J. King Saud Univ., Vol. 6, *Admin. Sci.* (2), pp. 81-98, Riyadh (A.H. 1414/1994)

Autocorrelation in Static Economic Models and Their Dynamic Respecifications: An Application to OPEC Behavior

Suliman M. Al-Turki
Assistant Professor, Department of Economics, College of Administrative Sciences
King Saud University, Riyadh, Saudi Arabia

(Received on 24/8/1413; Accepted for Publication 1/1/1414 A.H.)

Abstract. The presence of autocorrelation in a regression model hinders statistical inferences by biasing estimated variances. The usual procedure is, therefore, to avoid the presence of autocorrelation in the finally estimated model by transforming the data. Instead of transforming the data, a practical procedure is used, whereby the information embodied in autocorrelation is utilized to modify the model and reveal further aspects of the examined phenomenon. The procedure is applied to examine OPEC behavior, where it is seen that the partial market sharing model explains OPEC behavior best. In the long run, OPEC members with large oil reserves tend to expand their market shares more than those with low oil reserves.

Section I
Introduction

Autocorrelation is one of the most commonly faced problems in applied economic studies when time series data are used to estimate static economic models. In general, autocorrelation is viewed as a 'nuisance' that should be eliminated from the estimated regression model. This view is based on the well-established result that the application of the ordinary least squares (OLS) procedures to estimate a regression with autocorrelated errors will underestimate the regression variance. Hence, variances of all estimated coefficients will be biased downward. This leads to an upward bias in all confidence tests (t and F) and makes the model seem statistically more reliable than it really is, has autocorrelation been accounted for. Therefore, the usual and acceptable practice is to attempt to avoid the presence of autocorrelation in the final estimation of the model(1).

(1)Downward biases mentioned here arise in the general case of positive autocorrelation in both the error term and explanatory variables. This result is well-documented in any Econometrics textbook. See for example Johnston [1; pp. 310-313] and Maddala [2; pp. 196-200]. See Maddala [2; p. 192] for a discussion and comparison of alternative methods of dealing with autocorrelation in regression models.

In this study, we show that autocorrelation provides valuable information about the regression model and the phenomenon being analyzed. Such information should be utilized before attempting to eliminate autocorrelation. In particular, we employ the procedure of dealing with autocorrelation which was first suggested by Hendry and Mizon [3] and later extended and formalized by Thursby [4]. The procedure provides tests for the source(s) of autocorrelation and suggests the direction to modify the original regression model. We apply the procedure of dealing with autocorrelation to examine the behavior of Organization of Petroleum Exporting Countries (OPEC) in the international oil market.

There are two reasons for selecting the behavior of OPEC countries as an application to the suggested procedure. First, the absence of a serious econometric study which is based on accurate foundations that explains OPEC behavior. In spite of the large number of studies that had come out after the adjustments in oil price in 1973-74 to explain OPEC behavior and analyze its influence on the world oil market, most of these studies have been theoretical and used simulation methods(2). The theoretical nature of existing literature has led to conflicting views of OPEC behavior, ranging from pure competition to pure monopoly. The need for an empirical study to evaluate and interpret OPEC behavior is obvious in the face of such conflicting views. Griffin [7] attempted to do this by estimating major economic models of oil supply from OPEC countries to determine which,if any, model can best explain OPEC behavior. By using quarterly data for the period 1971. I to 1983. III and applying the OLS procedures, he concluded that OPEC behavior could best be understood according to a cartel theory where each member tried to maintain its market share. Although this conclusion is consistent with the widely held view of OPEC as a cartel (see for example, Adelman [8] and Loderer [9]) as well as the official announcements of OPEC members in their periodical meetings, Griffin's study represents an excellent example of the misuse of static economic models when faced with the autocorrelation problem. It is based on flawed testing and estimating procedures and hence, may be deemed insufficient to select the best model explaining OPEC behavior. In an attempt to base the selection of best model on accurate and improved testing procedures, we reestimate OPEC models as suggested in Griffin by using his data set which is provided to us kindly by him. The data set was updated to 1987.IV, the latest period for which data are available for all variables.

