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The International Oil Market:
An Application of the Three-Agent Model

Kamilah Williams[1]

International Economics Department
Research and Economic Programming Division
Bank of Jamaica

Abstract

This paper develops a model of the crude oil market with a view to improving the Bank of Jamaica's capacity to forecast spot prices over the short term, as well as to empirically evaluate the structure of the market. This is in a context of the recent jump in prices, the evolving structure of the market and the relative paucity of successful models in the literature for predicting spot prices. Using a modification of a model developed by Kawai (1983), we take the view that the interaction of three agents (the consumer, the producer and the speculator) is important in determining spot oil prices. When compared with a range of other models, the Three-Agent model provides the best fit for monthly data. The model also shows that both market fundamentals and speculative behaviour have significant influences on crude oil prices.

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[1] The views contained in this paper do not represent those of the Bank of Jamaica.

3.0 Introduction

Average crude oil prices have risen in recent times. Annual average prices, as measured by the West Texas Intermediate (WTI) measure, rose from US$19.25 per barrel in 2000 to US$66.09 per barrel in 2006, representing an increase of 40.5 per cent. This rate of increase was significantly above the annual average growth in prices between 1990 and 1999 of 3.1 per cent. The surge in prices was not anticipated by most traders, policy makers, investors and speculators. In the case of the Bank of Jamaica, the dynamics of the market put an upward bias on oil price forecasts and underpinned the need to develop internal models of the oil market to inform policy making and short-term forecasts.

Most research on the oil market has focused almost exclusively on either macroeconomic variables or financial variables as the determinants of oil prices. This paper takes a novel approach and models the microeconomic decision making processes of three agents in the market (producers, consumers and pure speculators), the view being that the interaction of these agents determines the spot price of crude oil. A modification of the three-agent model developed by Kawai (1983) has the high forecasting power for short-term crude oil prices, relative to other traditional models.

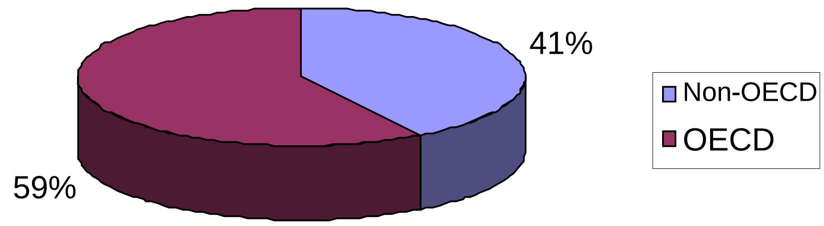
In what follows, section 2 presents the general structure of the global oil market. Section 3 examines recent research on crude oil spot price determination and examines the shortcomings of each model. Section 4 presents the model while sections 5 and 6 present the results and concludes, respectively.

2.1 Structure of the Oil Market

Petroleum, or crude oil, has been the world's most important source of energy since the mid-1950s and is, increasingly, the most traded commodity worldwide. The United States (US) is the largest user of oil, accounting for one quarter of global oil demand (see Table 1). The US was also the largest importer in 2006, buying 60 per cent of its oil, or 12.22 million barrels per day, from its trading partners. A relatively large proportion of world oil demand also comes from developing countries. In 2005, oil demand from non-OECD countries accounted for 41 per cent of total demand.

India and South Korea, which are classified as non-OECD countries, are ranked among the top ten world consumers of oil.

Figure 1
Distribution of World Oil Demand (2005)

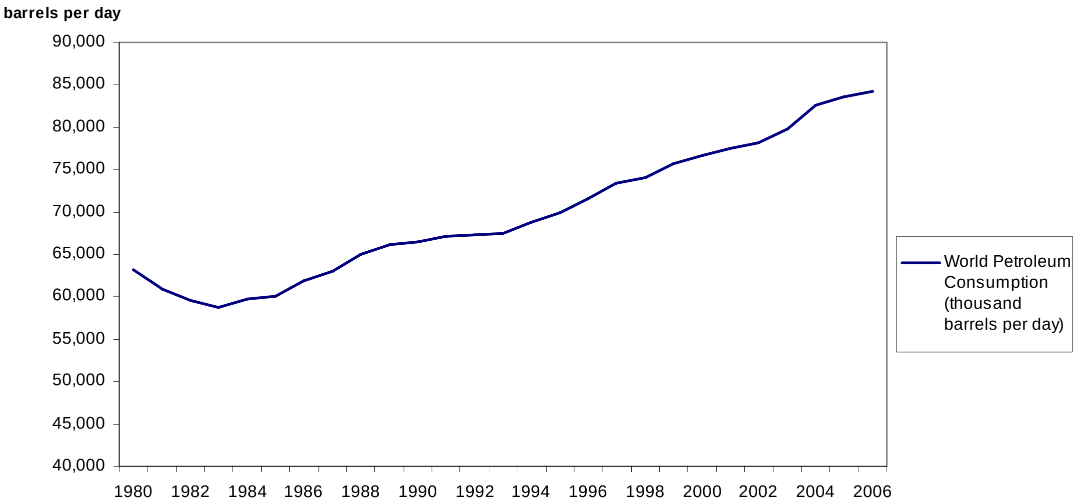


Source: International Energy Agency

Oil demand is dependent on broad macroeconomic conditions as well as seasonal influences. While demand is related to the level of global economic activity, the nature of this relationship has changed over time, particularly after the oil shocks of the 1970s and 1980s. These shocks led to the substitution of other forms of energy for oil usage. With regard to seasonal influences, demand for crude oil tends to be higher in the fourth quarter of each year, relative to the other quarters, because of cold weather as well as stock building. Demand tends to be lowest in the first quarter as warmer weather ensues.

