AN EXAMINATION OF CURRENT CRUDE-OIL PRICE FORMULAS

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Introduction

Volatile world crude oil prices during much of the 1990s posed a problem for many crude buyers not only for the uncertainty in crude expenditures but also for paying the right price for a specific crude. Since world crude oils vary widely, e.g., quality and production, it is difficult to decide what is the right price for a crude.[1] Although current crude oil price formulas do consider the quality differentials by adhering to some benchmark prices with similar characteristics,[2] the less precise formulas may not reflect the real market value of a crude. Rather than the programming packages utilized in most oil companies, this paper seeks to apply a hedonic model to reveal those various attributes of petroleum in the global crude market. By clarifying the characteristics of most internationally traded crude oils, we suggest that the world market value of a crude can be better evaluated from our method.

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The Essence of the Crude

Indeed, a crude oil price is a pooling concept of many varieties of crude that differ not only in the area of production but also in their qualities.[3] A crude price should reflect its true value of quality, other characteristics, and the market demand/supply conditions if the market is transparent. In fact, one of the important criteria to be a benchmark price currently is due to its quality representative. However, the selection of a benchmark crude is based more on the experienced and intuitive consideration than on a theoretical foundation.[4] Instead of the experienced consideration, this paper investigates the essence of crude oil and applies a more suitable model to find a better crude-oil price formula.

There are many types of crude, and there is difficulty in distinguishing the quality difference among them. Generally, we can judge their characteristics by the American Petroleum Institute (API) gravity value, percentage of sulfur content, production area, and the like. With the information available today, the *International Crude Oil Market Handbook* provides much crude-oil-characteristics-related information.[5] From this abundant information but due to some data limitations, this paper selects 48 kinds of crude oil for analysis. The criterion for sample crude selection is dependent mainly on having complete information. Thus, the exclusion of crude oils from our sample set occurred if their correspondent spot price data or some main characteristics (e.g., API value, sulfur content, or production area) were missing.

Based on the above criteria, those selected crude oils for this paper are given in table 1. As these samples include most of the internationally traded crude oils at this time, the analysis and findings in this paper will be highly representative.

Although the *International Crude Oil Market Handbook* offers substantial information, fewer spot price data are revealed. In order to look at the oil characteristics in greater detail, this research also collects and analyzes the monthly average spot price of many crude oils from *Oil & Gas Journal*.[6] Combining with those crude characteristics collected from the *International Crude Oil Market Handbook*, some interesting results can be observed by sorting these crude oils according to the characteristics of production area (tables 2-7), sulfur content (tables 8-12), and API gravity (tables 13-17).

Tables 2-7 depict the monthly price trend of those crude oils sorted by six production areas: Africa, the Western Hemisphere, Asia, Europe, the Mediterranean, and the Middle East. All crude oil prices vary consistently during the observation period. However, the price differentials among different crude are large in most of all areas, especially in the Western Hemisphere. This phenomenon indicates that other important factors exist in the determination of the crude oil price.

Tables 8-12 illustrate the monthly price trend of those crude oils when sorted by sulfur content. The sulfur content is separated as five categories: less than 0.3 percent, 0.3 to 1 percent, 1 to 1.5 percent, 1.5 to 2 percent, and greater than 2 percent. Compared to tables 2-7, all crude oil prices vary consistently in each

Table 1

SELECTED SAMPLES OF CRUDE OILS BY AREAS AND COUNTRIES[a]

Africa	Western Hemisphere	Asia	Europe	Mediterranean	Middle East
Cabinda–32° (Angola)	Cano Limon–38° (Colombia)	Daqing–32° (China)	Ekofisk–40°; Oseberg–36°; Statfjord–39°; (Norway)	Condensate–65°; Saharan Blend–46° (Algeria)	Iran Light–33°; Iran Heavy–30° (Iran)
Kole–35° (Cameroon)	Oriente–29° (Ecuador)	Ardjuna–37°; Arun Condensate–54°; Attaka–43°; Minas–34° (Indonesia)	Brent–38°; Flotta–35° (United Kingdom)	Amna–36°; Brega–40°; Es Sider–37°; Sarir–37°; Sirtica–42°; Zueitina–42° (Libya)	Kuwait–31° (Kuwait)
Mandji–30° (Gabon)	Alaska North Slope–29°; West Texas Intermediate–40°; West Texas Sour–34° (United States)	Tapis–45° (Malaysia)		Suez Blend–32°; Zeit Bay–34° (Egypt)	Oman–35° (Oman)
Bonny Light–36°; Bonny Medium–26.5°; Forcados–29° (Nigeria)		Kutubu–44° (Papua New Guinea)		Urals–33° (Russia)	Dukhan–41°; Marine–36° (Qatar)
					Arabian Light–33° (Saudi Arabia)
					Souedieh–24°; Syrian Light–37° (Syria)
					Abu Dhabi Murban–40°; Abu Dhabi Umm Shaif–37°; Dubai Fateh–31° (United Arab Emirates)
					Marib–48°; Masila–30.5° (Yemen)

[a]The crude oils listed in table 1, which differ somewhat from those in tables 2 through 17, are used to run regressions. The selection of crudes differs because of the data sources. The econometric analysis requires complete information for all related variables, as listed in tables 18 and 19. As it was not possible to collect complete related variables data for some of the crudes given in tables 2 through 17, the regression analysis was run only on those 48 crudes in table 1 for which complete data were available.

Source: T. Wallin and I. Joseph, *International Crude Oil Market Handbook*, 2d ed. (New York: PIW Publications and Washington, D.C.: The Oil Daily Company, 1997).

