THE CAPTURE OF OIL PRICE SHOCK — OIL PRICE CHANGE FORECASTING

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Introduction

After the severe impact of the oil price collapse of 1986 and Iraq's invasion of Kuwait in 1990, oil price prediction models are challenged again, with most energy analysts questioning the reliability of long-term oil-price forecasting models.[1] Instead of emphasizing the unreliability of these models, a method is addressed in this paper to enhance the forecasting power of such models. By running oil price regressions, we find that oil price shocks are the major source of prediction errors.[2] We proceed to create a probability index to capture oil price shocks based on market imbalance. With this index, we are able to forecast previous price shocks with reasonable accuracy and also find another positive shock is most likely to occur around 1996.

The Crucial Role of an Oil Price Shock

In modeling the world oil price, the most important factors are world oil demand, the "fringe" oil supply, and the coalition behavior of the Organization of

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the Petroleum Exporting Countries (OPEC).[3] The following independent variables are chosen to capture these effects. First, the changing rates of world refining and gas reserves are selected to represent the world oil demand effect. The former variable is to measure the trend of the world oil demand, while the latter can be regarded as a substitution effect since world oil demand would be reduced given access to other energy sources. Moreover, gas is believed to be a more important primary energy than other energy resources due to its advantage as "green energy."

The changing rates of world reserves and that of OPEC's relative production indicate the influence of world oil supply. We expect the world oil price to be lower if there are abundant oil reserves, whereas we expect it to be higher if OPEC members occupy a larger share of the world oil market and thus have more monopoly power.

The Middle East relative reserves and the relative production of Saudi Arabia are chosen to consider the monopoly power of OPEC and the degree of harmonious relationship among that organization's members. As most OPEC states are scattered in the Middle East area, higher relative oil reserves would enhance the monopoly power of OPEC. As the largest producer in OPEC and its swing producer for many years, Saudi Arabia's relative oil production is usually regarded as an important indicator for the relationship among OPEC members. If Saudi Arabia is a swing producer and adjusts its output to meet the optimal production quota, then the OPEC members can more easily keep a harmonious relationship.

Based on the above illustrations, the oil price changing rate can be regressed as a linear form equation,

$$\begin{aligned} P_t = \beta_0 &+ \beta_1 MRR_t + \beta_2 WDCR_t + \beta_3 WRCR_{t-1} + \beta_4 MRR_{t-1} \\ &+ \beta_5 ORPCR_t + \beta_6 GRCR_t + \beta_7 SRPS_t + \beta_8 D1_t + \beta_9 D2_t \\ &+ \beta_{10} D3_t + \beta_{11} D4_t + \varepsilon_t \end{aligned} \tag{1}$$

where

P_t = world oil price changing rate in year t, $(P_t - P_{t-1})/P_{t-1}$;
MRR_t = Middle East relative oil reserves in year t (Middle East oil reserve/world oil reserve);
$WDCR_t$ = world oil refining changing rate in year t;
$WRCR_{t-1}$ = world oil reserves changing rate in year t-1;
MRR_{t-1} = Middle East relative oil reserves in year t-1;
$ORPCR_t$ = OPEC relative production changing rate in year t;
$GRCR_t$ = world gas reserves changing rate in year t;
$SRPS_t$ = Saudi Arabia's relative production share in year t (Saudi Arabia's oil production/world oil production);

$D1_t$ = 1 if the first oil price shock[4] occurs in year t, 0 if the first oil price shock does not occur in year t;
$D2_t$ = 1 if the second oil price shock occurs in year t, 0 if the second oil price shock does not occur in year t;
$D3_t$ = 1 if the third oil price shock occurs in year t, 0 if the third oil price shock does not occur in year t; and
$D4_t$ = 1 if the fourth oil price shock occurs in year t, 0 if the fourth oil price shock does not occur in year t.

