

Oil Depletion and its Terms of Trade

Marina Irimia-Vladu
American University of Sharjah

Henry Thompson
Auburn University

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Offer curves are combined with optimal depletion in a model of the international oil market suggesting importers and exporters face backward bending offer curves. In such an international market, an oil tariff would raise oil imports and lower the price of oil inclusive of the tariff. The paper simulates long term paths of price, extraction, and depletion.

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Contact author: Henry Thompson, Economics-Comer Hall, Auburn University, AL 36849, 334-844-2910, fax 5639, *thomph1@auburn.edu*

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The present model of the international oil market integrates offer curves and optimal depletion. Oil suppliers set production according to the transversality condition tying the growth rate of the resource price to the real interest rate. The demand side of the market is closed with the oil import elasticity leading to simulated paths of extraction and depletion that some provide perspective on the long term international oil market.

Under reasonable assumptions about production and utility, the exporter offer curve is backward bending. An oil tariff would then not only lower the international price, but also raise imports and lower price inclusive of the tariff in the Metzler (1949) effect. The empirical evidence suggests inelastic oil import demand, implying a backward bending oil importer offer as well.

The OPEC offer curve

Offer curves and optimal depletion have not been integrated in the literature. Neoclassical offer curves of Marshall (1879) and Meade (1952) are derived from a production frontier and utility maximization by Mundell (1960) and Johnson and Bhagwati (1960) in general functional form. Dixit and Norman (1980) and Wong (1995) illustrate links between production and consumption using general expenditure and revenue functions.

The comparative static factor proportions model of production and trade of Samuelson (1953) and Jones (1965) links factor and product markets under assumptions of exogenous international prices, competitive pricing, and full employment. There is no utility maximization or determination of consumption, however, and trade levels cannot be derived in the factor proportions model. Bhagwati and Srinivasan (1983) derive offer curves assuming complete specialization with constant cost production in a model that includes consumption and trade levels with production.

The present paper utilizes neoclassical offer curves in an international trading equilibrium between oil exporter OPEC and oil importer OECD in two products, oil and manufactures. The OPEC offer curve in Figure 1 has a backward bending portion where a lower relative price of oil raises OPEC exports and lowers OECD exports. The income effect of the falling terms of trade erodes OPEC purchasing power and lowers OPEC imports. An OECD tariff in Figure 1 shifts its offer curve as shown, lowering the relative price of oil, increasing oil imports, and lowering manufactured exports in the Metzler (1949) paradox.

* Figure 1 *

Metzler (1949), Kemp (1964), and Minabe (1974) develop the conditions of a backward bending offer curve in terms of the marginal propensity to import and the exporter offer curve elasticity. There are four underlying conditions of supply and demand that favor a backward bending OPEC offer curve:

- (1) a high level of trade
- (2) a low marginal utility of imports
- (3) a large difference in factor intensity
- (4) little substitution in production.

A higher level of trade implies a larger income effect with a change in the price of oil. Satiated OPEC consumption implies low marginal utility of imports with little substitution in consumption. The very high capital intensity and lack of input substitution in oil production imply a relatively concave OPEC production frontier and little adjustment in oil production with a change in the relative price of oil.

These conditions suggest the OPEC offer curve is backward bending as in Figure 1. An OECD tariff would raise imports and lower the price of oil inclusive of the tariff in the Metzler effect.

Optimal depletion and price

Optimal depletion is based on the principle that owners of oil in the ground treat it as an asset and sell it to equalize its rate of return with other assets. The model implicitly assumes unambiguous property rights to known reserves. The dynamic inter-temporal condition for optimal profit is a constant marginal profit per barrel,

$$\pi_t = \rho\pi_{t+1}, \quad (1)$$

where

$\pi_t \equiv (p_t - c_t)$ is marginal profit at time t

$p_t \equiv$ the price of oil

$c_t \equiv$ marginal extraction cost

$\rho \equiv 1/(1 + r)$ is the discount factor

$r \equiv$ the real interest rate.

The present paper assumes the real interest rate and marginal extraction cost are constant but this can be relaxed without altering the qualitative properties of the model. OPEC chooses the output path in (1) implying the transversality condition

$$r = (\pi_{t+1} - \pi_t)/\pi_t. \quad (2)$$

Marginal profit increases at a rate equal to real interest rate with the marginal barrel earning its opportunity cost, the real interest rate.

For any OECD offer curve, the relative price of oil rises as extraction diminishes with the shrinking OPEC offer curve. The changes in the international relative price of oil and extraction depend on the OECD offer curve. According to empirical evidence, oil imports are inelastic suggesting the OECD offer curve is backward bending. The shrinking OPEC offer curve then results in a large oil price decrease relative to extraction. In the upward sloping portion of the OPEC offer curve, imports are elastic and the oil price increase is small relative to the decrease in

extraction. The present simulations report results with import demand elasticities of -0.5 and -1 for sensitivity.

