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Estimating Supply and Demand in the World Oil Market

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Abstract

This paper uses instrumental variables to jointly estimate aggregate monthly supply and demand curves for world oil under the assumptions of a static and perfectly competitive oil market. Results indicate that world oil demand is inelastic. Although the supply and demand curves were consistent with economic theory in the cases of world demand, non-OPEC demand and two specifications for supply, this was not the case for either OPEC demand or for most specifications for supply. The assumptions of a static and perfectly competitive world oil market are thus unrealistic, especially in modeling oil supply.

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Working paper.

1 Introduction

One of the most important resources on the planet today is oil. Indeed, oil is a form of power, not only because it is a primary source of the energy needed to power modern industrialized society (Yergin, 1992), but also because its possession itself is a source of power. Oil not only fuels our cars, heats our homes and runs our factories, but also drives national economic, political and military policy around the world.

Because oil is such a valuable resource, academics, businesspeople and policymakers alike have spent an inordinate amount of time and energy studying the oil industry. Yet, although their efforts have yielded many important insights, models and theories, the world oil market still remains somewhat a mystery, and many questions remain unanswered.

As with any other commodity, one of the fundamental questions economists would want to ask and answer about oil is: "How do we model the world market for oil?" In particular, what determines the supply for oil, what determines the demand for oil, and by what equilibrium process are oil prices and quantities determined?

Economic theory has much to say about how commodity markets might function. The most basic economic model of a market, as first envisioned by Adam Smith in 1776, posits that, under assumptions of perfect competition, the market price acts to equilibrate supply and demand (Mankiw, 1998). In addition to assuming perfect competition and price-taking on the part of both producers and consumers, this most basic model is also agnostic about the time period over which transactions take place, and, in particular, assumes that there are no dynamic considerations linking the static markets from one time period to the next.

Ever since Adam Smith introduced the notion of a perfectly efficient market, economists have developed an impressive corpus of theoretical models to explain how markets might function when one or more of Smith's simplifying assumptions are relaxed. While the economic *theory* of markets is fairly well developed, however, plausible *empirical applications* of this theory to actual real-world commodities are less so. As with most fields in economics, empirical studies lag behind the theory, not only because theoretical models can serve as the motivation behind empirical studies, but also because econometric techniques that confront the myriad statistical and identification problems that arise in any attempt to apply theory to actual data must be developed before any credible empirical application can take place.

One central econometric question in empirical studies of markets is how to infer the structure of supply and demand from actual observations of equilibrium prices and quantities (Manski, 1995). Indeed, it owed in part to the desire of economists to analyze competitive markets that statistical models for estimating and identifying simultaneous equations were first developed (Angrist, Graddy & Imbens, 2000). To this day, econometricians are still developing techniques to analyze the functioning of markets and to tackle the identification problem that plagues such analyses.

Although there have been countless empirical studies of the world oil market, not one has produced a satisfactory model that adequately explains historical data, much less accurately predicts future developments (William Hogan, personal communication, February 23, 2004). Moreover, the preponderance of these studies were conducted over two decades ago, and few, if any, address the identification problem that arises in empirical analyses of supply and demand (see e.g., Adelman, 1962; Berndt & Wood, 1975; Gately, 1984; Gately & Huntington, 2002; Griffin, 1985; Hausman, 1975; Kennedy, 1974; Nordhaus, 1980). As a consequence, while instrumental variables techniques have been used to estimate the basic economic model of static competitive markets for a variety of commodities, including the demand for fish (Angrist et al.,

2000) and the labor supply of stadium vendors (Oettinger, 1999), these econometric methods have yet to be applied to the market for oil.

In this paper, I use a variety of econometric methods to estimate supply and demand curves for oil under the simplifying assumptions of a static and perfectly competitive world oil market.

This paper makes two main contributions. First, by re-examining the timeless issue of oil supply and demand estimation using updated data and simultaneous equation estimation techniques, I innovate upon the existing literature on the world oil market. Second, results of my econometric model of oil supply and demand under the simplifying assumptions of a perfectly competitive and static world oil market is in part a test of whether these simplifying assumptions are indeed correct. Previous literature has provided ample anecdotal evidence and theoretical models suggesting that the world oil market is neither static nor perfectly competitive; this paper presents an empirical test.[1] Moreover, by providing a benchmark against which one can compare more complicated econometric models incorporating oligopoly behavior, dynamics, or both, an estimation of the world oil market using the most basic but perhaps unrealistic simplifying assumptions enables one to sense the tradeoffs that might occur as one moves toward the more complex—but also more realistic—models. I hope to develop these more complex models in future work.

According to the results, world oil demand is inelastic to price. Moreover, while monthly world oil demand, monthly oil demand in countries that are not part of the Organization of Petroleum Exporting Countries (OPEC), and two specifications for monthly oil supply appear consistent with static perfect competition, monthly OPEC oil demand and most specifications for

[1] Griffin (1985) tests four models of world oil production – cartel, competitive, target revenue, and property rights – but does not address the endogeneity of price in the supply equation.

monthly oil supply do not. Thus, in the latter cases, the simplifying assumptions of a static and perfectly competitive oil market are unrealistic.

The balance of the paper proceeds as follows. In Section 2, I present my model of the world oil market and explain the identification problem that arises in empirical analyses of supply and demand. In Section 3, I outline the econometric methods I use to address this identification problem. I describe my data set in Section 4. My results are presented in Section 5. Section 6 concludes.

2 A Model of Oil Supply and Demand

In this section, I present my model of world oil supply and demand, and explain the identification problem that arises in its estimation. More thorough treatments of the identification problem that arises in empirical analyses of supply and demand are given by Angrist et al. (2000), Goldberger (1991), and Manski (1995); the notation and exposition that follows were inspired in part by these sources.

2.1 The General Framework

Suppose there are T oil markets isolated in time and indexed by $t = 1, ..., T$. For each market t, let p_t denote the price of oil, q_t denote the quantity of oil transacted and x_t denote a vector of covariates characterizing the market. For each market t, the market demand function $q_t^d(\bullet)$ gives the quantity of oil that price-taking consumers would purchase, while the market supply function $q_t^s(\bullet)$ gives the quantity of oil that price-taking firms would offer, both as functions of price.

Markets are assumed to clear, which means that the transaction (p_t, q_t) is assumed to be an equilibrium outcome. In other words, for all markets *t*, the price p_t acts to equate supply and demand:

$$q_t^d(p_t; x_t) = q_t^s(p_t; x_t) \quad . \tag{1}$$

Markets vary in their values of $(q_t^d(\bullet), q_t^s(\bullet), p_t, q_t, x_t)$. For each market *t*, the econometrician can only observe the equilibrium price p_t, the equilibrium quantity q_t and the covariates x_t, but cannot observe either the demand function $q_t^d(\bullet)$ or the supply function $q_t^s(\bullet)$. Econometric analysis therefore seeks to learn about the supply and demand functions when only equilibrium transactions and covariates are observed. The identification problem that arises when observations of market transactions are used to infer the structure of supply and demand is called the *simultaneity problem*.

More formally, the simultaneity problem is as follows. Econometricians would like to infer the distribution $\Pr\left(q_t^d(\bullet), q_t^s(\bullet) \mid x_t\right)$ of demand and supply functions conditional on the covariates x_t. However, they can only observe the variables $\left(p_t, q_t, x_t\right)$. If the observations $\left(p_t, q_t, x_t\right)$ were obtained by a random sampling process, then the distribution $\Pr\left(p_t, q_t, x_t\right)$ of the observed variables could be inferred. The simultaneity problem is that, although the econometrician can infer $\Pr\left(p_t, q_t, x_t\right)$, knowledge of $\Pr\left(p_t, q_t, x_t\right)$ is not sufficient for identifying $\Pr\left(q_t^d(\bullet), q_t^s(\bullet) \mid x_t\right)$. Thus, it is possible that neither supply nor demand is identified.

2.2 A Linear Market Model

In my study, I assume that both demand and supply functions are linear with fixed coefficients and additive residuals. Though perhaps unrealistic, the linearity and additivity assumptions simplify the estimation techniques and provide a useful benchmark for assessing whether they need to be relaxed in future work.[2]

The structural form of my model is given by:

$$\begin{aligned}
&\text{demand:} && q_t^d(p_t;x_t) = \beta_p^d p_t + x_t'\beta_x^d + \varepsilon_t^d \\
&\text{supply:} && q_t^s(p_t;x_t) = \beta_p^s p_t + x_t'\beta_x^s + \varepsilon_t^s \\
&\text{market clearing:} && q_t^d(p_t;x_t) = q_t^s(p_t;x_t) = q_t
\end{aligned}$$

which simplifies to:

$$\text{demand:} \qquad q_t = \beta_p^d p_t + x_t'\beta_x^d + \varepsilon_t^d \tag{2}$$

$$\text{supply:} \qquad q_t = \beta_p^s p_t + x_t'\beta_x^s + \varepsilon_t^s. \tag{3}$$

The demand equation (2) and the supply equation (3) are the *structural* equations of my linear oil market model. Because economic theory predicts that demand curves should be downward-sloping while supply curves should be upward-sloping, we expect that $\beta_p^d \leq 0$ and $\beta_p^s \geq 0$.