Table 2
MONTHLY CRUDE OIL PRICE BY PRODUCTION AREA: AFRICA, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/Year	Nigeria		Gabon
	Bonny Light	Forcados	Mandji
1/1989	17.35	17.21	15.35
7/1989	18.14	17.29	15.84
1/1990	21.64	21.83	19.45
7/1990	17.25	16.69	13.81
1/1991	24.55	24.13	20.44
7/1991	19.81	19.25	15.87
1/1992	18.60	18.28	15.03
7/1992	20.94	20.75	17.89
1/1993	17.80	17.45	14.58
7/1993	17.51	17.29	14.59
1/1994	14.74	14.69	12.32
7/1994	17.85	18.00	15.73
1/1995	16.92	16.85	15.36
7/1995	15.95	15.93	14.20
1/1996	18.55	18.55	16.69
7/1996	20.04	19.83	17.89
1/1997	24.04	24.16	21.71
7/1997	18.95	18.77	15.92

Source: *Oil & Gas Journal.*

Table 3
MONTHLY CRUDE OIL PRICE BY PRODUCTION AREA: WESTERN HEMISPHERE, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/Year	United States		Colombia	Ecuador	Mexico		Venezuela	
	Alaska North Slope	West Texas Intermediate	Cano Limon	Oriente	Isthmus	Maya	Tia Juana Light	Tia Juana Medium
1/1989	16.08	17.95	17.24	16.41	15.57	12.13	14.95	13.16
7/1989	17.44	19.99	17.98	17.49	18.01	15.65	17.22	17.00
1/1990	20.26	22.75	21.00	20.59	20.29	16.28	20.06	17.09
7/1990	15.65	18.28	15.88	15.59	15.46	11.47	14.41	12.88
1/1991	21.69	25.29	23.03	22.98	21.85	17.40	20.51	20.17
7/1991	18.30	21.34	18.64	18.15	18.48	13.36	16.69	15.84
1/1992	15.70	18.79	16.65	15.79	15.56	9.78	14.10	13.20
7/1992	19.65	21.74	19.75	19.65	19.43	15.45	18.14	17.95
1/1993	16.55	19.03	16.50	16.56	16.47	12.31	15.35	14.17
7/1993	15.86	17.85	15.93	15.24	15.48	11.53	14.56	13.70
1/1994	13.21	15.01	13.69	13.08	12.87	10.16	12.07	11.55
7/1994	17.40	19.61	17.71	16.88	17.32	14.76	16.48	15.88
1/1995	16.88	18.04	17.44	16.64	16.38	13.96	16.06	15.31
7/1995	16.25	17.30	16.28	15.96	15.65	13.43	14.95	15.15
1/1996	17.62	18.85	18.50	17.36	17.59	14.74	17.33	17.01
7/1996	19.72	21.30	20.32	19.45	19.61	16.09	18.77	18.79
1/1997	23.60	25.15	24.63	22.36	23.21	18.55	21.91	20.76
7/1997	17.48	19.65	18.23	16.54	17.28	14.40	16.49	n.a.[a]

[a]n.a. = not available.
Source: *Oil & Gas Journal.*

Table 4
MONTHLY CRUDE OIL PRICE BY PRODUCTION AREA: ASIA, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

	Indonesia		China	Malaysia	
Month/Year	Attaka	Minas	Daqing	Miri	Tapis
1/1989	17.81	17.01	16.73	17.70	17.94
7/1989	18.49	18.09	17.84	18.21	18.49
1/1990	20.45	20.44	20.09	20.52	20.77
7/1990	15.66	16.03	15.74	16.88	17.17
1/1991	24.57	23.96	23.52	24.57	24.99
7/1991	19.92	19.07	18.53	19.98	20.28
1/1992	19.66	18.08	17.89	19.87	20.17
7/1992	22.55	21.24	20.99	22.61	22.90
1/1993	18.80	18.48	18.35	18.67	18.99
7/1993	17.88	17.64	17.51	18.60	18.80
1/1994	15.46	14.58	13.75	16.03	16.22
7/1994	18.43	19.25	17.69	18.64	18.72
1/1995	17.91	17.55	17.34	18.31	18.32
7/1995	16.45	16.04	16.08	17.15	17.24
1/1996	20.27	20.26	20.25	20.52	20.61
7/1996	20.45	20.11	20.16	20.70	20.69
1/1997	25.68	25.04	24.86	25.78	25.86
7/1997	18.58	18.04	18.12	19.17	19.05

Source: *Oil & Gas Journal.*

Table 5
MONTHLY CRUDE OIL PRICE BY PRODUCTION AREA: EUROPE, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

	United Kingdom		Norway	
Month/Year	Brent	Forties	Ekofisk	Oseberg
1/1989	17.10	16.99	17.18	n.a.[a]
7/1989	17.71	17.65	17.85	17.10
1/1990	21.28	21.18	21.39	20.56
7/1990	16.88	16.76	17.06	15.53
1/1991	23.99	24.03	24.01	23.15
7/1991	19.38	19.35	19.76	18.58
1/1992	18.18	18.41	18.58	17.44
7/1992	20.24	20.29	20.40	19.33
1/1993	17.34	17.38	17.50	16.14
7/1993	16.79	16.84	17.09	15.65
1/1994	14.14	14.24	14.33	14.51
7/1994	17.54	17.41	17.50	17.47
1/1995	16.58	16.65	16.68	16.70
7/1995	15.83	15.91	15.99	15.92
1/1996	17.97	18.26	18.27	18.40
7/1996	19.58	19.89	19.95	19.89
1/1997	23.41	23.81	23.65	23.83
7/1997	18.51	18.90	18.76	18.74

[a]n.a. = not available.
Source: *Oil & Gas Journal.*

Table 6
MONTHLY CRUDE OIL PRICE BY PRODUCTION AREA: THE MEDITERRANEAN, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/Year	Algeria		Libya	Egypt	Russia
	Saharan Blend	Zarzaitine	Brega	Suez Blend	Urals
1/1989	17.49	17.44	17.16	14.56	16.10
7/1989	17.94	17.89	17.63	15.33	16.90
1/1990	21.68	21.63	21.32	18.83	20.28
7/1990	16.85	16.75	16.60	13.53	15.26
1/1991	25.00	24.75	24.56	20.67	23.04
7/1991	20.07	19.85	19.47	16.05	18.14
1/1992	19.30	19.04	18.51	15.11	17.09
7/1992	20.69	20.39	20.29	17.38	18.91
1/1993	17.76	17.63	17.45	14.04	15.53
7/1993	17.24	17.18	16.89	13.43	15.13
1/1994	14.88	14.75	14.20	11.71	13.54
7/1994	17.64	17.49	17.54	15.55	16.44
1/1995	16.99	16.86	16.78	15.48	16.74
7/1995	16.11	16.11	15.93	13.91	14.83
1/1996	18.66	18.63	18.32	16.49	18.12
7/1996	20.10	20.05	19.87	17.37	18.55
1/1997	24.18	24.13	23.81	21.11	22.55
7/1997	19.01	18.95	18.75	16.42	17.83

