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STOCKPILING TO CONTAIN OPEC

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Abstract

I maximize present valued world GDP over the stockpile of petroleum used to contain price shocks administered by OPEC. Long run price elasticity of demand and non-OPEC supply exceed those in the short run, so OPEC profits from sudden, as opposed to gradual, increases in price. These shocks damage the world economy. I simulate interaction among consumers, non-OPEC producers, a profit-maximizing, monolithic OPEC, and an International Energy Agency that punishes OPEC by releasing oil from stockpiles onto the market during upward shocks to price. A stockpile of 6 billion barrels would add much more to world GDP than the cost of holding it and the lost profits to OPEC under a range of assumptions, though private actors do not have incentive to maintain and use stocks to maximize GDP. Authority over stockpiles should be shielded from the influence of the energy industry, whose profits may not be maximized at oil prices that maximize GDP. Prices equal to marginal costs would be low into the 2030's, then rise rapidly with costs. World consumption of petroleum reaches a peak of 67 bbl/yr in 2045, and declines quickly thereafter.

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1 INTRODUCTION

1.1 Stockpiles and Price Shocks

There is an ongoing debate regarding the use of government oil stocks to stabilize oil prices. Proponents argue that governments of oil-consuming countries can release oil from their stockpiles as an effective way to counter short term restrictions on supply imposed by the Organization of Petroleum Exporting Countries (OPEC). Opponents argue that government-controlled stockpiles should only be used to address catastrophic disruptions in supply, and that using stockpiles to stabilize prices would deplete them, leaving consuming countries vulnerable when catastrophic disruptions occurred, or that the stockpiles are not useful and should be liquidated[1]. Authors such as Considine (2006) have concluded that existing stocks are inadequate to appreciably influence price. I and a few others, whose work I discuss below, ask a somewhat different question: How large a stockpile would be needed, and how much of it would need to be released onto the market, to best contain an OPEC-administered price shock? I estimate the petroleum stockpile and potential releases needed to maximize present valued world GDP.[2] I provide context in Section 1, discussing related research in Section 1.5, describe a model in Section 2, report results in Section 3, and conclude in Section 4.

1.2 Motivation

Price shocks are endemic to the cartelized world market for oil. OPEC profits more from a price path punctuated by occasional sudden increases than from a totally smooth path. The immediate decline in demand and increase in non-OPEC supply following a price shock are small compared to the changes in the long run.[3] OPEC's sales volume remains high for a time following a sharp rise in price, affording it substantial profits in the short run, as consumers and non-OPEC producers take time to adjust their capital and durables to the new, higher prices.[4] The real world price of petroleum was about the same in 1974:II

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[1] See Taylor and Van Doren (2005).

[2] Another way to reduce consuming economies' vulnerability to oil price shocks would be to reduce consumption of oil; in fact, as shown in Table A1, world demand for petroleum has been growing only half as fast as world GDP. See Zycher for a brief history of OPEC.

[3] See Pindyck (1978) and Huntington (1993).

[4] If consumers and non-OPEC producers had rational expectations regarding OPEC's pricing strategy, they would optimize their capital and durables ahead of time, and there would be no difference between short run and long run elasticities. OPEC would then have no reason to effect price shocks. My estimates of demand and non-OPEC supply, discussed in Vatter (2008), are consistent with a failure of rational expectations.

and 2004:IV. During the 55 quarter-to-quarter increases in price, the average rate of increase was 9.5%. During the 66 quarter-to-quarter decreases in price, the rate of decrease averaged 7.9%.[5]

Oil price shocks are damaging because of the oil-intensiveness of the world economy. At $100 per barrel, global oil revenue is 4.5% of GDP. When oil prices jump, costly structural dislocations ensue, and cyclical effects also result because of efficiency wages, confusion between relative and absolute price changes, and other non-Walrasian features of the macroeconomy. Empirically, the adverse effects of increases in oil prices exceed the benefits of declines[6], and macroeconomic shocks generally have persistent effects, so the costs of rapid increases in oil prices accumulate over time in their wake. Oil price shocks have been a major contributor to macroeconomic downturns since World War II, with the attendant effects on poverty and unemployment. There is a large literature on the role of oil prices in causing recessions[7], much of which is reviewed in Jones and Leiby (1996). The seminal article is Hamilton (1983).

That oil price shocks are both endemic and destructive motivates this work. According to Williams and Wright (1991; p. 417), "Macroeconomic justifications for storage intervention rest on shaky ground. This is not to deny their potential importance; but the arguments must be made more precise before it is possible to conduct the critical evaluation that would make them persuasive." Here and in Vatter (2008), I have tried to do that.

Oil-consuming economies' vulnerability to OPEC's price shocks will increase as rapid depletion of reserves in non-OPEC countries and rising demand move the world toward greater dependence on oil from OPEC members in the Persian Gulf.[8] Excluding Canadian oil-sands, non-OPEC countries contain about a fifth of proven reserves, but currently meet three fifths of world demand. (Including the sands brings non-OPEC reserves to one third of proven reserves.) Acceleration in world demand growth driven by economic growth in emerging economies like China and India will increase the world's dependence on OPEC.[9] According to the report issued by the White House's National Energy Policy Development [NEPD] Group in May of 2001 (p. 8-4) , "By 2020, Gulf oil producers are projected to supply between 54 and 67 percent of the world's oil. Thus, the global economy will almost certainly continue to depend on the supply of oil from [OPEC] members, particularly in the Gulf."

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[5] Source: U.S. Energy Information Administration;
[6] See Gately and Huntington (2002) and Vatter (2008).
[7] See, for example, Gisser (1986), Bohi (1989) and Bohi (1991).
[8] A countervailing effect is also in process as the world economy becomes less petroleum intensive.
[9] Source: U.S. Energy Information Administration, http://www.eia.doe.gov/emeu/steo/pub/3tab.html.

1.3 Existing Stockpiles of Petroleum

Organization for Economic Cooperation and Development (OECD) countries now have access to almost 3.9 billion barrels in emergency stockpiles, 1.4 billion of which are held directly by member governments, including 700 million in the U.S. Strategic Petroleum Reserve. The accessibility of industry stocks is not assured because they may constitute "working inventory" in pipelines or refineries, and because private firms do not internalize the macroeconomic benefits of increasing the amount of oil supplied to the market during price shocks, so I focus on stocks held directly by governments.

1.3.1 International Energy Agency Stocks

According to the New Zealand Ministry of Economic Development, "The International Energy Agency (IEA) is an autonomous body within the OECD. It was established in 1974 following the first oil crisis *and in response to the enhanced power of OPEC* [emphasis added]... The legal basis for the IEA is the Agreement on an International Energy Programme, the heart of which is a collective emergency response system for a major disruption in international oil supply. Most members of the OECD (totalling 29) are also members of the IEA (currently 24)."

IEA members must hold minimum oil stocks equivalent to 90 days of the previous year's imports and have measures to reduce the call on the world oil market ready for quick implementation.[10] Their stocks include 1.4 billion barrels of government-owned stocks, and 2.5 billion barrels of industry stocks. Member countries are capable of releasing up to 9.6 mb/d of crude oil and 3.3 mb/d of downstream oil products from government-owned stocks. The IEA acted to make available 2.5 mb/d at the outset of the Gulf War in January, 1991.[11] The United States is by far the most influential member of the group. Its Strategic Petroleum Reserve constitutes half of the IEA's government-owned stocks, and the U.S. holds 46 of the 175 voting rights over Agency decisions.[12]

[10] See http://www.med.govt.nz/ers/int_en_rel/iea.html.
[11] See http://www.iea.org/Textbase/papers/2004/factsheetcover.pdf.
[12] See page 23 of Organization for Economic Cooperation and Development (1974).

1.3.2 The U.S. Strategic Petroleum Reserve

The United States' Strategic Petroleum Reserve (SPR) was created through the Energy Policy and Conservation Act of December 1975. The act allowed the federal government to store up to 1 billion barrels of petroleum in salt caverns located near the Gulf of Mexico. Stockpiling of oil began in June 1977. Decisions to withdraw crude oil from the SPR are made by the President under the authority of the act. In the event of an energy emergency, SPR oil would be distributed by competitive sale. The G.H.W. Bush administration withdrew 17.3 million barrels from the SPR during the Persian Gulf War of 1991. OPEC acted to reduce the supply of oil during the winter of 1999-2000. The following September, the Clinton administration released 30 million barrels of crude oil from the SPR.

1.4 Should Government Oil Stocks be Used to Contain Price Shocks? [13]

As noted above in Section 1.3.1, the IEA stockpiles, including the U.S. Strategic Petroleum Reserve, were created in response to an OPEC-administered price shock in 1973. The argument that they are sufficient to stabilize prices rests on the smallness of the short-run elasticities of demand for oil and non-OPEC supply:

> ....if [OPEC] withholding a few hundred thousand barrels a day from the market can drive prices sky-high, putting a similar amount back in can bring them back down to earth, as demonstrated by the sharp drop in oil prices that followed the announcement of plans to tap U.S. strategic reserves. And Western governments have more than a billion barrels in reserve. Why not use those reserves to break the market corner, or at least to limit its effectiveness? [14]

Opponents see such moves as either ineffective or irresponsible.

> ...I have always viewed the Strategic Petroleum Reserve as a reserve in the event of a serious crisis. By that, I mean a shutdown in Middle East oil or something of that nature, because of a catastrophe of some form.

[13] A summary of this debate as it relates to the U.S. Strategic Petroleum Reserve and a number of references are available at http://www.swlearning.com/economics/policy_debates/oil.html.
[14] Krugman (2000).

> I think it would be a mistake to try to move market prices by small additions or subtractions from the Strategic Petroleum Reserve. We are dealing with an overall world market which is huge relative to our Strategic Petroleum Reserve. It is foolishness to believe that we could have any significant impact short of a very major liquidation in the short term of that reserve, and I don't think anybody is arguing for that.[15]

According to the NEPD report, "The NEPD Group recommends that the President reaffirm that the [Strategic Petroleum Reserve] is designed for addressing an imminent or actual disruption in oil supplies, and not for managing prices."[16] However, it could be difficult to distinguish a price shock that OPEC could prevent from a catastrophic disruption. Adelman (2004; p. 21) writes "IEA discourages importing nations from using strategic stocks, including the United States' Strategic Petroleum Reserve. The importer nations have agreed not to use those stocks unless there is a serious 'real shortage'. If so, they will never be used. In a market economy, the price changes to equate the amount supplied to the amount demanded, precluding a 'real shortage'."

