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**Research Report**

## Oil market structure, network effects and the choice of currency for oil invoicing

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## OCCASIONAL PAPER SERIES

NO 77 / DECEMBER 2007

### **OIL MARKET STRUCTURE, NETWORK EFFECTS AND THE CHOICE OF CURRENCY FOR OIL INVOICING**

by  
Elitza Mileva and Nikolaus Siegfried



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by Elitza Mileva  
and Nikolaus Siegfried<sup>1</sup>

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## ABSTRACT

A recurring theme in recent years in the debate on the international role of currencies has been the possibility of pricing oil in euro. This paper contributes to these debates by providing a detailed review of the empirical evidence regarding the market for crude oil and current oil invoicing practices. It introduces a network effect model to identify the conditions under which a parallel invoicing in different currencies would be possible. The paper also includes a simulation designed to illustrate the dynamics of the currency choice of oil invoicing.

JEL Classification: G14, O13, Q41

Keywords: trade invoicing, currency substitution, network effects, oil trade.

## SUMMARY

The traditional economic literature provides ample reasons why oil is invoiced in one single currency around the globe. Specifically the literature on trade invoicing underscores the critical characteristics of crude oil as a homogeneous good traded on specialised exchanges and quoted and invoiced predominantly in one currency, the US dollar. In addition, a number of features of the US economy – macroeconomic stability, deep financial markets and global trade power – facilitate the use of the US dollar to provide a store of value and price transparency in the oil market.

Despite the strong case for the use of one vehicle currency in the oil trade, the analysis of this paper suggests that the introduction of a new currency in the crude oil market is possible. Our detailed survey of the oil market reveals that, contrary to the suggested homogeneity of the crude oil market, the international oil trade is predominantly regional in nature. For example, the United States, the biggest importer of petroleum, purchases oil mainly from countries in the western hemisphere. This market segmentation is due primarily to the specific features of the oil industry. Geographical proximity, for one, translates into lower transportation costs. Second, it is very costly to adapt refineries processing light oil in order to switch to a heavy grade. A closer look at the overall trade patterns of the oil exporting countries shows that the outflow of crude oil from most of these nations is matched by an inflow of other goods and services from their trading partners. This finding prompts the question of whether it would be more efficient for oil producers to invoice their exports in the currency they use to pay for their imports.

In addition to the review of physical oil trading, this paper examines the markets for oil spot and futures contracts. These markets are dominated by two commodity exchanges – NYMEX in New York and IPE in London – and the benchmark grades traded there are commonly used to price various other grades of oil.

However, developments in some markets have contributed further to the segmentation of the crude oil market. India and Japan, for example, have introduced the trading of futures contracts for petroleum grades more relevant to local industry. These are denominated in domestic currency. Trading oil futures contracts in different currencies will lower and eventually eliminate the cost of quoting, comparing prices and invoicing physical crude oil contracts in currencies other than the US dollar.

To explain the dominant use of one currency in oil invoicing, and to show that the use of several currencies is possible, we sketch a model that is based on the theory of network effects, i.e. we treat currencies as network goods. Sellers in the market respond to the currency choices of buyers so as to minimise costs associated with the use of an established vehicle currency or a newly introduced currency. We calibrate the model using low actual values (to the tune of 4 basis points) for the transaction costs of using one or two currencies, as well as a proxy for information costs, which decline with the use of a new currency. The results show that there will be a switch to parallel invoicing in both currencies when two conditions are met: first, oil exporters expect that a certain minimum number of other oil exporters will also start using the new currency; and second, the information costs associated with quoting oil contracts in two currencies are low.

## I INTRODUCTION<sup>1</sup>

A recurring theme in recent years in the debate on the international role of currencies has been the possibility of pricing oil in euro. Discussions have taken place in the media (Islam, 2003), academia (Alhajji, 2005) the European Parliament (2004) and OPEC (Koch, 2004).

The literature on trade invoicing suggests that primary commodities, such as crude oil, tend to be priced in vehicle currencies, because they are homogeneous and prices are easily comparable. Petroleum has mostly been traded in US dollars since the Seneca Oil Company drilled the first oil well in Pennsylvania in 1859. There are only a few exceptions to this statement. In the 1940s Anglo-Iranian (now known as BP) concluded some large crude oil contracts with Standard Oil of New Jersey and Standard Oil of New York (now ExxonMobil) in pounds sterling (Bamberg, 2000). A second case in point is the 1950s sterling-dollar oil controversy, in which the British government established exchange controls on oil imports and required the pricing of petroleum in pounds sterling in order to stop a short-term dollar drain (Schenk, 1996). A third example is the practices of the countries of the Persian Gulf which were part of the sterling area, which quoted their oil prices in US dollars but accepted payment in pounds sterling (McKinnon, 1979, p. 77). More recently, in October 2000 the Iraqi government demanded the settlement of its petroleum exports in euro under the UN Oil-for-Food Programme (CNN, 2000). In addition to these four instances, when actual settlement of the international oil trade occurred in pounds sterling or euro, there is also the case of crude oil exports to the United States being priced in Canadian dollars but settled in US dollars, so that the producers bear the exchange rate risk. Finally, Chinese oil companies – such as the two largest, CNOOC Ltd and Petrochina Company Ltd – price their locally produced crude oil in US dollars on the basis of international benchmark grades, but settle domestic contracts (the majority of their crude oil sales) entirely in renminbi. While these

are, admittedly, just exceptions, the examples cited above have prompted the present study of the oil market and the possibility of invoicing and settling oil trades in a currency other than the US dollar.

This paper reviews in detail the empirical evidence regarding the crude oil market and current oil invoicing/settling practices and develops a network effect-based model defining the conditions under which a complete switch in the oil invoicing currency or parallel invoicing in different currencies would be possible. This paper is in five parts. The following section discusses the literature on currency use in international trade. Section 3 explores the oil market in some detail. Section 4 considers network effects in the use of money and, on the basis of these considerations, presents a small theoretical model and some simulations for illustration. The last section concludes.

<sup>1</sup> This paper has profited considerably from a number of helpful suggestions and comments. We would like to thank Adalbert Winkler, Domiciano Calvo Garcia, Francesco Mazzaferro, Michael Sturm, Oscar Calvo-Gonzalez and Troy Tassier for their contributions. The views expressed in this paper are solely those of the authors.



## 2 THEORETICAL LITERATURE ON THE USE OF CURRENCIES IN INTERNATIONAL TRADE

This section provides an overview of the theoretical explanations for the choice of invoicing currency in trade, reflecting the three functions of money: medium of exchange, unit of account and store of value.<sup>2</sup> Note that the terms *invoicing* and *settlement* are used throughout this paper in relation to the medium of exchange function of money, as is standard practice in the literature. The important issue here is who bears the exchange rate risk – the buyer or the seller. A distinction is made, however, between the medium of exchange function and the unit of account function, with the term *quotation* used in this paper in relation to the latter.

