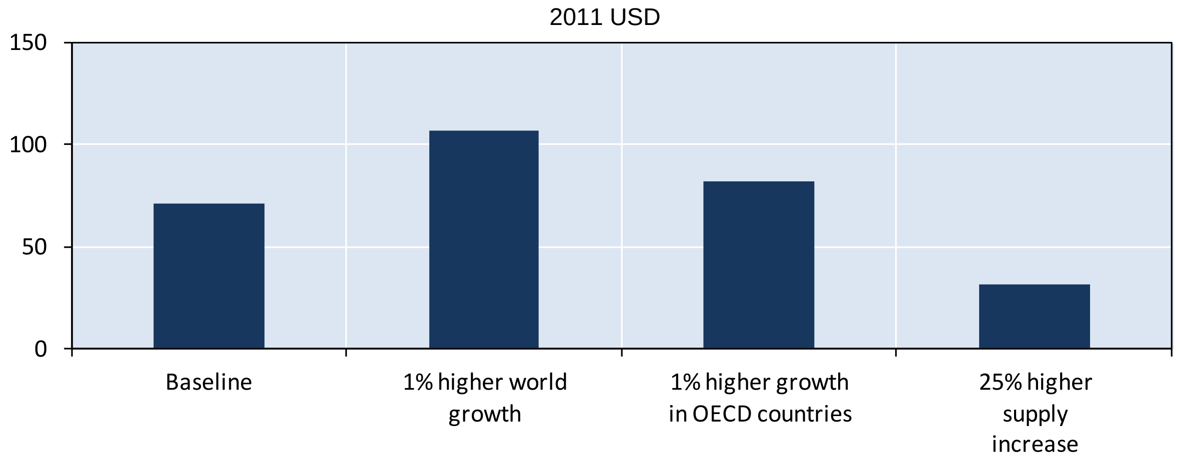
35. One reason why consumers may respond more to oil price increases in the future compared to the past is the decoupling of gas from oil prices. While the price of gas closely followed the price of oil in the past, the recent surge in the oil price was not matched by a corresponding surge in the gas price, making substitution more attractive.

oil resources such as shale oil. The difference vis-à-vis the baseline scenario shown in Figure 7 essentially reflects diverging assumptions about the underlying elasticities. For instance, the IEA's price and supply paths would be consistent with a responsiveness of oil demand to GDP lowered by half, a price elasticity of oil demand doubled and a price elasticity of oil supply raised by 50%, relative to the elasticities used for this paper. The US Energy Information Administration predicts a price of light sweet crude oil (West Texas Intermediate) of around 130 USD by 2020, in 2011 prices (EIA, 2012). By contrast, in its 2011 World Economic Outlook the IMF points to sizable upside risk for the oil price in the short run – because oil demand is little responsive to price changes in the short run – which goes even beyond the upper bound scenario of the present note (IMF 2011*b*). Dargay and Gately (2010) focus on oil demand and project an increase to around 110 million barrels per day by 2020 based on the price and GDP projections of the 2008 World Energy Outlook (IEA, 2008), suggesting that their oil demand functions are similar to those underpinning the present paper.

5.3. Alternative scenarios

44. Alternative scenarios are investigated to analyse how changes in macroeconomic conditions and policies could influence the future oil price path. If world economic growth were higher than assumed in the baseline scenario, the real oil price would increase substantially more. For example, if both OECD and non-OECD economies grew each year one percentage point faster than in the baseline scenario, the oil price could end up about 40 USD higher in 2020 (Figure 11). Again, this is mainly driven by non-OECD economies. If growth were 1 percentage point higher only in OECD countries, the oil price would be pushed up by a mere 13 USD by 2020 compared to the baseline case.

Figure 11. Rise in the price of Brent crude between 2011 and 2020 under different assumptions



Source: OECD estimates.

45. One policy change that would help to at least curb somewhat the future increase in the oil price would be the gradual removal of fossil fuel subsidies. Governments support consumption and production of fossil fuels in numerous ways including selective reductions of energy taxes and other interventions to affect cost or prices. Simulations carried out for the 2012 edition of the OECD Environment Outlook indicate that a multilateral removal of price-distorting fossil fuel subsidies to consumers in non-OECD countries (where such subsidies are largest) would lead to a 5.5% lower oil price in 2020 than implied by the baseline projection.