A major disruption in oil supplies would result in a large increase in the price of oil, and, barring an upward shock to demand, a sudden increase in oil prices would result from a disruption to supply. OPEC may time its shocks to assist in accomplishing political or military objectives, it may profit from a catastrophic disruption and deliberately fail to increase output in response, or it may use a catastrophic shock as occasion to further restrict supply. Allowing events beyond its control to influence the timing of price shocks increases the element of surprise and, therefore, their profitability. OPEC administered large, sudden increases in the price of oil in the 1970's that coincided with the 1973 Yom Kippur War and the 1979 Iranian Revolution.[17] Some might view these events as catastrophes. The results of these reductions in oil supplies included the worst economic downturns in industrialized economies since the Great Depression.

Hamilton (2003) uses disruptions to petroleum supplies as instruments to measure variation in petroleum prices that are exogenous to U.S. GDP, finding that they explain GDP comparably well to models that allow non-linear, asymmetric effects of petroleum prices on GDP. He compares certain transformations of price that emphasize upward shocks to predicted values from a regression of price on his instruments, noting their similarity. He further compares a regression of income on a non-linear transformation of

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[15] Greenspan (2000).
[16] *National Energy Policy* (Washington, D.C.: White House, May 17, 2001), p. 8-17.
[17] See http://www.buyandhold.com/bh/en/education/history/2002/arab.html, and http://www.eia.doe.gov/emeu/cabs/chron.html#a1979 for history.

price to the results of a second stage regression of income on prices predicted by his instruments, again noting their similarity.

These disruptions occurred because OPEC opted not to increase production to fill the gap, but, rather, further restricted supply. The largest disruption occurred at the time of the Iranian Revolution. Student protests against the government of Shah Reza Pahlavi began in January of 1978. "Throughout the year increasing anti-Shah activities were led by Muslim fundamentalists seeking to establish a Muslim state." The Shah put Iran under military rule in September. He left Iran for the last time in January 1979. Iranian oil production dipped severely between November 1978 and April 1979. In December 1978, OPEC decided on a 14.5 percent price increase for 1979, which it made effective the following April. It raised prices by 15 percent again in July 1979.[18] Adelman (1990; p. 21) writes "...in 1978-80, the oil price tripled for the usual reason: not that wells were giving out but because OPEC nations, particularly Saudi Arabia, shut in production rather than let it expand to make up for Iranian fluctuations."

1.5 Other Economic Analyses of Government-Controlled Stockpiles of Oil

Leiby, Bowman and Jones (2002) and Teisberg (1981) address questions most similar to the one that I address here. They each estimate an optimal size for consuming nations' collective stockpiles, based on benefit-cost and "insecurity cost" criteria, respectively.

Leiby, Bowman, and Jones (LBJ) simulate oil shocks at random thousands of times and average across simulations to arrive at the expected net benefit to oil-consuming nations of expanding petroleum stockpiles. The frequency and magnitude of LBJ's disruptions in supply are governed by a Weibull distribution, so they are infrequent. Their expected duration appears to be 4.5 months. There is nothing wrong with this reduced form approach, but the more structural approach I take here adds perspective. A key result from LBJ is that the joint optimal petroleum stockpile for all major consuming regions in the world is about 1.3 billion barrels of oil.

On pages 528-529 of his paper, Teisberg states: "Although this model of world price determination makes the analysis simple, there are certain theoretical problems in such an analysis. First, if oil production is set by a 'dominant country', or by a cartel, the supply of oil may depend upon U.S. policies

[18] See http://www.iea.org/Textbase/papers/2004/factsheetcover.pdf, http://www.eia.doe.gov/emeu/international/petroleu.html, and page 18 of http://www.iea.org/textbase/nppdf/free/2000/oilsecu2001.pdf.

in complicated ways not captured in the supply function representation. Second, because oil is an exhaustible resource, there is intertemporal dependence in the supply functions, and this is not reflected in the model specified here." I model OPEC as a profit-maximizing cartel in control of an exhaustible resource whose cost of extraction increases as remaining recoverable resources[19] dwindle.

Jabir (2001) estimates U.S. demand for petroleum, taking account of the impact of changes in the size of the Strategic Petroleum Reserve. On page 664, he states "...as a result of a one million barrel increase in [SPR]..., the average price in the successive year is offset by only 0.4%." At this rate, a change of 100 million barrels in strategic reserves would move prices by 40%.

Other work focuses on use of existing SPR to mitigate the effects of generic oil shocks. Yücel (1994) estimates the welfare loss in the United States due to randomly generated disruptions in world supplies of oil. She compares the effects of an import tariff and gasoline tax with and without drawdowns from the SPR at its then-current stockpile. She concludes that the drawdowns combined with a gasoline tax would be the best protection from disruptions in supply. Das et al. (1990) examine the effects of a political or military disruption of world oil supplies in 1995. They find that drawdowns from the SPR obviate the need to reallocate oil supplies under the International Energy Agency's oil-sharing agreement.

Takagi and Fujii (2000) urge creation of an Asian Strategic Petroleum Reserve in the face of rapidly rising Asian imports from the Middle East.

2 MODEL

I model an integrated world oil market with centralized IEA authority over the stockpiles of petroleum used to counter OPEC's price shocks. However, the results of the model could apply to any institution interested in containing OPEC's price shocks, such as Takagi and Fujii's Asian reserve. Agents in the model include the world's consumers of oil, non-OPEC producers, OPEC itself, and the IEA. The model is based loosely on Pindyck (1978).

[19] For a definition of "remaining recoverable resources", see SPE/WPC/AAPG/SPEE (2007).

2.1 A World Price

I assume that the world market for petroleum is fully integrated in the sense that any grade of crude will be made available at any location to the buyer willing to pay the most for that oil at the wellhead plus a competitively determined delivery charge. I assume that, if arbitrage is needed, its costs are negligible. Under this assumption, only price shocks resulting from disruptions in supply to the world market as a whole are of interest.

The case that the market is worldwide follows from the fact that there are many ways for oil to make its way to consumers. According to Adelman (2004; p. 19), "Most oil moves by sea, and ships can be diverted from one destination to another relatively easily. Moreover, much additional oil can be diverted from land shipment to sea. Hence, it is fairly easy to reroute shipments of oil from nations that have a sufficient supply to nations that are experiencing a shortage. It is only a minor exaggeration to say that every barrel in the world competes with every other."[20]

Any seller in control of a large part of the world's oil can control the amount of oil she sells, but she cannot control what happens to that oil after she sells it. To make oil available to a large part of the world, but deny it to the U.S., for example, would require being able to block the many ways that oil can be transported to the U.S. To make oil available to only a few other parties would substantially cede the seller's market power to those few other parties. Targeted embargoes are either ineffective or unprofitable. According to Teisberg (1981), "...arbitrage on the world market appears capable of defeating efforts to target embargoes. The Arab Oil Embargo [against the U.S. and The Netherlands] experience supports this view: prices rose by about the same amount in all countries, regardless of which countries were embargoed. See Stombaugh (1975)."[21]

According to Zycher, "The embargo against the United States and The Netherlands had no effect whatever: both nations were able to obtain oil at the same prices as all other nations... Nor, as is commonly believed, was OPEC the cause of oil shortages and gasoline lines in the United States. Instead, the shortages were caused by price and allocation controls on crude oil and refined products,

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[20] The recent abrupt increase in oil and gas prices sold by Russia to Ukraine is not a counterexample. The previous prices were below market, and the abrupt increase only brought prices up to world market levels. See http://usinfo.state.gov/eur/Archive/2006/Jan/03-530814.html.

[21] See p. 528 of Teisberg.

originally imposed in 1971... Countries that avoided price controls, such as West Germany and Switzerland, also avoided shortages, queues, and the other perverse effects of the controls."[22]

2.2 A Monolithic OPEC

An in depth discussion of the problem of cooperation within OPEC is beyond the scope of this paper. I assume that OPEC chooses price to maximize the present value of its profits. Griffin and Xiong (1997) find that punishment of cheating on OPEC quotas is a dominant strategy for Saudi Arabia. Because unstable prices are more profitable for OPEC than stable ones, declines in price that follow sharp increases, such as the "price collapse" of the mid-1980's that followed the shock a few years earlier, do not indicate a breakdown in cooperation among OPEC members. Stevens (2005; p. 24) writes "…[Saudi Arabia] decided in 1985 to maintain lower stable prices to encourage a reversion to oil by energy consumers."

According to Van Vactor (2008; p. 34), "Under-investment in oil producing capacity is not coordinated by the cartel, but it is the primary method by which prices have been sustained at higher than competitive levels. This occurs because ownership of the resource is concentrated in the ruling elite and managed as a block by the country's national oil company." I submit that while there may be no formal coordination, the ability and incentive for governments of OPEC countries to collude informally over investment in exploration and development are great. Exploration and development of oil fields takes time and requires substantial expenditure. It would be easy for member governments to observe one another expanding capacity beyond what they need to meet production quotas, and to punish such activity by responding in kind. Any member who had the capacity to increase sales well beyond its quota would have no trouble doing so if it undercut the world price somewhat. Since that price is far above the marginal cost of extraction in OPEC countries, the payoff for such cheating would be large. The cartel is much stronger when that large payoff is not available to any of its members. Limiting investment, then, is critical to OPEC's ability to control price. Krugman and Wells (2005; p. 369) write "…when firms are restricted in how much they can produce, it is easier for them to avoid excessive competition and to "divvy up" the market, thereby pricing above marginal cost and earning profits. It is easier for them to achieve an outcome that looks like collusion without a formal agreement."