Solving the structural equations (2) and (3) for price and quantity as functions of the covariates, one obtains the following *reduced-form* equations for my linear oil market model:

$$\text{price:} \qquad p_t = x_t'\gamma_x^p + u_t^p \tag{4}$$

$$\text{quantity:} \qquad q_t = x_t'\gamma_x^q + u_t^q. \tag{5}$$

[2] Angrist et al. (2000) investigate the consequences of relaxing both the linearity and additivity assumptions for the interpretation of linear instrumental variables estimators, and apply their approach to estimating the demand for fish.

Econometric analysis seeks to estimate the structural parameters $\left(\beta_p^{\,d}, \beta_x^{\,d}, \beta_p^{\,s}, \beta_x^{\,s}\right)$. However, estimating the demand equation (2) and the supply equation (3) separately by ordinary least squares (OLS) will *not* yield efficient or consistent estimates of these structural parameters, for two reasons.

The first problem with equation-by-equation ordinary least squares is a lack of identification. Because prices are endogenously determined in the supply-and-demand system, the coefficients $\left(\beta_p^{\,d}, \beta_p^{\,s}\right)$ on price are not identified (Goldberger, 1991). Thus, unless one uses instruments for price, these estimates will not be consistent.[3] This lack of identification has not been addressed in most of the empirical work on the oil market to date (see e.g., Kennedy, 1974; Nordhaus, 1980).

The second problem with equation-by-equation ordinary least squares is a lack of efficiency. If there are restrictions on the parameters in the model, then joint estimation of the demand and supply equations will be more efficient than equation-by-equation OLS is (Goldberger, 1991; Ruud, 2000).

Thus, equation-by-equation OLS yields estimates that are neither consistent nor efficient. I now turn to describing the econometric methods I will use to improve upon equation-by-equation OLS.

3 Methods for Efficient and Consistent Estimation

As explained above, equation-by-equation OLS suffers from both an identification problem and an efficiency problem. In order to address the identification problem, I will use

[3] Identification is a necessary condition for consistency.

instrumental variables techniques that exploit exclusion restrictions on both the supply and demand equations. In particular, I will assume that the vector of covariates x_t can be decomposed into four components:

$$x_t = \left(x_t^d, x_t^s, x_t^n, x_t^c\right),$$

where the demand shifters x_t^d are exogenous covariates that shift the demand curve but not the supply curve; where the supply shifters x_t^s are exogenous covariates that shift the supply curve but not the demand curve; where the endogenous covariates x_t^n may enter the structural equation for supply or demand, or both; and where the market controls x_t^c are exogenous covariates that affect both demand and supply.

Substituting $x_t = \left(x_t^d, x_t^s, x_t^n, x_t^c\right)$ into the structural equations (2) and (3) for demand and supply, respectively, one gets:

$$\text{demand:} \qquad q_t = \beta_p^{\ d} p_t + x_t^{d\,\prime} \beta_{x,d}^{\ d} + x_t^{s\,\prime} \beta_{x,s}^{\ d} + x_t^{n\,\prime} \beta_{x,n}^{\ d} + x_t^{c\,\prime} \beta_{x,c}^{\ d} + \varepsilon_t^{\ d} \tag{6}$$

$$\text{supply:} \qquad q_t = \beta_p^{\ s} p_t + x_t^{d\,\prime} \beta_{x,d}^{\ s} + x_t^{s\,\prime} \beta_{x,s}^{\ s} + x_t^{n\,\prime} \beta_{x,n}^{\ s} + x_t^{c\,\prime} \beta_{x,c}^{\ s} + \varepsilon_t^{\ s}. \tag{7}$$

Formally, my exclusion restriction is the following:

Assumption 1. (Exclusion)

In the expanded structural equations (6) and (7) for demand and supply, $\beta_{x,s}^{\ d} \equiv 0$ and $\beta_{x,d}^{\ s} \equiv 0$.

Under Assumption 1, the structural model can be rewritten as:

$$\text{demand:} \qquad q_t = \beta_p^{\ d} p_t + x_t^{d\,\prime} \beta_{x,d}^{\ d} \qquad\qquad + x_t^{n\,\prime} \beta_{x,n}^{\ d} + x_t^{c\,\prime} \beta_{x,c}^{\ d} + \varepsilon_t^{\ d} \tag{8}$$

$$\text{supply:} \qquad q_t = \beta_p^{\ s} p_t + \qquad\qquad x_t^{s\,\prime} \beta_{x,s}^{\ s} + x_t^{n\,\prime} \beta_{x,n}^{\ s} + x_t^{c\,\prime} \beta_{x,c}^{\ s} + \varepsilon_t^{\ s}. \tag{9}$$

With the above exclusion restriction, I can now identify each equation by using the exogenous variables excluded in that equation as instruments (Manski, 1995). In particular, because the exogenous demand shifter x_t^d do not affect supply except through their effect on price, they can be used as instruments for price in the supply equation. Similarly, because the exogenous supply shifters x_t^s do not affect demand except through their effect on price, they can be used as instruments for price in the demand equation. Exogenous market controls x_t^c can serve as instruments for both equations. My vector of instruments z_t is therefore given by $z_t = \left(x_t^d, x_t^s, x_t^c\right)$.

So that these proposed instruments z_t are indeed valid, I also make the following additional assumption:

Assumption 2. (Correlation)

The instruments z_t have a non-zero correlation with price p_t.

Under Assumptions 1-2, the instruments z_t can be used to obtain consistent and identified estimates of the structural parameters. Analogous arguments and assumptions can be used for why exogenous demand shifters, supply shifters and market controls might be valid instruments not only for price, but also for any endogenous covariates x_t^n as well.

Thus, in order to address the identification problem, I use instrumental variables techniques that exploit exclusion restrictions on both the supply and demand functions.

Unfortunately, if the exclusion restriction in Assumption 1 holds, then efficiency becomes an issue. As mentioned above, the second problem with equation-by-equation OLS is that if there are restrictions on the parameters in the model, then equation-by-equation OLS would be inefficient, and joint estimation of the equations would be preferred. More generally, in the presence of any parameter restrictions, joint estimation will be more efficient than its equation-by-equation analog (Goldberger, 1991; Ruud, 2000). Because Assumption 1 imposes exclusion restrictions on the structural parameters, joint estimation of the structural equations should be used to improve efficiency.

In this paper I use several estimation methods to obtain estimates that are consistent, efficient, or both. First, as a benchmark, I estimate the demand equation (8) and supply equation (9) separately by OLS. As explained above, these estimates are neither consistent nor efficient.

Second, to enhance the efficiency of my OLS estimates, I estimate the structural equations (8) and (9) jointly. I thus treat the system of simultaneous equations as seemingly unrelated regressions (SUR) that I can estimate using feasible generalized least squares. If all the dependent variables in the structural equations were exogenous, then estimation of the SUR using feasible generalized least squares would be more efficient than OLS. However, because price is endogenous, SUR lacks consistency.

In order to identify the price coefficients, the third technique I use is that of equation-by-equation two-stage least squares (2SLS). Each of the two structural equations (8) and (9) is estimated using the instruments z_t. The estimates obtained via 2SLS are consistent.[4] However, although the estimates yielded by 2SLS are identified, they are not efficient because, in estimating each equation individually, 2SLS does not make use of all the available information.[5] Owing to the cross-equation restrictions imposed by Assumption 1, estimating the equations jointly can enhance efficiency.

[4] Although the 2SLS estimates are consistent, they are still biased. No method for obtaining unbiased estimates of the structural parameters exists (Goldberger, 1991, p. 343).
[5] Since 2SLS does not fully use all the available information to potentially enhance the efficiency of its estimates, it is sometimes referred to as "limited information estimation" (Ruud, 2000).

In order to address both the identification and the efficiency issues, the fourth estimation method I employ is that of three-stage least squares (3SLS). In 3SLS, not only are instruments used to help identify the structural parameters, but the equations (8) and (9) are also jointly estimated via generalized method of moments to improve efficiency. 3SLS is more efficient than its equation-by-equation analog, 2SLS, because 3SLS uses all the available information at one time.[6] Thus, 3SLS estimates are both consistent and efficient.

In this paper I therefore use a variety of methods (OLS, SUR, 2SLS, and 3SLS) to estimate the world supply and demand for oil under the assumptions of a perfectly competitive static oil market. If the theoretical and econometric assumptions of my model are correct, then the 3SLS estimates should be consistent and efficient.

I now proceed to describing the data used in my study.

4 Data

In my empirical analysis of the world oil market, I use a monthly data set spanning the years 1981-2000.[7] Because the preponderance of empirical studies of the world oil market were conducted over 20 years ago, this data set includes newer data not used in previous work on the topic. Moreover, all the observations in my monthly data set took place after the 1973 Arab oil embargo. Previous studies reveal that the oil market appeared to have changed dramatically after 1973 (see e.g. Lin, 2005). My monthly data thus enables me to focus on the post-1973 oil market.

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[6] For this reason, 3SLS is sometimes referred to as "full information estimation" (Ruud, 2000).