46. The projected oil price increase could also be dampened by a large increase in supply beyond that embedded in the baseline and alternative scenarios featured in Figure 7. The supply of oil does not only depend on its price, but also on the discovery of new fields, improvements in extraction methods and technological innovations that make available completely new sources of oil and are only partially related to the price. For instance, if the supply of oil were to rise unexpectedly by 25% more than in the baseline scenario, to about 107 million barrels per day in 2020 (while other baseline assumptions were kept unchanged) the oil price would still increase to 150 USD per barrel (Figure 11). To put the assumed total increase in supply in perspective, it would be equivalent to about two times the current production of Saudi Arabia or almost three times the increase in renewable energy production over the past decade.

47. This exercise also helps to put in perspective the recent offshore discoveries in Brazil as well as the supply potential of Canadian oil sands and US oil shale. Petrobras expects to extract close to 1.1 million barrels per day from the offshore fields by 2020 (Petrobras, 2010), while the IEA puts the additional supply from Canadian oil sands in the same year at around 1.3 million barrels per day (IEA, 2012). If oil supply were to rise by respectively 1.1 and 1.3 million barrels per day less than implied by the baseline scenario, the oil price would increase by around almost 10 USD more. The price would rise by 15 USD more if the supply increase were curbed by 2 million barrels per day, which corresponds to the IEA's projection of additional supply from US oil shale by 2020 (IEA, 2012). This figure increases to around 20 USD when taking into account US production of natural gas liquids (as a by-product of shale gas production), which the IEA projects to grow by 1 million barrels per day between now and 2020.

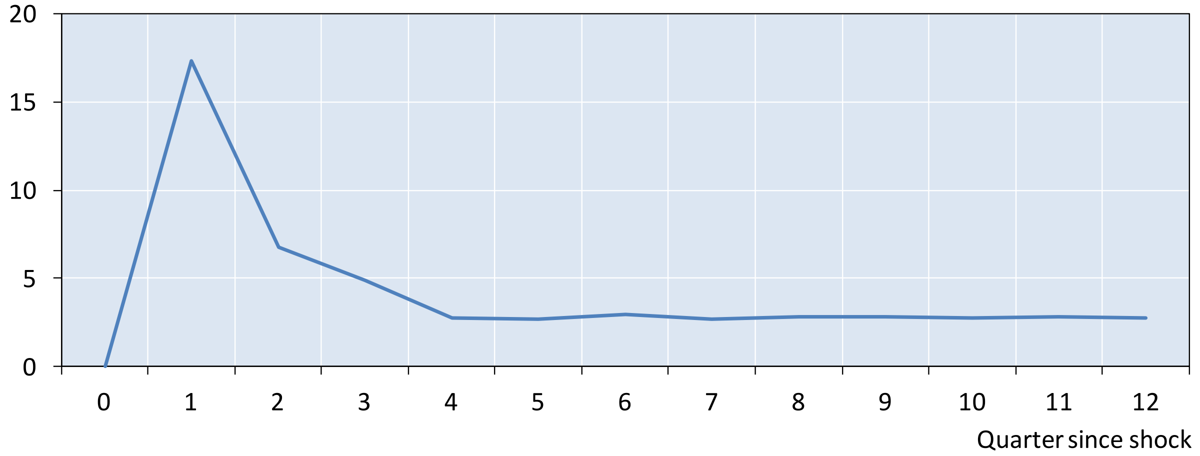
48. A substitution of oil by other forms of energy could also lessen the projected price increase. The rapid growth in US shale gas supply and the associated drop in natural gas prices are revitalising interest in new market outlets for natural gas. The potential for large-scale substitution of gas for oil seem limited in the near term, however. Exporting gas would require the construction of liquefaction plants. While several such plants are currently considered, building them would take several years. Fuel switching from oil to natural gas within the United States has already taken place on a large scale for power generation and space heating and further penetration is limited by market saturation and lacking infrastructure (IEA, 2012b). In the road transport sector, where gas could be used in the form of compressed natural gas or via electric vehicles powered by gas-fired electrical stations, progress would depend on policy support and infrastructure building – both of which look unlikely in the near to medium term given fiscal constraints. In the rail transport sector, several companies are considering a conversion to natural gas (through micro liquefaction plants), though the time horizon of these projects is unclear.