Most theoretical literature on trade invoicing focuses on money as a *medium of exchange* and discusses the role of vehicle currencies in the trading of goods or the exchange of currencies. Swoboda (1968) argues that, if residents of a country may only hold non-interest bearing foreign currency assets, and their revenues or expenditures are at least partly denominated in a foreign currency, it is, owing to transaction costs (e.g. brokers' fees, bookkeeping, psychological inconvenience, etc.), profitable for them to hold foreign currency cash balances. Krugman (1980) develops a formal three-country, three-currency model, in which transaction costs as a proportion of the transaction size decline as the size of the exchange market increases. He shows that only the currency of an economically dominant country can serve as a vehicle currency. Moreover, once a currency is established as an international medium of exchange, its vehicle role becomes self-reinforcing and may persist even if the country's economic power diminishes. Krugman's static analysis also allows for multiple equilibria with more than one vehicle currency in international payments at any one time. Extending Krugman's model, Rey (2001) integrates international goods and currency exchange and suggests that the "thick market" externality (i.e. economies of scale in foreign exchange markets) and trade parameters such as the degree of openness, the

level of integration between the countries or transportation technologies are the key variables which characterise these multiple steady state equilibria and have an impact on the choice of vehicle currency.

Invoicing decisions in international trade are also modelled and tested empirically by Goldberg and Tille (2005). They contrast factors that influence the choice of currency and find that industry characteristics, such as the degree of product differentiation, are more important than macroeconomic factors such as exchange rate volatility. Their analysis presents evidence that the vehicle role of the US dollar is explained by both the importance of transactions in goods traded in organised exchanges and the significant role played by the United States as an international trade partner.

A different branch of the vehicle currency literature assumes positive network externalities in the use of money. Section 4.1 of this paper deals in greater detail with the theory of network effects for the use of currencies.

The theoretical literature on the second role of money, as a *unit of account*, is not well developed. It is often assumed that the quotation currency is the same as the invoicing or settlement currency and the theory of vehicle currencies is applied. McKinnon (1979) treats money as a medium of exchange but reaches an important conclusion regarding the unit of account function. McKinnon suggests that the use of vehicle currencies in the trading of homogeneous goods such as primary commodities is dictated by the need for price transparency. He also argued that trade on Britain's commodity exchanges had continued to be conducted in pounds sterling, despite sterling's relative decline (at that time) as a vehicle currency, because of the long history of such currency use and the familiarity with the pound of merchants involved in these exchanges.

2 For a detailed survey of the theoretical literature on the topic, including vehicle currencies in foreign exchange markets, see Hartmann (1998, pp. 11-29).

Thirdly, investment currencies fulfil the purpose of international money as a *store of value*.<sup>3</sup> The general result of international asset pricing models is that efficient portfolios are usually well diversified across many currencies because of risk-reducing considerations, which is in contrast to the predictions of the medium of exchange theory that there may be only a limited number of vehicle currencies. However, considerable currency diversification in financial portfolios is not actually observed. This may occur, because the store of value and medium of exchange functions of money are interrelated. On the one hand, countries important in international trade tend to have deep financial markets and no capital controls, and therefore they attract foreign investors. On the other hand, countries with large and sophisticated financial markets experience high demand for their currencies for international trade payments (Hartmann, 1998, p. 28).

To explain the role of money as a store of value, Giovannini and Turtelboom (1994) use a cash-in-advance-constrained model and incorporate the costs incurred in instantly transforming financial assets into cash for use in purchasing goods. The demand for domestic or foreign currencies is determined by their expected “liquidity services”. Thus, in countries with underdeveloped financial markets (i.e. financial assets are illiquid), the liquidity services of money are significant and, if the domestic currency provides low expected returns (as is the case in high inflation countries), the foreign currency becomes an attractive liquid investment.

The analyses in many of the studies reviewed above apply to the trading of crude oil as a homogeneous good traded in organised exchanges (though only recently and mostly speculatively) and denominated in the currency of the country which dominates international trade. However, as the discussion of the oil market in the following section suggests, multiple currency invoicing in this particular industry might prove to be more likely than has previously been assumed.

<sup>3</sup> The concept of money as a store of value is ambiguous in the literature. McKinnon (1985), for example, differentiates between *direct* and *indirect currency substitution*, the former referring to the competition between currencies to serve as a means of payment, the latter to switching between non-monetary financial assets. Giovannini and Turtelboom (1994) attempt to clarify this issue. In their model, *direct* is the substitution of currencies and *indirect* is the substitution of bonds. In the interests of simplicity and for practical reasons, this paper focuses only on the monetary aspect (i.e. *direct currency substitution*).

### 3 THE OIL MARKET

The most widely accepted theoretical approach to the economics of oil focuses on the prevailing oligopolistic market. According to Adelman (1993), the long-term marginal cost is a small fraction of the price of oil, even when making considerable allowances for the future values of the resources used up today (“user costs”). To support high price levels, the excess supply is restricted by a cartel. The market works in the following way: higher-cost producers sell all they can produce, while low-cost producers satisfy the remainder of the demand at current prices and cut back production if needed. Econometric evidence on Saudi Arabia confirms the asymmetric behaviour of the low-cost petroleum suppliers: the country restricts production in reaction to negative demand shocks but does not expand production in response to positive ones, in order to sustain high prices (De Santis, 2000). The oligopolistic structure of the oil market or the dominant role of Saudi Arabia is supported in a number of other empirical studies (cf. Griffin, 1985; Alhajji and Huettnner, 2000; and Dees et al., 2003).

#### 3.1 OVERVIEW OF SUPPLY

The power of the producing countries is, in general, rooted in the characteristics of oil. Producers incur no storage costs, since petroleum is simply left in the ground, while consuming countries have to cover the technical costs of building storage facilities, interest on the value of oil stocks and various risks (e.g. environmental risks). In addition, oil production is not labour intensive and, therefore, the oil supply can be controlled easily by reducing depletion rates without affecting the labour market. Since there are no short-term substitutes for petroleum, changes in supply are also effective. Moreover, demand for crude oil is highly insensitive to price changes (cf. Cooper, 2003).

The most important player in the oil market – the Organization of the Petroleum Exporting

Countries (OPEC), founded in 1960 in Baghdad – comprises a diverse group of developing nations,<sup>4</sup> highly dependent on oil exports and unified by their common interest in oil revenue maximisation. On average, petroleum exports represent over 68% of the total exports of these countries. Aiming to sustain world demand for oil (as opposed to replacing it with alternative energy sources), OPEC has to balance market share and profits. The oil cartel’s market power comes from the sheer size of its proven oil reserves (891 billion barrels) and exports (19.5 million barrels per day) – 78.3% and 48.7% respectively of the 2003 worldwide totals (OPEC, 2003). The Gulf countries also have the lowest production costs: USD 4.00 per barrel for Saudi Arabia or USD 4.50 for Iran, as compared, for example, with USD 9.85 for the North Sea and USD 12.50 for Brazil (Energy Intelligence, 2004). In addition, most OPEC oil is produced by 100% state-owned companies (as is the case in Algeria, Iran, Kuwait, Qatar, Saudi Arabia and Venezuela) or majority state-owned companies (Libya, Nigeria and United Arab Emirates). Only in Indonesia is government participation in the oil sector very limited.