[22] Not everyone has confidence in the world oil market's ability to supply oil reliably to the highest bidder. According to He Jun, an energy consultant in Beijing who advises Chinese oil companies, "A popular saying abroad is that oil is just a commodity that anyone who has money can buy, but this saying is most popular in the countries that already control the supplies." See Kahn (2005).

2.3 Centralized Authority Over Stockpiles

I am also assuming centralized decision-making regarding those petroleum stockpiles used to deter OPEC's price shocks. The IEA agreement places requirements on participants to hold stockpiles of oil and defines conditions under which releases from those stockpiles occur. It also defines a voting mechanism by which decisions are made. The United States holds over a fourth of the voting power.

LBJ find that consuming nations need to cooperate to prevent free-riding on accumulation of stockpiles, but there is no need to coordinate drawdown during disruptions because the incentive to tap reserves is large at such times. The cost of constructing storage capacity is significant (about six dollars a barrel), but the costs of operation and maintenance "(during filling, drawing, and standby) are modest compared to the larger costs of capacity construction and oil purchase".

Inasmuch as use of petroleum stockpiles to contain price shocks reduces OPEC's and other sellers' profits, one would expect the oil industry to oppose this use of petroleum stockpiles. Every oil firm involved in upstream activity profits from a successful OPEC cartel. The firm itself may control some oil resources, or it may share revenue with the oil-producing countries for whom it extracts, refines, or markets oil, so it benefits when OPEC manipulates prices. Downstream firms may also use price shocks as occasion to restrict sales, if collusion is feasible. In hearings on potential price regulation of the oil industry, Senator Pryor asked "What other industry behaves like the oil industry (where) when the cost of the raw material increases, their profits multiply?"[23] When the Clinton administration responded to a move by OPEC to raise prices in 2000 by tapping the U.S. Strategic Petroleum Reserve, Clinton stated that the country had an interest in stable oil prices and expressed a willingness to use the Reserve to stabilize them.[24] The G.W. Bush administration, more closely linked to the energy sector[25], opposes such moves, as indicated in the quote above from its National Energy Policy Document.

Taylor and Van Doren (p. 15) emphasize the problem of "government failure" in holding and using strategic stocks. The IEA did succeed in managing a response to the disruption associated with the 1991 Gulf War, releasing 2.5 mb/d onto the market.[26] The scale of action contemplated here could be much larger, and done without the urgency of wartime. Petroleum stockpile authority, be it national or

[23] See Associated Press (2006).
[24] See Clinton (2000) and Krugman (2000).
[25] See Wetherell (2002).
[26] See http://www.iea.org/textbase/work/2004/cambodia/bj_session3.1-Houssin%20presentation.pdf.

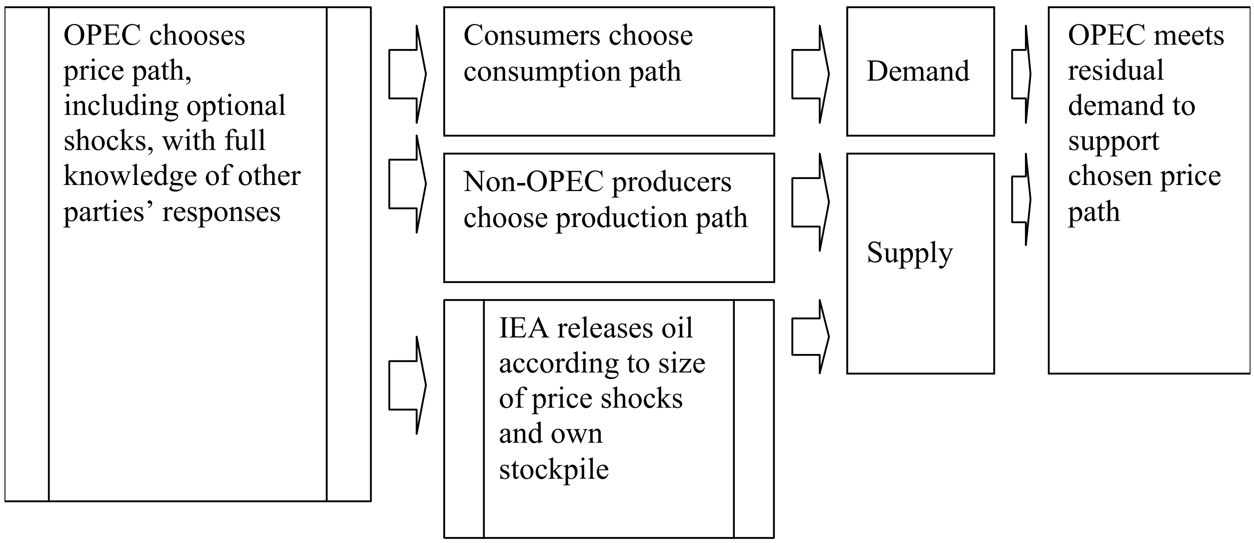
multinational, that is influenced by oil-producers may not respond to the strong incentive, identified by LBJ, to release reserves in a time of shortage because it faces a conflicting incentive to boost industry profits. At the time of the Iranian Revolution, IEA had about a hundred days worth of net imports in industry stocks, but it did not take coordinated action. Adelman (2004; p. 21) writes that in 1978-80, "There was no use of strategic stocks. The Carter administration had previously agreed not to use the Strategic Petroleum Reserve without Saudi permission."

One can envision structures of governance over stockpiles whose interests were aligned with those of the general public, and such structures should be contemplated in tandem with any increase in stockpiles. The compensation of the central banker of New Zealand is tied to the rate of inflation. The budget of the IEA could be tied to the performance of the world economy, and membership could be expanded beyond the current OECD to include other large consuming nations. In particular, authority over stockpiles should be shielded from interests in the energy industry that conflict with those of the general public.

2.4 Agents in the Model

Agents in the model include the world's consumers of oil, non-OPEC producers, OPEC, and the IEA. Consumers and non-OPEC producers are non-strategic price-takers. I model their behavior using reduced form econometric specifications, absent any structural optimization such as maximization of utility subject to a budget constraint. OPEC, on the other hand, maximizes the present discounted value of future profits by choosing a path over time for the price of oil, and the IEA maximizes the present value of world GDP over the size of its stockpile and the price that triggers releases from the stockpile. The price path includes price shocks of OPEC's choosing. The IEA has central authority over the stockpiles of oil that governments tap to counter price shocks. The IEA pursues a strategy designed to reduce the size of price shocks; the greater the price shock, the more oil the IEA puts on the market. OPEC adjusts its price path taking account of how the IEA, consumers, and non-OPEC producers will respond. OPEC then supplies the market with the difference between consumption on the one hand and non-OPEC output and releases from stockpiles on the other. If the IEA has no oil, OPEC's output is the difference between world demand for oil and non-OPEC production at OPEC's profit-maximizing price path.

Figure 1: Interaction Among Agents



OPEC and the IEA attempt to influence each other's behavior. The IEA punishes shocks in OPEC's chosen price path by releasing oil onto the market, and OPEC adjusts its price path in order to avoid some or all of this punishment. I set the size of the IEA stockpile and the price shock that triggers IEA intervention so as to maximize present valued world GDP.[27]

I have defined price, rather than quantity, as OPEC's choice variable. Stevens (p. 24) writes "OPEC comes to assess world oil demand, non-OPEC supply, and the consequent call on OPEC..." Adelman (1990; p. 12) writes "OPEC is the swing producer, restricting oil production to maintain the price." Historically, OPEC has both targeted prices and imposed production quotas. Van Vactor (2004; p. 72) describes the two-step process employed by OPEC during the second major oil shock of the 1970's and 1980's:

> In the first step OPEC set a 'marker' price for crude oil. They chose 'Arabian Light' as the marker. This is the crude oil from the Ghawar field, the largest oil field in the world, producing on the order of 4.5 million barrels per day. Once the marker price was set, Saudi Arabia was allowed to adjust production up or down as demand for petroleum waxed and waned. The second step was equally simple. Other members of OPEC were to accept fixed production quotas, but could allow prices to vary. In other words, an unexpected surge in oil demand would have two

[27] I do not address the problem of initially accumulating petroleum stockpiles. Depending on how large a stockpile would suffice to contain a price shock, this could be a significant problem. OPEC might punish stockpiling by spiking price as reserves are acquired.

types of consequences for cartel members. Algeria, for example, could respond to the increased call on its crude oil by increasing price, holding production constant. Saudi Arabia would hold its price constant but allow production to increase. The cartel would meet periodically to assess production rates from each of the countries with respect to the overall price level they set.

2.5 Specification

I model the market for $T = 60$ years, with the initial conditions set in 2005, before the current run-up in price began. I describe world demand for petroleum and non-OPEC supply in Equations (1), (2), and (3). I discuss the design and estimation of these equations in detail in Vatter (2008).

2.5.1 The Demand for Petroleum

I model consumers as passive price-takers. They do not attempt to influence other agents' behavior. They accept OPEC's chosen price path and choose a path of consumption so as to, implicitly, optimize according to their preferences. In practice, people who make decisions about consumption of oil include households, businesses, voters, elected officials, dictators, and urban planners.

World demand for petroleum depends directly on the price of petroleum, on world GDP, and on a trend toward greater efficiency in the use of petroleum, and there is persistence in demand that renders own price elasticity greater in the long run than the short.

$$D_t = -6.05604 - 0.02675P_t + 12.48769GDP_t - 0.235671t + 0.83554Dave_{t-1} \quad (1)$$

D_t is quarterly world demand for crude petroleum, in bbl/yr. P_t is the real price of petroleum, in 2005\$/bl, GDP_t is world gross domestic product ($GDP_t = 1$ in 2005:II), t is time in years ($t = 0$ in 2005:II), and $Dave_{t-1}$ is annual world demand for petroleum for the four quarters ending with quarter $t-1$, in bbl/yr. I have estimated this demand relation based on historical data in which the price of petroleum fluctuated between \$10 and \$80/bl, in 2005\$. The price in my forward-looking simulations rises to much higher levels. I do not consider the possibility that the relationship would change in the future. However, one attractive property of Equation (1) in this respect is that demand is linear in price.