49. With so many factors bearing on oil markets in the short-term, future increases in oil prices are unlikely to follow the smooth trend path shown above. For instance, sudden drops in the supply of oil can have very large effects on the price in the short run, as economies cannot easily adjust. To take an illustrative example, the modelling framework suggests that if oil supply were to be curtailed by 1% of total world oil production in 2011 (900 000 barrels per day), the oil price could rise by almost 20% in real terms in the immediate aftermath of the shock, compared with the baseline scenario. This number needs to be interpreted with care, but the magnitude of the oil price rise is broadly in line with IMF (2012) arguing that a fall in supply by 1.5 million barrels per day would trigger an initial oil price rise of 20% to 30% (Figure 12). The size of the reaction would depend on the supply and inventory situation at the time of the shock. The simulated supply shock is based on the assumption that countries (both producers and consumers) would not react beyond the usual response of supply to higher prices. However, such a price hike would likely be alleviated in practice as it would trigger a major policy response, such as a release of stocks (both government and private-sector owned) in consuming countries and greater use of spare capacity in some producing countries. Estimates by the International Energy Agency put current OPEC spare capacity at around 3 million barrels per day and current stocks at around 4 billion barrels (or 90 days of forward demand), of which 1.5 billion barrels are government-owned or held by holding organisations for emergency purposes (IEA, 2012b). Still, this simulation is illustrative of the magnitude of the challenge

policy makers would be facing under severe supply-side stress. If the illustrative supply reduction persisted for some time, oil demand (and to some extent supply) would gradually adjust and prices would decline from their initial peak, remaining only about 2½ per cent higher than before the shock one year after the drop in supply occurred.

Figure 12. Oil price effect of a sudden 1% drop in oil supply

Deviation from baseline in per cent



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ANNEX

Table A1. Augmented Dickey-Fuller tests for quarterly data

	ADF (constant)		ADF (constant plus trend)		ADF (constant)		ADF (constant plus trend)	
	Demand	Δ Demand	Demand	Δ Demand	GDP	Δ GDP	GDP	Δ GDP
USA	-1.440	-12.786***	-0.554	-12.927***	-1.507	-4.251***	-1.263	-6.665***
Japan	-0.748	-14.252***	-0.862	-14.510***	-4.309***	-8.577***	-2.580	-9.244***
EU	-2.136	-12.776***	-0.307	-13.404***	-1.638	-5.335***	-1.299	-5.548***
Other OECD	-3.499***	-12.198***	-0.340	-13.384***	-1.025	-6.533***	-2.901	-6.574***
China	-0.093	-15.195***	-3.347*	-15.125***	0.042	-3.166**	-2.418	-3.099
India	-1.369	-11.912***	-1.731	-12.236***	2.858	-5.542***	-0.642	-6.450***
Indonesia	-1.714	-7.930***	-3.751**	-7.931***	-0.344	-6.514***	-1.801	-6.475***
Rest of world	1.321	-9.966***	-0.690	-10.510***	1.917	-2.177	-0.527	-3.183*
	ADF (constant)		ADF (constant plus trend)					
	Price	Δ Price	Price	Δ Price				
World Brent	-0.893	-8.793***	-2.516	-9.052***				

Note: t-statistics are reported. Asterisks (*, **, ***) indicate significance level (10%, 5%, 1%).

Table A2. Augmented Dickey-Fuller tests for annual data

	ADF (constant)		ADF (constant plus trend)		ADF (constant)		ADF (constant plus trend)	
	Demand	Δ Demand	Demand	Δ Demand	GDP	Δ GDP	GDP	Δ GDP
USA	-1.875	-4.252***	-2.837	-4.160**	-1.701	-4.745***	-1.873	-4.926***
Japan	-2.086	-4.837***	-2.025	-4.878***	-4.412***	-4.154***	-0.551	-5.626***
EU	-2.107	-5.192***	-2.202	-5.108***	-1.453	-4.573***	-1.996	-4.791***
Other OECD	-1.857	-2.493	0.373	-3.151	-0.288	-5.756***	-2.460	-5.679***
China	-0.833	-3.684***	-1.755	-3.615**	0.301	-2.312	-3.917**	-2.210
India	-0.787	-5.271***	-1.145	-5.230***	3.251	-3.663***	0.016	-4.633***
Indonesia	-3.588**	-5.544***	-2.087	-6.577***	-0.410	-3.352**	-1.593	-3.262*
Rest of World	-0.949	-2.789*	-2.371	-2.614	2.761	-2.622	-0.259	-3.256*
	ADF (constant)		ADF (constant plus trend)					
	Price	Δ Price	Price	Δ Price				
World Brent	-1.489	-1.570	-6.276***	-6.193***				

Note: t-statistics are reported. Asterisks (*, **, ***) indicate significance level (10%, 5%, 1%).