The empirical results were shown in table 1.[5] It is found that the Middle Eastern relative reserves lag variable, the OPEC relative production changing rate, and Saudi Arabia's relative production share are significant in explaining the oil-price changing rate in most equations. Such a result is consistent with the findings in literature. The less significant results of the world demand changing rate may be due to the overlapping of related variables. Since the world demand changing rate is highly correlated with Saudi Arabia's relative production share, the estimated coefficients will turn out to be insignificant. In fact, the t value of the worked demand changing rate will be very significant after dropping Saudi Arabia's relative production share in column 6. Table 1 also indicates that the oil price changing rate can be well explained if we consider all the shock impacts, since $\bar{R}^2$ is 0.99. On the other hand, the $\bar{R}^2$ will drop to be just 0.42 if we ignore the shock impacts, especially for the first and second oil price shocks. Such a result implies that the current forecasting models may produce large prediction errors if they ignore the analysis of shock impact because missing relevant important explained variables will result in biased regression coefficients.

It should be noted, however, that the regression results in column 6 are *ex post* evidence. As no one knows the exact period *ex ante* of the oil price shock, it is impossible to derive correct regression results without any prior information of an oil price shock. In the next section, we develop a statistical model to help capture the probability of an oil shock.

Capturing Oil Price Shocks

Many energy analysts believe that oil price shocks are more related to political events, e.g., the first, second, and third oil price crisis are attributed to the Middle East war of October 1973, Iran's revolution (1979-1980), and Iraq's invasion of Kuwait (1990-1991), respectively. The oil price collapse in 1986 may be traceable to the application of the netback pricing by Saudi Arabia. Unfortunately, political impacts are not always quantifiable. Further, these authors believe that the political events may be used as excuses and that, behind these political occurrences, lie economic imbalances that are quantifiable. For example, the oil price

Table 1

OIL PRICE REGRESSION RESULTS[a]

Variable	1	2	3	4	5	6
Constant	1.99	0.23	2.23	1.75	1.70	0.66
	(0.81)	(0.11)	(1.21)	(0.64)	(0.64)	(2.61)[b]
Middle East relative	11.97	2.98	11.64	12.93	12.59	−2.19
reserves (MRR_t)	(1.45)	(0.38)	(1.88)	(1.38)	(1.44)	−1.97
World demand changing	10.16	4.40	7.65	10.22	9.65	0.31
rate ($WDCR_t$)	(1.54)	(0.74)	(1.53)	(1.48)	(1.38)	0.45
World reserves changing	1.35	−0.03	1.79	1.33	1.10	0.28
rate (lag) ($WRCR_{t-1}$)	(0.64)	(−0.01)	(1.14)	(0.61)	(0.49)	(1.34)
Middle East relative	−19.39	−5.13	−19.79	−20.40	−19.51	0.43
reserves (lag) (MRR_{t-1})	(−2.16)[c]	(−0.01)	(−2.94)[b]	(−2.02)[c]	(−2.08)[c]	(0.32)
OPEC relative production	4.91	2.53	5.60	5.23	5.228	1.77
changing rate ($ORPCR_t$)[e]	(2.34)[c]	(1.27)	(3.53)[d]	(2.09)[c]	(2.25)[c]	(5.53)[d]
Gas reserves changing	2.74	1.96	2.67	2.99	3.09	0.93
rate ($GRCR_t$)	(0.96)	(0.82)	(1.25)	(0.95)	(1.00)	(2.95)[d]
Saudi Arabian	10.74	0.03	0.79	0.08	0.07	0.01
production share ($SRPS_t$)	(2.18)[c]	(1.01)	(3.09)[b]	(1.75)	(2.10)[c]	(2.02)[c]
D1	–	1.75	–	–	–	2.25
		(2.45)[b]				(23.72)[d]
D2	–	–	1.27	–	–	1.39
			(3.09)[b]			(26.69)[d]
D3	–	–	–	20.41	–	−0.36
				(0.26)		(−4.62)[d]
D4	–	–	–	–	−0.27	0.22
					(−0.40)	(3.52)[b]
$\bar{R}^2$	0.42	0.60	0.67	0.37	0.38	0.99

[a]Number in parentheses is t-value.
[b]5 percent significant.
[c]10 percent significant.
[d]1 percent significant.
[e]OPEC = Organization of the Petroleum Exporting Countries.

crisis in the end of 1973 is usually blamed on the Middle East war. However, OPEC would not have been able to quadruple oil prices if it had not accumulated enough monopoly power. Hence, this paper believes that the market imbalance was the main cause of oil price shock, although the war offered a political catalyst.