[7] In previous work (Lin, 2005), I also run my analysis using an annual data set spanning the years 1965-2000. However, because the instruments for this annual data set were weak, the results are not reported here.

I use two measures of price p_t: the real average OPEC crude oil price and the real average non-OPEC crude oil price. Both were collected by the U.S. Department of Energy and were deflated to 1982-1984 U.S. dollars using the consumer price index (CPI).[8] I use three measures of quantity q_t: world oil production, OPEC oil production, and non-OPEC oil production. The world and OPEC production data are from the Oil and Gas Journal. The non-OPEC production data were constructed as the difference between the two.

For my covariates x_t, I use data on the following annual variables: real world gross domestic product (GDP), real GDP for the Middle East and North Africa, population, world commercial energy use, total electricity production, electricity production from oil, electricity production from gas, world oil reserves, and Organization of Petroleum Exporting Countries (OPEC) oil reserves. I break down both the electricity production from oil and that from natural gas into several regional aggregates: world; high-income OECD, high-income non-OECD; and Middle East and North Africa.[9] GDP, population and electricity production data were obtained from the World Bank Group World Development Indicators (WDI) online database. Reserve data were obtained from the Oil and Gas Journal. GDP data were deflated to 1982-1984 U.S. dollars using the CPI. In addition to the annual covariates, I also use a monthly covariate: total world rig count as reported by Baker Hughes, Inc.

Table 1a presents the summary statistics for the monthly variables in my data set; Table 1b presents the summary statistics for the annual variables used in my monthly analyses when,

[8] I use a U.S. deflator rather than a world deflator because the original nominal time series was in current U.S. dollars.

[9] See Appendix A for a list of the countries included in each aggregate. I also collected data for GDP for not only the world aggregate, but for the other three regional aggregates of high-income OECD, high-income non-OECD, and Middle East and North Africa as well. However, because these series were highly collinear, I used only the world GDP in my estimations. Similarly, world population is highly correlated with population in high-income OECD and in high-income non-OECD. Likewise, world electricity production is highly correlated with than in high-income OECD and high-income non-OECD. World commercial energy use is highly correlated with commercial energy use in Middle East and North Africa, the only other of the four regional aggregates for which data for this variable was available. Lastly, world crude oil reserves and natural gas reserves are highly correlated with their respective variables for OPEC only.

for each year, the same annual value is repeated for all months in that year.[10] Monthly oil price has a significant negative trend over 1981-2000. Production has a significant positive trend. World rig count is declining. World commercial energy use has a significant positive trend. Electricity production from oil and that from gas in different parts of the world all have trends of the same sign as the world aggregate: electricity production from oil is decreasing while that from natural gas is increasing. Over the period 1981-2000, the world thus appears to be substituting away from oil and towards natural gas as its source of electricity.

How correlated are my different measures of price, and how correlated are my different measures of quantity, both over 1981-2000? My two measures of price, OPEC oil price and non-OPEC oil price, are highly correlated, with a correlation of 0.99. Table 2 presents the correlation between my various measures of quantity. While world oil production and OPEC oil production are highly correlated with each other, non-OPEC oil production is not highly correlated with either of the two.

Figure 1 presents the time series for the various measures of price and quantity. Once again, over the 1981-2000 time period, OPEC quantity and world quantity are highly correlated and all three measures of quantity are increasing. OPEC and non-OPEC prices are also correlated over this time period, but are declining. The oil price collapse of the mid-1980s is apparent.

Figure 2 displays a scatter plot of the following combinations of price and quantity that I will later use for my supply and demand estimations: (1) OPEC price and world quantity; (2) OPEC price and OPEC quantity; (3) non-OPEC price and world quantity; and (4) non-OPEC

[10] For most of the annual variables (e.g., population), it made more sense to use the actual annual observation for each month rather than dividing it by 12 to convert it to an average month's share. Moreover, because using an average value for each month rather than the actual annual value only changes the scale of the corresponding coefficient, for simplicity I chose to use the annual value for each month for all the variables.

price and non-OPEC quantity. As before, because these prices and quantities are equilibrium observations, one cannot identify either a supply curve or a demand curve. However, unlike before, the least-squares regression line now has a negative rather than a positive slope. Figure 3 plots the analogous scatter plots using logs rather than levels. The qualitative features of the plots are the same whether the variables are in logs or in levels.

Having described my data, I now proceed to estimating world oil demand and supply.

5 Results

So that my monthly supply and demand curves are identified, I make the following exclusion restrictions. First, I assume that the following covariates are exogenous demand shifters x_t^d that affect the demand for oil but not its supply: world GDP; world population; world commercial energy use; world electricity production; electricity production from oil in the world, in high-income OECD countries, in high-income non-OECD countries, and in the Middle East and North Africa; electricity production from gas in the world, in high-income OECD countries, in high-income non-OECD countries, and in the Middle East and North Africa; and world natural gas reserves. All else equal, GDP, population, energy use, and electricity production would shift demand curves outward. In contrast, because natural gas is a substitute for oil, electricity production from gas and world natural gas reserves would shift demand curves inwards.

My second exclusion restriction is that the following covariates are exogenous supply shifters x_t^s that affect the supply of oil but not its demand: total world rig count and world oil reserves. Both variables would shift the marginal cost of producing oil and therefore its supply.

For endogenous covariates x_t^n, I use GDP in the Middle East and North Africa, which I assume affects the supply of oil but not its demand.

For exogenous market controls x_t^c that affect both supply and demand I use an indicator variable for the summer months (June, July and August), and an indicator variable for the winter months (December, January and February).[11]

All the exogenous covariates $z_t = \left(x_t^d, x_t^s, x_t^c\right)$ will be used as instruments in my instrumental variables estimations.

Tables 3a and 3b present the estimates of the reduced-form relationships (4) and (5) between price of oil and quantity of oil production, respectively, and all the covariates. For the reduced-form price regressions, the signs of the significant coefficients appear to be robust to whether or not the price is the OPEC price or the non-OPEC price, and to whether or not the price is logged. Among the covariates with a positive effect on price are the total world rig count, GDP in the Middle East and North Africa,[12] world electricity production, electricity production from natural gas in high-income OECD countries, and world oil reserves. Among the covariates with a negative effect on price are world population, world commercial energy use, electricity production from oil in the Middle East and North Africa, and electricity production from natural gas in high-income non-OECD countries.

For the reduced-form quantity regressions, more coefficients are significant in the regressions of non-OPEC oil production than in those of world or OPEC oil production. For world production, world commercial energy use, electricity production from oil in high-income OECD countries, and electricity from gas in high-income non-OECD countries all have a

[11] The year of the monthly market was too highly correlated with some of the annual covariates to be included as an additional market control.

[12] Because GDP in the Middle East and North Africa may be endogenous, I instrument for it in my estimations of the structural demand and supply equations. In the reduced-form regressions, however, I treat it as exogenous.

significant positive effect on world oil production, while electricity production from gas in high-income OECD countries has a significant negative effect.

To test whether Assumption 2 that the instruments are correlated with price appears reasonable, I regress price on the instruments $z_t = \left(x_t^d, x_t^s, x_t^c\right)$. The results are provided in Table 4. The difference between the regressions in Table 4 and the analogous price regressions in Table 3a is that the former no longer includes the endogenous covariate GDP in the Middle East and North Africa as a regressor. Unlike in the annual analyses, the instruments used in my monthly analyses appear to be highly correlated with price. Not only are all the instruments together jointly significant (p-value = 0.00 in all regressions), but the demand shifters and supply shifters are significant as well. Thus, my instruments appear not only credible, but also strong as well.

The demand shifters that have a significant positive effect on price are world electricity production and electricity production from natural gas in high-income OECD countries. The demand shifters that have a significant negative effect on price are population, commercial energy use, electricity production from oil in the world and in the Middle East and North Africa, and electricity production from natural gas in the world, in high-income non-OECD countries, and in the Middle East and North Africa. The demand shifters are jointly significant (p-value = 0.00 in all regressions). Because many demand shifters are individually significant, and because they are together jointly significant, the supply equation should be identified when these shifters are used as instruments.

For the supply shifters, the rig count and world oil reserves both have significant positive effects on price. These signs seem reasonable, as rig counts and world oil reserves should both shift the supply curve upward. The supply shifters are jointly significant (p-value = 0.00 in all regressions). Because the supply shifters are individually and jointly significant, the demand equation should be identified when these shifters are used as instruments.

Thus, Assumption 2 that the instruments are correlated with price appears to hold, and the use of these instruments should yield identification.[13] As a consequence, if the estimates of supply and demand arising from instrumental variables techniques are not consistent with a simple theoretical model of a static and perfectly competitive world oil market, the fault is likely to lie in the theoretical assumptions themselves rather than in its econometric estimation.

Tables 5a and 5b present the 3SLS estimates for demand and supply, respectively, for the four price-quantity combinations: (1) OPEC oil price and world oil production., (2) OPEC oil price and OPEC oil production, (3) non-OPEC oil price and world oil production, and (4) non-OPEC oil price and non-OPEC oil production.[14]

For the estimates of demand, economic theory predicts that price should have a negative effect on demand, and econometric theory predicts that, if the theoretical model is correct, properly instrumenting for price will yield consistent price coefficients of the appropriate sign. However, while the price coefficient is significantly negative in all of the (non-instrumented) OLS and SUR specifications for all the price-quantity combinations used, once instruments are added in 2SLS, the coefficients, while still negative, are no longer significant.