Table A3. Panel ADF-tests for quarterly data

	ADF (constant)		ADF (constant plus trend)		ADF (constant)		ADF (constant plus trend)	
	Demand	Δ Demand	Demand	Δ Demand	GDP	Δ GDP	GDP	Δ GDP
OECD	0.374	83.361***	0.090	78.163***	14.554***	50.833***	2.475	51.420***
BRIICS	0.500	23.151***	5.132*	53.719***	0.000	28.242***	2.208	29.913***
	ADF (constant)		ADF (constant plus trend)					
	Price	Δ Price	Price	Δ Price				
Brent OECD	1.458	48.502***	5.912*	46.100***				
Brent BRIICS	0.479	51.549***	2.280	48.615***				

Note: ADF-Fisher Chi-square statistics are reported. Asterisks (*, **, ***) indicate significance level (10%, 5%, 1%). The price of Brent is measured in local currency units.

Table A4. Panel ADF-tests for annual data

	ADF (constant)		ADF (constant plus trend)		ADF (constant)		ADF (constant plus trend)	
	Demand	Δ Demand	Demand	Δ Demand	GDP	Δ GDP	GDP	Δ GDP
OECD	0.374	83.361***	0.090	78.163***	14.554***	50.833***	2.475	51.420***
BRIICS	24.532**	86.336***	11.714	75.479***	0.543	44.294***	11.403	35.668***
ROW	138.087	1152.420***	175.929**	984.987***	84.939	701.815***	225.094***	625.966***
	ADF (constant)		ADF (constant plus trend)					
	Price	Δ Price	Price	Δ Price				
Brent OECD	1.458	48.502***	5.912*	46.100***				
Brent BRIICS	9.687	83.638***	22.756**	69.211***				
Brent ROW	121.920	988.853***	186.872***	793.097***				

Note: ADF-Fisher Chi-square statistics are reported. Asterisks (*, **, ***) indicate significance level (10%, 5%, 1%). The price of Brent is measured in local currency units.

Table A5. Detailed quarterly estimation results (TSLS)

	USA	Japan	EU	Other OECD	China	India	Indonesia	Rest of World
α_i	-0.118 (0.054)	-0.194 (0.065)	-0.179 (-0.117)	-0.027 (0.036)	-0.305 (0.097)	-0.151 (0.052)	-0.166* (0.051)	-0.048 (0.045)
$\beta_{i,0}$	-4.840* (2.722)	-8.025* (4.634)	-0.467 (3.494)	15.819 (44.21)	-14.513*** (1.87)	-19.976*** (2.179)	-21.664*** (7.605)	8.297 (10.549)
$\beta_{i,Y}$	0.502*** (0.095)	0.603*** (0.163)	0.344*** (0.118)	-0.218 (1.526)	0.806*** (0.072)	1.014*** (0.084)	1.083*** (0.297)	0.022 (0.367)
$\beta_{i,P}$	-0.115** (0.058)	-0.248*** (0.037)	-0.095*** (0.033)	-0.061 (0.241)	-0.127 (0.082)	-0.255*** (0.069)	-0.199 (0.15)	0.266 (0.178)
$\gamma^1_{i,D}$	-0.331*** (0.124)	-0.385*** (0.086)	-0.284*** (0.107)	-0.230** (0.099)	-0.408*** (0.117)			
$\gamma^2_{i,D}$	-0.224** (0.110)							
$\gamma^3_{i,D}$			0.222** (0.086)		0.182* (0.098)			
$\gamma^0_{i,Y}$	0.641** (0.283)	0.580*** (0.214)			2.312*** (0.780)			1.053** (0.453)
$\gamma^1_{i,Y}$	0.709*** (0.265)	0.716*** (0.218)						
$\gamma^3_{i,Y}$		0.474** (0.235)						
$\gamma^0_{i,P}$	-0.036* (0.019)		-0.053* (0.027)				0.130** (-0.065)	0.055* (0.028)
$\gamma^1_{i,P}$					0.102** (0.044)			-0.056** (0.022)
$\gamma^2_{i,P}$			0.059*** (0.018)					
Implied short-run income elasticity	0.868*** (0.217)	1.279*** (0.271)	0	0	1.885*** (0.705)	0	0	1.053** (0.453)
Implied short-run price elasticity	-0.023* (0.013)	0	0.006 (0.032)	0	0.083** (0.036)	0	0.13** (0.065)	-0.001 (0.024)
Sample period	1987Q1 - 2011Q2	1987Q1 - 2011Q2	1987Q1 - 2011Q2	1987Q1 - 2011Q2	1992Q2 - 2011Q2	1991Q2 - 2011Q2	1991Q2 - 2011Q2	1987Q1 - 2010Q2
Cragg-Donald F-statistic	1.760	2.959	1.141	5.060	1.862	2.114	2.097	1.018
J-Stat	8.200	14.520	17.892	13.172	22.665	17.512	15.750	12.787
Prob (J-Stat)	0.830	0.411	0.119	0.513	0.046	0.230	0.263	0.385