The second reason for selecting OPEC behavior as an application to the suggested testing procedures is that the employed data set shows an interesting pattern of autocorrelation and therefore should be more valuable to empirical researchers than a Monte Carlo study.

(2)For a survey, see Fisher *et al.* [5] and Gately [6].

This study is organized as follows. Section II briefly discuses the theoretical model of OPEC behavior. Section III presents the empirical estimates of the OPEC behavior as suggested by Griffin, discuses the problems with the empirical estimates, and suggests a way to deal with them. Section IV presents the conclusion of this study.

Section II
Models of OPEC Behavior

There exists a large number of studies about OPEC behavior. In general, OPEC members are viewed as wealth-maximizers under alternative market structures or nonwealth-maximizers trying to satisfy some specific objectives. Our discussion here is concerned with the model to be estimated in the next section, although we provide a brief discussion of other competing models.

The most acceptable model of OPEC behavior is the cartel model. According to one version of this model, each OPEC member is assumed to maintain its market-share over time. Therefore, given the net demand for OPEC oil, which is defined as the difference between world demand for oil and supply of oil from non-OPEC countries (i.e. the demand for OPEC oil is a residue), each OPEC member's production (q_{it}) is assumed to be a fraction (a_i^*) of total OPEC production (Q_t^o). That is:

$$q_{it} = a_i^* \, Q_t^o \tag{1}$$

Alternatively, we may express q_{it} in terms of other members' production ($Q_{it} = Q_t^o - q_{it}$) to avoid simultaneity between q_{it} and Q_t^o. That is:

$$q_{it} = a_i \, Q_{it} \tag{2}$$

where $a_i = a_i^* / (1 - a_i^*)$

It is assumed that market shares are functions of real prices (P_t) so that we can write:

$$q_{it} = a_i \, P_t^{bi} \, Q_{it}^{ci} \tag{3}$$

Taking logarithms of (3) and adding a random error term (e_{it}, to capture errors in measurements, random effects, and unaccounted for variables)[3], we can write (3) as:

[3]Model (3) and its estimating specification (4) represent the conjectural industry output variation model. See Geroski *et al.* [10]. Geroski *et al.* [11] consider a conjectural industry price variation model.

$$\ln q_{it} = \ln a_i + b_i \ln P_t + c_i \ln Q_{it} + e_{it} \quad (4)$$

Equation (4) is the estimating equation suggested by Griffin [7]. It represents a standard model to test market behavior. If $c_i = 1$ and $b_i = 0$, we have a constant market-sharing model. In this case, each member observes other members' production and adjusts its production accordingly. Price does not play any role in this type of model. If $c_i = 1$ and $b_i \gtrless 0$, we have a market-sharing model, where each member still observes others' production and responds to price changes. If $0 < c_i < 1$ and $b_i \gtrless 0$, we have a partial market-sharing model. Here, each member responds partially to changes in both price levels and other members' production.

It is worth mentioning that, in all versions of the market-share model, changes in market-shares are assumed to be a function of price only; but clearly changes in market-shares may result from changes in major determinants of wealth-maximizing behavior such as reserve size and extraction costs. However, in the absence of complete data for a more comprehensive model, it is impossible to include all variables thought to influence production levels. Moreover, it is interesting to note that prices may reflect all (new and changes in) necessary information and hence, even when data are available, inclusion of many variables in the regression model may lead to a multicolinearity problem. A second thing to note about model (4) is that the supply curve is not constrained to be positively sloped as is the case in perfectly competitive markets for final goods. The reason for this is that oil revenues are the main source of income in OPEC countries. This may induce some members to cut back production when prices are rising, since their financial needs can be met at a low level of production and vice versa when prices are falling. Other justifications for a non-positively sloped supply curve include non-economic objectives and concerns over stability of the world oil market. What is difficult to justify is the way in which the three versions of the market-sharing have been specified. That is, if one is comparing the partial market-sharing model to market-sharing, then the former is more likely to be selected, since it is more likely to observe $c_i \in (0,1)$ than $c_i = 1$. The coefficient on price level does not provide any discriminatory power between these two versions on one hand and the constant market-sharing on the other because it is acceptable for b_i to be any where between $-\infty$ and ∞ (i.e. $b_i \in [-\infty, \infty]$). However, since there exists no alternative to the above specifications in economic theory, we have no choice but to adopt it.