For the (instrumented) 3SLS estimations, which should yield coefficients that are both identified and efficient, the signs of the price coefficients are mixed. The price coefficient is significantly *positive* in the regression of OPEC oil demand on OPEC price, with a demand elasticity at mean price and quantity of 0.50 (s.e. = 0.12), but is significantly negative in the regression of non-OPEC oil demand on non-OPEC price, with a demand elasticity of –0.95 (s.e.

[13] Similarly, regressions could be run of the endogenous GDP in the Middle East and North Africa on the instruments to see if the instruments can also be appropriately used for this regressor as well.
[14] The OLS, SUR and 2SLS results are presented in Lin (2005).

= 0.20). The price coefficient is not significant at a 5% level in the regressions of world oil demand on either OPEC or non-OPEC price: demand elasticities less than –0.04 and –0.03, respectively, can be rejected at a 5% level. World oil demand therefore appears inelastic to oil price, OPEC or otherwise. Moreover, while world oil demand and non-OPEC oil demand are consistent with a static and perfectly competitive world oil market, OPEC oil demand is not.

For the estimates of supply, on the other hand, economic theory predicts that price should have a positive effect on demand, and econometric theory predicts that, if the theoretical model is correct, properly instrumenting for price will yield identified price coefficients of the appropriate sign. As expected, the price coefficient has the wrong sign in the (non-instrumented) OLS and SUR specifications for all the price-quantity combinations. Using instruments for price and for GDP in the Middle East and North Africa does not yield a significantly positive price coefficient in any of the 2SLS or 3SLS specifications, although in some cases it yields coefficients that are no longer significantly negative. In particular, the use of instruments yields an OPEC supply curve that is inelastic to OPEC price. Thus, while OPEC supply is consistent with a static and perfectly competitive oil market, both world supply and non-OPEC supply are not.

For any given combination of price and quantity, the signs of the significant coefficients on the covariates tend to be robust across the different estimation methods used (OLS, SUR, 2SLS, and 3SLS). However, for the 3SLS results, the signs are not robust across the different price-quantity combinations: while the signs are similar in the 3SLS estimations using OPEC price and world quantity; OPEC price and OPEC quantity; and non-OPEC price and world quantity, the signs are often flipped in the 3SLS estimations using non-OPEC price and non-OPEC quantity. For example, world population, world commercial energy use, electricity production from oil in the Middle East and North Africa, and electricity production from natural gas in the Middle East and North Africa all have significant positive effects on demand in all price-quantity combinations except that of non-OPEC price and non-OPEC quantity, in which case the effects are significantly negative. Similarly, electricity production from natural gas in high-income OECD countries has a negative effect in all price-quantity combinations except that of non-OPEC price and non-OPEC quantity, in which case the effect is significantly positive. For the 3SLS estimates of supply, world crude oil reserves has a significant positive effect on supply in all price-quantity combinations except that of non-OPEC price and non-OPEC quantity, in which case the effects are significantly negative.

Many of the signs of the 3SLS coefficients on the covariates in the demand equations that are robust with respect to the price-quantity combination used appear realistic. For example, electricity production from oil both in high-income OECD countries and in high-income non-OECD countries has a positive effect on oil demand. This is reasonable, as the more oil is needed for electricity, the higher should be oil demand. The stock of natural gas reserves has a negative effect on demand, which again is reasonable because natural gas is a substitute for oil.[15] One potentially surprising result is that world GDP has a negative effect on demand, which suggests that, controlling for such covariates as energy use and electricity production, oil is an inferior good, perhaps because a richer world economy would use oil more efficiently.

The signs on the 3SLS coefficients in the supply equation appear realistic as well. For example, total rig count has a positive effect on supply, since, all else equal, the more exploration and production there is that takes place, the more oil there is to supply. GDP in the Middle East

[15] Ideally, natural gas price should be used as a regressor in the demand equation. However, owing to the localized nature of natural gas markets, data on world natural gas prices is difficult to construct (William Hogan, personal communication, April 16, 2004).

and North Africa has a positive effect on supply. Except in the regression of non-OPEC supply on non-OPEC price, the stock of crude oil reserves has a positive effect on supply, as expected.

Do the results change when oil prices and quantities are logged? The 3SLS results for estimates of demand and supply for the various price-quantity combinations when prices and quantities are in logs rather than in levels are presented in Tables 6a and 6b, respectively. For the most part, the qualitative results from 3SLS appear robust to whether the equations are in levels or logarithmic form. The main exception is that for the estimates of supply, the only supply curve that has a non-negative slope consistent with economic theory when the prices and quantities are logged is non-OPEC supply, not OPEC supply. However, the result that, for most specifications of supply, the price coefficients are *not* consistent with the assumptions of a static and perfectly competitive market appears robust to the functional form of the supply curve.

Because the instruments used in my monthly analyses are both strong and credible, 3SLS yields efficient and consistent price coefficients. Are these coefficients consistent with economic theory? Well, yes and no. Non-OPEC oil demand does indeed exhibit a negative slope with respect to non-OPEC oil price, while world oil demand is inelastic to both OPEC price and non-OPEC price. Thus, both non-OPEC and world demand functions are consistent with economic theory, which predicts that demand should be (weakly) downward-sloping. Moreover, OPEC supply in levels form appears inelastic to OPEC price, and log non-OPEC supply appears inelastic to log non-OPEC price, which are both consistent with the theoretical prediction that supply should be (weakly) upward-sloping. However, the 3SLS estimates for OPEC demand (in both levels and logs), OPEC supply (in logs), non-OPEC supply (in levels), and world supply (in both levels and logs) all yield price coefficients of the wrong sign. It thus appears that OPEC demand and most specifications for supply do not satisfy the simply theoretical assumptions of a static perfectly competitive oil market.

6 Conclusion

Is it possible to obtain efficient and consistent estimates of aggregate supply and demand curves for world oil under the assumptions of a static and perfectly competitive world oil market, or is the endeavor doomed to yield a dry hole? The answer at first blush appears mixed. Although the monthly supply and demand curves were consistent with economic theory in the cases of world demand, non-OPEC demand and two specifications for supply, this was not the case for either OPEC demand or for most specifications for supply.

That even the use of strong and credible instruments and of joint estimation did not yield price coefficients of the expected sign for OPEC demand or for most specifications for supply suggests that either my econometric specification or the underlying economic theory is incorrect.

Is the econometric specification to blame? In addition to my Assumptions 1-2 on the instruments, which appear to be satisfied for my monthly analyses, another underlying assumption of my econometric model is that both demand and supply are linear with fixed coefficients and additive errors. This assumption could be relaxed in future work using methods such as those developed by Angrist et al. (2000), Manski, (1997), and by Newey, Powell and Vella (1999). To a first-order approximation, however, one would expect that imposing linearity and additivity should not affect the sign of the price coefficients.

A potentially more devastating culprit for my counter-intuitive results, in addition to the underlying econometric assumptions of linearity and additivity, is the theory itself. My model of the world oil market assumed that it was both static and perfectly competitive. However, the oil market is unlikely to be either.

The first problematic theoretical assumption is that the oil market consists of static markets isolated in time. Because oil production is a capital-intensive process involving irreversible investments, and because oil itself is a nonrenewable resource whose extraction costs are likely to increase over time, the amount of oil supplied at any point in time is unlikely to be independent of the amount of oil supplied at any other point in time. Indeed, the Hotelling model of nonrenewable resource extraction predicts that, even if the market were perfectly competitive, market price would exceed marginal costs, with the difference reflecting the scarcity rent of the resource (Hotelling, 1931). Thus, oil supply is unlikely to be static. Similarly, since energy-using capital is durable and adjusts slowly to prices, demand is unlikely to be static either. To better estimate the demand and supply for oil, a dynamic model is needed.

The second problematic theoretical assumption is that the oil market is perfectly competitive. In his tests of alternative models of oil supply, Griffin (1985) finds that the partial market-sharing cartel model could not be rejected among the OPEC countries, and that this model dominates the competitive model. A more realistic model would thus account for the substantial market power exerted by the OPEC oil cartel.

However, perfect competition may be an appropriate characterization especially for more recent years. Results from Lin's (2008) empirical dynamic model of the world oil market over the period 1970-2004 do not support either oligopoly among non-OPEC producers or collusion among OPEC producers in the production of oil in the last 15 years. Similarly, Lin (2007) finds in her simulations of the basic Hotelling model that while a monopolistic market structure better explains the world oil market than perfect competition does prior to the 1973 Arab oil embargo, perfect competition fares better in the years following it.

It thus appears that the theoretical assumptions of a static and perfectly competitive market may be unrealistic, especially in modeling the supply of oil. Indeed, the consistent but inefficient 2SLS estimates for monthly demand all exhibited the appropriate negative sign; the sign for OPEC demand only flipped when OPEC demand was estimated jointly with OPEC supply in effort to obtain estimates that were not only consistent but also efficient. Had the supply side been more realistically modeled, then joint estimation of demand and supply may not only have increased the efficiency and significance of the already-negative and consistent price coefficients for demand, but also yielded significant positive price coefficients for supply as well.