Global oil demand has risen significantly over the past two decades. The International Energy Agency (IEA) estimates that between 1980 and 2006 world oil consumption rose by 33.4 per cent, from 63.1 million barrels to 84.2 million barrels per day. The majority of this increase came from the US, China and other emerging economies. Oil consumption in China rose by 34.0 per cent between 2002 and 2005 to 6.9 million barrels per day. This growth was related to the vigorous investment cycle in that country over the past decade and was exacerbated by an inadequate electricity distribution network.

Figure 2: World Consumption of Oil
1980-2004
(Millions of barrels per day)



Source: International Energy Agency

The Middle East is the largest oil-producing region. In particular, Saudi Arabia holds the majority of the world's proved reserves[2] (see Table 3). Non-OPEC oil producers are, however, playing an increasingly important role in global production. Although non-OPEC members have only 25.0 per cent of proved oil reserves, they produced 50.8 million barrels of crude oil per day in 2005, representing 68.0 per cent of world production (see Figure 4). The major non-OPEC countries include Canada, the United Kingdom, Mexico, Norway, China, the US and Russia.

In tandem with demand, global oil supply has also shown considerable growth. Between 1980 and 2006, world oil consumption rose by 33.4 per cent, from 64.1 million barrels to 84.2 million barrels per day. Between 1980 and 1995, oil production

[2] Proved reserves are oil and gas that are "reasonably certain" to be producible using current technology at current prices, with current commercial terms and government consent, also known in the industry as 1P. Industry specialists refer to this as P90, i.e., having a 90 per cent certainty of being produced.

was insufficient to meet demand. However, since 1995, excess supply averaged 346.7 million barrels per day (bpd).

Figure 3: World Supply of Oil
1980-2006
(millions of barrels per day)

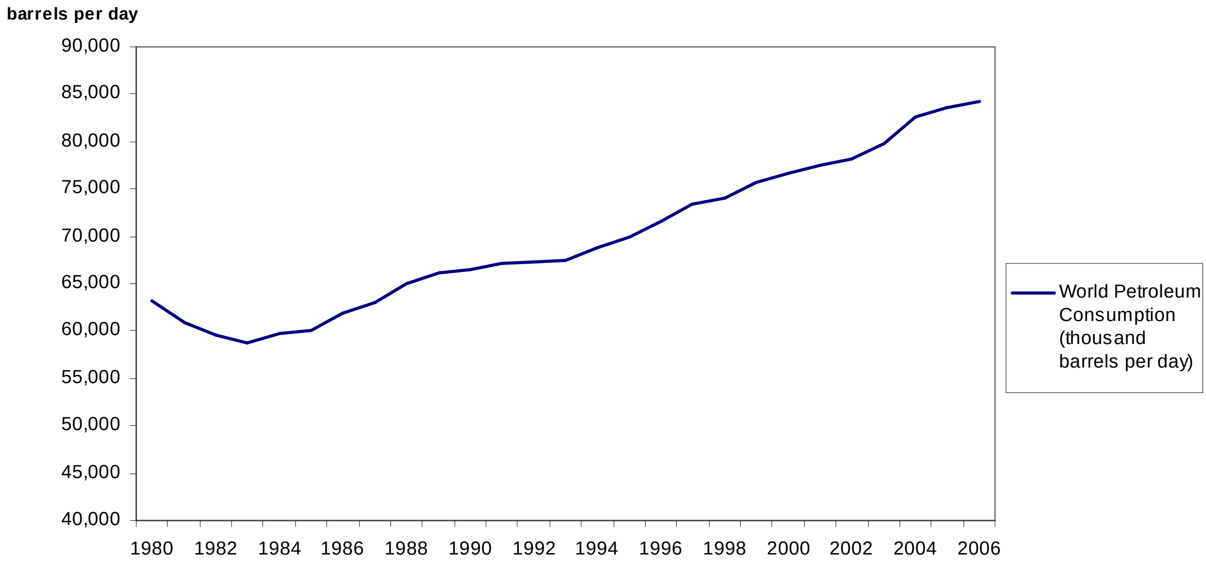
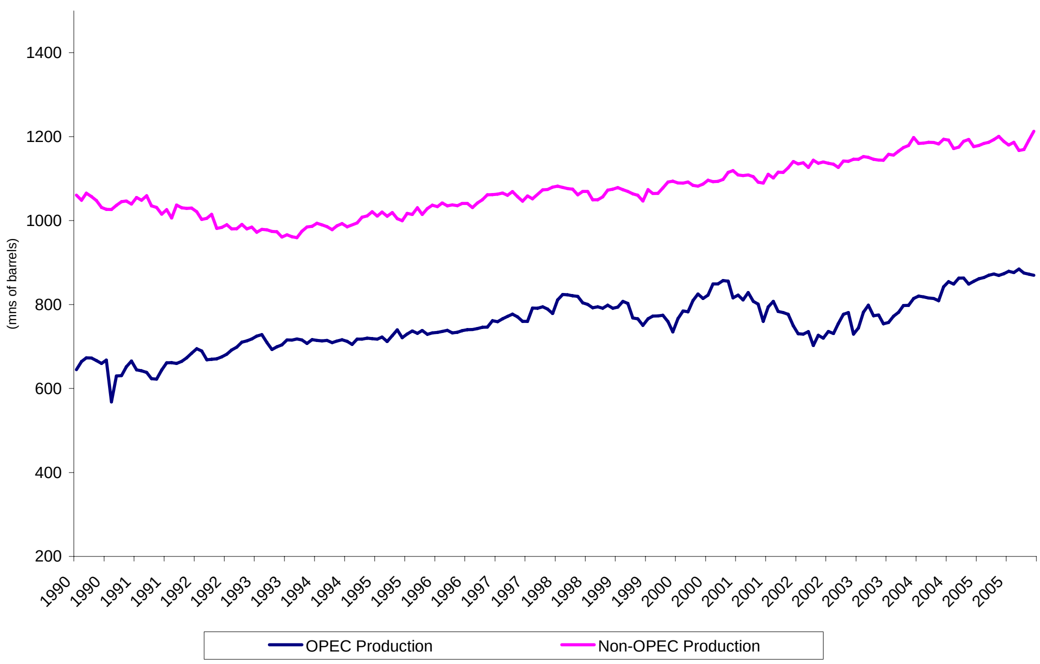