Source: *Oil & Gas Journal.*

Table 7
MONTHLY CRUDE OIL PRICE BY PRODUCTION AREA: THE MIDDLE EAST, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/ Year	Saudi Arabia			Iran		Qatar Dukhan	OPEC[a] Reference Basket	United Arab Emirates		Oman
	Heavy	Light	Medium	Heavy	Light			Dubai	Murban	
1/1989	13.36	14.61	13.51	13.88	14.38	14.80	15.90	14.30	15.21	14.70
7/1989	14.63	16.03	15.19	15.48	15.89	15.75	17.27	15.45	16.28	15.86
1/1990	17.27	18.32	17.24	17.35	18.05	18.08	19.98	17.39	18.76	17.81
7/1990	13.03	14.81	13.46	13.78	14.53	15.79	15.68	14.95	16.13	15.40
1/1991	16.70	20.70	18.70	19.45	20.20	20.90	22.32	19.65	21.20	20.20
7/1991	13.88	17.02	15.44	15.77	16.82	17.45	18.20	16.22	18.06	16.77
1/1992	12.75	15.95	14.25	14.86	15.86	16.66	16.69	15.26	17.31	15.81
7/1992	16.65	19.25	17.80	18.05	19.05	19.84	19.74	18.50	20.00	19.00
1/1993	13.52	15.92	14.52	14.56	15.74	16.40	16.71	15.20	17.20	15.75
7/1993	12.32	15.12	13.52	13.13	15.16	15.96	15.96	14.18	16.66	15.46
1/1994	11.18	13.63	12.23	12.25	13.09	14.14	13.71	13.18	14.78	13.39
7/1994	15.67	17.07	16.27	16.52	16.56	17.33	17.43	16.40	17.65	16.73
1/1995	15.24	16.76	15.85	15.97	16.33	17.06	16.67	16.03	17.43	16.48
7/1995	14.77	15.67	15.12	15.32	14.89	15.40	15.63	15.03	15.85	15.30
1/1996	16.24	17.39	16.59	16.68	16.92	17.33	18.05	16.59	18.00	16.99
7/1996	16.96	18.66	17.56	17.48	18.32	18.66	19.29	17.76	19.50	18.44
1/1997	20.68	22.58	21.53	21.32	22.26	22.86	23.19	21.34	23.51	22.18
7/1997	16.22	17.85	17.03	17.25	17.25	17.83	17.86	17.38	18.53	17.52

[a]Organization of the Petroleum Exporting Countries.
Source: *Oil & Gas Journal.*

Table 8

MONTHLY CRUDE OIL PRICE: LESS THAN 0.3-PERCENT SULFUR CONTENT, JANUARY 1989-JULY 1997

(in U.S. dollars per barrel)

Month/	Algeria		China	Indonesia		Libya
Year	Saharan Blend	Zarzaitine	Daqing	Attaka	Minas	Brega
1/1989	17.49	17.44	16.73	17.81	17.01	17.16
7/1989	17.94	17.89	17.84	18.49	18.09	17.63
1/1990	21.68	21.63	20.09	20.45	20.44	21.32
7/1990	16.85	16.75	15.74	15.66	16.03	16.60
1/1991	25.00	24.75	23.52	24.57	23.96	24.56
7/1991	20.07	19.85	18.53	19.92	19.07	19.47
1/1992	19.30	19.04	17.89	19.66	18.08	18.51
7/1992	20.69	20.39	20.99	22.55	21.24	20.29
1/1993	17.76	17.63	18.35	18.80	18.48	17.45
7/1993	17.24	17.18	17.51	17.88	17.64	16.89
1/1994	14.88	14.75	13.75	15.46	14.58	14.20
7/1994	17.64	17.49	17.69	18.43	19.25	17.54
1/1995	16.99	16.86	17.34	17.91	17.55	16.78
7/1995	16.11	16.11	16.08	16.45	16.04	15.93
1/1996	18.66	18.63	20.25	20.27	20.26	18.32
7/1996	20.10	20.05	20.16	20.45	20.11	19.87
1/1997	24.18	24.13	24.86	25.68	25.04	23.81
7/1997	19.01	18.95	18.12	18.58	18.04	18.75

Month/	Malaysia		Nigeria		Norway		United States
Year	Miri	Tapis	Bonny Light	Forcados	Ekofisk	Oseberg	West Texas Intermediate
1/1989	17.70	17.94	17.35	17.21	17.18	n.a.[a]	17.95
7/1989	18.21	18.49	18.14	17.29	17.85	17.10	19.99
1/1990	20.52	20.77	21.64	21.83	21.39	20.56	22.75
7/1990	16.88	17.17	17.25	16.69	17.06	15.53	18.28
1/1991	24.57	24.99	24.55	24.13	24.01	23.15	25.29
7/1991	19.98	20.28	19.81	19.25	19.76	18.58	21.34
1/1992	19.87	20.17	18.60	18.28	18.58	17.44	18.79
7/1992	22.61	22.90	20.94	20.75	20.40	19.33	21.74
1/1993	18.67	18.99	17.80	17.45	17.50	16.14	19.03
7/1993	18.60	18.80	17.51	17.29	17.09	15.65	17.85
1/1994	16.03	16.22	14.74	14.69	14.33	14.51	15.01
7/1994	18.64	18.72	17.85	18.00	17.50	17.47	19.61
1/1995	18.31	18.32	16.92	16.85	16.68	16.70	18.04
7/1995	17.15	17.24	15.95	15.93	15.99	15.92	17.30
1/1996	20.52	20.61	18.55	18.55	18.27	18.40	18.85
7/1996	20.70	20.69	20.04	19.83	19.95	19.89	21.30
1/1997	25.78	25.86	24.04	24.16	23.65	23.83	25.15
7/1997	19.17	19.05	18.95	18.77	18.76	18.74	19.65

[a]n.a. = not available.