Thus, attempting to efficiently and consistently estimate aggregate oil supply and demand market in the context of a static and perfectly competitive oil market may indeed be a dry hole. It is a dry hole not because of the non-existence of either econometric methods or instruments to enable efficient and consistent estimation, but rather because of the non-plausibility of the static perfect competition assumptions in the first place. An econometric model that incorporates either the dynamic or oligopolistic aspects of the oil market, or both, appears to be a more promising prospect for exploration and development, and one from which richer and more realistic results are likely to be extracted.

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TABLE 1a. Summary statistics: monthly variables

Variable	mean	s.d.	min	max	trend
Price					
real average spot price for crude oil: total OPEC (1982-1984$/barrel)	17.02	9.00	5.91	39.72	-0.10 *** (0.01)
real average spot price for crude oil: total non-OPEC (1982-1984$/barrel)	17.28	8.82	5.75	43.94	-0.10 *** (0.01)
Quantity					
world oil production (million barrels/day)	59.40	4.48	49.39	69.32	0.06 *** (0.00)
OPEC oil production (million barrels/day)	22.50	3.93	13.90	29.59	0.05 *** (0.00)
non-OPEC oil production (million barrels/day)	36.89	1.52	33.17	40.86	0.011 *** (0.001)
Monthly Covariates					
total world rig count (100 rigs)	25.02	11.71	11.56	62.31	-0.13 *** (0.01)

Notes: The observations span the months from January 1981 to December 2000. The trend is the coefficient on month when the variable is regressed on month and a constant (standard error in parentheses). Significance codes: * 5% level, ** 1% level, and *** 0.1% level.

TABLE 1b. Summary statistics: Annual covariates

Variable	mean	s.d.	min	max	trend
Annual Covariates					
real world GDP (trillion 1982-1984$)	15.77	2.76	11.36	19.16	0.04 *** (0.00)
real GDP in Middle East and North Africa (trillion 1982-1984$)	0.35	0.04	0.30	0.42	-2e-4 *** (0.0000)
world population (billions)	5.28	0.48	4.50	6.05	0.007 *** (0.000)
world commercial energy use (million kt of oil equivalent)	8.53	0.86	7.10	9.94	0.01 *** (0.00)
world electricity production (trillion kwh)	11.70	2.08	8.39	15.30	0.03 *** (0.00)
electricity production from oil, world (%)	15.84	6.74	7.82	27.09	-0.09 *** (0.00)
electricity production from oil, high-income OECD (%)	8.62	2.35	5.40	15.24	-0.03 *** (0.00)
electricity production from oil, high-income non-OECD (%)	32.08	10.08	25.41	62.18	-0.10 *** (0.01)
electricity production from oil, Middle East and North Africa (%)	51.40	5.05	42.32	60.16	-0.06 *** (0.00)
electricity production from natural gas, world (%)	11.86	3.70	7.48	17.45	0.05 *** (0.00)
electricity production from natural gas, high-income OECD (%)	11.30	2.06	8.70	15.72	0.03 *** (0.00)
electricity production from natural gas, high-income non-OECD (%)	18.86	2.86	14.14	24.13	0.03 *** (0.00)
electricity production from natural gas, Middle East and North Africa (%)	37.28	6.96	27.90	49.90	0.10 *** (0.00)
world crude oil reserves (billion barrels)	881.68	152.95	648.53	1034.27	2.00 *** (0.06)
world natural gas reserves (10^{15} cubic feet)	4.14	0.83	2.63	5.15	0.012 *** (0.0002)

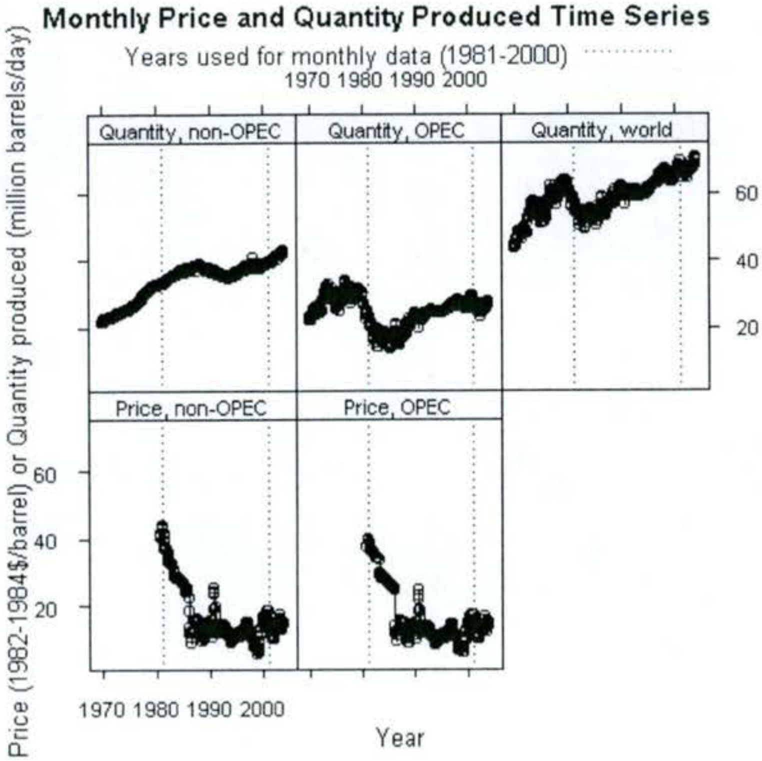
Notes: The observations span the months from January 1981 to December 2000. Each annual value is repeated for all twelve months in the corresponding year. The trend is the coefficient on year when the variable is regressed on year and a constant (standard error in parentheses). Significance codes: * 5% level, ** 1% level, and *** 0.1% level.

TABLE 2. Correlation between various measures of monthly oil quantity

	world oil production	OPEC oil production	non-OPEC oil production
world oil production	1.00		
OPEC oil production	0.94	1.00	
non-OPEC oil production	0.51	0.20	1.00

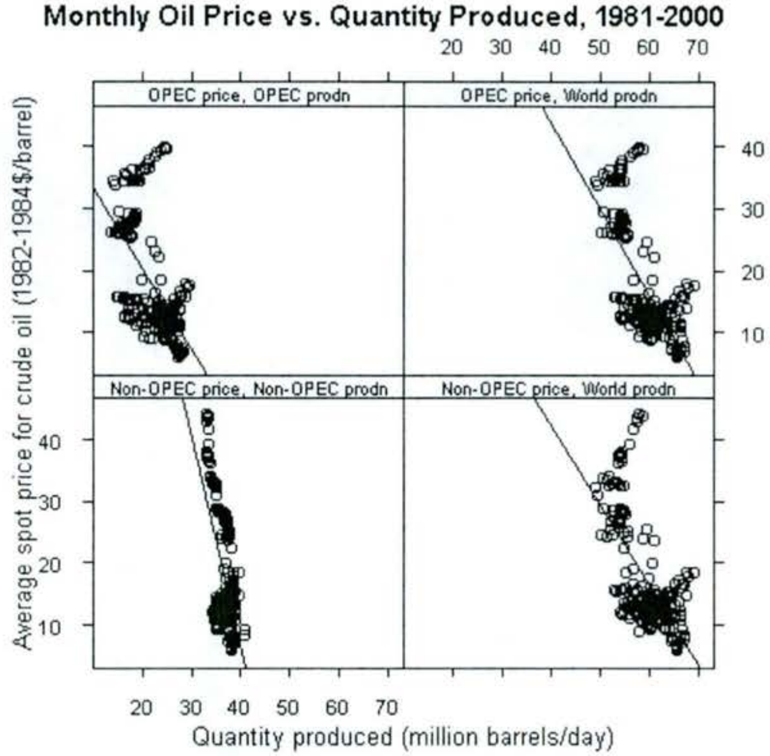
Note: Production is measured in million barrels/day.

FIGURE 1



Sources: Oil price data are collected by the DOE and are available from the Oil and Gas Journal. World and OPEC quantity data are from the Oil and Gas Journal. Non-OPEC quantity data were constructed by the author as the difference between the corresponding world and OPEC series.