Note: Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficient. Standard errors are in parentheses. The critical values for the assessment of the F-statistic (for the null hypothesis of weak instruments) are taken from Stock and Yogo (2005).

Table A6. Overview of annual estimation results (TSLS))

	USA	Japan	EU	Other OECD	China	India	Indonesia	Rest of World
α_i	-0.210 (0.115)	-0.343 (0.117)	-0.339 (0.202)	-0.232 (0.092)	-0.557 (0.231)	-0.186 (0.152)	-0.388 (0.130)	-0.214 (0.112)
$\beta_{i,0}$	-7.198 (5.013)	8.519** (3.400)	-5.226 (4.394)	-8.995*** (2.095)	-17.020*** (2.612)	-15.883*** (2.849)	-26.456*** (4.552)	0.325 (2.741)
$\beta_{i,Y}$	0.580*** (0.171)	0.029 (0.116)	0.502*** (0.148)	0.644*** (0.069)	0.903*** (0.101)	0.865*** (0.097)	1.284*** (0.18)	0.304*** (0.095)
$\beta_{i,P}$	-0.118* (0.064)	-0.229*** (0.043)	-0.103** (0.042)	-0.205*** (0.048)	-0.238* (0.118)	-0.171** (0.067)	-0.383*** (0.121)	0.130** (0.054)
$\gamma^1_{i,D}$							-0.435** (0.199)	0.348* (0.170)
$\gamma^0_{i,Y}$	1.078*** (0.232)		1.073** (0.508)		1.980** (0.704)		0.583** (0.236)	0.596*** (0.172)
$\gamma^0_{i,P}$	-0.056** (0.026)		-0.102* (0.058)				0.124* (0.070)	
Implied short-run income elasticity	1.078*** (0.232)	0	1.073** (0.508)	0	1.980** (0.704)	0	0.406** (0.169)	0.914*** (0.272)
Implied short-run price elasticity	-0.056** (0.026)	0	-0.102* (0.058)	0	0	0	0.086* (0.048)	0
Sample period	1983 - 2011	1983 - 2011	1983 - 2011	1983 - 2011	1993 - 2011	1983 - 2011	1991 - 2011	1985 - 2010
Cragg-Donald F-statistic	0.934	4.810	0.344	5.903	2.454	2.370	0.840	4.287
J-Stat	2.963	6.330	0.959	8.300	4.147	5.567	2.738	4.356
Prob (J-Stat)	0.564	0.275	0.916	0.140	0.528	0.351	0.603	0.499

Note: Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficient. Standard errors are in parentheses. The critical values for the assessment of the F-statistic are taken from Stock and Yogo (2005).

Table A7. Results of cointegration tests

p-values

		USA	Japan	EU	Other OECD	China	India	Indonesia	Rest of world	OECD panel	BRIICS panel
Johansen, rank=0	Q	0.000	0.005	0.000	0.000	0.001	0.013	0.009	0.167	0.000	0.000
Johansen, rank=1	Q	0.016	0.019	0.075	0.004	0.269	0.213	0.059	0.135	0.000	0.006
Engle-Granger	Q	0.393	0.041	0.095	0.348	0.409	0.475	0.157	0.636	0.000	0.370
Johansen, rank=0	A	0.016	0.006	0.062	0.030	0.001	0.001	0.091	0.002	0.000	0.023
Johansen, rank=1	A	0.136	0.091	0.121	0.217	0.133	0.012	0.205	0.146	0.000	0.425
Engle-Granger	A	0.189	0.074	0.531	0.044	0.634	0.109	0.933	0.717	0.010	0.622