Source: *Oil & Gas Journal.*

Table 9
MONTHLY CRUDE OIL PRICE: 0.3- TO 1.0-PERCENT SULFUR CONTENT, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/Year	Colombia Cano Limon	United Kingdom Brent	United Kingdom Forties	Oman
1/1989	17.24	17.10	16.99	14.70
7/1989	17.98	17.71	17.65	15.86
1/1990	21.00	21.28	21.18	17.81
7/1990	15.88	16.88	16.76	15.40
1/1991	23.03	23.99	24.03	20.20
7/1991	18.64	19.38	19.35	16.77
1/1992	16.65	18.18	18.41	15.81
7/1992	19.75	20.24	20.29	19.00
1/1993	16.50	17.34	17.38	15.75
7/1993	15.93	16.79	16.84	15.46
1/1994	13.69	14.14	14.24	13.39
7/1994	17.71	17.54	17.41	16.73
1/1995	17.44	16.58	16.65	16.48
7/1995	16.28	15.83	15.91	15.30
1/1996	18.50	17.97	18.26	16.99
7/1996	20.32	19.58	19.89	18.44
1/1997	24.63	23.41	23.81	22.18
7/1997	18.23	18.51	18.90	17.52

Source: *Oil & Gas Journal.*

Table 10
MONTHLY CRUDE OIL PRICE: 1.0- TO 1.5-PERCENT SULFUR CONTENT, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/ Year	Ecuador Oriente	Gabon Mandji	Mexico Isthmus	Qatar Dukhan	United States Alaska North Slope	Venezuela Tia Juana Light
1/1989	16.41	15.35	15.57	14.80	16.08	14.95
7/1989	17.49	15.84	18.01	15.75	17.44	17.22
1/1990	20.59	19.45	20.29	18.08	20.26	20.06
7/1990	15.59	13.81	15.46	15.79	15.65	14.41
1/1991	22.98	20.44	21.85	20.90	21.69	20.51
7/1991	18.15	15.87	18.48	17.45	18.30	16.69
1/1992	15.79	15.03	15.56	16.66	15.70	14.10
7/1992	19.65	17.89	19.43	19.84	19.65	18.14
1/1993	16.56	14.58	16.47	16.40	16.55	15.35
7/1993	15.24	14.59	15.48	15.96	15.86	14.56
1/1994	13.08	12.32	12.87	14.14	13.21	12.07
7/1994	16.88	15.73	17.32	17.33	17.40	16.48
1/1995	16.64	15.36	16.38	17.06	16.88	16.06
7/1995	15.96	14.20	15.65	15.40	16.25	14.95
1/1996	17.36	16.69	17.59	17.33	17.62	17.33
7/1996	19.45	17.89	19.61	18.66	19.72	18.77
1/1997	22.36	21.71	23.21	22.86	23.60	21.91
7/1997	16.54	15.92	17.28	17.83	17.48	16.49

Source: *Oil & Gas Journal.*

Table 11
MONTHLY CRUDE OIL PRICE: 1.5- TO 2.0-PERCENT SULFUR CONTENT, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/Year	Egypt Suez Blend	Iran		Saudi Arabia Light
		Heavy	Light	
1/1989	14.56	13.88	14.38	14.61
7/1989	15.33	15.48	15.89	16.03
1/1990	18.83	17.35	18.05	18.32
7/1990	13.53	13.78	14.53	14.81
1/1991	20.67	19.45	20.20	20.70
7/1991	16.05	15.77	16.82	17.02
1/1992	15.11	14.86	15.86	15.95
7/1992	17.38	18.05	19.05	19.25
1/1993	14.04	14.56	15.74	15.92
7/1993	13.43	13.13	15.16	15.12
1/1994	11.71	12.25	13.09	13.63
7/1994	15.55	16.52	16.56	17.07
1/1995	15.48	15.97	16.33	16.76
7/1995	13.91	15.32	14.89	15.67
1/1996	16.49	16.68	16.92	17.39
7/1996	17.37	17.48	18.32	18.66
1/1997	21.11	21.32	22.26	22.58
7/1997	16.42	17.25	17.25	17.85

Source: *Oil & Gas Journal.*

Table 12
MONTHLY CRUDE OIL PRICE: GREATER THAN 2.0-PERCENT SULFUR CONTENT, JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/Year	Kuwait Export	Mexico Maya	Saudi Arabia Heavy
January 1989	13.55	12.13	13.36
July 1989	15.13	15.65	14.63
January 1990	17.27	16.28	17.27
July 1990	11.98	11.47	13.03
January 1991	n.a.[a]	17.40	16.70
July 1991	n.a.[a]	13.36	13.88
January 1992	n.a.[a]	9.78	12.75
July 1992	18.17	15.45	16.65
January 1993	14.59	12.31	13.52
July 1993	14.67	11.53	12.32
January 1994	11.88	10.16	11.18
July 1994	15.12	14.76	15.67
January 1995	15.71	13.96	15.24
July 1995	15.74	13.43	14.77
January 1996	16.51	14.74	16.24
July 1996	17.08	16.09	16.96
January 1997	21.37	18.55	20.68
July 1997	16.95	14.40	16.22

[a]n.a.=not available. This was the period of Iraq's invasion of Kuwait and the subsequent Gulf War.