Alternative models of OPEC behavior which are based on competitive explanation view changes in production levels as a result of changes in supply and demand conditions in international market or as a result of changes in the underlying wealth-maximizing criteria in a competitive market. Basically, most of these studies are directed to explain OPEC behavior during the 1970's rather than OPEC behavior in general. Changes in production resulting from changes in supply and demand conditions was suggested by MacAvoy [12], who viewed changes in oil price as simply a result of supply distribution during the late 1970's. Changes in production resulting from changes in wealth-maximizing behavior was suggested by Johany [13] and Mead [14,15]. According to their theory, OPEC was irrelevant as an organization to the increase in oil price in the 1970's. Changes in the oil market were a natural result of the shift in the property rights from oil companies to host countries' governments. During the 1960's, changes in the ownership patterns were nontrivial in many countries and, therefore, the wealth-maximizing strategy on the part of oil companies involved a high discount rate and high production levels. As ownership shifted to host governments, they refused to continue expanding production because of lower discount rate.

Another competitive explanation of OPEC behavior that is not directed to explain OPEC behavior during the 1970's and is not based on wealth-maximizing criteria was provided by Teece [16]. His basic argument is that OPEC, or at least its principle members, determined oil production according to the requirements of the national budget. These requirements are limited by low-absorptive capacity of national economies. Therefore, an increase in oil price may lead to a reduction in production, at least in the short-run, if the additional revenues are more than the desired increase investment expenditures. This means that supply responses to an increase in price may not be an increase in production. On the other hand, a reduction in oil price, lowering oil revenues, may lead to an increase in oil supply, contrary to the usual supposition.

Griffin suggested different models to test the last three hypotheses (competitive, property rights, and revenue models). However, we strongly doubt the reliability of the data sets used to estimate the last two models. With regard to revenue model, Griffin suggested that national budgetary needs could be proxied by the level of gross fixed capital formation, hence he regressed each member's production on price and the proxy for budgetary needs. It is obvious that financial needs of OPEC members are not limited to internal investment, as most of them are involved in ambitious aid programs to other countries as well as international organizations. Even if one accepts the financial needs of OPEC countries to be limited to internal needs, the quality of data used by Griffin is not suitable for estimation. He stated that sources of gross fixed capital formation data were the IMF *International financial Statistics;* yet this publication reports only annual data for capital formation. Therefore, Griffin must have interpolated the annual into quarterly observations. Our problem with this is that he did not report the methods used in the interpolation, casting strong doubts on both the reliability of data and the interpretation of results. As for the property rights model, Griffin regressed production on government controlled production. However, only 11 observations were used in the estimation, which leaves 9 degrees of freedom in the model. Any attempt to expand the model, to deal with autocorrelation, will eat up desperately needed degrees of freedom and hinder the validity of statistical inferences. For the competitive model, it is clear that a test for a positively sloped curve can be nested in the cartel model and test $c_i = 0$ and $b_i > 0$. Therefore, we concentrate on the estimation of equation (4) in the next section.

Section III
Econometric Estimation and Testing Procedures

Epirical Results

Model (4) was estimated for 11 OPEC members (all OPEC members except Ecuador and Gabon due to data unavailability). The data are quarterly observations on production levels and prices for the period 1971.I to 1987.IV. The sample was truncated for Iran to delete the periods following the Iranian Revolution (1978.III) and for Iraq to delete the periods following the Iran-Iraq war (1980.III).