The country with the largest weight among the oil exporting nations is Saudi Arabia. It has the world’s largest proven petroleum reserves (one-quarter of the total) and some of the lowest production costs, and is the largest producer and net exporter of oil (see Appendix, Table 1). As of May 2005, owing to the recent rapid increase in demand for petroleum, Saudi Arabia is the only country with any surplus production capacity: 900-1,400 thousand barrels per day, or some 13% of total capacity (EIA, 2005b). This enormous capacity has allowed Saudi Arabia to play the role of “swing” producer.

The non-OPEC exporting countries, on the other hand, increased their international oil market share following the 1973-74 oil crisis,

4 Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates and Venezuela. Angola joined OPEC only in 2007.

at the expense of OPEC. By contrast with the Middle Eastern countries, their oil production is characterised by technological difficulties (e.g. the North Sea) and high transportation costs (e.g. Alaska). The development of these oil reserves contributes to the geographical dispersion of petroleum production and the increased energy independence of some countries. While this would in principle imply a decline in international trade in crude oil, no significant decrease has yet been observed. Because of the different qualities of crude oil, it is more economical for some countries, whose refineries have not been adapted to process the newly discovered petroleum, to export their own grade of oil and to import the quality suitable for refining at home. Owing to the difference in construction materials used (related mainly to the quality of steel), the cost of building a refinery which processes heavy crude oil, for instance, can be six times that of a refinery with the same capacity built to process light grades of petroleum. A good example of oil trading conducted for petroleum quality reasons is the United Kingdom, which in 2003 exported 1,345 thousand barrels per day while importing 968 thousand barrels per day (see Appendix, Tables 1 + 2). Because North Sea oil is of a high quality, it is more suitable for processing at US refineries. Similarly, as is the case in Alaska, national oilfields may be located a long way from refineries and consumption locations and it may, therefore, be better to export the petroleum they produce (e.g. to Japan). In the end, these quality considerations contribute to the segmentation of the oil market.

In addition to the producing countries discussed above, the oil market includes both major oil companies and various smaller firms. The former are five very large, vertically integrated multinational corporations: British Petroleum (BP), ExxonMobil, Total, Royal Dutch/Shell and ChevronTexaco. Together, these produce 15.6% of the total annual world petroleum output (OPEC, 2003). Three of these companies have headquarters in the EU and account for their profits in euro or pounds sterling and use financial

instruments to hedge against exchange rate risk.<sup>5</sup> The two American corporations also report some use of foreign currency derivatives. The smaller oil companies (the “independents”) tend to operate in only one of the oil sector’s technically segmented productive stages or to rely on a single country or region for their oil supplies.

### 3.2 THE DEMAND FOR OIL

Unlike supply, demand for crude oil depends on the choices of many individual households and firms. However, owing to its importance for the economy and national security, the demand side is influenced by various private interest groups, the most influential of which being domestic oil refiners without foreign supply sources and governments, whose aim is to acquire sufficient quantities of petroleum from stable sources. Oil importing governments influence the petroleum market by means of fiscal instruments, anti-trust policies, public funds for alternative energy research or petroleum exploration activities, political intervention in situations in which the interests of the nation are at stake,<sup>6</sup> environmental regulations<sup>7</sup> and strategic oil reserves.<sup>8</sup>

In addition to policy measures, governments in some oil importing countries, such as China, South Korea, Singapore, Taiwan, Thailand, Turkey and Brazil, own majority stakes in their countries’ main oil companies. Nevertheless, the tendency over the last decade has been to privatise and deregulate the energy sector. As a

5 In 2004, for example, Royal Dutch/Shell reported foreign exchange contracts, swaps and options worth USD 18.8 billion, while Total reported instruments with a value of € 116 million (notional amounts; 2004 annual reports).

6 One example is the political controversy which surrounded the cancellation of the bid by the state-owned China National Offshore Oil Company (CNOOC) to buy Unocal, the California-based ninth largest US petroleum corporation (Barboza and Sorkin, 2005).

7 For instance, the Kyoto Protocol, which was negotiated in 1997 and has, to date, been ratified by 141 countries.

8 Some countries, such as the United States and Japan, hold segregated petroleum stocks. These totalled nearly 1.38 billion barrels in 2003. Elsewhere (e.g. in the EU), oil companies are required to hold a minimum level of extra stocks – currently 90 days’ worth of consumption (Energy Intelligence, 2004).

result of its rapidly growing oil demand, China has begun to allow minority private ownership of its petroleum companies,<sup>9</sup> as well as seeking to invest in foreign private companies.<sup>10</sup>

Among the consuming countries, the United States is the dominant player, being the world's largest producer, consumer and importer of petroleum (see Appendix, Table A2). In 2004 this country imported over 10 million barrels of crude oil per day, over half of it coming from western hemisphere sources and another quarter coming from Atlantic basin sources, such as the North Sea, and north and west Africa. Saudi Arabia, the most important Middle Eastern source of crude oil for the United States, accounted for around 15% of total imports (see Appendix, Table 3). In that year US petroleum consumption accounted for 25% of total world consumption. A distant second in terms of oil consumption was China with 7.6%, while the EU15 consumed 17.6% (BP, 2004). Because the United States is the most important market for oil, its West Texas Intermediate (WTI) grade of crude oil, though not traded internationally, is a leading benchmark for world petroleum prices.