In the early part of the 1970s, world production was more concentrated in OPEC (51 percent in 1970 and 54 percent in 1974), world oil demand was increasing rapidly, and the world oil price was still low (less then U.S. $2 per barrel). Such a low price would seem to deviate from the monopoly market price, leading to a market imbalance before the oil price shock in the end of 1973. Similarly, the second and third oil crises and the oil price collapse were also due to economic imbalances. During the late 1970s, crude oil reserves were thought to be decreasing (714 billion barrels in 1975 but 640 billion barrels in 1979), while world oil demand was still increasing and which should raise prices.

The oil price collapse in 1986 is another story. Being a swing producer, Saudi Arabia needed to reduce its oil output to maintain a high price as world oil demand declined. Since world oil demand dropped rapidly for many years, as a swing producer, Saudi Arabia lost more oil revenues[6] than other OPEC members. The imbalance among OPEC members and the oil price collapse occurred after the application of netback pricing system by Saudi Arabia.

With lower prices, world oil demand increased from 60 million barrels per day (b/d) in 1985 to 66 million b/d in 1989. The increment in OPEC's production was even higher, from 16 million b/d in 1985 to 22 million b/d in 1989. From this viewpoint, the monopoly power by OPEC increased at the end of the 1980s, which might suggest prices would increase.

Based on the above examples, it is possible for us to capture the shock impact by examining the imbalance among economic variables. If these variables deviate further and further from an equilibrium point, an oil price shock is more likely to occur. Obviously, world oil demand, OPEC's market share (OPEC's output relative to the world oil production), and Saudi Arabia's relative oil production share (relative to OPEC's oil production) are important in explaining the possibility of a shock occurrence.[7] Applying the idea of imbalance, the movement of these three variables is traced back to 1970 by examining diagrams to detect their relationship with oil price shocks. For example, it is found that an oil price shock occurs once oil demand increases consecutively for more than three years by observing the data from 1970 to 1993. Four significant events are then defined as follow: A is that world oil demand increases consecutively in the previous three years; B is a good relationship among OPEC members; B' is a poor relationship among OPEC members; and C is that Saudi Arabia's relative production share drops consecutively in the previous three years.

Apparently, events A and C can be judged clearly, but events B and B' are hard to calculate because the definitions are ambiguous. To clarify events B and B', the concept of imbalance is applied again. Both texts and oil market history tell us that OPEC members get along well when all of them are growing richer, as in the period of oil demand increasing (the 1970s and the end of the 1980s). In contrast, when demand is decreasing, many members produce more than their quotas to maintain oil revenue, which breaks down their harmonious relationship. In brief, OPEC members can keep better relationships when all are getting richer, but not when some of them are getting poorer.

Further, "richer" can be separated into absolute (AS) and relative (R), where OPEC's market share (AS) is the best variable to catch the "richer" evidence for the organization's members. If OPEC's market share grew during the period of increasing oil demand, both the oil price and quantity sold will rise due to the enhancement of monopoly power and higher output quotas. R is calculated by comparing the fluctuation in OPEC's relative production. Based on human psychological principles, the relative factor is separated further into three parts, the balance effect, the turning point effect, and the cumulated effect. The balance effect could be written as

$$R_t = R_{t-1} \text{ if } AS_t = AS_{t-1}. \tag{2}$$

The turning point effect could be expressed as

$$R_t = +1 \text{ if } AS_t > AS_{t-1} \text{ and } AS_{t-1} \leq AS_{t-2} \tag{3}$$

or

$$R_t = -1 \text{ if } AS_t < AS_{t-1} \text{ and } AS_{t-1} \geq AS_{t-2}. \tag{3a}$$

The cumulated effect could be given as

$$R_t = R_{t-1} + 1 \text{ if } AS_t > AS_{t-1} \text{ and } AS_{t-1} > AS_{t-2} \tag{4}$$

or

$$R_t = R_{t-1} - 1 \text{ if } AS_t < AS_{t-1} \text{ and } AS_{t-1} < AS_{t-2}. \tag{4a}$$