Simulated extraction, depletion, and price

Simulations start with the current world production of 22 billion barrels and use a constant extraction cost of \$20/barrel, the approximate extraction cost in West Texas. Extraction costs are much lower in most producing areas but can be expected to begin a gradual climb. Historically, improved technology and discoveries have kept extraction costs relatively constant. Simulated paths of depletion and price are relatively robust to reasonable growth in extraction cost. The real rate of interest is assumed to be 2%, and simulations are robust to reasonable variation.

For simulations, the present price is set to \$25 or 25% above extraction cost. The recent higher oil prices are a result of supply disruptions and production bottlenecks. Basing price on extraction cost seems more realistic for a long term study. Price paths would shift upward from any higher starting point resulting in similar extraction and depletion paths.

The simulations assume constant elasticity OECD oil import demand. An import elasticity of -0.5 results in the inverse demand function scaled to present consumption and price of $p_t = 2.3 \times 10^{10} / q_t^2$. The present simulations assume OECD oil import demand does not grow but projections are not overly sensitive to reasonable demand growth. Extraction and depletion paths are reported for an OECD import elasticity of -1.

The simulated price schedule in Figure 2 is independent of the OECD oil import elasticity and extraction cost due to (2). Over time, the OPEC offer curve in Figure 1 shifts in with depleting reserves. With the 2% real interest rate, the price of oil doubles after about a century. The price path is more sensitive to the real interest rate than other exogenous variables in the model. With a real interest rate of 4% the price doubles in 40 years and reaches \$250 after a century. Real interest rates are generally steady and low, depending on estimation techniques.

* Figure 2 *

Rehrl and Frederich (2006) predict steeper price increases than in Figure 2 due to rising extraction costs. Extraction costs, in fact, generally fell over the past 100 years due to improved technology. The present assumption of constant extraction cost provides a benchmark. The price path in Figure 2 is consistent Energy Information Agency (2007) price projections for 25 years.

Given the price schedule in Figure 2, extraction paths in Figure 3 are derived using the OECD oil import elasticity along its offer curve. As the OPEC offer curve shifts in with depletion, extraction falls. With the oil import elasticity of -0.5 extraction is 68% of its present level after a century. Higher import elasticity implies slower extraction, an elasticity of -1 leading to extraction of 45% of its present level after a century. Ultimately, investment in oil substitutes would increase oil import elasticity and the present extraction paths can be considered upper limits.

* Figure 3 *

Assuming an annual 1% increase in demand, extraction may rise for some time before beginning a decline. With an import elasticity of -0.5 extraction continuously increases and reserves are depleted after 100 years. The growing demand simply overpowers the oil import elasticity. With an import elasticity of -1 extraction peaks after 75 years and reserves are depleted after 120 years. It is unreasonable to assume such long term growth in oil import demand regardless of its price but these simulations provide reasonable parameters. Wood, Long, and Moorehouse (2004) predict extraction will peak after 30 years due to growing demand before beginning a long gradual decline.

Global recoverable oil reserves are set at 3 trillion barrels in Figure 4. There is a wide range of estimates of proven, economic, recoverable, and physical endowments of various grades. The reserves in Figure 4 are calculated by subtracting extraction each year from the beginning reserves of 3 trillion barrels. Reserves fall to 51% (38%) of their present level after a century with

an elasticity of -0.5 (-1). The economizing effects of rising oil prices are often neglected in projections of reserves but are very apparent in Figures 3 and 4. In principle, reserves are never depleted due to the rising price and economizing behavior implied by the constant elasticity of import demand.

* Figure 4 *

Table 1 summarizes price, extraction, and oil export revenue given an oil import elasticity of -0.5. The OPEC offer curve shrinks with depletion tracing the OECD offer curve. Holding the price of OECD manufactured exports constant, the rising price of oil in Figure 2 is the relative price of oil or the OPEC terms of trade. OPEC oil export revenue then equals OPEC imports given a constant unit price of imports, the last column *\$bil revenue* in Table 1. With the improved terms of trade *\$/bbl*, OPEC exports *bil bbl* fall as imports rise. After 25 years OPEC terms of trade improve 12%, extraction falls 5%, and imports rise 7%. After 100 years OPEC terms of trade improve 32%, extraction falls 32%, and imports rise 53%. The inelastic oil import demand is pictured by a backward bending OECD offer curve.

* Table 1 *

With unit elastic OECD oil import demand, OPEC oil revenue would be constant, the OECD offer curve flat, and extraction slower. Extraction would fall to 10 billion barrels after 100 years compared to 150 years to reach that level with the -0.5 elasticity in Table 1.

As the price of oil rises over the decades, the demand for oil may become more elastic leading to in slower extraction. The elasticity can also be expected to increase due to improved technology and backstop energy sources. A rising OECD oil import elasticity implies increased extraction and faster depletion.