As a result, the price elasticity of demand is increasing in price, so demand becomes increasingly responsive to changes in price as price goes up. Adelman (1990; p. 11) writes "…the higher the price, the greater the response to a given price change."

Demand for petroleum responds to price directly and through the effect of petroleum prices on the world economy. I model world GDP as following a stochastic trend and depending on increases, but not decreases, in the price of petroleum. Hamilton (2003) explains the asymmetry in the relationship as the result of allocative disturbances and uncertainty. An unexpected change in oil prices in either direction changes the optimal mix of industrial equipment and consumer durables that firms and consumers, respectively, desire. If the change makes them uncertain about the future direction of prices, then they are likely to postpone major purchases until the uncertainty is resolved. Thus, there is a contractionary element in the effects of either increases or decreases in the price of petroleum, but no corresponding expansionary element in the effects of increases.

$$GDP_t = \text{-}0.0008312 \text{ - } 0.00016\left(\frac{dP_{t-1}^{+}}{GDP_{t-1}}\right) + 1.010725GDP_{t-1} \qquad (2)$$

where dP_{t-1}^{+} is the positive quarter-to-quarter change in the real price of petroleum, lagged one quarter (zero if the change is negative). I divide the change in price by GDP. This functional form is designed to capture the decreasing sensitivity of the world economy to changes in the price of petroleum as the world economy "outgrows" its petroleum intensiveness.

Annual world demand for crude oil was 30 bbl (billion barrels) in 2005:II, the outset of my simulations.

2.5.2 Non-OPEC Producers

Non-OPEC producers, like consumers, are modeled as price takers. Some writers refer to this as the "competitive fringe" of the cartelized world market for petroleum. In practice, these producers may be maximizing present valued profits, or they may be driven by political motives if publicly owned. As with consumers, I do not model an optimization problem for them. I do, however, assume that there is a relationship between output and prices and estimate it in reduced form.

Non-OPEC production depends log price, cumulative non-OPEC production, time, a dummy for pre-1988:III, and a one quarter lag in production:

$$S_t = 1.00358 + 0.06468 p_t - 0.00671 CS_{t-1} + 0.10857 t + 0.1741 M_t + 0.92064 S_{t-1} \qquad (3)$$

where S_t is quarterly non-OPEC supply, in bbl/yr, p_t is log price, in 2005$/bl, CS_{t-1} is cumulative non-OPEC supply, in bbl, lagged one quarter and normalized to zero in 2005:II, *t* is time in years, equaling zero in 2005:II, and M_t equals 1 before 1988:III and zero thereafter.

With non-OPEC supply as a function of log price, the price elasticity of supply is decreasing in supply, reflecting an increase in unit costs as the rate of extraction from existing wells increases and increasingly costly wells are pumped. The negative coefficient on cumulative supply reflects increasing costs of exploration and development as new resources become harder to find and develop. The positive coefficient on time reflects technological advances. The positive coefficient on the dummy variable M_t reflects a change in the non-OPEC supply relation in the late 1980's, probably due to a lowering of expectations of future prices in the wake of the 1986 "price collapse", but also perhaps due to the development of commodity market institutions for the exchange of petroleum[28]. The positive coefficient on lagged supply reflects the impact of past investment and prices on current non-OPEC supply.

I assume initial non-OPEC remaining recoverable resources of 900 bbl. EIA lists proven non-OPEC reserves at about 400 bbl, with about 1300 bbl worldwide.[29] The U.S. Geologic Survey[30] (USGS) estimated that there existed 700 bbl of petroleum in undiscovered fields worldwide at the end of 1995, of which it estimated about 400 bbl to be in the Middle East, Africa, and Central and South America, which I attribute to OPEC countries. It also estimated potential reserve growth in known fields to be about 600 bbl worldwide. For the last couple of decades, new discoveries in non-OPEC countries have maintained proven reserves around 400 bbl, as discoveries have kept pace with depletions. USGS estimated about 300 bbl oil equivalent of recoverable natural gas liquids remaining worldwide at the end of 1995, which I apportion according to proved reserves of petroleum. The world consumed about 250 bbl of oil from 1996 through 2004, of which OPEC provided 90 bbl. Table 1 summarizes.

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[28] See Verleger (2005).
[29] See http://www.eia.doe.gov/emeu/international/petroleu.html#WorldReserves.
[30] See http://pubs.usgs.gov/dds/dds-060/sum1.html#TOP.

Table 1: OPEC and Non-OPEC Resources

(bbl and BBOE)

		OPEC	Non-OPEC	World
a	Proven Reserves 2005	900	400	1300
b	Undiscovered Resources 1995	400	300	700
c	Reserve Growth from 1995	343	257	600
d	NG Liquids 1995	208	92	300
e	Oil Consumption 1996-2004	90	160	250
f	Remaining Recoverable Resources 2005	1761	889	2650

a from EIA; b, c, d from USGS; e from EIA and OPEC
f = a + b + c + d - e

I assume that OPEC's remaining recoverable resources are 1.8 trillion barrels and non-OPEC remaining recoverable resources are 900 bbl as of 2005:II.

Non-OPEC production was 15.49 bbl annually in 2005:II.

2.5.3 OPEC

OPEC chooses the path of price at time $t = 0$ to maximize the present value of future profits, discounted to $t = 0$ in 2005:II:

$$PVP = \sum_{t=0}^{T} (P_t - C_t) \cdot Q_t(P) \cdot e^{-\rho t} \tag{4}$$

C_t is OPEC's average lifting cost in 2005 dollars per barrel.

$$C_t = 12{,}783{,}287 Q_t^{0.3026} \left(R_t^p\right)^{-2.3356} \tag{5}$$

where Q_t is OPEC production in Quarter *t*, in bbl/yr, and R_t^p is proven OPEC reserves at the beginning of Quarter *t* in bbl. Celta and Dahl (2000) estimate OPEC's marginal costs in 1995 dollars as

$$\ln(MC) = 46.3263 + 0.3026\ln(Q_{OPEC}) - 2.3356\ln(R_{OPEC}) \quad (6)$$

where Q_{OPEC} is OPEC production in thousand b/d and R_{OPEC} is proven OPEC reserves in thousands of barrels. Taking exponents of both sides of (6) gives

$$MC = \exp(46.3263) Q_{OPEC}^{0.3026} R_{OPEC}^{-2.3356}$$

Since varying production involves activating and deactivating as well as varying the output of wells, integrating over and dividing by Q_{OPEC} gives average avoidable cost:

$$AAC = \frac{\exp(46.3263)}{1+0.3026} Q_{OPEC}^{0.3026} R_{OPEC}^{-2.3356} \quad (7)$$

Initial proven OPEC reserves are 900 bbl, and I assume remaining recoverable resources of 1.8 trillion barrels. I assume that proven reserves continue to equal the same fraction of remaining recoverable resources over time. Recalling that R_{OPEC} is in thousands of barrels and that that Q_{OPEC} is in thousand b/d, $Q_{OPEC} = 10^6 \times Q_t / 365$, where Q_t is in bbl/yr, and $R_{OPEC} = 10^6 \times R_t^p$, where R_t^p is in bbl. I also note that the U.S. GDP implicit price deflator increased 19% between 1995 and 2005. Putting this all together, I transform (7) into the appropriate units as follows:

$$C_t = 1.19 \times \frac{\left((\exp(46.3263)) \times \left(\left(10^6 \times \frac{Q_t}{365} \right)^{0.3026} \right) \times \left(\left(10^6 \times R_t^p \right)^{-2.3356} \right) \right)}{(1+0.3026)}$$

which simplifies to Equation (5).

In Equation (4), $Q_t(P) = D_t - S_t - I_t$ is OPEC output, where $P \equiv (P_0, \ldots, P_t, \ldots, P_T)$ is the price path that OPEC chooses at $t = 0$, and OPEC meets all demand D_t net of non-OPEC supply, S_t, and intervention by the IEA, I_t.

ρ is OPEC's real discount rate, which I set at 10%. This is the rate that Celta and Dahl use as a rate of return in estimating OPEC's cost function. Adelman (1990; pp. 11-13) explains at length that OPEC countries have high discount rates. The risk-premium implicit in OPEC's discount rate is high because the economies of OPEC countries have not diversified beyond production of petroleum, so changes in the petroleum market are not hedged by negative covariance with other sectors. Also, because OPEC is a swing producer within the petroleum market, adjusting output to maintain price, the own-variance of OPEC's income from petroleum is high. The insecure property rights of the sometimes tenuous regimes in OPEC countries adds further risk. Adelman (2004; p. 21) is fond of quoting a mid-20th century oilman who described Persian Gulf leaders as follows: "The future leaves them cold. They want money now." He also describes a history of profligacy among Gulf regimes.

2.5.3.1 *The Path of Price Over Time*

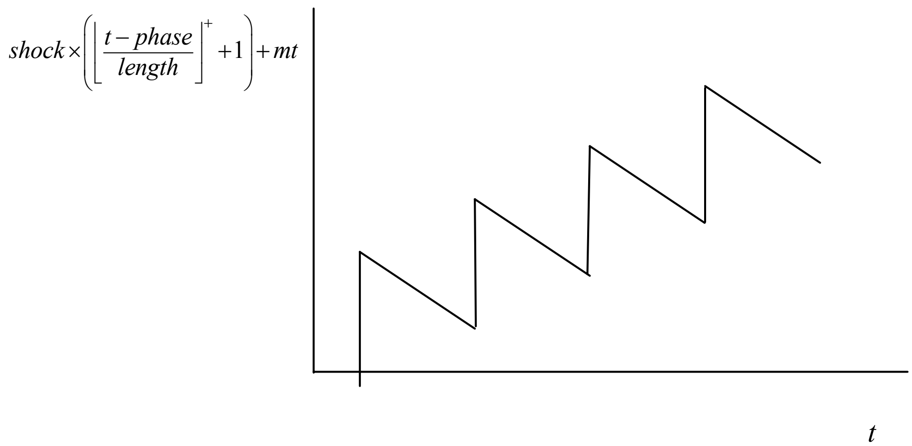
I specify the price of crude oil at time *t* as

$$P_t = P_0 e^{gt} + shock \times \left(\left\lfloor \frac{t - phase}{length} \right\rfloor^{+} + 1 \right) + mt \qquad (8)$$

where $\lfloor x \rfloor^{+}$ is the largest positive integer less than or equal to *x*, zero if $x < 0$, and $m \le 0$. OPEC chooses the price path in two stages. In the first stage, I restrict OPEC to choose its most profitable price path without shocks, by choosing P_0 and *g*, with *shock* = 0 and *m* = 0, to maximize *PVP* from Equation (4).