Figure 4: Total OPEC and Non-OPEC Production (1990-2005)



Source: Energy Information Administration

Crude oil is classified according to its grade and origin. The grade of oil is determined by its relative weight (API gravity[3]), sulphur content ('sweet' or 'sour') and viscosity ('light', 'intermediate' or 'heavy'). In terms of origin, oil is classified into "streams", which are then priced in relation to a 'benchmark' grade. One such benchmark oil stream is **Brent Crude,** which comes from the Brent and Ninian pipeline systems in the East Shetland Basin of the North Sea. Oil produced in Europe, Africa and the Middle East tends to be priced off this benchmark. The other benchmarks are **West Texas Intermediate** (WTI) for North American oil (a light, sweet crude); **Dubai,** a benchmark for Middle East oil flowing to the Asia-Pacific region; **Tapis** from Malaysia, used as a reference for light Far East oil; and **Minas**, from Indonesia, which is used as a reference for heavy Far East oil. There is also the OPEC basket which is a mix of light and heavy crude and is therefore heavier than both Brent and WTI[4].

2.2 The Futures Market

Crude oil is currently traded on spot, futures and over-the-counter (OTC) markets.[5] Up until the late 1970s, most of the world's crude oil was sold under long-term contracts at prices set by the major oil companies. In the late 1970s and early 1980s, as producing countries began to exercise greater control over their resources and the major oil companies were free to bid for crude oil wherever it was sourced, market-based spot trading gained in importance. This resulted in greater volatility in spot crude oil prices, which, in conjunction with the impact of high real interest rates in the 1980s on oil storage costs, encouraged the development of an oil futures market. WTI futures contracts began trading on the New York Mercantile Exchange (NYMEX) in 1983, contributing to an acceleration in investor interest in the market. This interest is

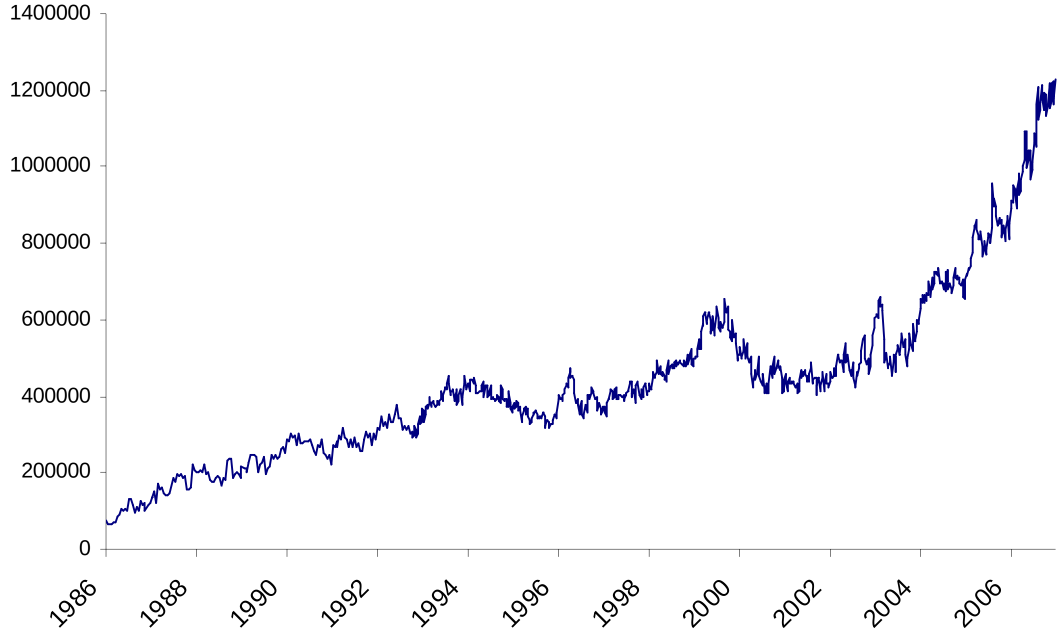
[3]API gravity is a specific gravity scale developed by the American Petroleum Institute (API) for measuring the relative density of various petroleum liquids. API gravity is graduated in degrees on a hydrometer instrument and most values would fall between 10 and 70 API gravity degrees. Light crude oil is defined as having an API gravity higher than 31.1 °API. Medium oil is defined as having an API gravity between 22.3 °API and 31.1 °API. Heavy oil is defined as having an API gravity below 22.3 °API.