Moreover, it is also found that the occurrence of a positive shock is mainly related to the intersection set of A and B, or

$$\Pr(\text{positive shock}) \propto \Pr(A \cap B) \tag{5}$$

where $\propto$ represents the correlation relationship. According to the Baysian theorem, equation (5) can be rewritten as

$$\Pr(\text{positive shock}) \propto \Pr(B) * \Pr(A \mid B). \tag{6}$$

On the other hand, it is found that the negative shock depends more on the intersection set of B′ and C, or

$$\Pr(\text{negative shock}) \propto \Pr(B' \cap C) = \Pr(B') * \Pr(C \mid B'). \tag{7}$$

The Estimation of the Oil Price Shock Probability

Following the inference in the above section, the probability applied in regression analysis is calculated as follows:

$$Pr(A_t) = 1 \text{ if A is observed in year t, 0 otherwise;} \tag{8}$$

$$Pr(C_t) = 1 \text{ if C is observed in year t, 0 otherwise;} \tag{9}$$

$$Pr(B_t) = AS_t + 0.03 * R_t; \tag{10}$$

and

$$Pr(B_t') = 0.05 * [1/Pr(B_t')] \tag{11}$$

where the digit of 0.03 and 0.05 are the largest numbers, which guarantees that the probability of event B and event B′ are between 0 and 1. As a bad relationship is opposite a good relationship, thus the probability of B_t' is the opposite value of B_t.

By equations (6) to (11), the probability of $(A \cap B)$ and $(B' \cap C)$ can be calculated. Consequently, the possibility of positive shock and negative shock can be estimated by ordinary least square (OLS) regression method,[8] which can be described as

$$PS_t = \alpha + \beta Pr(A_t \cap B_t) + \varepsilon_1 \tag{12}$$

and

$$NS_t = \alpha' + \beta' Pr(B_t' \cap C_t) + \varepsilon_2 \tag{13}$$

where

PS_t = 1 if a positive oil price shock occurs in year t,[9] 0 if a positive oil price shock does not occur in year t;
$Pr(A_t \cap B_t)$ = calculated probability of $(A \cap B)$ in year t;
NS_t = 1 if negative oil price shock occurs in year t,[10] 0 if negative oil price shock does not occur in year t; and
$Pr(B_t' \cap C_t)$ = calculated probability of $(B' \cap C)$ in year t.

By regressing equations (12) and (13), the results are shown in table 2. The t-value is very significant for both regression equations. These outcomes indicate that the probability of $(A \cap B)$ and $(B' \cap C)$ are important for explaining the occurrence of a shock, with a $\overline{R}^2$ of only 0.62 for a positive shock regression and 0.63 for negative shock regression.

Table 2

OIL PRICE SHOCK REGRESSION RESULTS

Variable	PS	NS
Positive shock (PS)	1.35	–
Coefficient	(6.51)[a]	
Negative shock (NS)		0.79
Coefficient	–	(5.52)[a]
$\bar{R}^2$	0.62	0.63

[a]1 percent significant.

Based on the regression results in table 2, the estimated and predicted shock probabilities are listed in table 3.[11] Three positive shocks and one negative shock are all captured well. Although there are no shocks in 1984 and 1987, shocks occur around these years. Since the shock probabilities in the exact years are much higher than those years without any shock, the shock probabilities listed in table 3 are acceptable. The most interesting result is the high possibility of a positive shock around 1996. With world oil demand increasing in recent years (and expected to rise annually in the next few years), event A will then be equal to 1 in 1996; the possibility of event B is greater due to OPEC's better internal relationship.[12] Thus, the positive and high probability of $(A \cap B)$ will yield a greater possibility of an oil price shock around 1996.

Conclusion and Remarks

Shocks are important in explaining world oil prices as shown by the regression results listed in table 1. We find a shock will occur if some important economic variables have deviated further and further from equilibrium. Based on the theoretical inference, historical evidence, and econometric analyses, the estimated and predicted possibilities of an oil price shock occurrence are calculated. It is found that all three positive shocks and one negative shock are captured well.

The most interesting result is the high possibility of a positive shock around 1996. Since world oil demand is currently expected to increase consecutively for several years and as OPEC members seem capable at maintaining good relationships for some time, there is great possibility for OPEC to accumulate enough monopoly power that could lead to another oil price shock in the near future.