In the next stage, OPEC chooses *shock*, *phase*, *length*, and m, which are the amplitude, phase, wavelength, and slope of a sawtooth wave that oscillates around $P_0 e^{gt}$, in an attempt to increase *PVP*. The sawtooth wave has instantaneous upward shocks followed by gradual linear declines. It looks something like this:

Figure 2: Sawtooth Shockwave in Price



The instantaneous upward shocks maximize the profitability of increases in price by exploiting the small short run price elasticities of demand and non-OPEC supply. The gradual declines that follow rebuild net demand to OPEC. I use the two-stage process for OPEC's choosing the price path because computational cost is lower than if OPEC chose all parameters of the price path simultaneously, and to focus the IEA on quelling shocks. It is possible that using strategic stocks to force OPEC to choose one shockless price path over another would also raise world GDP, but that is beyond the scope of this paper. Experimentation with the model indicated that upward shocks, during which "demand destruction" occurs, were more profitable if they were followed by relative declines in price, which rebuilt demand. These observations, together with the empirical record cited in the first paragraph of Section 1.2, gave rise to the sawtooth shockwave as characteristic of OPEC's profit-maximizing price-path.

2.5.4 The International Energy Agency

The IEA puts oil on the market so as to discourage OPEC from including shocks in its chosen price path. The oil the IEA puts on the market displaces some of OPEC's sales and reduces OPEC's profits, thus inducing OPEC to choose a smaller price shock. The IEA is endowed with a stockpile of crude oil. The larger the initial stockpile, the more oil it puts on the market in response to any given price shock, and the larger the reduction in OPEC's profits. Similarly, given some stockpile of crude, the larger the price shock OPEC chooses, the more oil the IEA puts on the market.

The objective of the IEA is to increase the present value of world GDP. The IEA discounts GDP at a real rate of 7%, consistent with U.S. government practice.[31] The amplitude (*shock*) and frequency (1/*length*) of OPEC's price shocks are damaging to world GDP by Equation (2). A positive value for *phase* implies that the first shock occurs after an initial lag beginning at $t = 0$ in 2005:II, but the jump from the actual price of $45/bl at that time to the optimal path and subsequent growth at rate g also simulates the most recent run-up in price. Because OPEC discounts future profits, the threat of early punishment is more effective than the threat of late punishment. Accordingly, I specify a rule by which the IEA releases oil of the following form:

$$I_t = x\left(P_t - P_t^{smooth}\right)e^{-\rho t} \tag{9}$$

where

$$P_t^{smooth} = P_0 e^{gt} + trigger \times \left(\left\lfloor \frac{t - phase}{length} \right\rfloor^{+} + 1 \right) + mt$$

$I_t = 0$ for all t if OPEC chooses $shock \le trigger$, where *trigger* is the price shock that triggers IEA intervention. The IEA's maximum drawdown from its current 1.4 billion barrels of publicly-owned stocks is 12.9 mb/d. When the U.S. SPR held about 600 million barrels, it could be released at 4 mb/d, or 1.5 bbl annually, so the entire reserve could be released in five months' time.[32] These figures imply a maximum annual rate of drawdown of $5/2$ of the initial stockpile. I set the maximum annual rate for drawdown at $(3/2) \times SPRI$, where *SPRI* is the IEA's initial stockpile at $t = 0$.

Cumulative intervention at time t is a function of the price path P:

$$CI_t(P) = x\sum_{s=0}^{t}\left(P_s - P_s^{smooth}\right)e^{-\rho s}$$

[31] See U.S. Office of Management and Budget (1992).
[32] See the National Energy Policy Document, pages 8-16.

P^b is the price path that OPEC chooses when the IEA does not intervene in the market. *shockb*, *lengthb*, *phaseb*, and *mb* are the values assumed by the variables *shock*, *length*, *phase*, and *m* along P^b. I set *x* so that the IEA releases all of its strategic stocks when OPEC chooses $P = P^b$. I solve for *x* by letting maximum cumulative intervention under P^b equal the IEA's initial stockpile, *SPRI*. Maximum cumulative intervention at time *t*, with $P = P^b$, is

$$\max_t CI_t\left(P^b\right) = x\left(\max_t \sum_{s=0}^{t}\left(P_s^b - P_s^{smoothb}\right)e^{-\rho s}\right)$$

where

$$P_t^{smoothb} = P_0 e^{gt} + trigger \times \left(\left\lfloor \frac{t - phaseb}{lengthb} \right\rfloor^{+} + 1\right) + mbt$$

Setting this equal to *SPRI* and solving for *x* gives

$$x = \frac{SPRI}{\max_t \sum_{s=0}^{t}\left(P_s^b - P_s^{smoothb}\right)e^{-\rho s}}$$

So, IEA intervention at time t is

$$I_t = SPRI \frac{\left(P_t - P_t^{smooth}\right)e^{-\rho t}}{\max_\tau \sum_{s=0}^{\tau}\left(P_s^b - P_s^{smoothb}\right)e^{-\rho s}} \tag{10}$$

IEA sells petroleum according to Equation (10), but subject to limits on drawdown.

OPEC controls the size, number, frequency, and timing of, and rate of decline subsequent to, shocks in the path of price. This allows OPEC to endure the IEA's response to early shocks, drain the IEA's stockpile, and perpetrate later shocks with no response from the IEA. OPEC knows the IEA's strategy, including the amount of stockpiled petroleum at its disposal. OPEC can provoke the IEA into releasing oil to deplete its stockpile, so that the IEA would have little or no oil with which to respond to subsequent price shocks. Since OPEC has this option in the model, the estimates here are of petroleum stockpiles and triggers that maximize present valued world GDP even when OPEC "games" the IEA.

With a large enough endowment of crude, the IEA can limit the shock to *trigger* and avoid the need to put *any* oil on the market. That is, it can induce OPEC to choose $shock \leq trigger$ with only the *threat* of intervention. Past use of strategic stocks should be seen in this light. The 30 million barrels released in September 2000 may, in itself, have had little effect, but may have demonstrated a willingness to use the reserve to punish shocks. As Krugman points out, spot prices dropped when plans for the release were *announced*.

2.5.5 The Model Considered

The major advantage of this model over other models involving strategic reserves is that it depicts strategic interaction between OPEC and the IEA. OPEC activity has historically been a prominent cause of volatility in oil prices. This volatility is profitable to OPEC because of the difference between short run and long run elasticities of demand and non-OPEC supply, a feature that is also built into this model. This basic structure follows Pindyck (1978). Pindyck's main point is that a cartelized market leads to more volatile prices than a competitive market. Other models, such as those of Yücel and LBJ, which generate shocks at random based on historical patterns, reflect this in reduced form, but not in an explicit, structural way.

The major disadvantage of this model is that it takes hours, on my personal computer, to run a simulation based on a single set of assumptions. Where LBJ ran thousands of scenarios and averaged across them, I have attempted to assess the robustness of results by running sensitivities to key inputs. I have tried to define the strategy sets to include the overall optimizers, but constrained OPEC to identical price shocks at regular intervals. The size, number, frequency, and onset of, and rate of decline subsequent to, the shocks are matters of choice for OPEC, and this does afford OPEC substantial flexibility in its choice of price path, but it is certainly possible that allowing greater flexibility would open more profitable options to OPEC. On the other hand, I have allowed OPEC to optimize the timing of shocks even though, in practice, it may depend on exogenous events to imbue the shocks with an element of surprise, or to conceal its pricing strategy. In that sense, OPEC has more flexibility in this model than in actuality.

I have specified the IEA's strategy intuitively. In earlier stages of this research, I experimented with more formal derivations of an IEA strategy using techniques of dynamic optimization, but, for whatever reason, none of the resulting strategies out-performed the intuitive approach in terms of minimizing the size of stockpile needed to dampen a given price shock.