Source: *Oil & Gas Journal.*

Table 13
MONTHLY CRUDE OIL PRICE: 20-25 DEGREE API,[a] JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/Year	Mexico Maya	Venezuela Tia Juana Medium
1/1989	12.13	13.16
7/1989	15.65	17.00
1/1990	16.28	17.09
7/1990	11.47	12.88
1/1991	17.40	20.17
7/1991	13.36	15.84
1/1992	9.78	13.20
7/1992	15.45	17.95
1/1993	12.31	14.17
7/1993	11.53	13.70
1/1994	10.16	11.55
7/1994	14.76	15.88
1/1995	13.96	15.31
7/1995	13.43	15.15
1/1996	14.74	17.01
7/1996	16.09	18.79
1/1997	18.55	20.76
7/1997	14.40	n.a.[b]

[a]American Petroleum Institute.
[b]n.a. = not available.
Source: *Oil & Gas Journal.*

Table 14
MONTHLY CRUDE OIL PRICE: 25-30 DEGREE API,[a] JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/Year	Ecuador Oriente	Gabon Mandji	Nigeria Forcados	Saudi Arabia Heavy	United States Alaska North Slope
1/1989	16.41	15.35	17.21	13.36	16.08
7/1989	17.49	15.84	17.29	14.63	17.44
1/1990	20.59	19.45	21.83	17.27	20.26
7/1990	15.59	13.81	16.69	13.03	15.65
1/1991	22.98	20.44	24.13	16.70	21.69
7/1991	18.15	15.87	19.25	13.88	18.30
1/1992	15.79	15.03	18.28	12.75	15.70
7/1992	19.65	17.89	20.75	16.65	19.65
1/1993	16.56	14.58	17.45	13.52	16.55
7/1993	15.24	14.59	17.29	12.32	15.86
7/1994	16.88	15.73	18.00	15.67	17.40
1/1995	16.64	15.36	16.85	15.24	16.88
7/1995	15.96	14.20	15.93	14.77	16.25
1/1996	17.36	16.69	18.55	16.24	17.62
7/1996	19.45	17.89	19.83	16.96	19.72
1/1997	22.36	21.71	24.16	20.68	23.60
7/1997	16.54	15.92	18.77	16.22	17.48

[a]American Petroleum Institute.
Source: *Oil & Gas Journal.*

Table 15
MONTHLY CRUDE OIL PRICE: 30-35 DEGREE API,[a] JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/ Year	China Daqing	Colombia Cano Limon	Egypt Suez Blend	Indonesia Minas	Iran		Mexico Isthmus	Saudi Arabia		UAE[b] Dubai Fateh	Venezuela Tia Juana Light
					Heavy	Light		Light	Medium		
1/1989	16.73	17.24	14.56	17.01	13.88	14.38	15.57	14.61	13.51	14.30	14.95
7/1989	17.84	17.98	15.33	18.09	15.48	15.89	18.01	16.03	15.19	15.45	17.22
1/1990	20.09	21.00	18.83	20.44	17.35	18.05	20.29	18.32	17.24	17.39	20.06
7/1990	15.74	15.88	13.53	16.03	13.78	14.53	15.46	14.81	13.46	14.95	14.41
1/1991	23.52	23.03	20.67	23.96	19.45	20.20	21.85	20.70	18.70	19.65	20.51
7/1991	18.53	18.64	16.05	19.07	15.77	16.82	18.48	17.02	15.44	16.22	16.69
1/1992	17.89	16.65	15.11	18.08	14.86	15.86	15.56	15.95	14.25	15.26	14.10
7/1992	20.99	19.75	17.38	21.24	18.05	19.05	19.43	19.25	17.80	18.50	18.14
1/1993	18.35	16.50	14.04	18.48	14.56	15.74	16.47	15.92	14.52	15.20	15.35
7/1993	17.51	15.93	13.43	17.64	13.13	15.16	15.48	15.12	13.52	14.18	14.56
1/1994	13.75	13.69	11.71	14.58	12.25	13.09	12.87	13.63	12.23	13.18	12.07
7/1994	17.69	17.71	15.55	19.25	16.52	16.56	17.32	17.07	16.27	16.40	16.48
1/1995	17.34	17.44	15.48	17.55	15.97	16.33	16.38	16.76	15.85	16.03	16.06
7/1995	16.08	16.28	13.91	16.04	15.32	14.89	15.65	15.67	15.12	15.03	14.95
1/1996	20.25	18.50	16.49	20.26	16.68	16.92	17.59	17.39	16.59	16.59	17.33
7/1996	20.16	20.32	17.37	20.11	17.48	18.32	19.61	18.66	17.56	17.76	18.77
1/1997	24.86	24.63	21.11	25.04	21.32	22.26	23.21	22.58	21.53	21.34	21.91
7/1997	18.12	18.23	16.42	18.04	17.25	17.25	17.28	17.85	17.03	17.38	16.49

[a]American Petroleum Institute.
[b]UAE=United Arab Emirates.
Source: *Oil & Gas Journal.*

category, and the price differentials among different crude are usually much smaller in every category. It implies that the sulfur content should be a major factor in determining the crude oil price.

Tables 13-17 show the monthly price trend of those crude oils classified by five API gravity (grades): 20°-25° API, 25°-30° API, 30°-35° API, 35°-40° API, and 40°-45° API. By this measure we find again that all crude oil prices vary consistently in each API level, while the price differentials among different crudes are large in almost all categories. This phenomenon implies that there are other, more influential factors for the crude oil price.

Thus, the data in tables 2-17 indicate that all the variables of production area, sulfur content, and API gravity should be quite important in explaining the value of a crude oil. In fact, the price of a crude oil involves many characteristics or factors. The value of a crude oil must truly reflect its contributions (or costs) of all characteristics. In other words, any model can link sufficiently the value of a product and the product characteristics should be suitable to finding the crude oil price. Based on this illustration, the hedonic model is selected as our analysis framework to seek the value of the crude.