[4] As of June 15 2005, the OPEC Basket Price is calculated as the average price of the Saharan Blend (Algeria), Minas (Indonesia), Iran Heavy (Islamic Republic of Iran), Basra Light (Iraq), Kuwait Export (Kuwait), Es Sider (Libya), Bonny Light (Nigeria), Qatar Marine (Qatar), Arab Light (Saudi Arabia), Murban (UAE) and BCF 17 (Venezuela).

[5] Over-the-counter (OTC) trading involves the trade of financial instruments, commodities or derivatives directly between two parties. This is usually due to an inability to meet listing requirements. For such securities, broker/dealers negotiate directly with one another over computer networks and by phone, and their activities are monitored by the National Association of Securities Dealers (NASD)

indicated by the trends in total open interest[6] in the oil futures market (see Figure 9). Activity in the futures market has exhibited particularly strong growth between 2002 and 2006 where total open interest increased at an annual average rate of 36.1 per cent, compared with a growth rate of 3.1 per cent during the 1996 to 2001.

Figure 9: Total Open Interest (1990-2005)



Source: Commodity Futures Trading Commission

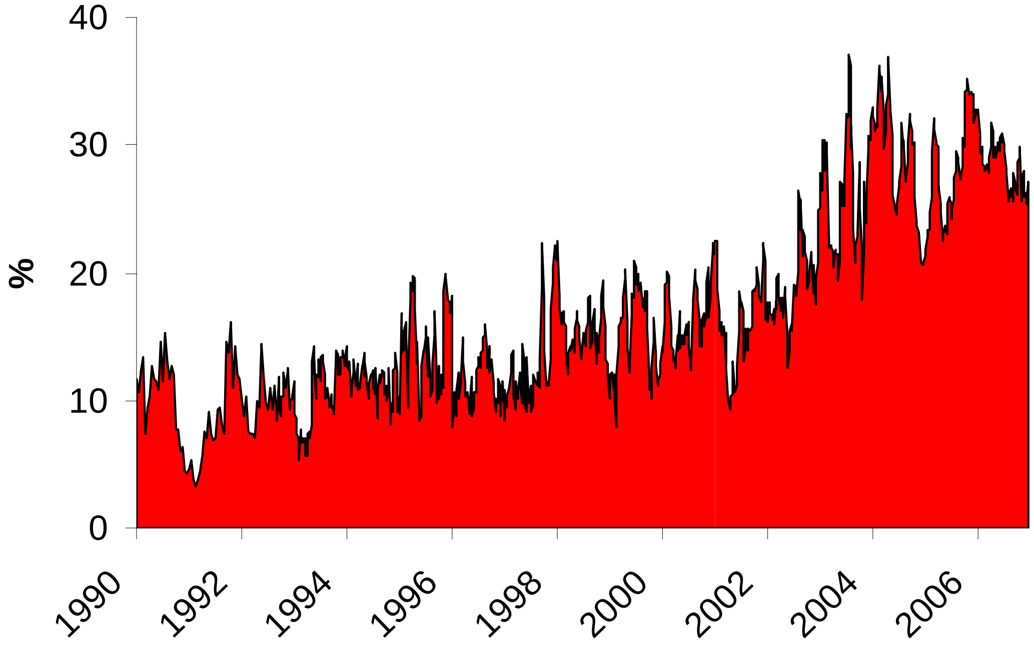
Several times the world's production of oil is traded daily in futures markets. The Commodity Futures Trading Commission (CFTC) reports that in 2006, an average 1.1 billion barrels of crude oil were traded daily on the NYMEX, while an estimated 73.3 million bpd was produced globally.

In the context of the growth and deepening of the oil market, speculative forces have emerged. Between 2001 and 2006 total non-commercial positions as a percentage of total open interest grew from 12.7 to 25.2 per cent. The profile of the speculator is, however, difficult to determine. Commercial investors are also taking part in speculation through swap arrangements with non-commercial investors.[7]

[6] Open interest refers to the amount of outstanding contracts on a specific underlying security. A contract is considered to be outstanding if it is has not expired, or been exercised or closed out.

[7] A trader's reported futures position is determined to be commercial if the trader uses futures contracts for the purposes of hedging as defined by Commodity Futures Trading Commission (CFTC) regulations. The group referred to as commercial traders, which traditionally consisted of oil producers

Figure 9: Total Non-Commercial Positions as a percentage of Total Open Interest



Source: Commodity Futures Trading Commission

and energy companies, is expanding with the entry of investment banks and hedge funds. The non commercial category includes participants who are not involved in the underlying cash business, and are thus referred to as speculators.

3.1 Literature Review

There are three schools of thought in relation to the determination of crude oil prices, but none have been entirely successful in predicting the path of oil prices. The first school examines the interaction of demand and supply in the determination of the spot price. Microeconomic theory states that if there is excess demand, prices will rise to restore equilibrium. Alternatively, if there is excess supply, prices will fall. The presence of excess supply or demand is evidenced in crude oil inventories. There has been much research on the relationship between inventory levels and primary commodity prices [Gustafson (1958); Thurman (1988); Pindyck (1993)]. Ye et al (2002) used projected inventory levels as a predictor of crude oil spot prices. The traditional relationship between spot prices and inventory levels, however, broke down after 2004.

The second school of thought posits that commodity markets are generally efficient and holds the view that futures prices have the power to forecast realized spot prices. The majority of the recent literature takes this view. A widely supported approach was that taken by Chinn, LeBlanc and Coibion (2001), who postulated that the best predictor of future spot prices is futures prices. While they found that futures prices are unbiased predictors of future spot prices, the prediction errors were large. Tabak (2003) also found similar results but found that the explanatory power of futures prices was low for changes in spot prices.