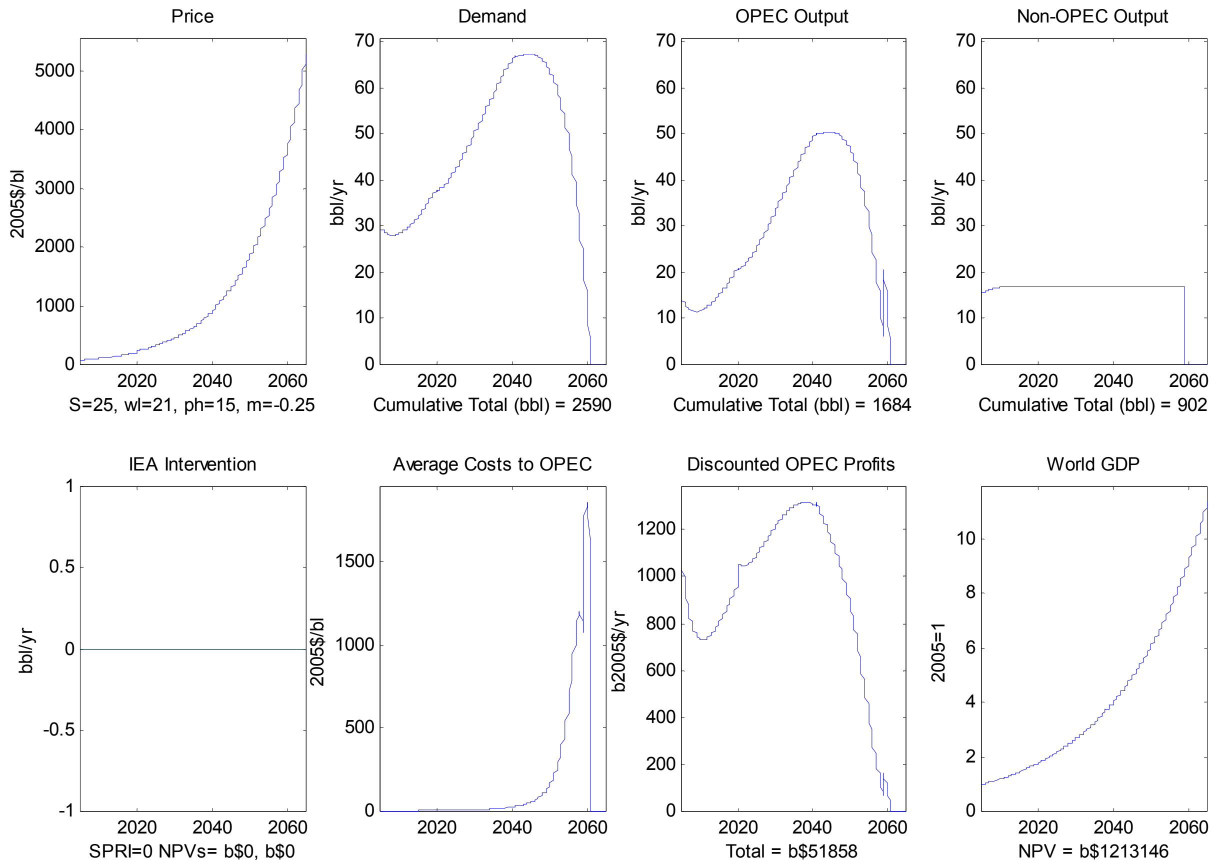
3 SIMULATIONS

I let OPEC choose a price path in the absence of an IEA stockpile. I then adjust the level of petroleum stockpiles held by the IEA by 1 bbl increments and the size of shock that triggers IEA intervention by $5 increments to maximize the present value of world GDP. So long as OPEC chooses price shocks greater than the *trigger*, there will be some releases from the petroleum stockpile. The IEA will punish OPEC by setting $I_t > 0$ when the numerator in (10) is positive. In the base case simulation, I choose the size of stockpile and the trigger so as to maximize the present value of world GDP. In sensitivity analyses, I hold the stockpile constant and optimize over the trigger, since the trigger can be more easily adjusted as conditions change and to limit computational costs.

3.1 Base Case

Base case results are shown in Figures 3 and 4. The price of petroleum is $45/bl in 2005:II, before OPEC optimizes over price.

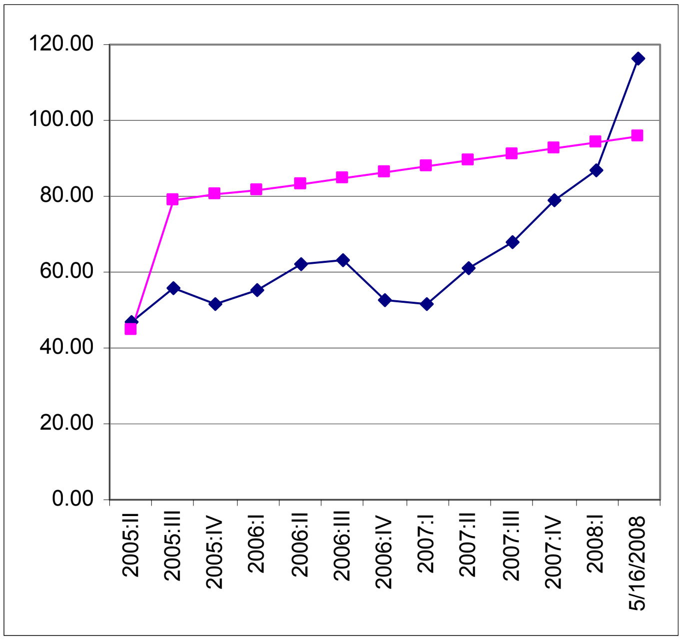
Figure 3: No IEA Stockpile



In Figure 3, the IEA has no stockpile. OPEC chooses $P_0 = \$79/\text{bl}$, $g = 7.00\%$, $shockb = \$25$, $lengthb = 21$ years, $phaseb = 15$ years, and $mb = -25¢/\text{bl/yr}$, where monetary amounts are in 2005 dollars. The run-up in the actual price of crude oil since 2005:II is a shock in its own right. The jump from \$45 to \$79 at $t = 0$ and subsequent annual growth at 7.00% in the base case simulation roughly mimics the actual run-up in price. Figure 3-A plots the base case backcast against actual crude prices[33].

[33] http://tonto.eia.doe.gov/dnav/pet/pet_pri_wco_k_w.htm.

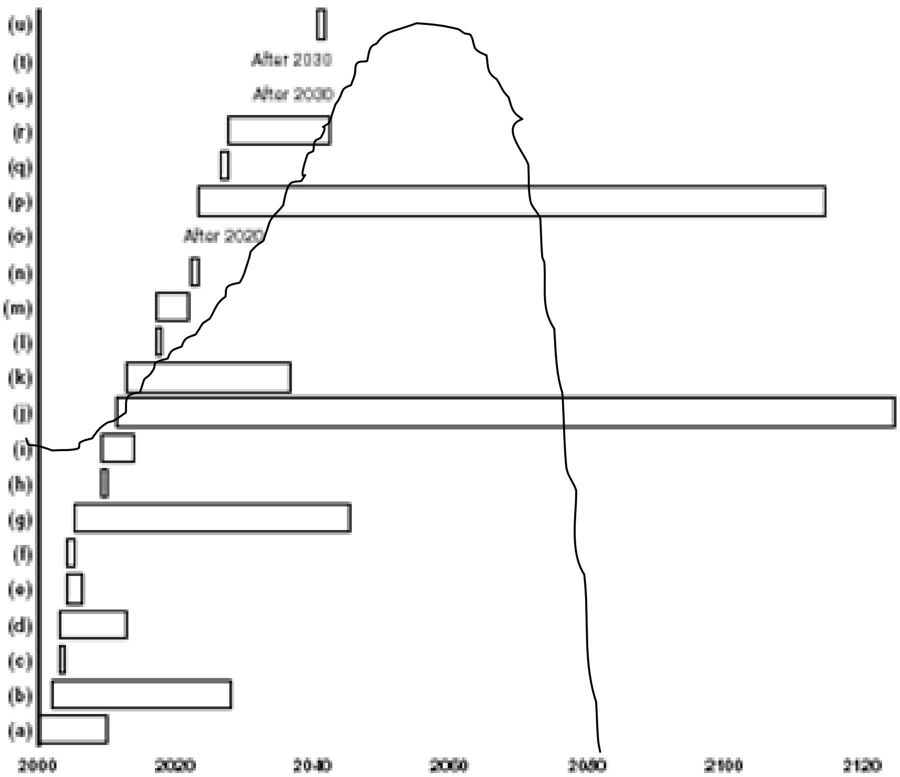
Figure 3-A: Base Case Backcast and Actual Crude Prices in 2005$



With a phase shift of 15 years, the optimal time for OPEC to effect the next shock is in 2020. The price of petroleum at the end of the oil age is in the thousands of dollars per barrel. I have chosen not to impose a cap on oil prices based on some backstop technology because the form of the demand function allows the elasticity of demand to increase as price increases. While price is very high late in the simulation, demand is very low. This is plausible if there are a few specialized uses for petroleum for which close substitutes do not exist, but for which consumers are willing to pay high prices for the petroleum content of the product. Possible examples include pharmaceuticals, specialized plastics, and cosmetics.

World consumption of petroleum reaches a peak of 67 bbl/yr in 2045, and declines quickly thereafter. Figure 3-B is reprinted from a recent study by the Government Accountability Office. It compares several forecasts of worldwide peak oil, which are listed in the report. I have superimposed my own forecast on these others. In terms of the peak itself, my forecast is on the optimistic (late) side, but is not symmetric around the peak; it declines rapidly after the peak occurs.

Figure 3-B: Forecasts of Peak Oil



Source: GAO study.

Increases in demand are largely met through additional production by OPEC; non-OPEC production is steady at about 17 bbl/yr throughout the simulation. Non-OPEC output is known to be insensitive to price in the short run.[34] In this simulation, the balance between advancing technology and increasingly difficult extraction render it steady in the face of rising prices in the long run as well. (This is not an artifact of the non-OPEC supply equation itself, as will be apparent from the sensitivity analysis in which OPEC completely breaks down.) Thus, OPEC's market share rises dramatically, as predicted in the National Energy Policy Document. OPEC's average costs begin to rise quickly after about 30 years, as depletion of reserves begins to make further extraction difficult. World GDP grows at 4.13% annually over the 60-year period, at 4.01% over the first 30 years and 4.24% over the latter 30 years.