It was possible to exactly reproduce 32 models out of the 43 models for the period used by Griffin (1971.I - 1983.III), the property rights models were not reproduced due to data unavailability[4]. Table 1 reports regression estimates for the complete period (1971.I - 1987.IV).

By comparing the estimates in Table 1 with those reported in Griffin's study, we see that the general conclusion of Griffin remains intact after extending the estimation period to 1987.IV. That is, the partial market-sharing model best explains OPEC behavior.

Looking closely at the estimated models, it is obvious that all Durbin-Watson (DW) statistics indicate that the hypothesis of uncorrelated errors terms is rejected. What was missing from Griffin's study is a report of such statistics. The case we have in Table 1 and in Griffin's study is a good example of what Granger and Newbold [17; p. 205] referred to as 'spurious regressions', where high R^2's are accompanied with low DW statistics. For some countries, DW statistics are even *lower* than R^2, casting strong doubt on the validity of any statistical inference from the estimated models. If autocorrelation is caused by omission of relevant variables in regression model, then the situation becomes even worse: biases in all estimated coefficients.

---

(4)Reproductions of Griffin's estimates are not reported here but can be made available upon request.

Table 1. OLS estimates of OPEC market-sharing models in $q_{it} = a + b \ln P_{it} + c \ln Q_{it}$.

Country	a	b	c	$\bar{R}^2$	r_1	D-W
Algeria	1.12 (0.66)	−0.04 (0.03)	0.57 (0.06)	0.60	0.73	0.54
Indonesia	3.72 (0.55)	0.22 (0.02)	0.31 (0.05)	0.63	0.75	0.49
Iran	0.28 (1.48)	0.04 (0.02)	0.88 (0.15)	0.69	0.52	0.96
Iraq	7.78 (4.78)	0.30 (0.05)	−0.06 (0.47)	0.49	0.62	0.75
Kuwait	−4.28 (0.79)	−0.37 (0.03)	1.25 (0.08)	0.90	0.38	1.24
Libya	−1.88 (1.22)	−0.23 (0.04)	0.97 (0.12)	0.66	0.76	0.48
Nigeria	0.96 (0.89)	0.04 (0.03)	0.64 (0.09)	0.45	0.58	0.85
Qatar	−1.94 (0.70)	−0.01 (0.02)	0.79 (0.07)	0.70	0.40	1.20
Saudi Arabia	−3.03 (1.32)	0.34 (0.05)	1.15 (0.13)	0.55	0.81	0.39
UAE	−0.15 (0.70)	0.16 (0.03)	0.72 (0.07)	0.63	0.75	0.50
Venezuela	3.69 (0.69)	−0.21 (0.03)	0.45 (0.07)	0.70	0.82	0.37

Notes: Numbers in parentheses are standard errors. $\bar{R}^2$ is the adjusted coefficient of determination. r_1 is the first-order autocorrelation coefficient. D-W is the Durbin-Watson statistics. Variables are defined in the text.

Testing for Sources of Autocorrelation

Although the DW statistic was designed to detect first-order autoregressive (AR(1)) error terms, it has substantial power in detecting higher order autoregressive processes as well as a nonzero mean error due to omission of relevant variables or misspecified functional form [18; p. 4]. Since the correction for autocorrelation depends on its source, it is important to ascertain the source of autocorrelation.

Before we proceed to test for the source of autocorrelation, it is necessary to determine the degree of autocorrelation. Because the data used in the estimation are quarterly, one would suspect a fourth-order autocorrelation in the error term. Two tests can be employed to detect this. The first is the Wallis test for a particular fourth-order autocorrelation. The result of this test indicates that the null hypotheses of no fourth-order autocorrelation is not rejected (at the 5% level of significance). The second test is the Breusch-Godfrey test for up to fourth-order autocorrelation. The Breusch-Godfrey also did not reject the null hypotheses of no autocorrelation(5). Therefore, we conclude that the estimations of equation (4) have only first order autocorrelation.