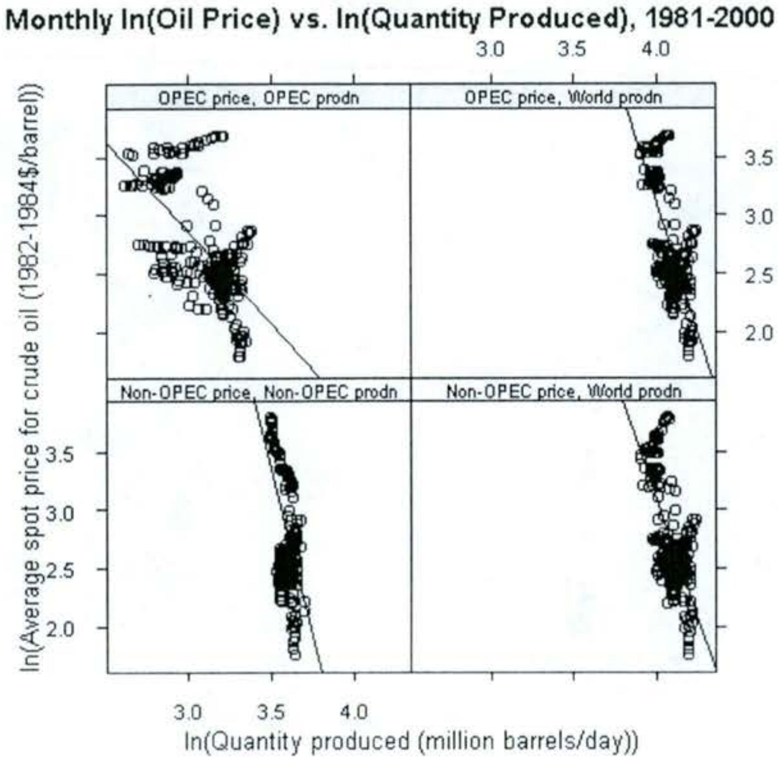
FIGURE 2



Note: The solid line indicates the linear trend.

Sources: Oil price data are collected by the DOE and are available from the Oil and Gas Journal. World and OPEC quantity data are from the Oil and Gas Journal. Non-OPEC quantity data were constructed by the author as the difference between the corresponding world and OPEC series.

FIGURE 3



Note: The solid line indicates the linear trend.

Sources: Oil price data are collected by the DOE and are available from the Oil and Gas Journal. World and OPEC quantity data are from the Oil and Gas Journal. Non-OPEC quantity data were constructed by the author as the difference between the corresponding world and OPEC series.

TABLE 3a. Reduced form estimates for monthly oil price (1981-2000)

	Dependent variable is: Price		ln(Price)	
	(1) OPEC	(2) non-OPEC	(3) OPEC	(4) non-OPEC
Monthly Covariates				
total world rig count (100 rigs)	0.23 ***	0.19 ***	0.015 ***	0.015 ***
	(0.05)	(0.05)	(0.004)	(0.004)
summer dummy (Jun, Jul, Aug)	-0.40	-0.48	-0.02	-0.02
	(0.35)	(0.35)	(0.03)	(0.02)
winter dummy (Dec, Jan, Feb)	-0.10	0.09	-0.02	-0.03
	(0.37)	(0.37)	(0.03)	(0.03)
Annual Covariates				
GDP, world (trillion 1982-1984$)	57.22	-0.02	0.15 **	0.11 *
	(25.21)	(0.77)	(0.06)	(0.05)
GDP, Mid East & N.Afr. (trillion 1982-1984$)	57.22 *	36.99	5.76 **	4.57 *
	(25.21)	(25.51)	(1.84)	(1.81)
population, world (billions)	-72.01 ***	-87.3 ***	-5.92 ***	-6.25 ***
	(13.55)	(13.71)	(0.99)	(0.97)
commercial energy use, world (mill. kt of oil equivalent)	-40.14 ***	-34.7 ***	-2.84 ***	-2.78 ***
	(7.04)	(7.12)	(0.51)	(0.51)
electricity production, world (trillion kwh)	23.86 ***	26.62 ***	1.72 ***	1.89 ***
	(5.00)	(5.06)	(0.36)	(0.36)
electricity prodn from oil, world (%)	-2.48	-3.68 **	-0.04	-0.10
	(1.37)	(1.39)	(0.10)	(0.10)
electricity prodn from oil, high-inc OECD (%)	-2.02	-0.44	-0.22 **	-0.16
	(1.16)	(1.18)	(0.08)	(0.08)
electricity prodn from oil, high-inc non-OECD (%)	-0.16	-0.20	-0.02	-0.02 *
	(0.16)	(0.17)	(0.01)	(0.01)
electricity prodn from oil, Mid East & N.Afr. (%)	-2.42 ***	-2.63 ***	-0.12 *	-0.14 **
	(0.69)	(0.70)	(0.05)	(0.05)
electricity prodn from natural gas, world (%)	-4.93 **	-6.00 **	-0.16	-0.24
	(1.83)	(1.86)	(0.13)	(0.13)
electricity prodn from natural gas, high-inc OECD (%)	6.68 ***	7.13 ***	0.37 ***	0.39 ***
	(1.08)	(1.09)	(0.08)	(0.08)
electricity prodn from natural gas, high-inc non-OECD (%)	-1.81 ***	-1.48 ***	-0.15 ***	-0.14 ***
	(0.39)	(0.40)	(0.03)	(0.03)
electricity prodn from natural gas, Mid East & N.Afr. (%)	-1.78 *	-2.12 **	-0.06	-0.09
	(0.73)	(0.74)	(0.05)	(0.05)
crude oil reserves, world (billion barrels)	0.05 ***	0.04 **	0.004 ***	0.004 ***
	(0.01)	(0.01)	(0.001)	(0.001)
natural gas reserves, world (10^{15} cubic ft)	-6.41	-8.32 *	-0.18	-0.30
	(3.75)	(3.79)	(0.03)	(0.27)
constant	673.5 ***	107.6 ***	42.64 ***	46.82 ***
	(106.4)	(107.6)	(7.76)	(7.63)
p-value (Prob > F)	0.00 ***	0.00 ***	0.00 ***	0.00 ***
adj. R squared	0.94	0.94	0.89	0.88
# observations	240	240	240	240

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, and *** 0.1% level. Prob>F is the p-value from F-tests on all the coefficients. Oil price is in 1982-1984$/barrel.

TABLE 3b. Reduced form estimates for monthly oil quantity produced (1981-2000)

	Dependent variable is:					
	Quantity			ln(Quantity)		
	(1) world	(2) OPEC	(3) non-OPEC	(4) world	(5) OPEC	(6) non-OPEC
Monthly Covariates						
total world rig count (100 rigs)	0.04	0.01	0.03 *	0.00	0.00	6e-4
	(0.03)	(0.03)	(0.01)	(0.00)	(0.00)	(3e-4)
summer dummy (Jun, Jul, Aug)	-0.33	-0.03	-0.30 ***	-0.01	0.00	-8e-3 ***
	(0.21)	(0.19)	(0.08)	(0.00)	(0.01)	(2e-3)
winter dummy (Dec, Jan, Feb)	0.08	-0.04	0.12	0.00	-0.00	0.00
	(0.22)	(0.20)	(0.08)	(0.00)	(0.01)	(0.00)
Annual Covariates						
GDP, world (trillion 1982-1984$)	-0.74	-0.24	-0.50 **	-0.01	0.01	-0.013 **
	(0.46)	(0.41)	(0.17)	(0.01)	(0.02)	(0.005)
GDP, Mid East & N.Afr. (tr. 1982-1984$)	-12.28	13.99	-26.3 ***	-0.15	1.08	-0.70 ***
	(15.19)	(13.53)	(4.65)	(0.26)	(0.68)	(0.15)
population, world (billions)	0.73	-17.79 *	18.5 ***	-0.01	-0.86 *	0.51 ***
	(8.16)	(7.27)	(3.04)	(0.14)	(0.37)	(0.08)
commercial energy use, world (m. kt of oil equiv)	8.47 *	1.58	6.88 ***	0.17 *	0.13	0.18 ***
	(4.24)	(3.78)	(1.58)	(0.07)	(0.19)	(0.04)
electricity production, world (trillion kwh)	2.56	5.19	-2.64 *	0.03	0.17	-0.07 *
	(3.01)	(2.68)	(1.12)	(0.05)	(0.14)	(0.03)
elec. prodn from oil, world (%)	-0.31	5.19	-0.66 *	-0.00	0.05	-0.02 *
	(0.83)	(2.68)	(0.31)	(0.01)	(0.04)	(0.01)
elec. prodn from oil, high-inc OECD (%)	1.98 **	1.51 *	0.48	0.03 **	0.06	0.02
	(0.70)	(0.62)	(0.26)	(0.01)	(0.03)	(0.01)
elec. prodn from oil, high-inc non-OECD (%)	0.02	-0.15	0.17 ***	-0.00	-0.010 *	0.005 ***
	(0.10)	(0.09)	(0.04)	(0.00)	(0.004)	(0.001)
elec. prodn from oil, Mid East & N. Afr. (%)	0.30	-0.50	0.79 ***	0.01	-0.02	0.02 ***
	(0.42)	(0.37)	(0.16)	(0.01)	(0.02)	(0.00)
elec. prodn from gas, world (%)	0.20	1.18	-0.98 *	0.01	0.10 *	-0.03 *
	(1.11)	(0.99)	(0.41)	(0.02)	(05)	(0.01)
elec. prodn from gas, high-inc OECD (%)	-1.82 **	-1.43 *	-0.40	-0.03 **	-0.08 **	0.01
	(0.65)	(0.58)	(0.24)	(0.01)	(0.03)	(0.01)
elec. prodn from gas, high-inc non-OECD (%)	0.76 **	0.42 *	0.34 ***	0.01 **	0.02	0.009 ***
	(0.24)	(0.21)	(0.09)	(0.00)	(0.01)	(0.002)
elec. prodn from gas, Mid East & N.Afr. (%)	0.22	-0.46	0.68 ***	0.00	-0.02	0.02 ***
	(0.44)	(0.39)	(0.16)	(0.01)	(0.02)	(0.00)
crude oil reserves, world (billion barrels)	-0.01	0.00	-0.02 ***	-0.00	0.00	-5e-4 ***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.1e-4)
natural gas reserves, world (10^{15} cubic ft)	-2.42	3.59	-6.02 ***	-0.03	0.25 *	-0.17 ***
	(2.26)	(2.01)	(0.84)	(0.04)	(0.10)	(0.00)
constant	-41.94	45.47	-87.4 ***	2.17	2.67	0.19
	(64.08)	(57.07)	(23.8)	(1.12)	(2.88)	(0.64)
p-value (Prob > F)	0.00 ***	0.00 ***	0.00 ***	0.00 ***	0.00 ***	0.00 ***
adj. R squared	0.91	0.92	0.90	0.91	0.90	0.90
# observations	240	240	240	240	240	240

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, and *** 0.1% level. Prob>F is the p-value from F-tests on all the coefficients. Oil production is in million barrels/day.