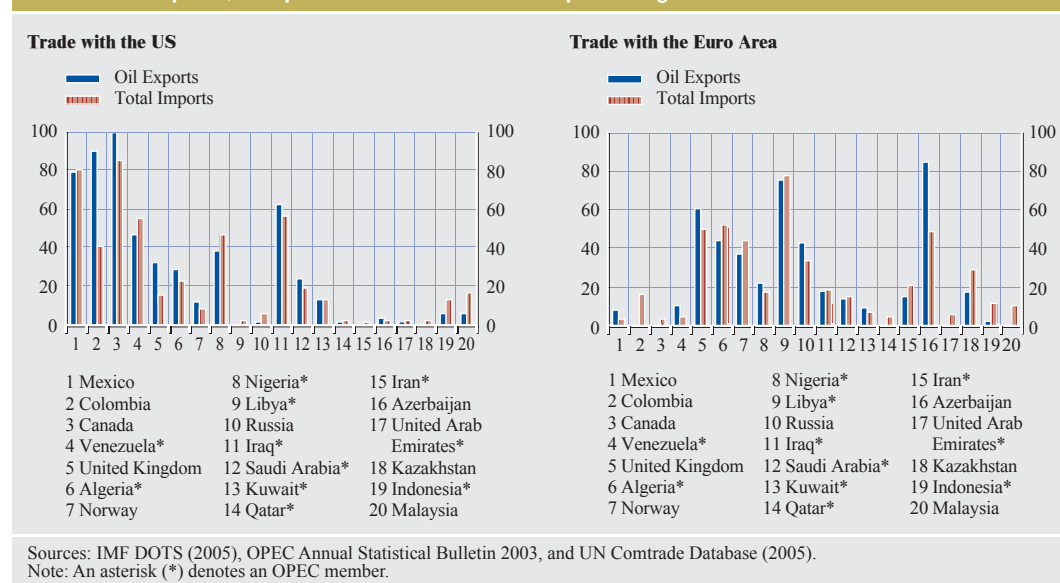
### 3.3 WORLD OIL TRADE FLOWS

This section focuses on crude oil, as it dominates the international oil trade, because it is cheaper to transport. Oil should move to the nearest market first because of transportation costs. The “nearest first” pattern can, however, be distorted by refinery configurations, product demand mix, quality specifications and politics as discussed in previous sections. In addition, geographical proximity could be a source of short-term vulnerability (e.g. in the event of natural disasters such as hurricanes). This last point notwithstanding, the international oil trade is a relatively regional phenomenon, as Chart 1 demonstrates. All panels show the same oil exporting countries ordered by time zone on the horizontal axis. The charts indicate oil exports to the United States, the euro area, Japan and four of the emerging economies of Asia for which there is bilateral data (i.e. China, India, Singapore and South Korea) as a percentage of a country's total oil exports. It is apparent that oil exports go predominantly to users that are geographically close.

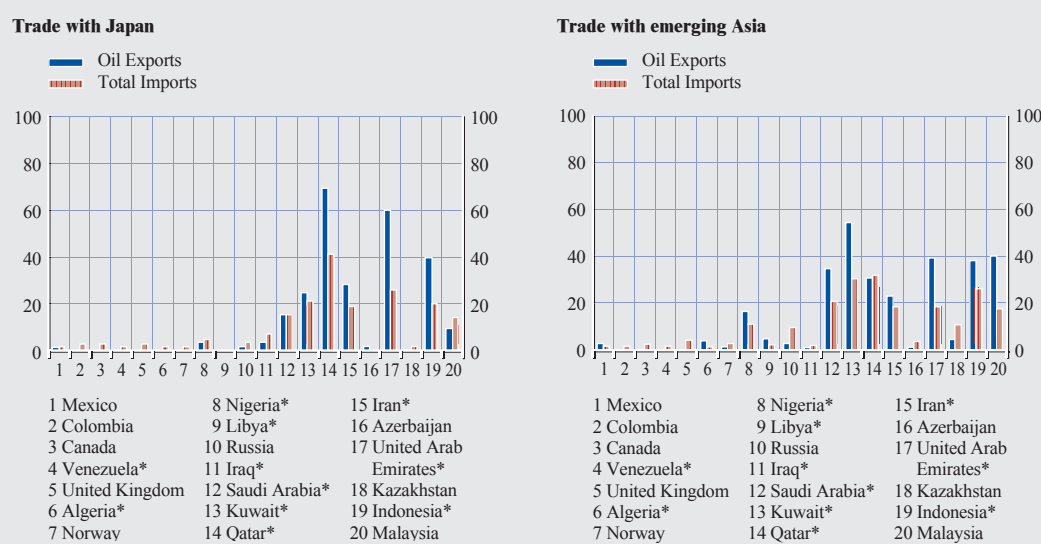
9 Petrochina, for instance, was spun off from the state-owned China National Petroleum Corp. as a publicly traded company in 1999.

10 See, for example, footnote 6 above.

**Chart 1 Oil exports to the United States, the euro area, Japan and emerging Asia as a percentage of total oil exports, compared with the share of imports of goods and services from these areas**



**Chart 1 Oil exports to the United States, the euro area, Japan and emerging Asia as a percentage of total oil exports, compared with the share of imports of goods and services from these areas (cont'd)**



Sources: IMF DOTS (2005), OPEC Annual Statistical Bulletin 2003, and UN Comtrade Database (2005).  
Note: An asterisk (\*) denotes an OPEC member.

The charts in Chart 1 also show the oil producing countries' imports of goods and services from the United States, the euro area, Japan and emerging Asia as a percentage of their total imports. Thus, not only do oil exports go predominantly to adjacent markets, but the oil exporting countries also generally import an equivalent percentage of goods and services from the countries to which they sell petroleum. Notably, the important oil exporting countries on the Arabian peninsula import most goods from emerging Asia.

Apart from influencing trade in non-oil goods and services, oil export revenues also have an impact on financial markets. Until a few years ago, oil earnings were deposited in international banks in US dollars. However, since 2002, OPEC countries have increasingly deposited their oil wealth in euro-denominated accounts (12% in the third quarter of 2001, against 25% in the second quarter of 2004) at the expense of US dollar-denominated accounts (75% in the third quarter of 2001, against 61.5% in the second quarter of 2004).<sup>11</sup> These observations support the view that the oil exporting countries, as well as some oil importing countries, such as those within the euro area or in

its vicinity, could potentially be willing to invoice or settle their oil contracts in euro or in another currency other than the US dollar. The next section discusses current practices as regards price setting in the oil market.

### 3.4 THE SPOT, TERM AND FUTURES MARKETS

Initially, most trade flows were conducted under term contracts, i.e. commitments to supply petroleum for a price and time period specified in advance. The price of crude oil was set by the major oil companies and later by the oil exporting countries. Although producers had to take into consideration market forces such as petroleum supply and demand and competition, predetermined selling prices were a feature of the oil sector. Since the early 1980s, however, the petroleum industry has become increasingly dependent on the spot market, and spot prices have replaced the official selling prices.<sup>12</sup> Today, term contracts are estimated to account for just

<sup>11</sup> See ECB (2005)

<sup>12</sup> Owing to high prices, the demand for oil declined substantially and OPEC countries abandoned the administered prices in order to compete with each other and with new entrants (Energy Intelligence, 2004).



over 50% of global trade in crude oil: Saudi Arabia, Kuwait, Qatar, Oman and Libya sell predominantly using contracts; Russia and Nigeria mainly use spot markets; and Norway, Mexico and Venezuela actually split their sales in line with the global average shares for the different types of selling price (Energy Intelligence, 2004).

Spot deals, on the other hand, are defined as immediate deliveries of crude oil outside of any continuing supply commitment. Although the spot market accounts for less than 50% of physical oil sales, spot prices are the primary determinant of almost all other petroleum prices. They are, for example, used in most pricing formulae for the term crude oil sales of OPEC and many other producing countries (Energy Intelligence, 2004).