Note: Q=quarterly data; A=annual data. The presence of an intercept without time trend in the cointegration relationship is assumed in all tests. Engle-granger tests make use of MacKinnon's (1996) p-values, considering oil demand as the dependent variable. Switching to another dependent variable hardly changes the results. The Pedroni v-statistic and the Fisher maximum-eigenvalue test are reported for panel data as the counterparts of respectively Engle-Granger and Johansen tests. For the panel data cointegration tests, the oil price is expressed in local currency units. Expressing the oil price instead in US dollars hardly alters the cointegration results obtained for the two panels.

Table A8. Detailed quarterly panel estimation results

	OECD (USD)	OECD (LC)	BRIICS (USD)	BRIICS (LC)
α_i	-0.102***	-0.118***	-0.115***	-0.104***
	(0.011)	(0.013)	(0.02)	(0.021)
$\beta_{i,Y}$	0.745***	0.797***	0.733***	0.752***
	(0.065)	(0.063)	(0.089)	(0.118)
$\beta_{i,P}$	-0.197***	-0.253***	-0.051	-0.086
	(0.03)	(0.033)	(0.059)	(0.108)
$\gamma^1_{i,D}$	-0.535***	-0.541***		
	(0.019)	(0.02)		
$\gamma^2_{i,D}$	-0.283***	-0.286***		
	(0.021)	(0.021)		
$\gamma^3_{i,D}$	-0.059***	-0.061***	-0.078*	-0.087*
	(0.018)	(0.018)	(0.046)	(0.048)
$\gamma^0_{i,Y}$	0.551***	0.505***	0.401***	0.421***
	(0.071)	(0.071)	(0.122)	(0.128)
$\gamma^1_{i,Y}$	0.492***	0.527***		
	(0.071)	(0.072)		
$\gamma^2_{i,Y}$	0.275***	0.330***		
	(0.07)	(0.072)		
$\gamma^3_{i,Y}$	0.119*			
	(0.068)			
$\gamma^1_{i,P}$	-0.069***	-0.076***		
	(0.015)	(0.016)		
$\gamma^3_{i,P}$	-0.026**	-0.026**		
	(0.012)	(0.012)		
Implied short-run income elasticity	0.765*** (0.069)	0.721*** (0.062)	0.372*** (0.114)	0.387*** (0.118)
Implied short-run price elasticity	-0.051*** (0.012)	-0.054*** (0.012)	0	0
Sample period	1986Q1 - 2011Q2	1986Q1 - 2011Q2	1992Q1 - 2011Q2	1992Q1 - 2011Q2
Cross-sections included	34	34	6	6
Total panel (unbalanced) observations	3160	3116	437	404

Note: Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficient. Standard errors are in parentheses. The critical values for the assessment of the F-statistic are taken from Stock and Yogo (2005). USD = oil price is specified in US dollar, LC = oil price is specified in local currency units.

Table A9. Detailed annual panel estimation results

	OECD (USD)	OECD (LC)	BRIICS (USD)	BRIICS (LC)	ROW (USD)	ROW (LC)
α_i	-0.127***	-0.144***	-0.136**	-0.125**	-0.119***	-0.171***
	(0.015)	(0.017)	(0.037)	(0.035)	(0.012)	(0.014)
$\beta_{i,Y}$	0.802***	0.703***	0.822***	0.856***	0.806***	0.619***
	(0.089)	(0.084)	(0.082)	(0.148)	(0.085)	(0.096)
$\beta_{i,P}$	-0.216***	-0.215***	-0.132**	-0.203	-0.141**	0.033
	(0.031)	(0.036)	(0.061)	(0.134)	(0.064)	(0.072)
$\gamma^0_{i,Y}$	0.803***	0.743***	0.419***	0.454***	0.308***	0.269***
	(0.085)	(0.068)	(0.09)	(0.103)	(0.048)	(0.079)
$\gamma^1_{i,Y}$						0.199***
						(0.07)
$\gamma^0_{i,P}$	-0.065***	-0.063***			0.044***	0.095**
	(0.023)	(0.019)			(0.017)	(0.04)
$\gamma^1_{i,P}$						0.064***
						(0.018)
Implied short-run income elasticity	0.803***	0.743***	0.419***	0.454***	0.308***	0.469***
	(0.085)	(0.068)	(0.09)	(0.103)	(0.048)	(0.099)
Implied short-run price elasticity	-0.065***	-0.063***	0	0	0.044***	0.159***
	(0.023)	(0.019)			(0.017)	(0.042)
Sample period	1983 - 2011	1983 - 2011	1983 - 2011	1985 - 2011	1985 - 2010	1985 - 2010
Cross-sections included	34	34	6	6	72	71
Total panel (unbalanced) observations	882	821	138	113	1765	1559