Two possible sources of autocorrelation are discussed in this section. These are omitted variables and misspecified dynamics. Misspecification of the functional forms as a source of autocorrelation is not discussed here, since this limits the alternative of a zero mean error to be a misspecified functional form, whereas our interest is in a general alternative to nonzero mean error due to any reason rather than just a misspecified functional form(6).

1. Omitted variables

As discussed in the previous section, there is a reason to believe that equation (4) excludes a relevant cost-of-production variable. In a regression involving omitted variables, all coefficient estimates are biased. Biases are linear combinations of the coefficients of excluded variables [1; p. 260]. Therefore, although autocorrelation biases only estimated variances, if it is resulting from omitted variables, the latter will destroy the unbiasedness property of coefficient estimates. It is interesting to note that testing (4) for an omitted variable is equivalent to testing whether prices reflect all other information.

To statistically determine whether equation (4) has an omitted variable problem we employ the RESET (Regression Specification Error Test) test as suggested by Thursby and Schmidt [19] and Thursby [4]. RESET is designed to test the null hypothesis of a zero mean error against the alternative of nonzero mean error. It amounts to using a standard F-test of the significance of d in the regression:

$$\ln q_t = a + b \ln P_t + c \ln Q_t + X_t d + e_t \quad (5)$$

(5)These tests are discussed in Johnston [1; pp. 317-321]. Notice that the Wallis tests the null hypothesis $r_4 = 0$ in the autoregressive process: $e_t = r_4 e_{t-4} + u_t$, where u_t are independently and identically distributed (iid) random errors with mean zero and constant variance. The Breusch-Godfrey tests the null hypothesis $r_1 = r_2 = r_3 = r_4 = 0$ in the process: $e_t = r_1 e_{t-1} + r_2 e_{t-2} + r_3 e_{t-3} + r_4 e_{t-4} + u_t$. All tests in this study refer to the 5% level of significance.

(6)Even if one is interested only in testing for the functional form Thursby [4] stated that he had found in a Monte Carlo study that the RESET test (to be discussed shortly) is more powerful in detecting incorrect functional forms than other testing procedures such as Box-Cox transformation. See Thursby [4], footnote 1, p. 118.

Where X is 1XG vector of G test variables, and d is a GX1 vector of unknown coefficients. Country subscripts are superseded.

There exists a number of choices for the test variables to be included in X. Two sets of test variables are used in (5). The first includes the squares and cubes of the predicted values resulting from (4). The second set includes squares and cubes of all explanatory variables. In both cases, the test indicates that there is no omitted variable problem(7). In conclusion, autocorrelation in the estimation of (4) is not caused by an omitted variable problem.

2. Misspecified dynamics

The remaining possible source of autocorrelation is misspecified dynamics(8). Recall that further testings of (4) indicate that autocorrelation is of first order. Therefore, the error term in (4) can be written as

$$e_t = r_1 e_{t-1} + u_t \tag{6}$$

where u_t are identically and independently distributed (iid) random errors with mean zero and constant variance. Using (6), we can write (4) as

$$\ln q_t = a(1 - r_1) + b \ln P_t - br_1 \ln P_{t-1} + c \ln Q_t - cr_1 \ln Q_{t-1} + r_1 \ln q_{t-1} + u_t,$$

or equivalently,

$$(1 - r_1L) \ln q_t = a(1 - r_1) + b(1 - r_1L) \ln P_t + c(1 - r_1L) \ln Q_t + u_t \tag{7}$$

wher L is the lag operator: $LX_t = X_{t-1}$.

Model (7) can be considered as a special case of a more general model(9):

$$(1 - \psi_1L) \ln q_t = \alpha + (b - \psi_2L) \ln P_t + (c - \psi_3L) \ln Q_t + u_t \tag{8}$$

(7)Godfrey [20] disputed the power of RESET in the presence of autocorrelation, as suggested by Thursby [4]. See Godfrey [20; p. 107].