Table 16
MONTHLY CRUDE OIL PRICE: 35-40 DEGREE API,[a] JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/ Year	Algeria Zar-zaitine	Malaysia Miri	Nigeria Bonny Light	Oman	Norway Oseberg	United Arab Emirates Murban	United Kingdom Brent	United Kingdom Forties	Russia Urals
1/1989	17.44	17.70	17.35	14.70	NA	15.21	17.10	16.99	16.10
7/1989	17.89	18.21	18.14	15.86	17.10	16.28	17.71	17.65	16.90
1/1990	21.63	20.52	21.64	17.81	20.56	18.76	21.28	21.18	20.28
7/1990	16.75	16.88	17.25	15.40	15.53	16.13	16.88	16.76	15.26
1/1991	24.75	24.57	24.55	20.20	23.15	21.20	23.99	24.03	23.04
7/1991	19.85	19.98	19.81	16.77	18.58	18.06	19.38	19.35	18.14
1/1992	19.04	19.87	18.60	15.81	17.44	17.31	18.18	18.41	17.09
7/1992	20.39	22.61	20.94	19.00	19.33	20.00	20.24	20.29	18.91
1/1993	17.63	18.67	17.80	15.75	16.14	17.20	17.34	17.38	15.53
7/1993	17.18	18.60	17.51	15.46	15.65	16.66	16.79	16.84	15.13
1/1994	14.75	16.03	14.74	13.39	14.51	14.78	14.14	14.24	13.54
7/1994	17.49	18.64	17.85	16.73	17.47	17.65	17.54	17.41	16.44
1/1995	16.86	18.31	16.92	16.48	16.70	17.43	16.58	16.65	16.74
7/1995	16.11	17.15	15.95	15.30	15.92	15.85	15.83	15.91	14.83
1/1996	18.63	20.52	18.55	16.99	18.40	18.00	17.97	18.26	18.12
7/1996	20.05	20.70	20.04	18.44	19.89	19.50	19.58	19.89	18.55
1/1997	24.13	25.78	24.04	22.18	23.83	23.51	23.41	23.81	22.55
7/1997	18.95	19.17	18.95	17.52	18.74	18.53	18.51	18.90	17.83

[a]American Petroleum Institute.
Source: *Oil & Gas Journal.*

Application of the Hedonic Model

The hedonic model has been applied to many kinds of products such as the price of cars, houses, and agriculture products.[7] However, the complete model was not addressed until S. Rosen in 1974.[8] K. Leffler and C. Hegji improved the hedonic model in their two respective articles, which emphasized the endogenous characteristics of both price and quality.[9] Nevertheless, such revisions were not suitable for our analysis since higher crude oil prices do not enhance crude quality for its naturally created property. The quality of crude is generally decided by the geological conditions, not the human production process.[10] As a consequence, it is more suitable to apply the original hedonic model.

According to the hedonic model, the crude oil price is explained by its quality as the following equation:

$$P_i = \alpha + \beta_j X_{ij} + \varepsilon_i, \quad (1)$$

where

P_i = the oil price of crude i;

X_{ij} = j characteristics of crude i (e.g., sulfur content, API gravity, and production area);

Table 17
MONTHLY CRUDE OIL PRICE: 40-45 DEGREE API,[a] JANUARY 1989-JULY 1997
(in U.S. dollars per barrel)

Month/Year	Algeria Saharan Blend	Indonesia Attaka	Libya Brega	Malaysia Tapis	Norway Ekofisk	Qatar Dukhan	United States West Texas Inter-mediate
1/1989	17.49	17.81	17.16	17.94	17.18	14.80	17.95
7/1989	17.94	18.49	17.63	18.49	17.85	15.75	19.99
1/1990	21.68	20.45	21.32	20.77	21.39	18.08	22.75
7/1990	16.85	15.66	16.60	17.17	17.06	15.79	18.28
1/1991	25.00	24.57	24.56	24.99	24.01	20.90	25.29
7/1991	20.07	19.92	19.47	20.28	19.76	17.45	21.34
1/1992	19.30	19.66	18.51	20.17	18.58	16.66	18.79
7/1992	20.69	22.55	20.29	22.90	20.40	19.84	21.74
1/1993	17.76	18.80	17.45	18.99	17.50	16.40	19.03
7/1993	17.24	17.88	16.89	18.80	17.09	15.96	17.85
1/1994	14.88	15.46	14.20	16.22	14.33	14.14	15.01
7/1994	17.64	18.43	17.54	18.72	17.50	17.33	19.61
1/1995	16.99	17.91	16.78	18.32	16.68	17.06	18.04
7/1995	16.11	16.45	15.93	17.24	15.99	15.40	17.30
1/1996	18.66	20.27	18.32	20.61	18.27	17.33	18.85
7/1996	20.10	20.45	19.87	20.69	19.95	18.66	21.30
1/1997	24.18	25.68	23.81	25.86	23.65	22.86	25.15
7/1997	19.01	18.58	18.75	19.05	18.76	17.83	19.65

[a]American Petroleum Institute.
Source: *Oil & Gas Journal.*

α, β_j = constant, coefficients of independent variable j; and
ε_i = error term.

Data Selection and Econometric Model

Equation (1) only describes the relationship of crude oil price and its quality. In order to derive a better empirical result, all possible data problems and a suitable econometric model form should be well specified. Three main concerns on the data problems, illustrated below, are related to the data shortage, data representation, and consistency. The consideration of a better econometric model will be explained as well.

Concerning the data shortage problem, this research uses pooling data rather than the cross-section data although the latter are used more frequently in the hedonic model analyses. Only 48 spot oil prices are selected to be our samples (table 1) because the *International Crude Oil Market Handbook* does not provide full price information although it contains more than 100 kinds of crude oil

quality data. While the regression results are generally poor for 48 samples, the time series and cross-section data are pooled to enlarge our sample size. Thus, our samples include those monthly average spot prices of 48 crude oils from January 1995 to September 1996 provided by the *International Crude Oil Market Handbook*. The total sample size in our econometric analysis is 978.[11]

The sample period from January 1995 to September 1996 is chosen not only for data availability but also for two more considerations.[12] Data representation is considered first since the crude oil price is relatively stable in this period. Data consistency among all variables is another concern. Although the quality of most crude oils are quite stable over time, the quality of blended crude from more than one oil field will change due to the changing production volume of different oil fields. In other words, those spot prices in the earlier period may not correspond to the quality data in the observation period. Since the quality data of crude are collected around 1995-1996, the spot price should be considered also only for this period.[13] For this reason also, we gave up the abundant spot prices provides by *Oil & Gas Journal* in the earlier years.