Despite its significance, the spot market is not fully transparent (in terms of both prices and quantities), since physical spot market transactions have no central clearing house and are often confidential. Platts, the world's leading pricing service, which is quoted by Bloomberg and Reuters, bases its daily evaluations of 62 grades of crude oil on the prices of petroleum shipments from the main transportation hubs (maritime terminals or pipeline centres) under typical market conditions. This implies that Platts' oil price assessment methodologies differ depending on the characteristics of the market for a particular grade. Trade deals in the various oil regions differ in terms of pricing (e.g. prices of cargoes loaded free on board (FOB), delivered prices net of freight costs (CIF), or prices posted by refiners), cargo size, timing of delivery and so

on. To add to the complexity and segmentation of the market, the posted prices for some Canadian grades, such as Light Sour Blend and Par Crude, are quoted in Canadian dollars, although all other (non-Canadian) grades are priced in US dollars. Since 14 February 2005 Platts has also reported certain benchmark grades – such as Dated Brent, Urals and WTI – in euro as a supplement in order to allow price comparison across regions (Platts, 2005).

The other recent development in the oil industry is the growing influence of the market for futures contracts. In 1983 the New York Mercantile Exchange (NYMEX) introduced the first crude oil futures contract, Light, Sweet Crude Oil, the most actively traded commodity derivative today. In 1988 the International Petroleum Exchange (IPE)<sup>13</sup> in London started trading in Brent Crude futures. Data for 2003 suggest that, collectively, the annual trade of the two commodity exchanges is nearly three times the actual volume of physical oil produced (see Table 1).

In September 2001 the Tokyo Commodity Exchange (TOCOM) also listed a crude oil futures contract based on a benchmark Asian grade of petroleum – Middle East Crude Oil. In spite of its relatively low volume by comparison with those traded in New York and London, and despite its cash settlement requirement, the emergence of this futures contract is important,

13 In 2001 the IPE was acquired by the Intercontinental Exchange (ICE), a conglomerate of major banks and oil companies whose ambition is to establish a platform for the trading of all physical, forward, futures, and over-the-counter derivatives for all commodities (Energy Intelligence, 2004).

**Table 1 Trade volume by commodity exchange, 2003**

Exchange	Futures contract	Thousand barrels
NYMEX	Light, Sweet Crude Oil	45,436,931
	e-miNY <sup>sm</sup> Light, Sweet Crude Oil	138,706
IPE	Brent Crude	24,012,969
TOCOM	Crude Oil (Middle East Crude)	1,138,308
<b>Total world production</b>		<b>24,487,850</b>
<i>MCX India (Feb.-Dec. 2005)</i>	<i>Crude Oil (Light, Sweet Crude)</i>	<i>512,828</i>

Sources: NYMEX, IPE, TOCOM, MCX and OPEC.

as it is quoted and settled in Japanese yen and trading activity has been on the rise.

A fourth oil futures market was established in February 2005 with the introduction of the Crude Oil futures contract on the Multi Commodity Exchange of India Ltd. This was based on the Light, Sweet Crude Oil grade, priced in rupees and deliverable in Mumbai. As a result of the success of this contract, the exchange listed a second Brent Crude contract in June 2005. Although most companies trading on the Tokyo and Mumbai commodity exchanges are domestic, some are large international petroleum companies such as Reliance Industries of India (Economy Bureau, 2005) and Mitsui of Japan (TOCOM website, 2005).

The futures and spot markets are closely interrelated. On the one hand, the futures markets depend on the spot market at the point of contract delivery or settlement. On the other hand, the futures markets are increasingly acquiring prominence in the physical trading of crude oil. OPEC producers, for instance, are now using a weighted average of daily Brent futures prices on the IPE in the pricing formulae for petroleum shipments to European customers.

In conclusion, the crude oil market of today is highly segmented in terms of both geographical regions and grades of petroleum. Oil prices are almost exclusively quoted in US dollars, even though domestic contracts, both spot and futures, are settled in the domestic currency in a few countries. Why is crude oil predominantly invoiced in one currency? The next section attempts to answer this question.

## 4 CHOOSING A CURRENCY FOR OIL INVOICING – THE ROLE OF NETWORK EFFECTS

### 4.1 NETWORK EFFECTS IN THE USE OF MONEY

Network effects arise when the utility a consumer derives from a particular good is dependent upon the number of other individuals also consuming that good (Katz and Shapiro, 1985). The network property of a good has the following four implications for the market for that good. First, a minimum level of agents using the good (*critical mass*) is necessary for the initial adoption of a network good (Farrell and Saloner, 1986). Second, the demand for network commodities is associated with a *bandwagon effect*, i.e. the more individuals use the good, the more incentive there will be for other individuals to use it as well. Third, network effects may give rise to *multiple and unstable equilibria* related to the interplay of information, expectations and coordination (Stenkula, 2003). Finally, there are two problems linked to network goods, which may result in *market failures*: excess inertia, i.e. resistance by individuals to using a “superior” network commodity, and excess momentum, i.e. a rush by individuals to an “inferior” network good (Farrell and Saloner, 1985 and 1986).

Treating money as a network good is a recent development in economics and has led to interesting results concerning the origin of money, fiat currency and monetary integration. In a series of papers Kiyotaki and Wright (1989, 1990 and 1993) formalise the idea that individuals use a fiat currency to avoid the necessity of “the double coincidence of wants” and, based on a search-theoretic model, show that multiple currencies may coexist in equilibrium. The transition from commodity money (through convertible currencies) to fiat money is discussed by Dowd (2001). He argues that government intervention is needed to support a particular fiat currency, since network effects may also work against the establishment of fiat money. Selgin (2003) takes the search models a step further by introducing adaptive learning in the transition to

fiat money. Lotz and Rocheteau (2002) emphasise the role of the government in forcing a switch from one fiat currency to another.

### 4.2 A MODEL FOR OIL INVOICING

This section develops a model that captures network effects in the oil market, extending the models developed by Stenkula (2003) and Oomes (2003). The market consists of many buyers (*B*) and sellers (*S*) of *crude oil*. While the oil producers are sellers in this game, they have an incentive to invoice their oil contracts in the currency with which they will pay for their (non-oil) imports of goods and services from the rest of the world. In short, we will call these (non-oil) goods and services *food*. Similarly, the rest of the world are buyers of oil and sellers of food. Both parties aim to minimise foreign exchange risk and costs associated with the use of a specific currency for trade. In an environment where buyers and sellers are matched randomly and are subject to cash-in-advance constraints, both types of agents may choose between two currencies, i.e. euro (*e*) or US dollars (*d*), as the invoicing currency for their contracts. Each contract is fully invoiced in a single currency. In addition, the price of each contract is assumed to be constant and normalised to one. At time *t*, the sellers sell oil to the buyers, while at time *t + 1*, the buyers of oil sell food to the oil sellers. Hence, all agents try to anticipate the currency they will need for purchases in the next period.