Figure 4 shows the effects of IEA stockpiles and strategy that maximize present valued world GDP. The optimal stockpile is 6 bbl and the optimal trigger is $10/bl. The straight line at zero in the panel labeled "IEA Intervention" is actual IEA intervention. OPEC complies with the limits laid down by the IEA by limiting shocks to $10, so the IEA does not actually intervene in the market. The IEA contains the shocks by the threat of intervention alone. The jagged line in the same panel is the intervention the IEA would

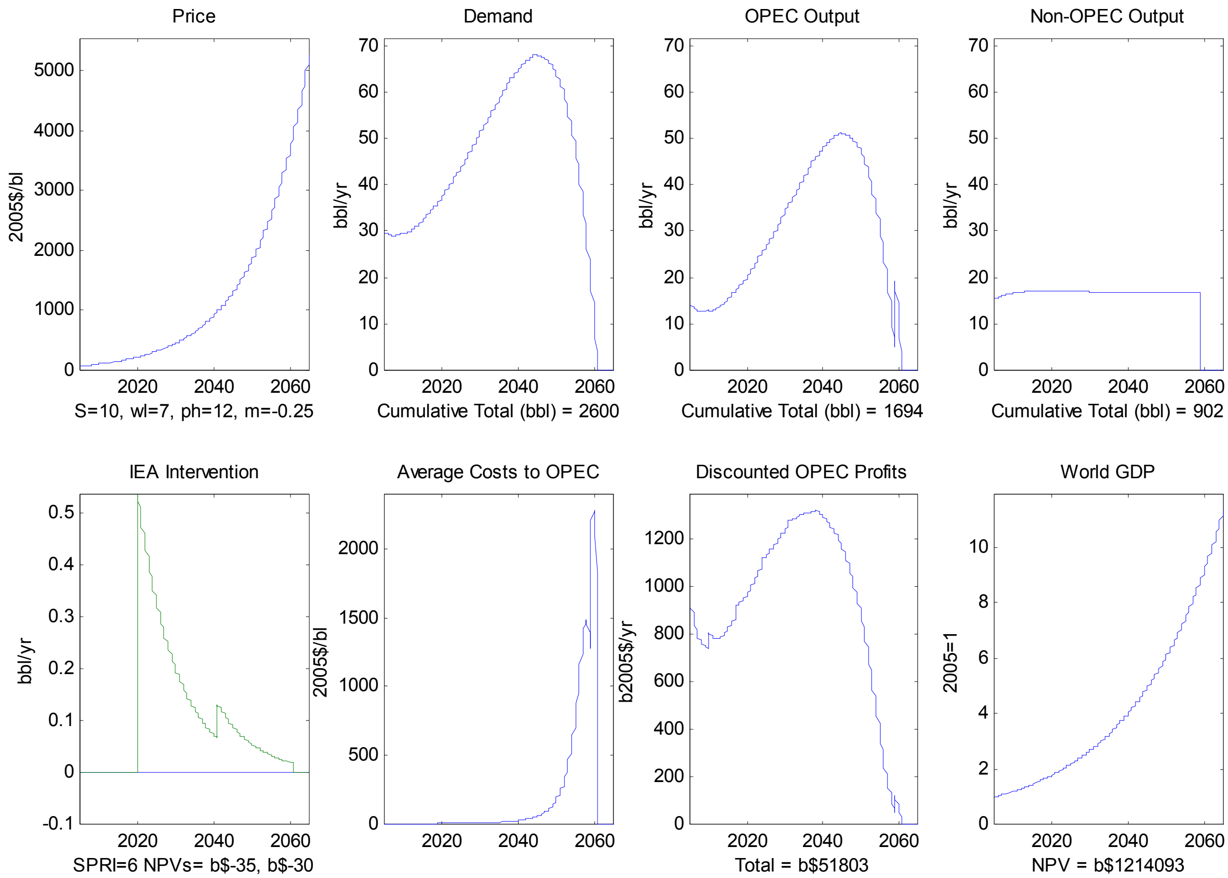
[34] See the discussion of non-OPEC supply in Vatter (2008).

undertake if OPEC ignored the threat from the IEA and chose $P = P^b$. In this event, it is more profitable for the IEA to intervene than not; the present value of IEA activity rises from -$35 billion to -$30 billion. However, the overall IEA project is internally unprofitable. If it were profitable, then private activity would maximize present valued world GDP. I assume that IEA purchases its initial stockpile at $P_0 = \$79 / \text{bl}$, and sells it at the going price over the course of the simulation. I assume storage costs of $6/bl, according with LBJ. As with GDP, I discount the revenues from IEA's sales to 2005 at a real discount rate of 7%.

The IEA's threat causes the present value of OPEC's profits to fall by $55 billion, and present valued world GDP increases by $946 billion, so the net social benefits of IEA's stockpiling and threatening to intervene are $946 - $55 - $35 = $856 billion, in 2005 dollars, or $931 billion in 2008 dollars. I have estimated GDP in reduced form, but the large impact of oil prices on GDP may be explained by allocative disturbances, uncertainty associated with volatility, price-stickiness, and contractionary monetary policy[35] made in response to oil price shocks. Oil shocks shift the Phillips curve out.[36] The first major price shock occurred in 1973. In 1974, the Consumer Price Index (CPI) increased by 11%; in 1975 U.S. unemployment was 8.3%.[37] The second major shock, which was larger, occurred in 1979. In 1980, the CPI rose 13.5%; in 1982 unemployment peaked at 9.5%.[38] Both the dovish Burns Fed and the hawkish Volcker Fed divided the impact of OPEC's price shocks between inflation and unemployment, suggesting that the shifts in the Phillips curve were large enough to make holding either inflation or unemployment constant unattractive under a variety of preferences.

[35] The Bernanke Fed seems to be more dovish that either the Volcker or Greenspan Fed, but the Burns Fed is also represented in the sample on which these simulations are based.
[36] See Darby (1982).
[37] See Mork and Hall (1980).
[38] *Economic Report of the President*, 1984, Tables B-33 and B-55.

Figure 4: Initial Stockpile = 6 bbl; IEA Tolerates Shocks up to $10



If an agreement were enforceable, the world could pay OPEC $55 billion or more to keep prices stable, but $55 billion is more than $35 billion, paying OPEC to keep prices stable would involve compensating some governments with abysmal human rights records, and arranging an enforceable system of compensation presents challenges, as well. Paying compensation in the form of military goods and services seems to entail violence and, with the exception of the Kuwaitis and the Kurds, anti-American sentiment. Western governments do not appear to withdraw military support to punish oil price shocks, although S.J. Resolution 32, currently in Congress, is an effort to do so.

The IEA could conduct a program of intervention without the use of government stocks by selling petroleum short during price shocks, rolling the contracts over until the time it would liquidate a reserve, and then covering its position. The short sales would be in amounts equal to I_t in Equation (10). Open interest in light, sweet crude for delivery in July 2008 on the New York Mercantile Exchange was 363 bbl as of May 27, 2008[39]. From Figure 4, I_t would be on the order of no more than 0.05 bbl per month. The

[39] http://www.nymex.com/lsco_fut_csf.aspx?product=CL, accessed May 27, 2008.

effect of this approach would be similar to that of intervention from government stocks, but the physical work would be undertaken by private firms rather than government agencies.

Currently, drilling and storage capacity in non-OPEC countries are non adequate to bring I_t to market, even when government stocks are included.[40] Whether the IEA intervened by using government stocks or by trading derivatives, OPEC might punish the IEA by increasing price before capacity could expand to support IEA's intervention. The IEA could minimize the threat of a price increase if it IEA institutes its intervention program when an oil price shock is already at its peak because further increases in price would reduce, rather than increase, OPEC's profits. Another way to reduce the threat of such an increase in price would be for member governments to incent the IEA not to respond to it, or to otherwise commit to expanding drilling or storage capacity, but OPEC would have to regard the commitment as credible if it were to see raising price as an ineffective way to deter investment in drilling or storage. The U.S. government's commitment to the Volker Fed's restrictive monetary policy turned out to be credible after the fact, but the world economy suffered the second worst downturn of the 20th century before excessive inflationary expectations abated.

3.2 Sensitivities

Table 2 shows results of sensitivities to size of the IEA stockpile, IEA and OPEC discount rates, OPEC's costs and remaining recoverable resources, non-OPEC remaining recoverable resources, growth in GDP, and a total breakdown in the OPEC cartel.

[40] http://www.eia.doe.gov/emeu/cabs/nonopec.html, accessed May 27, 2008.

Table 2: Sensitivities

A	B	C	D	E	F	G	H
Case	Shock that Triggers IEA Intervention	Change in NPV of OPEC's Profits	Private Incentive to Maintain Stockpile	Private Incentive to Punish OPEC	Gain in Present Valued World GDP	Net Benefits	Benefits / Costs
	2005$/bl	b2005$	b2005$	b2005$	b2005$	b2005$	
Base [a]	10	-55	-35	5	946	856	10.51
Current IEA Stockpile; 1.5 bbl	0	-19	-8	-2	276	249	10.22
High IEA Discount Rate; 8% real	10	-55	-249	110	794	490	2.61
Low IEA Discount Rate; 6% real	10	-55	355	-237	1162	1462	27.58
High OPEC Discount Rate; 11.5% real	30	-2	23	-61	169	190	96.00
Low OPEC Discount Rate; 8.5% real	5	-69	-122	43	838	647	4.39
High OPEC Costs; (25% above base)	5	-66	-34	5	660	560	6.60
Low OPEC Costs; (25% below base)	25	-2	21	-30	1076	1095	548.50
High OPEC Resources; 2100 bbl	10	-46	-34	6	218	138	2.73
Low OPEC Resources; 1500 bbl	35	-18	-5	-33	339	316	14.74
High Non-OPEC Resources; 1200 bbl	0	-71	-27	8	285	187	2.91
Low Non-OPEC Resources; 600 bbl	10	-87	-4	-10	848	757	9.32
High GDP Growth; 1.005 x trend	20	-11	118	-263	993	1100	101.00
Low GDP Growth; trend/1.005	0	-95	-99	75	1483	1289	7.64
Bertrand Competition	NA	-50085	NA	NA	-189004	-239089	

[a] IEA stockpile is 6 bbl; OPEC Resources 1800 bbl; non-OPEC 900 bbl; real IEA discount rate is 7%; OPEC's is 10%.

The benefit/cost ratio in the base case is 10.51. It is not much different given a stockpile of 1.5 bbl, which represents current IEA government stocks plus a small fraction of industry stocks, but the absolute net benefits are much lower. In this scenario, the best the IEA can do is to induce OPEC to postpone its next price shock from 2020 to 2023, but this still raises present valued GDP by $276 billion. Though the IEA accomplishes this mainly through threat alone, the threat is credible only if the IEA is *willing* to undertake what Greenspan calls a "very major liquidation in the short term" of strategic reserves.