The third approach is that taken by Dees et al (2004), who used macroeconomic fundamentals such as GDP and interest rates to model fuel demand and supply and hence explained spot prices. A similar approach was taken by Krichene (2005) and Krichene (2007). Although the models captured supply and demand influences, significant forecast errors were evident in certain periods.

4.1 The Empirical Model

The inability of empirical models to accurately forecast shot-term crude oil price motivates our adaptation of the Kawai (1983) model. Our modified version attempts to incorporate the recent phenomenon of speculation and consequently assumes that three agents exist in the market: The consumer, the producer and the pure speculator.

The consumer (the refinery) is assumed to be a utility maximising agent who makes demand decisions on the spot market, and so is not exposed to price uncertainty. The demand function of this price-taking consumer is a declining function of price

$$C_t = a_0 + a_1 S_t + \varepsilon_t \qquad (1)$$

where C_t is the demand per time period t, S_t is the spot price in period t, a_1<0, a_1'>0 and ε_t ~N(0, σ^2).

The commodity producer is the agent who makes a decision in period t to produce output for period t+1 (Q_{t+1}). At time (t), S_{t+1} is unknown, but once the decision is made, the quantity is set. The price taking, risk-averse, producer maximises his expected utility of profit $E_t U(\prod_{t+1}^p)$ where $\prod_{t+1} = s_{t+1}Q_{t+1} - \rho G(Q_{t+1})$. E_t is the expectation operator conditional on information available at time t. U(.) is the strictly concave von Neumann-Morgenstern utility function; $\prod_{t+1}^p$ is profit at time t+1. Q_{t+1} is the quantity produced in the period t+1; G(.) is a strictly convex cost function which is fully known to the producer, $\rho = r+1$ and r are the market rate of interest. The production cost is discounted because capital is obtained at time t but profits are obtained at time t+1.

In order to obtain a linear form of the commodity production function, we assume the following quadratic cost function.

$$G(Q_{t+1}^p) = 1/2\, g(Q_{t+1}^p + \varepsilon_t) \qquad (2)$$

where (ε_t) is a disturbance term. We also assume that the utility function has the property of constant absolute risk aversion.

$$U^{p} = -\exp(-r^{p}\pi) \qquad (3)$$

where r^p us the Arrow-Pratt coefficient of absolute risk aversion. The maximization of expected utility is equivalent to the maximization of:

$$E_t\Pi^{p}_{t+`} - \frac{1}{2}r^{p}V_t\Pi^{p}_{t+1} \qquad (4)$$

where V_t is the conditional variance operator such that $V_t\Pi^{p}_{t+1}$ is defined as $E_t(\Pi^{p}_{t+1} - E_t\Pi^{p}_{t+1})$.

The optimum quantity of production can be obtained as:

$$Q^{P}_{t+1} = \frac{E_t s_{t+1} - \rho g}{\rho g + rV_t s_{t+1}} \qquad (5)$$

Equation (5) indicates that there is a positive relationship between supply and the expected one period ahead spot price. It also indicates an inverse relationship between the discount factor, the cost function coefficient g, the risk aversion coefficient and the spot price variance $V_t s_{t+1}$.

To incorporate the impact of futures trading, where the producer can enter into a forward contract to deliver (or receive delivery of) a specified quantity of the commodity in time t+1 at a known contract price, we re-specify $\Pi^{p}{}_{t+1}$ as follows:

$$\Pi^{P}_{t+1} = s_{t+1}Q^{P}_{t+1} - \rho G(Q^{P}_{t+1}) + R^{P}_{t}(s_{t+1} - f_t) \qquad (6)$$

where R_t is the quantity of futures contracts. If $R_t > 0$, the producer contracts to future purchases of the commodity. If $R_t < 0$, the contract is for futures sale and if $R_t = 0$, this implies no futures commitments. f_t is the period t futures contract for delivery at time t+1. Under these assumptions, optimal supply becomes

$$Q^{P}_{t+1} = {}^{1}\!\!/_{\rho g} \cdot f_t - \varepsilon^{p}_{t}, \qquad (7)$$

$$\text{and } R_t = -Q^{P}_{t+1} + Z^{P}_{t},\ Z^{P}_{t} = \frac{E_t s_{t+1} - f_t}{V_t s_{t+1}} \qquad (8)$$

Output is a function of the futures price at time t and a random disturbance term. The futures contract demand R_t is divided into two parts. The first term $-Q_{t+1}$ is the negative of the exact quantity that should be sold in a futures market if the producer wants to completely hedge price risk. This is referred to as the "hedging component". The second term represents the producer's subjective expectation about the period t+1's spot price and the corresponding futures price $E_t s_{t+1} - f_t$ represents the anticipated gain per unit of the commodity purchased in futures. This is referred to as the "speculation component". Overall supply is therefore completely separable from attitude to risk and consequently the decision of the producer to engage or not engage in futures trading.[8]

The presence of a futures market encourages activities by pure speculators[9] who take open positions in futures without having to commit themselves to the production, handling or processing of the commodity. If we assume that futures' trading is a costless operation (no transaction cost, no capital outlay), we can specify the objective of a risk-averse pure speculator as the maximization of:

$$E_t(\prod_{t+1}^{s}) \text{ where } \prod_{t+1}^{s} = Z_t(s_{t+1} - f_t) \qquad (9)$$

The speculator does not know the spot price at time t+1. It is therefore assumed that the level of speculation depends on the speculator's subjective expectations of the future spot price. Producers, consumers and pure speculators are assumed to have rational expectations in accordance with the findings of Muth (1961). In keeping with the view of Hart and Kreps (1986), we will assume that expectations of future spot prices are determined by news about future fundamentals. There is however asymmetry in information in the futures market, which means that $E_t s_{t+1} = \lambda s_t$.