Note: Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficient. Standard errors are in parentheses. The critical values for the assessment of the F-statistic are taken from Stock and Yogo (2005). USD = oil price is specified in US dollar, LC = oil price is specified in local currency units.

Figure A1. Goodness of fit of the TSLS regressions at quarterly frequency

Million barrels per day

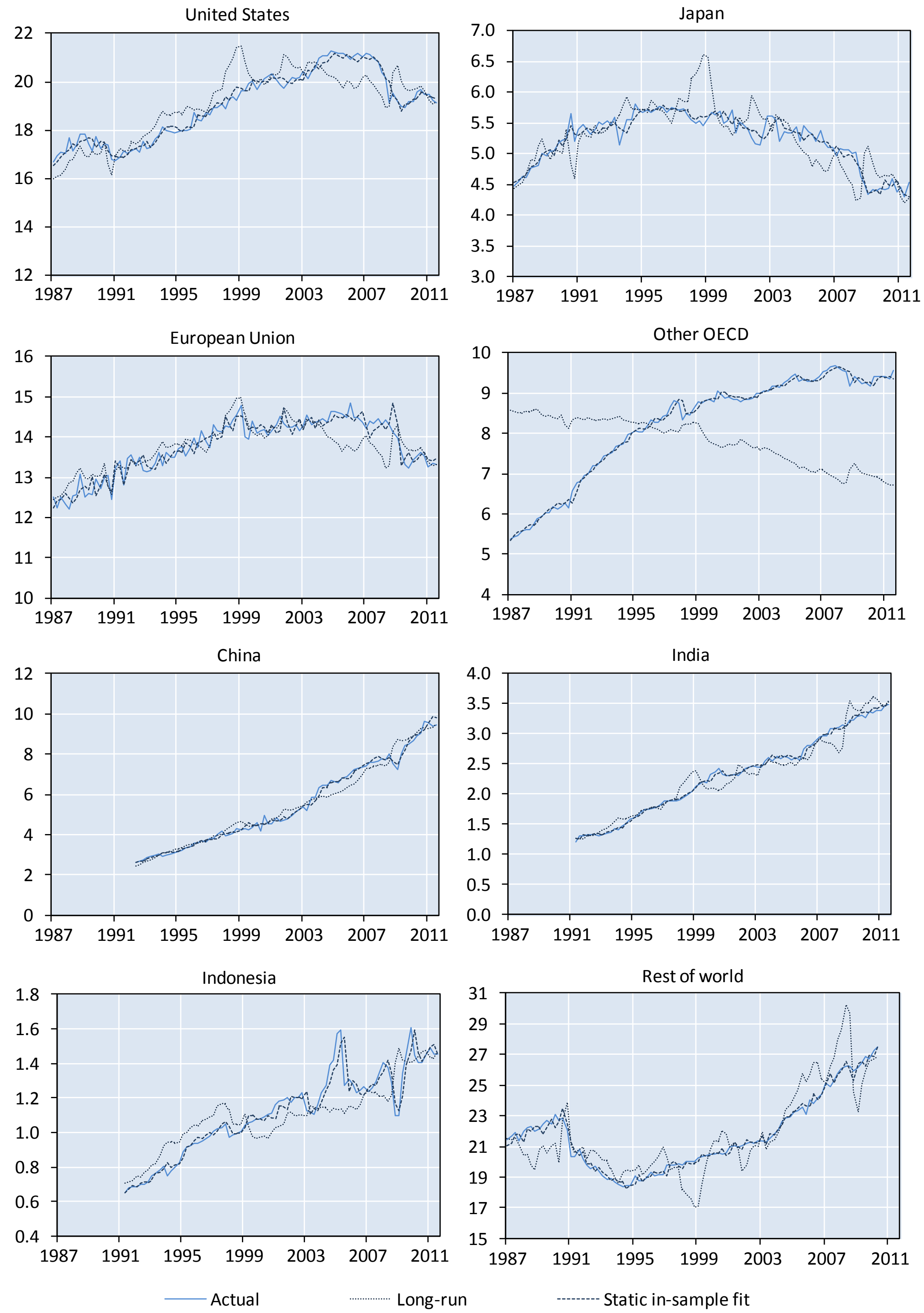
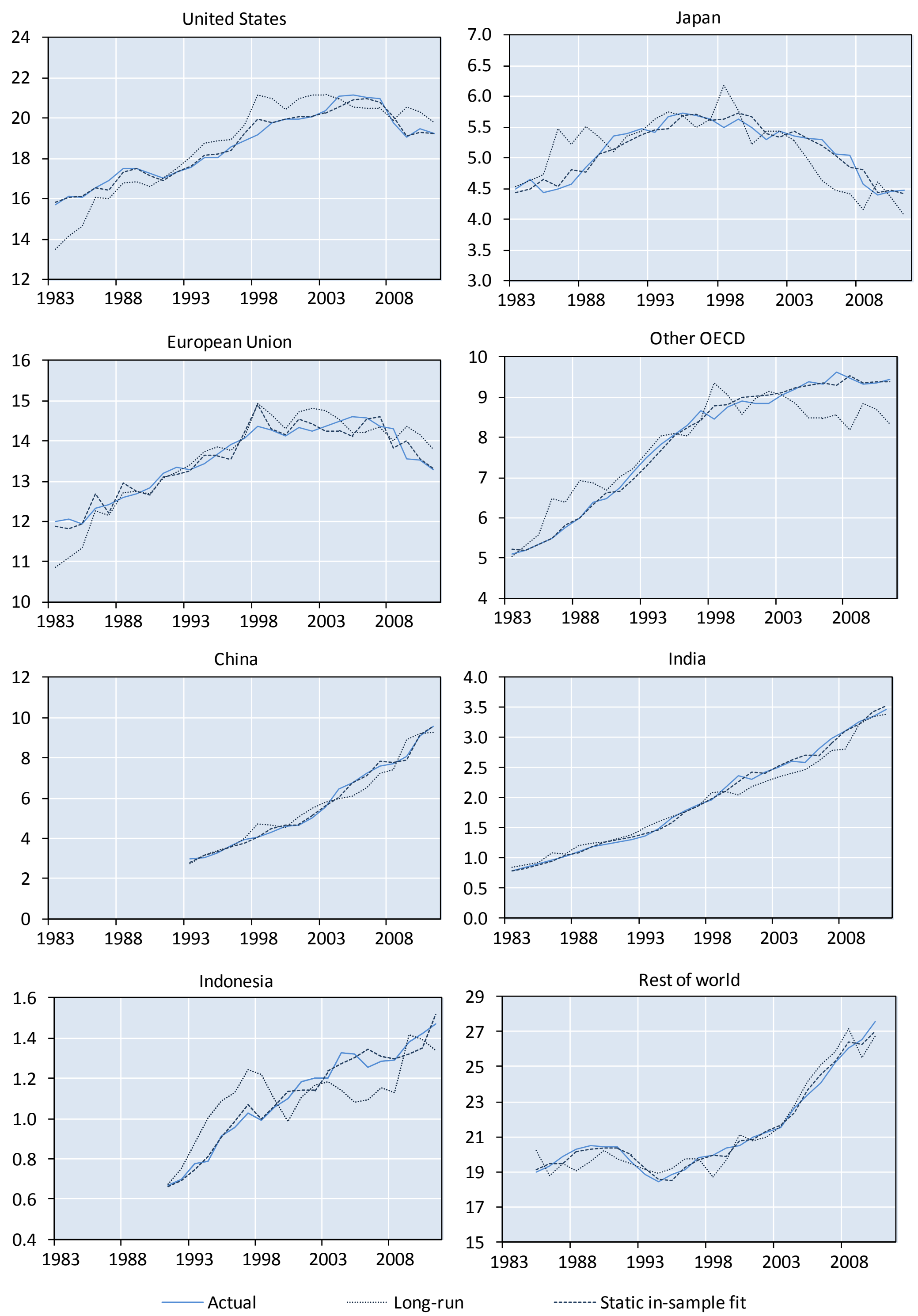


Figure A2. Goodness of fit of the TSLS regressions at annual frequency

Million barrels per day



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