To pursue a better regression model, this paper chooses the Box-Cox transformation method to derive our empirical results. By changing the model parameter, we can find the best model form for our data set.

The Estimated Crude-Oil Price Formula

Assuming that the world oil market is generally transparent, the spot prices of all kinds of crude oils do reflect their characteristics of product quality and market condition. Those oils should be more expensive if they have better quality, such as a lower sulfur content and higher API value. And the oil price should be higher if more oil is needed in an area or region. Although the world oil market is not transparent yet, the popular arbitrage of crude oil brings a more transparent market than we had expected. Consequently, those spot prices can be estimated by applying the hedonic model. And the price formulas between producers and consumers then can be derived.

According to the hedonic model, the price of a product can be explained by its characteristics. Thus, those property variables such as the gravity, sulfur content, production volume, and production areas are selected as the explanatory variables. Moreover, 20 time-related dummy variables are used to control the time variance for our pooling data. Two variables (Europe and January of 1996) are selected as the reference case in those five dummy area variables and those time-related dummy variables. All the dependent and independent variables are explained in table 18.

The Box-Cox transformation results are listed in table 19. In order to pursue the best model, λ is estimated to be –0.50 by maximizing the log likelihood function, which is shown in table 19. It should be noted that the coefficients listed in table 19

Table 18

THE DESCRIPTION AND CHARACTERISTICS OF ALL VARIABLES

Variable	Description	Mean	Standard Deviation
PRICE	Monthly average crude-oil spot price for crudes listed in table 1	18.03	1.85
API	American Petroleum Institute gravity of each crude	36.57	7.16
SULFUR	Sulfur content of each crude	0.73	0.79
VOLUME	Production volume (1,000 barrels/day) of each crude	601.34	826.83
POURPOINT	Absolute temperature (Centigrade) of each crude at pour point	268.26	15.71
RESID	Percent of residue volume of each crude	38.09	14.19
Dummy variables			
DMIDEAST[a]	=1 if oil produced in the Middle East; =0 otherwise	0.29	0.45
DAFRICA[a]	=1 if oil produced in Africa; =0 otherwise	0.12	0.33
DMEDITER-RANEAN[a]	=1 if oil produced in the Mediterranean; =0 otherwise	0.22	0.41
DASIA[a]	=1 if oil produced in Asia; =0 otherwise	0.14	0.35
DAMERICAS[a]	=1 if oil produced in the Western Hemisphere; =0 otherwise	0.10	0.30
Time-related dummy variables			
D95JAN[b]	=1 if price occurs in Jan. 1995; =0 otherwise	0.037	0.19
D95FEB[b]	=1 if price occurs in Feb. 1995; =0 otherwise	0.037	0.19
D95MARCH[b]	=1 if price occurs in March 1995; =0 otherwise	0.049	0.21
D95APRIL[b]	=1 if price occurs in April 1995; =0 otherwise	0.049	0.21
D95MAY[b]	=1 if price occurs in May 1995; =0 otherwise	0.049	0.21
D95JUNE[b]	=1 if price occurs in June 1995; =0 otherwise	0.049	0.21
D95JULY[b]	=1 if price occurs in July 1995; =0 otherwise	0.049	0.21
D95AUG[b]	=1 if price occurs in Aug. 1995; =0 otherwise	0.049	0.21
D95SEPT[b]	=1 if price occurs in Sept. 1995; =0 otherwise	0.049	0.21
D95OCT[b]	=1 if price occurs in Oct. 1995; =0 otherwise	0.049	0.21
D95NOV[b]	=1 if price occurs in Nov. 1995; =0 otherwise	0.049	0.21
D95DEC[b]	=1 if price occurs in Dec. 1995; =0 otherwise	0.049	0.21
D96FEB[b]	=1 if price occurs in Feb. 1996; =0 otherwise	0.049	0.21
D96MARCH[b]	=1 if price occurs in March 1996; =0 otherwise	0.049	0.21
D96APRIL[b]	=1 if price occurs in April 1996; =0 otherwise	0.049	0.21
D96MAY[b]	=1 if price occurs in May 1996; =0 otherwise	0.049	0.21
D96JUNE[b]	=1 if price occurs in June 1996; =0 otherwise	0.047	0.21
D96JULY[b]	=1 if price occurs in July 1996; =0 otherwise	0.047	0.21
D96AUG[b]	=1 if price occurs in Aug. 1996; =0 otherwise	0.047	0.21
D96SEPT[b]	=1 if price occurs in Sept. 1996; =0 otherwise	0.047	0.21

[a]Europe is chosen to be the reference case in these five dummy area variables.
[b]January 1996 is chosen to be the reference case in these time-related dummy variables.

do not represent the marginal effect of each explanatory variable because of the nonlinear model's characteristics. However, the marginal effect can be calculated easily by utilizing the calculation programs provided by various available software.[14] The estimated crude oil price also can be calculated more easily.

In table 19, numbers in parentheses are the t values.[15] From these values, we can find that all the independent variables except pour point and three dummy variables are significant in explaining the crude oil price. As illustrated earlier, API gravity and sulfur content are both important in determining the price of crude oil. The crude oil price will be higher if the API is higher, while the price will be lower if the percentage of sulfur content is greater. Moreover, the much larger t value of sulfur content implies that sulfur content is very important in explaining the crude oil price. Production volume and percentage of residue oil form another important explanatory variable as well. A higher production volume and lower percentage of residue oil will raise the price of a crude oil as larger output volume would accumulate more bargaining power for producers to bid up the market price, while a lower percentage of residue oil implies more refinery value of a crude oil.

Concerning the explanatory power of the five production area dummy variables, crude oil prices in Africa and in the Mediterranean are significantly lower than the prices in the European area, while crude oil prices in the Western Hemisphere are significantly higher than those in the European region. These results reflect the strong crude oil demand in the Western Hemisphere, particularly the United States. Similarly, time-related dummy variables play an important role in determining the crude-oil market price. Except February 1995, all the time-related dummy variables are very significant in explaining the crude oil price. Such a result explicates the apparent price movement from time to time, reflecting the market imbalance.