TABLE 4. Effects of instruments on monthly oil price

	Dependent variable is: Price		ln(Price)	
	(1) OPEC	(2) non-OPEC	(3) OPEC	(4) non-OPEC
Demand shifters				
GDP, world (trillion 1982-1984$)	-0.50	-0.75	0.03	0.02
	(0.58)	(0.58)	(0.04)	(0.04)
population, world (billions)	-69.63 ***	-85.76 ***	-5.67 ***	-6.06 ***
	(13.63)	(13.70)	(1.00)	(0.98)
commercial energy use, world (mill. kt of oil equivalent)	-39.86 ***	-34.50 ***	-2.82 ***	-2.76 ***
	(7.11)	(7.14)	(0.52)	(0.51)
electricity production, world (trillion kwh)	28.25 ***	29.46 ***	2.17 ***	2.24 ***
	(4.67)	(4.68)	(0.34)	(0.34)
electricity prodn from oil, world (%)	-5.02 ***	-5.33 ***	-0.29 ***	-0.30 ***
	(0.80)	(0.80)	(0.06)	(0.06)
electricity prodn from oil, high-inc OECD (%)	-0.17	0.76	-0.04	-0.01
	(0.83)	(0.84)	(0.06)	(0.06)
electricity prodn from oil, high-inc non-OECD (%)	0.13	-0.01	0.01	-0.00
	(0.10)	(0.10)	(0.01)	(0.01)
electricity prodn from oil, Mid East & N. Afr. (%)	-1.99 **	-2.35 ***	-0.07	-0.10 *
	(0.67)	(0.68)	(0.05)	(0.05)
electricity prodn from natural gas, world (%)	-7.96 ***	-7.96 ***	-0.47 ***	-0.48 ***
	(1.28)	(1.28)	(0.09)	(0.09)
electricity prodn from natural gas, high-inc OECD (%)	6.85 ***	7.24 ***	0.39 ***	0.40 ***
	(1.08)	(1.09)	(0.08)	(0.08)
electricity prodn from natural gas, high-inc non-OECD (%)	-1.24 ***	-1.11 ***	-0.09 ***	-0.09 ***
	(0.31)	(0.31)	(0.02)	(0.02)
electricity prodn from natural gas, Mid East & N.Afr. (%)	-1.56 *	-2.01 **	-0.04	-0.07
	(0.74)	(0.74)	(0.05)	(0.05)
natural gas reserves, world (10^{15} cubic ft)	-13.54 ***	-12.93 ***	-0.89 ***	-0.87 ***
	(2.07)	(2.08)	(0.15)	(0.15)
p-value from joint test of all demand shifters	[0.00] ***	[0.00] ***	[0.00] ***	[0.00] ***
Supply shifters				
total world rig count (100 rigs)	0.22 ***	0.19 ***	0.01 4***	0.01 4***
	(0.05)	(0.05)	(0.004)	(0.004)
crude oil reserves, world (billion barrels)	0.03 **	0.03 **	0.0012 *	0.0015 *
	(0.01)	(0.01)	(0.0006)	(0.0006)
p-value from joint test of all supply shifters	[0.00] ***	[0.00] ***	[0.00] ***	[0.00] ***
Market controls				
summer dummy (Jun, Jul, Aug)	-0.40	-0.48	-0.03	-0.03
	(0.35)	(0.35)	(0.03)	(0.03)
winter dummy (Dec, Jan, Feb)	-0.08	-0.07	-0.02	-0.03
	(0.37)	(0.37)	(0.03)	(0.03)
constant	708.1 ***	764.1 ***	46.13 ***	49.59 ***
	(106.2)	(106.8)	(7.83)	(7.65)
p-value from joint test of all coefficients (Prob > F)	0.00 ***	0.00 ***	0.00 ***	0.00 ***
adj. R squared	0.94	0.94	0.88	0.88
# observations	240	240	240	240

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, and *** 0.1% level. Prob>F is the p-value from F-tests on all the coefficients. F-tests are also conducted for all the demand shifters and for all the supply shifters. Oil price is in 1982-1984$/barrel. All covariates are annual values except the total world rig count, the summer dummy and the winter dummy.

TABLE 5a. 3SLS estimates of monthly demand

Dependent variable is quantity of oil production (million barrels/day) for:	(1) world	(2) OPEC	(3) world	(4) non-OPEC
OPEC oil price (1982-1984$/barrel)	0.03	0.66 ***		
	(0.08)	(0.16)		
non-OPEC oil price (1982-1984$/barrel)			0.06	-1.25 ***
			(0.09)	(0.26)
Monthly Covariates				
summer dummy (Jun, Jul, Aug)	-0.32	0.28	-0.30	-0.97
	(0.28)	(0.42)	(0.29)	(0.60)
winter dummy (Dec, Jan, Feb)	0.15	-0.29	0.14	0.60
	(0.28)	(0.42)	(0.28)	(0.59)
Annual Covariates				
GDP, world (trillion 1982-1984$)	-0.90 ***	-0.20	-0.82 ***	-1.75 *
	(0.17)	(0.45)	(0.19)	(0.69)
population, world (billions)	16.14 *	58.83 ***	18.84 *	-98.74 ***
	(6.94)	(16.45)	(8.75)	(28.58)
commercial energy use, world (million kt of oil equivalent)	8.06 *	30.16 ***	7.20 *	-40.12 ***
	(3.33)	(6.42)	(3.08)	(8.66)
electricity production, world (trillion kwh)	-1.81	-20.14 ***	-1.98	36.64 ***
	(2.73)	(5.59)	(3.01)	(8.76)
electricity production from oil, world (%)	-1.26 *	2.24	-1.11	-7.77 ***
	(0.58)	(1.16)	(0.63)	(1.81)
electricity production from oil, high-inc OECD (%)	1.64 ***	0.88	1.48 ***	3.01 **
	(0.21)	(0.58)	(0.27)	(1.01)
electricity production from oil, high-inc non-OECD (%)	0.23 ***	0.13	0.26 ***	0.22 *
	(0.04)	(0.09)	(0.03)	(0.11)
electricity production from oil, Mid East & N. Afr. (%)	0.75 ***	2.01 ***	0.86 ***	-2.61 ***
	(0.15)	(0.35)	(0.18)	(0.53)
electricity production from natural gas, world (%)	-1.13	4.00 *	-0.99	-10.30 ***
	(0.85)	(1.71)	(0.89)	(2.55)
electricity production from natural gas, high-inc OECD (%)	-1.15 *	-4.87 ***	-1.35 *	7.10 ***
	(0.58)	(1.18)	(0.65)	(1.86)
electricity production from natural gas, high-inc non-OECD (%)	0.74 ***	1.20 ***	0.73 ***	-0.52
	(0.09)	(0.20)	(0.08)	(0.28)
electricity production from natural gas, Mid East & N.Afr. (%)	0.45 **	1.56 ***	0.58 ***	-2.58 ***
	(0.15)	(0.37)	(0.17)	(0.54)
natural gas reserves, world (10^{15} cubic ft)	-3.61 *	5.08	-3.56 *	-12.96 **
	(1.52)	(2.90)	(1.55)	(4.19)
constant	-88.95	-562.8 ***	-107.5	947.4 ***
	(59.98)	(116.6)	(68.32)	(189.1)
adj. R squared	0.85	0.56	0.84	-4.82
# observations	240	240	240	240

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, and *** 0.1% level. The instruments used are: total world rig count; summer dummy; winter dummy; world GDP; world population; world commercial energy use; world electricity production; electricity production from oil for world, high-income OECD, high-income non-OECD, and Middle East and North Africa; electricity production from natural gas for world, high-income OECD, high-income non-OECD, and Middle East and North Africa; world crude oil reserves; and world natural gas reserves. Demand and supply equations corresponding to the same choice of price and quantity variables were estimated jointly, the maximum number of iterations was 1e6, and the toleration level for each iteration was 1e-5.