Depending on whether or not the currency they accept for payment for oil is the same as the currency they use for their imports, the oil producers (*S*) may incur three types of cost, related to the three functions of money – medium of exchange, unit of account and store of value.<sup>14</sup> Transaction costs ( $\tau$ ) are associated with the exchange of one currency for another or hedging against exchange rate risk in the event that oil producers export and import in different

14 Note that, although for the remainder of the paper we refer to oil exporting countries, the analysis for oil companies is similar: they are either buyers or sellers of oil, or both; and they too incur costs when they invoice oil in one currency and have to record profits and pay taxes and dividends in another.

currencies. Second, they incur *information costs* –  $i(p_t)$  – when quoting and comparing oil prices in the presence of a new vehicle currency. Since the US dollar is the historically established invoicing currency in the oil trade, i.e. the currency everyone is used to dealing with, participants must learn to use a new unit of account. Information costs decline exponentially over time, accounting for the learning curve effects (or experience curve effects)

$$i(p_t) = A \exp (-\alpha p_t),$$

where  $t$  is discrete time;  $p_t$  is the share of oil producers that invoice their contracts in euro and, equivalently, the probability that a seller will invoice a crude oil contract in euro;  $A$  is the value at  $p_t = 0$ ; and  $\alpha$  is a positive constant (rate of decay). Finally, oil producers incur *liquidity costs*, i.e. the opportunity cost of holding cash balances owing to the loss of purchasing power between periods  $t$  and  $t + 1$ . However, the liquidity costs do not depend on the invoicing currency. Consider the following example: if a country sells oil in US dollars at time  $t$  to buy food in euro at time  $t + 1$  and the opportunity cost of holding US dollars is higher than that of holding euro, it is optimal for the country to exchange US dollars for euro at time  $t$ . Therefore, for the sake of simplicity, we have excluded liquidity costs from our model.

Table 2 shows the cost matrix for the oil producers. The sellers incur no costs if they invoice oil exports in US dollars (line S(d)) and pay for their imports in the same currency (column B(d), i.e. the buyers prefer dollars). They have to cover transaction costs if exports are settled in US dollars but imports are paid for in euro. When the euro is used for invoicing oil and the US dollar is used for importing food, both transaction and information

costs are incurred by the oil producers. Finally, when the euro is the settlement currency of both exports and imports, the oil producers have to cover information costs.

Since the oil exporters’ willingness to accept a given currency for their crude oil sales depends on the currency they use for their purchases of food, we define  $\hat{p}_{t+1}$  as the expected share of imports of food invoiced in euro at time  $t + 1$ . Thus, a representative seller’s expected cost functions –  $C(d)$  and  $C(e)$  – for invoicing its oil contracts in US dollars or euro respectively are as follows:

$$C(d) = \hat{p}_{t+1} \tau + \varepsilon_t^d$$

$$C(e) = (1 - \hat{p}_{t+1}) [\tau + i(p_t)] + \hat{p}_{t+1} [i(p_t)] + \varepsilon_t^e$$

The last variables on the right-hand side of the above equations,  $\varepsilon_t^d$  and  $\varepsilon_t^e$ , represent other random costs, which are not explained by network effects and which are specific to each seller. These costs may be due, for example, to political decisions or historical events. To minimise costs, the sellers will use the euro as the invoicing currency for crude oil if

$$C(e) < C(d)$$

Therefore, the probability –  $p_t$  – that a seller will invoice a crude oil contract in euro at time  $t$  is as follows:

$$\begin{aligned} p_t &= \Pr \{ C(e) < C(d) \} \\ &= \Pr \{ (1 - \hat{p}_{t+1}) [\tau + i(p_t)] + \hat{p}_{t+1} i(p_t) + \varepsilon_t^e < \hat{p}_{t+1} \tau + \varepsilon_t^d \} \\ &= \Pr \{ \varepsilon_t^e - \varepsilon_t^d < 2 \hat{p}_{t+1} \tau - \tau - i(p_t) \}. \end{aligned}$$

Assuming that  $\varepsilon_d$  and  $\varepsilon_e$  are independently and identically distributed across sellers according to the extreme value distribution, the difference,  $\varepsilon_t^e - \varepsilon_t^d$ , is approximately logistically distributed. Therefore, the best response function is

$$p_t = \frac{1}{1 + \exp \{ -\beta [2 \hat{p}_{t+1} \tau - \tau - i(p_t)] \}},$$

Table 2 Cost matrix		
	B(d)	B(e)
S(d)		$\tau$
S(e)	$\tau + i(p_t)$	$i(p_t)$

in which  $\beta$  is a parameter indicating the weight of the deterministic variables. Assuming rational expectations, the expected share of imports of food invoiced in euro at time  $t + 1$  is  $\hat{p}_{t+1}$ . While no closed-form solution to the above equation can be found, the next section uses simulation to analyse the steady states and dynamics of the model.

### 4.3 STEADY STATES AND THE ADOPTION CURVE

Figure 2 plots the graph of the best response function using hypothetical values between 0.0004 and 0.20 for transaction costs. The value  $\tau = 0.0004$  is the actual average of the monthly bid-ask spreads as a percentage of the mid-price as reported by Bloomberg for the period January 1999-July 2005. Information costs –  $i(p_t)$  – are given a value of 0.20 when the market share of the euro in invoicing is  $p_t = 0$ , and  $i(p_t)$  approaches zero when the currency shares are equal, i.e.  $p_t$  approaches 0.50.<sup>15</sup> Here it is assumed that  $\beta = 20$  (or, alternatively, the dominance of the stochastic term,  $\varepsilon_t^e - \varepsilon_t^d$  is 0.05).

When transaction costs are high (0.15 and 0.20), the model predicts multiple steady states within the interval [0; 1]. There are two stable equilibria – low at  $p_t = 0$  and high where

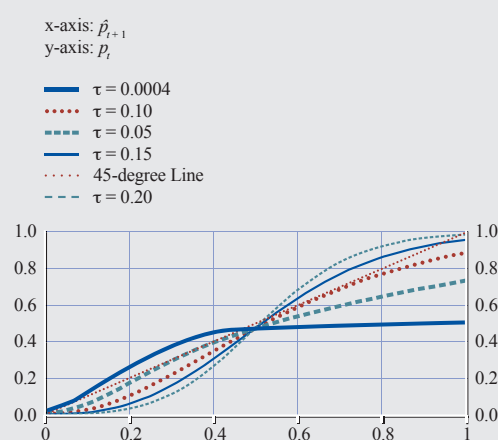
$p_t$  is close to 1. The equilibrium at  $p_t = 0.50$  is unstable. Therefore, when transaction costs are very high, parallel use of both currencies is not a stable equilibrium. Unless the majority of oil exporters switch simultaneously to invoicing in euro, the US dollar will remain the dominant currency in the market. In a more realistic environment of very low transaction costs, however, there is one stable equilibrium at around  $p_t = 0.50$ . Thus, with the assumptions made in order to plot Chart 2 and with low transaction costs, the market should move towards the use of both currencies in oil invoicing once a threshold level of around 10% of the market switches to the use of the euro. The next section relaxes the assumptions regarding non-network effects and information costs and analyses the impact of the size of  $\beta$  and  $i(p_t)$  on the model dynamics.