In general, the explanatory total of our regression result is high ($\overline{R}^2$ are as high as .875). This outcome indicates that those estimated prices calculated from table 19 could generally represent the market price accepted by both producers and consumers. In short, the regression equation listed in table 19 could be used as a price formula for both producers and consumers. Plug the properties of a crude oil into the formula listed in table 19, and the estimated crude oil price can be derived.

Conclusions

In investigating the current price formulas in the world crude oil market, one finds that most formulas stick to some benchmark crude oil prices or some combination of those benchmark prices, such as the spot price of West Texas Intermediate, Brent, and Dubai. Although the selection of these benchmark prices do have some representative features, it is always hard to find an exact representative characteristic by combining the characteristics of these benchmark prices. This drawback is overcome in this paper. The hedonic model is successfully applied to link the

Table 19

BOX-COX REGRESSION RESULT

Independent Variable	Coefficient	(T Value)
Constant	1.517	(225.50)[a]
API	.0002	(2.51)[b]
SULFUR	-.009	(-16.11)[a]
VOLUME	.000001	(2.54)[a]
POURPOINT	.00002	(.93)
RESID	-.0001	(-3.64)[a]
DMIDEAST	-.0008	(-.70)
DAFRICA	-.002	(-2.34)[a]
DMEDITERRANEAN	-.002	(-1.95)[b]
DASIA	.0006	(0.56)
DAMERICAS	.012	(9.74)[a]
D95JAN	-.007	(-4.34)[a]
D95FEB	.0007	(0.40)
D95MARCH	.015	(9.35)[a]
D95APRIL	.013	(8.18)[a]
D95MAY	-.005	(-3.05)[a]
D95JUNE	-.021	(-12.90)[a]
D95JULY	-.017	(-10.29)[a]
D95AUG	-.013	(-7.72)[a]
D95SEPT	-.018	(-10.68)[a]
D95OCT	-.006	(-3.58)[a]
D95NOV	.007	(4.30)[a]
D95DEC	.009	(5.50)[a]
D96FEB	.009	(5.75)[a]
D96MARCH	.030	(17.76)[a]
D96APRIL	.037	(22.33)[a]
D96MAY	.023	(14.15)[a]
D96JUNE	.018	(10.57)[a]
D96JULY	.027	(15.89)[a]
D96AUG	.035	(20.93)[a]
D96SEPT	.054	(31.53)[a]
λ		-0.50
Adjusted R-squared		0.8785
Log of likelihood function		-922.309
N (sample size)		978

[a]Represents 1-percent significant level.
[b]Represents 5-percent significant level.

relationship of crude oil price and its quality. Then the oil price is further derived from a "best" econometric model selected by the Box-Cox method, which appears more acceptable for both producers and consumers compared to other formulas.

NOTES

[1]R. Mabro, "OPEC and the Price of Oil," *The Energy Journal*, April 1992, pp. 1-17.

[2]See P. Horsnell and R. Mabro, *Oil Markets and Prices: The Brent Market and the Formation of Word Oil Prices* (Oxford: Oxford University Press, 1993).

[3]R. Mabro, op. cit.

[4]See P. Horsnell and R. Mabro, op. cit., chapter 15.

[5]See T. Wallin and I. Joseph, *International Crude Oil Market Handbook*, 2d ed. (New York: PIW Publications and Washington, D.C.: The Oil Daily Company, 1997).

[6]*Pricing Statistics Sourcebook*, OGJ Energy Database (Tulsa, Oklahoma: PennWell Publishing Company, 1998). It should be noted that the crudes selected in subsequent tables in this analysis are a little different from those in table 1, which is used for regression analysis later. In order to guarantee data consistency, all the data applied in the regression are collected from T. Wallin and I. Joseph, op. cit.

[7]There is abundant literature related to the application of the hedonic model. See K. Cowling and J. Cubbin, "Hedonic Price Indexes for United Kingdom Cars," *Economic Journal*, September 1972, pp. 963-78. Recently, it was applied more to agricultural products such as the beef price investigated by D. Feuz, "A Market Signals in Value-Based Pricing Premiums and Discounts," *Journal of Agricultural and Resource Economics*, December 1999, pp. 327-41.

[8]S. Rosen, "Hedonic Prices and Implicit Markets," Journal of Political Economy, January-February 1974, pp. 34-55.

[9]K. Leffler, "Ambiguous Changes in Product Quality," *American Economic Review*, December 1982, pp. 956-67 and C. Hegji, "Cost-Based Decision Rules for Output, Quality, and Price," Journal of Economics and Finance, spring 1995, pp. 27-37.

[10]The quality of blend may be varied. See P. Horsnell and R. Mabro, op. cit., p. 19.

[11]Since there are some missing data mostly in January and February 1995, we are not able to collect all data for the whole period [i.e., 48×(12+9)=1,008)] but a somewhat smaller sample size of 978.

[12]T. Wallin and I. Joseph, *International Crude Oil Market Handbook* published in 1997 provides the spot prices of many crude oils from January 1993 to September 1996. However, some data in 1993 and 1994 are missing. To consider the equal sample weight of each crude oil as accurately as possible, we gave up the incomplete data set in 1993 and 1994.

[13]Strictly speaking, quality may be changed over as short a period as two years, which also would incur a little bias, but it can be ignored relative to other, much stronger impacts.

[14]For example, the Time Series Processor (TSP), version 4.5 (Palo Alto, California: TSP International, 1999) and SHAZAM, version 7.0 (New York: McGraw-Hill Book Company, 1993) are frequently used.

[15]Since most explanatory variables have very significant results and can be explained reasonably, it is believed that the problem of heteroskedasticity and autocorrelation is not apparent. Thus, no generalized least-square estimation is considered here for further estimation process. However, to combine these two effects into a nonlinear model offers the potential for further research.