TABLE 5b. 3SLS estimates of monthly supply

Dependent variable is quantity of oil production (million barrels/day) for:	(1) world	(2) OPEC	(3) world	(3) non-OPEC
OPEC oil price (1982-1984$/barrel)	-0.17 ***	-0.07		
	(0.03)	(0.04)		
non-OPEC oil price (1982-1984$/barrel)			-0.14 ***	-0.15 ***
			(0.03)	(0.03)
Monthly Covariates				
total world rig count (100 rigs)	0.06 **	0.13 ***	0.04 *	-0.03
	(0.02)	(0.03)	(0.02)	(0.02)
summer dummy (Jun, Jul, Aug)	-0.40	-0.03	-0.40	-0.40 *
	(0.26)	(0.26)	(0.27)	(0.17)
winter dummy (Dec, Jan, Feb)	0.11	-0.28	0.12	0.30
	(0.27)	(0.26)	(0.28)	(0.17)
Annual Covariates				
GDP, Mid East & N.Afr. (trillion 1982-1984$)	49.96 ***	30.11 ***	49.92 ***	20.15 ***
	(3.49)	(3.46)	(3.68)	(2.26)
crude oil reserves, world (billion barrels)	0.029 ***	0.031 ***	0.030 ***	-0.0021 **
	(0.001)	(0.001)	(0.001)	(0.0008)
constant	18.02 ***	-17.47 ***	16.94 ***	35.13 ***
	(1.88)	(1.85)	(1.94)	(1.19)
adj. R squared	0.86	0.83	0.85	0.51
# observations	240	240	240	240

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, and *** 0.1% level. The instruments used are: total world rig count; summer dummy; winter dummy; world GDP; world population; world commercial energy use; world electricity production; electricity production from oil for world, high-income OECD, high-income non-OECD, and Middle East and North Africa; electricity production from natural gas for world, high-income OECD, high-income non-OECD, and Middle East and North Africa; world crude oil reserves; and world natural gas reserves. Demand and supply equations corresponding to the same choice of price and quantity variables were estimated jointly, the maximum number of iterations was 1e6, and the toleration level for each iteration was 1e-5.

TABLE 6a. 3SLS estimates of monthly demand, in logs

Dependent variable is log quantity of oil production (million barrels/day) for:	(1) world	(2) OPEC	(3) world	(4) non-OPEC
log OPEC oil price (1982-1984$/barrel)	-0.01	0.44 **		
	(0.02)	(0.15)		
log non-OPEC oil price (1982-1984$/barrel)			0.00	-0.19 ***
			(0.02)	(0.05)
Monthly Covariates				
summer dummy (Jun, Jul, Aug)	-0.01	0.01	-0.01	-0.014 *
	(0.00)	(0.02)	(0.00)	(0.006)
winter dummy (Dec, Jan, Feb)	0.00	-0.01	0.00	0.01
	(0.00)	(0.02)	(0.00)	(0.01)
Annual Covariates				
GDP, world (trillion 1982-1984$)	-0.017 ***	-0.04	-0.016 ***	-0.00
	(0.002)	(0.02)	(0.002)	(0.01)
population, world (billions)	0.32	3.16 **	0.34 *	-1.01 **
	(0.17)	(1.09)	(0.17)	(0.36)
commercial energy use, world (million kt of oil equivalent)	0.16 *	1.63 ***	0.16 *	-0.47 ***
	(0.07)	(0.39)	(0.07)	(0.12)
electricity production, world (trillion kwh)	-0.05	-1.13 **	-0.06	0.42 ***
	(0.06)	(0.35)	(0.06)	(0.11)
electricity production from oil, world (%)	-0.02	0.12	-0.02	-0.07 ***
	(0.01)	(0.06)	(0.01)	(0.02)
electricity production from oil, high-inc OECD (%)	0.028 ***	0.06 *	0.027 ***	0.01
	(0.003)	(0.03)	(0.004)	(0.01)
electricity production from oil, high-inc non-OECD (%)	0.003 ***	0.00	0.0040 ***	0.00
	(0.001)	(0.00)	(0.0004)	(0.00)
electricity production from oil, Mid East & N. Afr. (%)	0.011 ***	0.06 **	0.013 ***	-0.012 *
	(0.002)	(0.02)	(0.003)	(0.006)
electricity production from natural gas, world (%)	-0.01	0.22 *	-0.01	-0.11 ***
	(0.02)	(0.10)	(0.02)	(0.03)
electricity production from natural gas, high-inc OECD (%)	-0.02	-0.23 ***	-0.02 *	0.07 ***
	(0.01)	(0.07)	(0.01)	(0.02)
electricity production from natural gas, high-inc non-OECD (%)	0.013 ***	0.06 ***	0.013 ***	-0.013 **
	(0.002)	(0.01)	(0.002)	(0.004)
electricity production from natural gas, Mid East & N.Afr. (%)	0.006 *	0.04	0.008 **	-0.01
	(0.002)	(0.02)	(0.002)	(0.01)
natural gas reserves, world (10^{15} cubic ft)	-0.05	0.40 *	-0.05	-0.23 ***
	(0.03)	(0.17)	(0.03)	(0.05)
constant	1.43	-24.6 ***	1.11	12.17 ***
	(1.25)	(7.06)	(1.25)	(2.26)
adj. R squared	0.85	0.59	0.84	0.17
# observations	240	240	240	240

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, and *** 0.1% level. The instruments used are: total world rig count; summer dummy; winter dummy; world GDP; world population; world commercial energy use; world electricity production; electricity production from oil for world, high-income OECD, high-income non-OECD, and Middle East and North Africa; electricity production from natural gas for world, high-income OECD, high-income non-OECD, and Middle East and North Africa; world crude oil reserves; and world natural gas reserves. Demand and supply equations corresponding to the same choice of price and quantity variables were estimated jointly, the maximum number of iterations was 1e6, and the toleration level for each iteration was 1e-5.

TABLE 6b. 3SLS estimates of monthly supply, in logs

Dependent variable is log quantity of oil production (million barrels/day) for:	(1) world	(2) OPEC	(3) world	(3) non-OPEC
log OPEC oil price (1982-1984$/barrel)	-0.06 ***	-0.12 ***		
	(0.01)	(0.04)		
log non-OPEC oil price (1982-1984$/barrel)			-0.05 ***	-0.01
			(0.01)	(0.01)
Monthly Covariates				
total world rig count (100 rigs)	0.0008 *	0.008 ***	0.00	-3.5e-3 ***
	(0.0004)	(0.001)	(0.00)	(0.5e-3)
summer dummy (Jun, Jul, Aug)	-0.01	-0.00	-0.01	-0.010 *
	(0.00)	(0.01)	(0.00)	(0.005)
winter dummy (Dec, Jan, Feb)	0.00	-0.02	0.00	0.012 *
	(0.00)	(0.01)	(0.00)	(0.005)
Annual Covariates				
GDP, Mid East & N.Afr. (trillion 1982-1984$)	0.78 ***	1.06 ***	0.77 ***	0.53 ***
	(0.06)	(0.17)	(0.06)	(0.06)
crude oil reserves, world (billion barrels)	4.6e-4 ***	0.0014 ***	4.8e-4 ***	-4.9e-5 *
	(0.2e-4)	(0.0001)	(0.2e-4)	(2.2e-5)
constant	3.54 ***	1.65 ***	3.51 ***	3.57 ***
	(0.04)	(0.13)	(0.04)	(0.05)
adj. R squared	0.86	0.81	0.85	0.49
# observations	240	240	240	240

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, and *** 0.1% level. The instruments used are: total world rig count; summer dummy; winter dummy; world GDP; world population; world commercial energy use; world electricity production; electricity production from oil for world, high-income OECD, high-income non-OECD, and Middle East and North Africa; electricity production from natural gas for world, high-income OECD, high-income non-OECD, and Middle East and North Africa; world crude oil reserves; and world natural gas reserves. Demand and supply equations corresponding to the same choice of price and quantity variables were estimated jointly, the maximum number of iterations was 1e6, and the toleration level for each iteration was 1e-5.

Appendix A. Countries used in regional aggregates

The following lists the countries used in each of the regional aggregates for the World Bank Group World Development Indicators data. High-income economies are those in which 2002 GNI per capita was $9,076 or more.

High-income OECD:
Australia
Austria
Belgium
Canada
Denmark
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Japan
Korea, Rep.
Luxembourg
Netherlands
New Zealand
Norway
Portugal
Spain
Sweden
Switzerland
United Kingdom
United States

High-income non OECD:
Andorra
Antigua and Barbuda
Aruba
Bahamas, The
Bahrain
Barbados
Bermuda
Brunei
Cayman Islands
Channel Islands
Cyprus
Faeroe Islands
French Polynesia
Greenland
Guam
Hong Kong, China
Isle of Man
Israel
Kuwait
Liechtenstein
Macao, China
Malta
Monaco
Netherlands Antilles
New Caledonia
Puerto Rico
Qatar
San Marino
Singapore
Slovenia
Taiwan, China
United Arab Emirates
Virgin Islands (U.S.)

Middle East & North Africa (does not include high-income economies)**:**
Djibouti
Egypt, Arab Rep.
Iran, Islamic Rep.
Iraq
Jordan
Lebanon
Libya
Morocco
Oman
Saudi Arabia
Syrian Arab Republic
Tunisia
West Bank and Gaza
Yemen, Rep.