[8] Although the Kawai model defines an inventories dealer who seeks to profit from holding inventories, the role of inventories in the crude oil market is slightly different. Most of the world's storage capacity is owned by the companies that produce, refine, or market the oil. Although there is a small contingent of independent inventory holders who seek to profit, this data is highly scattered and difficult to obtain. It is assumed that inventories serve simply to balance supply and demand.

[9] The term pure speculator is used because the agent is speculating without engaging in any real commitment in the market.

5.1 Determination of the spot price

The determination of the spot price of crude oil in the presence of a futures market that allows speculation is given by the interaction of the following behaviours.

$$C_t = \alpha_{11} - \alpha_{12} s_t + \alpha_{13} Y_t + \alpha_{14} DS_t + \beta_j \sum_{j=1}^{12} DUM_j + u_t \qquad \text{(Consumer Demand)}$$

$$Q_t = \alpha_{15} f_{t-1} + \alpha_{16} r_t + \alpha_{17} SS_t + v_{t-1} \qquad \text{(Production)}$$

$$Z_t = \alpha_{37} \frac{(E_t s_{t+1} - f_t)}{s_t - s_{t-1}} \qquad \text{(Futures Speculation)}$$

$$Z_{t-1} = C_t + I_t \qquad \text{(Spot Market Clearing)}$$

$$Q_{t+1} + I_t = Z_t \qquad \text{(Futures Market Clearing)}$$

The spot market clearing equation shows that since the amount purchased in time t-1 by futures speculators (pure and other speculators) appears in time t as a spot supply $Z_{t-1,}$ this amount must match the demand by consumers. This is because producers have committed themselves as hedgers in period t-1 to delivering crude oil in the next period, so the speculators are the only ones who hold spot commodities for sale. The futures market clearing condition shows that the total supply of futures contracts by producers in their capacity as hedgers must equal the quantity demanded by speculators. The consumption function was adjusted to take into account seasonalities and shocks to demand. The production function was adjusted to take into account supply shocks.

By equating the one-period lag of the futures clearing equation the spot clearing equation spot prices are therefore a defined as:

$$s_t = a_1 + a_2 f_{t-1} + a_3 \Delta I_t + a_5 Y_t + a_6 r_t + a_7 DS_t + a_8 SS_t + \beta_j \sum_{j=1}^{12} DUM_j \qquad (10)$$

6.1 Methodology and Data

Consistent with 10, we assume a model of the form

$$\text{CRUDESPOT}_t = a_1 + a_2 f3_t + a_3\text{OECDSTOCKS}_t + a_4 OPECPROD \quad + a_5 WI_t + a_6 r_t + a_7 DS + a_8 SS$$

$$+ a_9\text{FEDRATE}_t + a_{10}\text{N}EER_t + \beta_j \sum_{i=1}^{12} DUM_j$$

CRUDESPOT is crude oil spot prices, *f*3 is the three months ahead futures contract price, OECDSTOCKS refer to OECD inventory levels, OPECPROD is OPEC production, WI is world industrial production, FEDRATE is the Fed benchmark rate and NEER is the U.S. nominal effective exchange rate. In addition to the role of inventories as the residual of demand and supply, OPEC production was added as a swing producer. The U.S. nominal effective exchange rate was also added as an explanatory variable as posited by Krichene (2005).[10]

Traditional economic theory has been applied on the assumption that economic series have a constant mean and finite variance. That is, the variables are stationary. In practice, however, most economic series are not stationary and consequently OLS estimation will lead to spurious results. Engle and Granger (1987) have shown that OLS estimation may still be valid if a linear combination of any non-stationary series is stationary in which case the variables are said to be cointegrated. If the variables are stationary then a Vector Auto Regression (VAR) can be estimated, in which case any shock to the stationary variables will be temporary. If the variables are non-stationary and not cointegrated, then they have to be transformed into stationary variables by differencing, before the VAR can be estimated. Shocks to the differenced variables will have a temporary effect on the growth rate but a permanent effect on its level. Cointegrated non-stationary variables require the inclusion of a vector of cointegrating residuals (adjustment matrix) in the VAR with differenced variables.

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[10] The U.S. Nominal Effective Exchange rate is the unadjusted weighted average value of the U.S. dollar relative to all major currencies being traded within an index or pool of currencies. The weights are determined by the importance a home country places on all other currencies traded within the pool, as measured by the balance of trade.

In the presence of cointegration, we can specify a vector error correction model (VECM) as follows:

$$\Delta Z_t = \delta_0 + \gamma_0 \sum_{i=1}^{n} \Delta Z_t - \delta_1 \left(Z_{t-1} - \frac{\gamma_0}{(\delta_1 - 1)} Z_{t-1} \right) + \varepsilon_t$$

where Z_t = [CRUDESPOT$_t$, $f3_t$, OPECPROD$_t$, OECDSTOCK$_t$ WI$_t$, FEDRATE$_t$, NEER$_t$]. The coefficient δ_1 measures inertia or persistence; the larger the value of δ_1 the faster the adjustment of the dependent variable to its long-term equilibrium. The coefficient γ_0 is a vector of short-run elasticities. The long-term impact (multiplier) of a unit change in Z_{t-1} on Z_t is given by $\sum_{i=0}^{\infty} \delta_1^i \gamma_0 = \frac{\gamma_0}{(\delta_1 - 1)}$.