### 4.4 SENSITIVITY ANALYSIS FOR THE MODEL PARAMETERS

The preceding analysis shows that even if an oil exporter expects all imports to be priced in euro and, at the same time, transaction costs

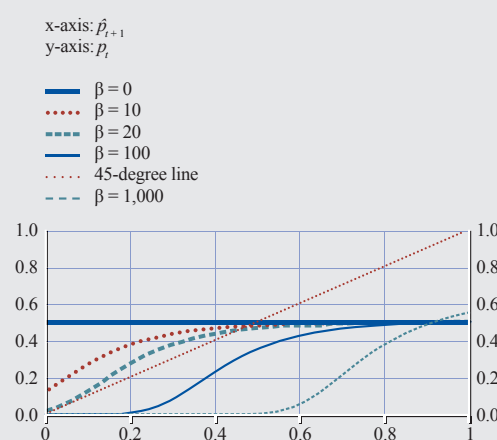
15 In this sample illustration of the model, the information cost function used is  $i(p_t) = 0.20 \exp(-7 p_t)$ . The exponential decay form is a proxy for information costs, which decrease as the size of the market increases.

Chart 2 Model dynamics for various transaction costs



Sources: Bloomberg (2005) and authors' calculations.  
Note:  $\beta = 20$ ;  $i(p_t) = 0.20 \exp(-7 p_t)$ .

Chart 3 Model dynamics for various values of  $\beta$



Sources: Bloomberg (2005) and authors' calculations.  
Note:  $\tau = 0.0004$ ;  $i(p_t) = 0.20 \exp(-7 p_t)$ .

are very low, its best response is to invoice its export contracts in euro with a probability of less than one. This is for two reasons. First, it has to learn, over time, how to compare oil prices in euro, i.e. its choice depends on the size and speed of decline of the information costs  $i(p_t)$ . Second, the possibility exists that stochastic, external shocks will reduce the likelihood of all oil contracts being invoiced in euro. The importance of stochastic shocks is measured by the size of  $\beta$ . Hence, the assumptions made about the parameter  $\beta$  and the information costs warrant further discussion of the behaviour of the best response function.

Chart 3 plots the best response function assuming the same information costs as before and low transaction costs ( $\tau = 0.0004$ ), but varying the magnitude of  $\beta$ . For the extreme value of  $\beta = 0$ , which is equivalent to an infinite influence of the stochastic term, the players choose their response as if flipping a coin, and so  $p_t = 0.50$ . For the higher values of  $\beta = 10$  and  $\beta = 20$ , there is a unique stable equilibrium at around  $p_t = 0.50$ . These results are consistent with a case in which non-network effects' specific costs have a considerable influence on the players' decision-making process (5% or above). In the other extreme, non-network effects have minimal impact ( $\beta = 100$  and

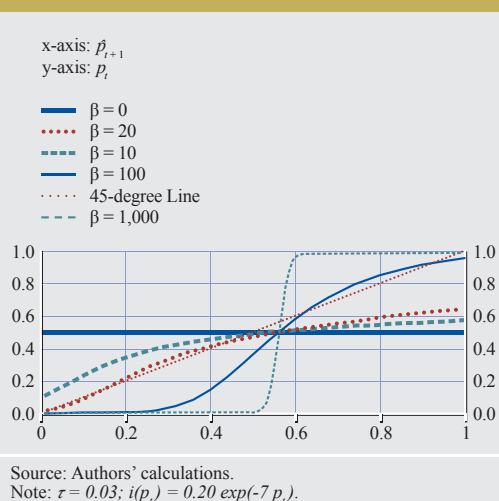
$\beta = 1,000$ ) and the players choose the oil invoicing currency mainly on the basis of economic considerations. Hence, very small transaction costs by comparison with the information costs preclude any switch away from the vehicle currency; the only stable equilibrium is at  $p_t = 0$ . The oil exporters prefer to use the US dollar as a vehicle currency and exchange it for euro when purchasing imports.

When transaction costs are non-trivial,<sup>16</sup> however, the best response function approximates a step function for large values of  $\beta$  (see Chart 4). Given the costs of invoicing in a particular currency, the players choose to invoice in euro if network effects work to their advantage, i.e. the correctly expected share of oil invoicing in euro is 0.50 or above.

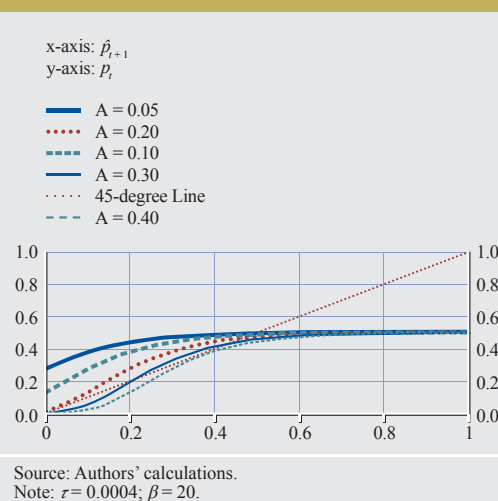
Chart 5 shows the behaviour of the best response function with information costs of the same functional form, but starting at various values of  $i(p_t)$  for  $p_t = 0$ . Lower information costs result in faster convergence toward the stable equilibrium at  $p_t = 0.50$ . More exporters

16 With these assumptions, the best response function approximates a step function when transaction costs are greater than 40 basis points. The lower the transaction costs, the higher the value of  $\hat{p}_{t+1}$ , at which the oil exporters switch to euro.

**Chart 4 Model dynamics for various values of  $\beta$  and high transaction costs**



**Chart 5 Model dynamics for various information costs**





invoice in euro if price transparency of euro-invoiced contracts is higher. Developments such as the new euro pricing of contracts by Platts or a commodity exchange quoting oil contracts in euro may contribute to the establishment of such a situation.

Our simulation results confirm the predictions of the network effects theory regarding the existence of multiple equilibria and the important role of critical mass. In particular, a stable equilibrium of parallel oil invoicing in two currencies can arise if: (a) non-network-related costs, such as political or social considerations, have a moderate impact on the players' decisions; (b) transaction costs are small; (c) a certain threshold share of euro invoicing is expected; and, finally, (d) information costs are either low or decline quickly with increasing use of the euro. According to our model, one explanation of the current state of the crude oil market (i.e. US dollar domination and very low transaction costs) may be very high information costs coupled with very low impact of specific non-network effects. When players' decisions are based mainly on the economic costs of the choice of invoicing currency, they prefer to pay the low transaction costs of exchanging currencies or hedging against a currency risk rather than incur the costs associated with information transparency. A second possibility is that no players rationally expect that the threshold level of euro invoicing will be reached in the forthcoming period.