Conclusion

The present model integrates offer curves and optimal depletion, simulating the long term parameters of the international oil market. Optimal depletion implies a rising relative price of oil and the present model predicts sizeable increases in oil export revenue over the coming century. A backward bending OPEC offer curve implies the Metzler effect, with a oil import tariff lowering price inclusive of the tariff and raising extraction. Regarding estimates of world wealth, there will be a substantial transfer of wealth toward oil exporters over the coming century.

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Table 1. Oil import elasticity -0.5

<i>year</i>	<i>\$/bbl</i>	<i>bil bbls</i>	<i>\$bil revenue</i>
0	\$25	22	\$550
25	\$28	21	\$588
50	\$33	19	\$627
100	\$56	15	\$840
150	\$116	10	\$1160

Figure 1. OECD Tariff and a backward bending OPEC offer curve

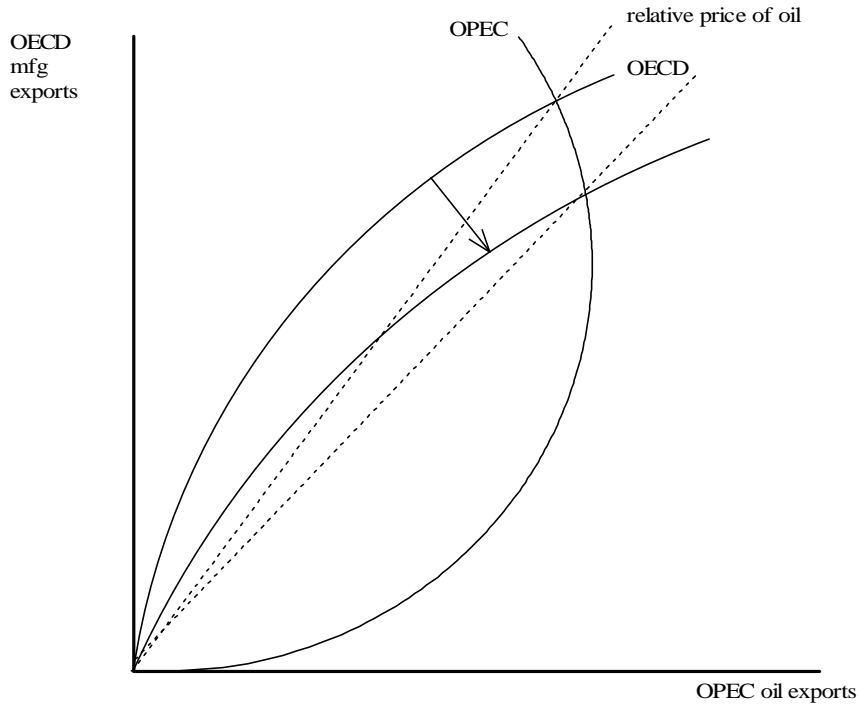


Figure 2. Price schedule

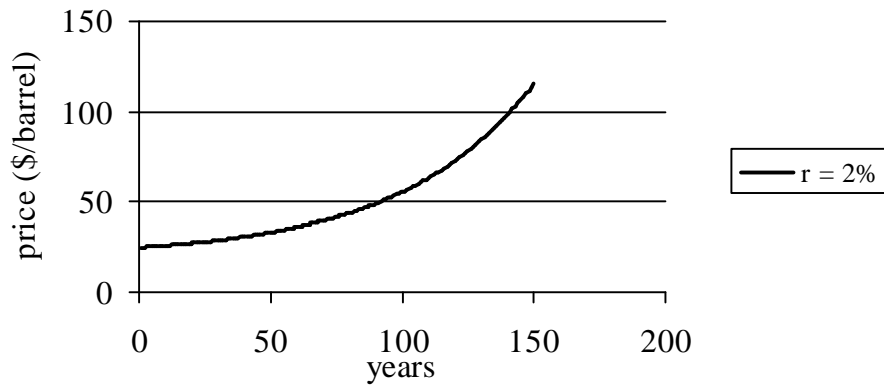


Figure 3. Extraction

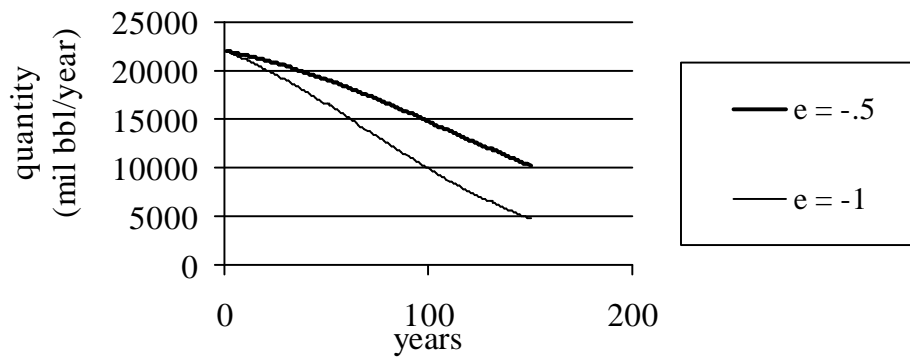


Figure 4. Reserves