Our model uses monthly data for the period January 1990 to December 2005. Crude oil spot and futures prices, inventory and production data were obtained from the Energy Information Administration. The series for the three-month futures contract prices was constructed by using the closing prices of the day immediately after the cessation of trading of contracts.[11] OECD inventories were selected as these exhibited a stronger correlation with the spot price than US inventory levels. This can be viewed as the first available forecast for subsequent months. The IMF's index of world industrial production was used as a proxy for GDP.

7.0 Results

Pairwise correlation tests were calculated to pre-test the relationships between the proposed variables in the model. Consistent with the prediction of the theoretical model, futures prices are strongly, positively correlated with crude spot prices. The relationship between GDP growth (proxied by WI) and crude spot prices appears smaller than that for crude spot and futures prices, suggesting a stronger role for speculative forces, relative to fundamentals. The contemporaneous correlations indicate positive relationships between OECDPROD and OECDSTOCKS, which contradicts model implications. The strong correlation between world GDP growth

[11] Futures trading in crude oil terminate at the close of business on the third business day prior to the 25th calendar day of the month preceding the delivery month. If the 25th calendar day of the month is a non-business day, trading shall cease on the third business day prior to the business day preceding the 25th calendar day.

and OPECPROD indicates a high level of responsiveness to demand growth by oil producers.

It is difficult to interpret the correlation between F3 and OPECPROD. On one hand, this fairly large positive coefficient would suggest that producers respond to increases in futures prices. On the other, it suggests that speculators are irrational in that they increase their demand for futures contract on observing an increase in production. The former explanation is more plausible given that futures prices can be observed immediately, while production data would be observed with a lag. Consistent with this view, OECD stocks is also positively (albeit weakly) correlated with increases in futures prices.

In estimating the model, it was necessary to first assess the time series properties of each variable. Augmented Dickey-Fuller (ADF) unit root tests for the order of integration did not reject the hypothesis that the series have unit-roots. Likelihood ratio tests indicated an optimal lag length of three in all the ADF models. The Johansen cointegration test on the system revealed one cointegrating equation at the 5% significance level (see Table A.6). The model was therefore estimated as a Vector Error Correction Model (VECM) with a deterministic trend and an intercept. Tests on the length of the lag based on the Schwartz information criterion indicate an optimal lag length of three. The Jarque-Bera test failed to reject the hypothesis of normally distributed residuals/disturbances. Lagrange multiplier test also indicated that there was no serial correlation among residuals.

The estimated long run equation from the model, along with the speed of adjustment parameter is:

$$\begin{aligned}\text{CRUDESPOT} = {} & 134.76 + 0.905*\text{F3} - 0.0358*\text{OECDSTOCKS} + 0.0457*\text{OPECPROD} \\ & - 0.0264*\text{WI} + 0.1509*\text{TREND}; \quad \delta_1 = -0.0816\end{aligned}$$

The speed of adjustment coefficient is significant less than one implying that in the long run crude oil spot prices do converge to the mean, albeit slowly. It is worth noting that the coefficient on F3 is particularly large, which speaks to the importance of speculative forces for crude spot prices. In keeping with a priori expectations, OECD inventory levels have a negative, albeit minimal effect on crude oil prices in the long run. The coefficients on OECDPROD and WI are not consistent with our prior expectations.

7.1 Impulse Response and Variance Decomposition

The variance decomposition at 10 lags indicates that the spot price of crude oil explains approximately 89.0 per cent of its forecast error variance (see table A.9), which suggests significant inertia in the market. Futures prices explain the smallest proportion of the variance in the crude oil spot price. This contradicts Tabak (2003) in regards to the information content of futures prices.

The impulse response graphs show the impact of a shock to the variables on the spot price of crude oil.[12] A shock to crude oil prices has an immediate and persistent effect on itself (see Figure A.1). This result strongly indicates that speculation plays an important role in price discovery. A shock to F3 has a small but positive effect on spot prices, which dissipates after three months when the contract expires. OECD stocks have a negative but persistent effect on prices, indicating that market has long-term memory in regard to demand/supply conditions. The effect of a shock to OPEC production is negative over three months but corrects after that. This may relate to a pattern of OPEC pre-announcements which stimulates market adjustments prior to the effective date of implementation. The fall in prices after implementation therefore reflects normalisation in positions, once the market is able to evaluate the impact of the production decision. This confirms the importance of news about OPEC behaviour and is consistent with the findings of Kaufman (2004). Curiously, a shock to WI stimulates increases in CRUDESPOT over four months.

7.3 Forecast Evaluation

To evaluate the model, we test its forecasting power, relative to three other models. The first model assumes that the crude oil spot price follows a random walk. The second adopts the market efficiency hypothesis, which asserts that futures prices are

[12] As check of robustness, we changed the Cholesky ordering and generated the same impulse response functions. The results did not change with these adjustments.

accurate predictors of spot prices. The third model is a variant of the Ye (2002) inventory model.

Model performance was evaluated using in-sample forecasts. The model was estimated over the full sample (1990 to present), and its forecasts were calculated for horizons that vary from one to twenty-four months. The criteria used are the root mean square error (RMSE), the Mean Absolute Error (MAE) and Theil U statistics. The three-agent model had the lowest RMSE, MAE and Theil-U statistics, relative to the competing models.