The highest net benefits occur in the case where IEA's real discount rate is 6%. The effect of the reduction from 7% on the IEA's optimal strategy is null, but it evaluates the net benefits of its program of storage intervention at $1462 billion. The lowest net benefits occur when OPEC's remaining recoverable resources are 2.1 trillion barrels. There is considerable disagreement over the level of remaining recoverable resources. According to EIA's country brief on Saudi Arabia,

> Saudi Arabia contains 261.9 billion barrels of proven oil reserves [and] may contain up to 1 trillion barrels of ultimately recoverable oil...
>
> Aramco claims that the average total depletion for Saudi oil fields is 28%, with the giant Ghawar field having produced 48% of its proved reserves. Aramco also claims that, if anything, Saudi oil reserves are underestimated, not overestimated. Some outside analysts, notably [Simmons (2005)], have disputed Aramco's optimistic assessments of Saudi oil reserves and future production, pointing to, among other things, more rapid depletion rates and a higher "water cut" than the Saudis claim.

When I endow OPEC with 2.1 trillion barrels, net gains from the IEA program fall from $856 billion to $138 billion, but present valued world GDP absent IEA stockpiling is $1.5 trillion higher than in the base case.

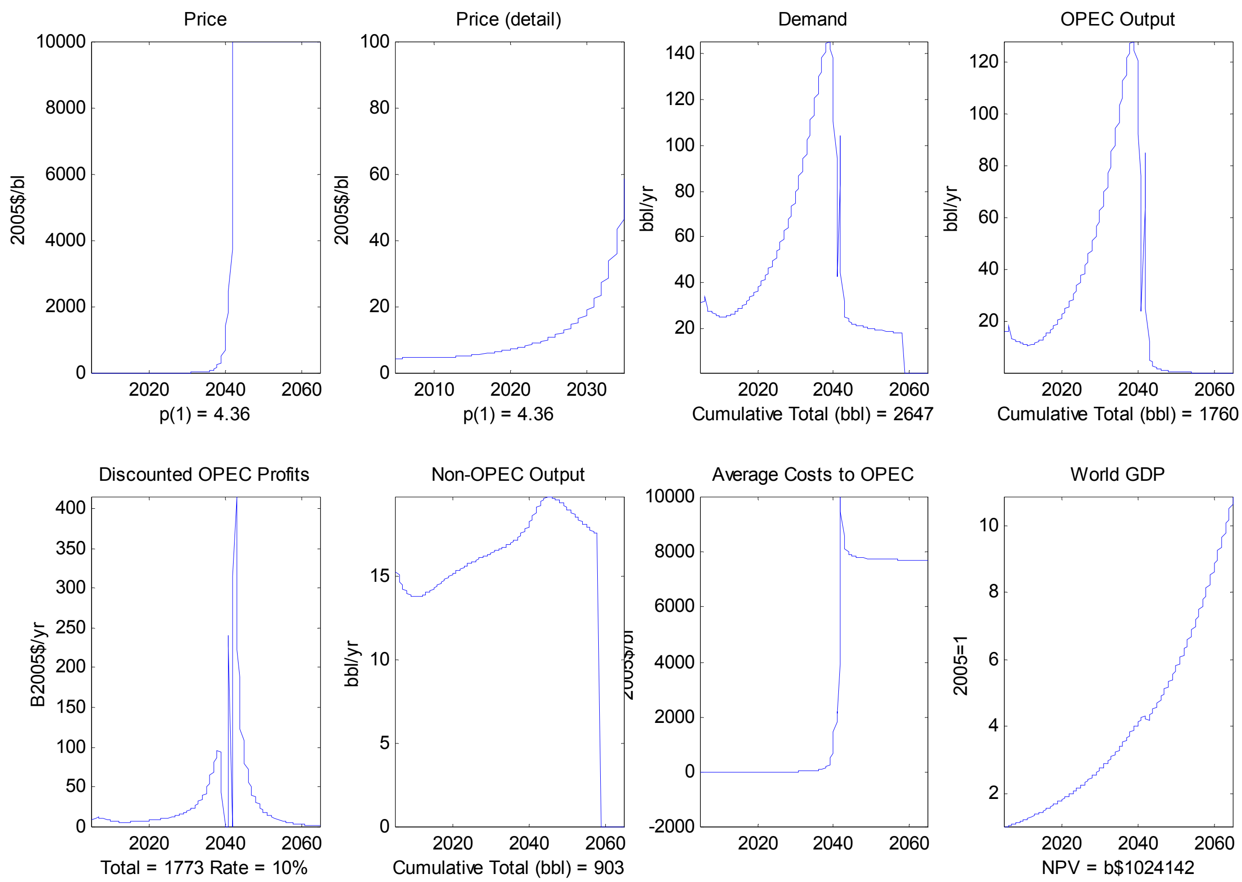
Lifting costs play an important role in the timing and ultimate extent of extraction. When OPEC's costs are high, net benefits of the stockpiling program are $560 billion, and, when they are low, $1095 billion.

The sensitivities overall show a lot of variability in net benefits, but substantial net benefits in every case. Base case net benefits plus the average deviation from the base case are $652 billion. The lowest benefit/cost ratio is 2.61, when the IEA's real discount rate is 8%.

In four of the scenarios the stockpiling is internally profitable to the IEA; the entry in Column D is positive, but in none of these four is it profitable for the IEA to punish OPEC if it reverts to the price path it would choose absent IEA stockpiling; the entry in Column E is negative. For private activity to maximize GDP under the IEA discount rates assumed (7% real in general, 6% and 8% in sensitivities), both maintaining the 6 bbl stockpile and using it to punish OPEC for its otherwise profit-maximizing price shocks would have to be profitable to a private actor. That is, the entries in both Columns D and E would have to be positive. This is not so in any of the cases I ran. Under none of these scenarios, then, would private activity maximize present valued world GDP.

The final scenario, "Bertrand Competition", is one in which OPEC completely breaks down and produces where price equals marginal cost. Of the largest two producers, Saudi Arabia's share of the world market is about 12%, and Iran's is 5%, so, absent OPEC, the market would be competitive. I add the condition that price equals marginal cost for OPEC to Equations (1), (2), and (3). This gives me a system which I solve implicitly for price in terms of predetermined variables. Figure 5 shows the results.

Figure 5: Bertrand Competition



This scenario suggests that OPEC's overall impact on the world economy is actually positive. Prices for the first couple of decades of Bertrand competition are reminiscent of the pre-OPEC era. Oil consumption peaks somewhat earlier than in the presence of OPEC, at a much higher level, and the age of oil comes to a more abrupt end, with prices skyrocketing to a backstop cost of $10,000/bl, which I impose only in this scenario, in a matter of a few years. This massive, final oil shock is terribly damaging to the world economy. While OPEC's periodic shocks are a serious problem, its general maintenance of high prices in the near term serves to avert a much more damaging shock about 30 years from now. By maintaining prices much higher than the cost of extraction, OPEC prevents prices from increasing as rapidly when the cost of extraction begins to rise rapidly, and it encourages investment in relatively oil-saving capital and durables on the demand side, which also mitigates the macroeconomic damage of the increases in price that do occur. Pindyck (p. 239) notes "…the monopolist will be relatively 'conservationist'…This is examined by Stiglitz (1976) and Sweeney (1975)."

The "NOPEC" legislation in the U.S. Congress (H.R. 2264 and S. 879) passed the House on May 20, 2008 with a veto-proof majority. It amends the Sherman Antitrust Act. H.R. 2264 reads:

> Sec. 7A. (a) It shall be illegal and a violation of this Act for any foreign state, or any instrumentality or agent of any foreign state, to act collectively or in combination with any other foreign state, any instrumentality or agent of any other foreign state, or any other person, whether by cartel or any other association or form of cooperation or joint action--
>
> (1) to limit the production or distribution of oil, natural gas, or any other petroleum product;
>
> (2) to set or maintain the price of oil, natural gas, or any petroleum product; or
>
> (3) to otherwise take any action in restraint of trade for oil, natural gas, or any petroleum product; when such action, combination, or collective action has a direct, substantial, and reasonably foreseeable effect on the market, supply, price, or distribution of oil, natural gas, or other petroleum product in the United States.

Unless this legislation were coupled with, say, an increase in taxes on petroleum, it could have severe unintended consequences down the road. It would be better for Americans if the difference between the price of crude and the cost of extraction went to Americans, rather than to a foreign cartel, but prices equal to the cost of extraction, while low in the near term, would rise very quickly when the cost of extraction began to do the same. Low prices for the next couple of decades would feed the "addiction to oil" by inducing investment in petroleum-specific capital and durables which would suddenly become very expensive to use when the marginal cost of extracting oil, and price, took off around 2035.

4 CONCLUSION

If the IEA managed government-held petroleum to maximize the present value of world GDP, stocks of 6 billion barrels could be used to cut $25 price shocks (2005$) to $10, though shocks would become more frequent. This would generate $946 billion in additional present valued world GDP, and cost OPEC $55 billion in lost profits and the IEA $35 billion to buy and hold the stocks for about half a century. Though this increase from current government-held stockpiles of 1.5 bbl may still be too small to completely "break the market corner", in Krugman's phrase, it appears to be realistic and worthwhile to "limit its effectiveness". Net benefits are substantial under a variety of assumptions, though private actors do not have incentive to maintain and use stocks in a way that maximizes world GDP. To insure that stockpiles are used to maximize world GDP, authority over stockpiles should be incented to do so and, in particular, shielded from the influence of the energy industry. World consumption of petroleum is expected to reach a peak of 67 bbl/yr in 2045, and decline quickly thereafter. If the price of oil equaled the marginal cost of extraction, it would be much lower for a couple of decades, then rise rapidly with costs.

4.1 Further Research

Access to additional computing power would allow some generalization of the model used to derive these results.

Adelman (1991; pp. 4-5) writes "The [oil] industry will disappear no matter how much remains in the ground - an amount unknown, probably unknowable, and ultimately unimportant. 'Finite limited resources', therefore, is an empty slogan. Only cost and price matter." I have simulated OPEC's costs depending on proven reserves, based on Celta and Dahl's estimates. It could be instructive, and obviate the need to make assumptions about remaining recoverable resources, and what part of those will be proven reserves in the future, to re-estimate OPEC's costs depending on cumulative production.

If the IEA began preparations for a program of storage intervention, OPEC might attempt to deter the IEA by effecting a price shock before sufficient expansion of drilling or storage capacity were complete. Further research could focus on strategic interaction between the IEA and OPEC during the preparation stage.

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