Although the results are far from perfect, we find we can forecast reasonably well the occurrence of oil price shocks, which can help us to better predict the oil price trend. In order to capture the oil price shock more accurately, further research is needed. Searching for other variables to improve the $\bar{R}^2$ in table 2 is the first aspect. We believe that gas production and reserves are two crucial factors in explaining oil price shocks. Moreover, the energy-substitution and energy-saving effects also should be considered. If these two effects improved significantly in the future, the possibility of an oil price shock will diminish due to the increase of world oil demand elasticity. In fact, we would expect no oil price shock in case of high, world oil demand short-run elasticity. Thus, from the viewpoint of energy security, the substitution and saving effects should be encouraged.

Table 3

THE ESTIMATED PROBABILITY OF OIL PRICE SHOCK

Year	Positive Shock	Negative Shock
1974	0.82147	0
1975	0	0
1976	0	0
1977	0	0
1978	0	0
1979	0.57510	0
1980	0.47579	0
1981	0	0
1982	0	0
1983	0	0
1984	0	0.27070
1985	0	0.37945
1986	0	0.64265
1987	0	0.11132
1988	0	0
1989	0.62803	0
1990	0.64221	0
1991	0	0
1992	0	0
1993	0	0
1994	0	0
1995	0	0
1996	0.73178	0

NOTES

[1]See R. Bacon, "Modelling the Price of Oil," *Oxford Review of Economic Policy*, summer 1991, pp. 17-34; M. Lynch, "Reliability of Long-Term Oil Market Forecasts," International Association for Energy Economics Conference paper, 1992; and R. Mabro, "OPEC and the Price of Oil," *The Energy Journal*, April 1992, pp. 1-17.

[2]Shock is defined as the oil price changes upward (positive shock) or downward (negative shock) more than one time in a short period of time (i.e., several months), which occurred in 1973-1974, 1979-1980, 1985-1986, and 1989-1990. Except for the oil price collapse in 1986, all others are regarded as positive shocks.

[3]D. Gately, "A Ten-Year Retrospective: OPEC and the World Oil Market," *Journal of Economic Literature*, September 1984, pp. 1100-114, and C. H. Tahmassebi, "World Energy Outlook through 2000," *The Journal of Energy and Development*, spring 1987.

[4]See the definition as given in note 2.

[5]The historical data are selected from Oil and Gas Journal Energy Data Base, *International Energy Statistics Sourcebook*, October 1993. All data used in this paper are nominal value.

[6]The oil revenues of Saudi Arabia from 1981 to 1988 were U.S. $118,998 million, $78,119 million, $44,851 million, $35,669 million, $27,500 million, $20,000 million, $21,500 million, and $20,000 million, respectively. *Oil Economist's Handbook*, vol. 1, 5th ed. (New York: Elsevier Applied Science, 1989). Saudi oil exports from 1981 to 1988 were 9.3 million b/d, 5.805 million b/d, 4.050 million b/d, 3.8 million b/d, 2.535 million b/d, 3.7 million b/d, 2.925 million b/d, and 3.49 million b/d. Oil and Gas Journal, *International Energy Statistics Sourcebook*, October 1993.

[7]D. Greene, "A Note on OPEC Market Power and Oil Price," *Energy Economics*, April 1991, pp. 123-29.

[8]Since the dependent variable is either 1 or 0, probit analysis is more efficient than OLS; when limited by the small sample size, the OLS method is relatively better.

[9]Those years are 1974, 1979, and 1990.

[10]It occurs only in 1986.

[11]The prediction value of world oil demand and OPEC's market share are calculated from "Asia-Pacific Refining," Energy Security Analysis, Inc., Washington, D.C., 1994, p. 14. The relative market share of Saudi Arabia is assumed to be constant due to the Saudi policy of keeping a constant market share in OPEC.

[12]In the near future, OPEC members may not be able to continue harmonious relationships once Iraq reenters the world oil market because of clashes of national interest observed when the quota of each member must be reduced. Thus, unless world oil demand can increase to more than offset increased Iraqi production, no oil price shock will occur around 1996.