8.0 Conclusions

In a context of growing tightness in the market, crude oil is increasingly traded on futures exchanges. This has prompted the emergence of speculative forces, which in turn appears to have assumed increased importance in the process of price discovery. Previous models of spot price of crude oil have focused on single aspects of the market and therefore have exhibited poor forecasting performance, particularly in recent times. This paper develops a model that takes into account all the factors that contribute to the determination of crude oil spot price with a view to improving Bank of Jamaica's forecasting ability.

The model broadly shows that despite the continued importance of market fundamentals, the futures market and consequently speculation have a significant influence on crude oil prices. It supports Kawai's (1983) hypothesis that rational speculators play a significant role in the determination of spot prices and these agents make their decisions based on information about the state of the market. The model also refutes the view that OPEC production decisions no longer have an impact on spot prices. Of the set of models evaluated, the three agent model had the best forecasting power.

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APPENDIX: A

Table A.1:
Top 10 Consumers of Oil (2005)
(Millions of barrels per day)

Countries	Total oil consumption
1. United States	20.7
2. China	6.4
3. Japan	5.4
4. Russia	2.8
5. Germany	2.6
6. India	2.5
7. Canada	2.3
8. South Korea	2.2
9. Brazil	2.1
10. France	2.0
Total	**82.6**

Source: Energy Information Administration

Table A.2:
Top 10 Oil Producers (2005)
(Millions of barrels per day)

Countries	**Total oil production (mn bbl/d)**
1. Saudi Arabia	11.4
2. Russia	10.9
3. United States	6.2
4. Iran	5.0
5. Mexico	4.0
6. China	4.3
7. Norway	3.2
8. Nigeria	3.2
9. Venezuela	3.1
10. United Arab Emirates	3.0

Source: Energy Information Administration

Table A.3:
Proved Oil Reserves (2006)

Country	Proved reserves (billion barrels)
1. Saudi Arabia	264.3
2. Canada	178.8
3. Iran	132.5
4. Iraq	115.0
5. Kuwait	101.5
6. United Arab Emirates	97.8
7. Venezuela	79.7
8. Russia	60.0
9. Libya	39.1
10. Nigeria	35.9
11.United States	21.4
12. China	18.3

Source: Oil & Gas Journal, Vol. 103, No. 47 (Dec. 19, 2005)

Table A.4: Pairwise Correlations

	CRUDESPOT	OPECPROD	OECDSTOCKS	WI	F3
CRUDESPOT	1				
OPECPROD	0.5801	1			
OECDSTOCKS	0.4530	0.6804	1		
WI	0.5765	0.7452	0.5264	1	
F3	0.9153	0.5903	0.4596	0.5539	1

Table A.5:
Augmented Dickey-Fuller Test Results

Variable	Level		First Difference	
	T-statistic	P-value	T-statistic	P-value
CRUDESPOT	0.304668	0.978	-11.4126	0.000
F3	-0.09441	0.9473	-12.7885	0.000
WI	1.827346	0.9998	-14.7291	0.000
OECDSTOCKS	-2.54539	0.1066	-11.7375	0.000
NEER	-2.75158	0.0674	-3.65114	0.006

Table A.6: Results of the Johansen Cointegration Test

Rank	Eigenvalue	Trace Statistic	Prob
1	0.133	72.569	0.030
2	0.086	46.259	0.070
3	0.077	29.721	0.049
4	0.068	14.980	0.060

Table A.7: Random Walk Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CRUDESPOT(-1))	0.190191	0.071295	2.667659	0.0083
R-squared	0.027930	Mean dependent var		0.205811
Adjusted R-squared	0.027930	S.D. dependent var		2.215959
S.E. of regression	2.184795	Akaike info criterion		4.406170
Sum squared resid	902.1589	Schwarz criterion		4.423260
Log likelihood	-417.5862	Durbin-Watson stat		1.961757

Table A.8: Futures-Spot Results

Dependent Variable: CRUDESPOT				
Method: Least Squares				
Date: 10/10/06 Time: 14:43				
Sample: 1990M01 2005M12				
Included observations: 192				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
FUTURES	0.996957	0.011957	83.37826	0.0000
C	0.292888	0.331768	0.882809	0.3785
R-squared	0.973397	Mean dependent var		25.71940
Adjusted R-squared	0.973257	S.D. dependent var		11.07141
S.E. of regression	1.810556	Akaike info criterion		4.035507
Sum squared resid	622.8412	Schwarz criterion		4.069439
Log likelihood	-385.4086	F-statistic		6951.935
Durbin-Watson stat	1.744864	Prob(F-statistic)		0.000000

Table A.9: Variance Decomposition

Period	S.E.	CRUDESPOT	F3	OECDSTOCKS	OPECPROD	WI
1	1.837	100.000	0	0	0	0
2	2.884	95.925	0.170264	3.292631	0.546125	1.001347
3	3.564	93.876	0.154023	11.15716	0.370916	1.40383
4	4.027	92.289	0.405431	13.66982	0.341077	1.229667
5	4.311	90.753	0.440818	15.5812	0.317553	1.164705
6	4.571	90.457	0.364712	15.84309	0.441255	1.144494
7	4.833	90.156	0.322357	15.53461	0.422865	1.051339
8	5.045	89.656	0.303664	16.0648	0.373011	1.067573
9	5.237	89.269	0.280635	16.54442	0.326309	1.054469
10	5.426	88.933	0.270312	16.72561	0.294196	0.994528

Table A.10: In–Sample Forecast Tests

	Three Agent Model	Random Walk	Futures Model	Inventories Model
RSME	5.306	25.007	18.776	17.745
MAE	4.245	22.174	16.380	15.932
Theil Inequality Coefficient	0.098	0.317	0.260	0.253

Figure A.1: Impulse Responses