## 5 CONCLUSION

The theoretical literature on trade invoicing explains the almost universal use of the US dollar in international trade in crude oil by means of the fact that petroleum is a homogeneous good traded in organised exchanges. Apart from serving as a medium of exchange, the US dollar fulfils the function of a unit of account by providing price transparency in the oil market. Thirdly, the macroeconomic stability of the United States and the depth of the US financial markets explain the role of the US dollar as a store of value and the low liquidity costs associated with holding the currency.

The literature makes a strong case for the use of one currency as a vehicle currency in the oil trade. However, a thorough review of the international market for crude oil points to several factors suggesting that the oil market is less homogeneous and global as commonly perceived, which indicates that invoicing in one currency may not be the only solution. A group of 11 developing countries highly dependent on petroleum exports dominates the international oil trade. The outflow of crude oil from most exporting countries is matched by an inflow of other goods and services from their trading partners – usually nearby developed countries. Similarly, the United States, the biggest importer of petroleum, relies mainly on western hemisphere sources. Thus, owing mainly to the specific features of the industry, the international oil trade is predominantly regional in nature. In addition, the introduction of trading in futures contracts for petroleum grades more relevant to local industry, with such contracts denominated in domestic currencies and traded in financial centres other than New York and London, has contributed further to the segmentation of the crude oil market.

To explain the dominant use of the US dollar in oil invoicing, the model developed in this paper treats currencies as network goods. Sellers in the market respond to the currency choices of buyers so as to minimise costs associated with the use of an established vehicle currency or a

newly introduced currency. The model explains the possibility of multiple equilibria with one or two vehicle currencies.

When calibrated using actual values for the transaction costs of using US and/or euro dollars, together with a proxy for information costs, which decline as use of the new currency increases, the model identifies the preconditions for a possible switch to parallel invoicing: a) players have to expect that a certain minimum number of other players will also start using the new currency, or b) the information costs associated with quoting oil contracts in two currencies are low.

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# APPENDIX

## WORLD CRUDE OIL TRADE FLOWS

Table I World exports of crude oil, 2003			
Ranking	Country	Thousand barrels per day	Percentage of total
1	Saudi Arabia*	6,522.9	16.28%
2	Former USSR	6,479.5	16.17%
3	Norway	2,694.2	6.72%
4	Iran*	2,396.3	5.98%
5	Nigeria*	2,303.5	5.75%
6	Mexico	2,102.9	5.25%
7	United Arab Emirates*	2,048.0	5.11%
8	Canada	1,553.6	3.88%
9	Venezuela*	1,535.0	3.83%
10	United Kingdom	1,345.4	3.36%
11	Kuwait*	1,242.9	3.10%
12	Libya*	1,126.5	2.81%
13	Oman	901.9	2.25%
14	Algeria*	741.0	1.85%
15	Angola	698.2	1.74%
16	Indonesia*	650.2	1.62%
17	Columbia	564.1	1.41%
18	Qatar*	540.7	1.35%
19	Malaysia	397.9	0.99%
20	Iraq*	388.6	0.97%
21	Syria	335.9	0.84%
22	Gabon	312.7	0.78%
23	Vietnam	302.3	0.75%
24	Australia	282.1	0.70%
25	Congo	253.5	0.63%
26	Ecuador	238.2	0.59%
27	Brunei	177.1	0.44%
28	China	163.1	0.41%
29	Cameroon	120.7	0.30%
30	Trinidad and Tobago	60.2	0.15%
31	Egypt	56.4	0.14%
32	United States	22.1	0.06%
TOTAL WORLD		40,065.8	100.00%
OPEC		19,495.7	48.66%
Source: OPEC Annual Statistical Bulletin, 2003.			
*OPEC members; Angola joined OPEC only in 2007.			



Table 2 World Imports of Crude Oil, 2003

Ranking	Country	Thousand barrels per day	Percentage of total
1	United States	10,348.8	25.56%
2	Japan	4,162.7	10.28%
3	South Korea	2,166.1	5.35%
4	Germany	2,138.8	5.28%
5	China*	1,829.5	4.52%
6	France	1,708.0	4.22%
7	Italy	1,686.3	4.16%
8	India	1,574.1	3.89%
9	Spain	1,150.7	2.84%
10	Netherlands	974.5	2.41%
11	United Kingdom	967.6	2.39%
12	Canada	888.9	2.20%
13	Singapore	823.0	2.03%
14	Taiwan	768.7	1.90%
15	Belgium	727.9	1.80%
16	Thailand	686.1	1.69%
17	Turkey	483.9	1.19%
18	Virgin Islands	443.6	1.10%
19	Brazil	419.7	1.04%
20	Sweden	406.1	1.00%
21	Greece	397.3	0.98%
22	Australia	377.9	0.93%
23	Indonesia	306.7	0.76%
24	Philippines	306.3	0.76%
25	Bahrain	225.0	0.56%
26	Netherlands Antilles	222.0	0.55%
27	Chile	195.2	0.48%
28	Morocco	145.2	0.36%
29	Romania	140.0	0.35%
30	Czech Republic	128.8	0.32%
31	Puerto Rico	123.9	0.31%
32	Bulgaria	115.8	0.29%
33	New Zealand	95.6	0.24%
34	Cote d'Ivoire	72.4	0.18%
35	Former USSR	40.0	0.10%
36	Kenya	36.3	0.09%
37	Cuba	14.5	0.04%
TOTAL WORLD		40,494.4	100.00%

Source: OPEC Annual Statistical Bulletin, 2003

\*Crude oil figure from BP 2004, because OPEC 2003 includes it under 'Asia and Pacific - Others'.

**Table 3 US crude oil imports by country of origin, 2004**

Country	Thousand barrels per day	Percentage of total
<b>Arab OPEC</b>	<b>2,634</b>	<b>26.11%</b>
Algeria	215	2.13%
Iraq	655	6.49%
Kuwait	241	2.39%
Libya	18	0.18%
Qatar	4	0.04%
Saudi Arabia	1,495	14.82%
United Arab Emirates	5	0.05%
<b>Other OPEC</b>	<b>2,408</b>	<b>23.87%</b>
Indonesia	34	0.34%
Nigeria	1,078	10.69%
Venezuela	1,297	12.86%
<b>Non-OPEC</b>	<b>5,046</b>	<b>50.02%</b>
Angola	306	3.03%
Canada	1,616	16.02%
Colombia	142	1.41%
Ecuador	232	2.30%
Gabon	142	1.41%
Mexico	1,598	15.84%
Norway	143	1.42%
Russia	158	1.57%
United Kingdom	238	2.36%
Other	467	4.63%
<b>TOTAL</b>	<b>10,088</b>	<b>100.00%</b>

Source: Energy Information Administration, June 2005 ; Petroleum Supply Annual, Volume I, 2004.  
Note: Angola joined OPEC only in 2007

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