(8)For a thorough discussion of this point, see Hendry and Mizon [3] and Hendry and Richard [21].

(9)Mizon and Hendry [22] consider a more general dynamic model.

with the following restrictions:

$$\begin{aligned} \alpha &= a(1 - r_1) \\ \psi_1 &= r_1 \\ \psi_2 &= br_1 \\ \psi_3 &= cr_1 \end{aligned} \tag{9}$$

The presence of autocorrelation has led many writers to estimate a model equivalent to (7), which is achieved by applying the OLS procedures to appropriate transformed data. However, it is obvious that this approach implies imposing restrictions (9) on (8) without testing for their validity. This ad hoc imposition of restrictions can lead to substantial bias in coefficient estimates. The appropriate strategy is to begin with a very general model, such as the one stated in (8) and sequentially test whether restricted versions of it is consistent with the data. This approach has the advantage of being consistent with whatever the 'true' model is (i.e. static, autoregressive, or dynamic model). This latter approach is the one adopted here. In particular, we start with a general, unrestricted dynamic model, examine the optimal number of lags, test for the restrictions stated in (9), and finally examine whether it is possible to further simplify the model.

The optimal number of lags is determined by using the mean-squares error (MSE) criterion. Notice that, tests of autocorrelation suggest a first-order autoregressive error term, which implies that the number of lags should be one, as indicated by equations (7) and (8). We have experimented with four lags, since data are quarterly. The test for improvements in the MSE amounts to comparing the sample F-statistics calculated as

$$\frac{(RSS_R - RSS_U)/q}{RSS_U/(n-k)}$$

where

RSS_R = restricted residual sum of squares (dynamic model with one lag),

RSS_U = unrestricted residual sum of squares (dynamic model with four lags),

q = number of restrictions.

with critical value from the noncentral F-distribution [1; p. 258].

The F-tests indicate that a one-period lag represents the data best for all countries.

After determining the optimal number of lags, we ask whether one should impose the restrictions embodied in (9) above. Since those restrictions are not linear, we cannot use the usual F-test. The common procedure in this case is to use the likelihood ratio (LR) test which can be calculated in a simple form as [see 4, p. 119]:

$$LR = -n \{ \ln RSS_U - \ln RSS_R)$$

where n is number of observations, ln is logarithm operator. LR is asymptotically χ^2 (q), where q is the number of restrictions.

The restricted model [i.e. model (8) subject to restrictions (9)] can be estimated by any autocorrelation correction procedures. The restricted model in this study is estimated using the Cochrane-Orcutt procedure.

It is important to note that the test for restrictions (9) is valid only if the error term of (8) is serially independent, since this is part of the null hypothesis which we are testing. The Durbin-Watson statistic is not appropriate to test for the dependence of the error term of (8), since we have a lagged dependent variable in the right-hand side. Alternative tests exist, but perhaps the widely used one is referred to as the Durbin alternative test (Durbin-h) and can be calculated by regressing u_t on u_{t-1} and the right-hand side variables of (8), where u_t is the OLS residuals of (8). If the coefficient of u_{t-1} is significantly different from zero, we then reject the null hypothesis of no autocorrelation and, hence, must transform the data [i.e. impose restrictions (9)]. The application of the Durbin-h to our group of countries did not lead to the rejection of the null hypothesis of no autocorrelation (at the 5% level of significance) in the unrestricted dynamic model (8).

The next step is to perform the LR test for restrictions (9). As stated above, we estimated the restricted model by the Cochrane-Orcutt procedure. The results of these LR tests are the rejection of the restriction stated in (9).

This conclusion provides us with a warning against the common practice of transforming the data on the basis of the Durbin-Watson statistic without testing for the restrictions implied by such transformations.

The fact that we have chosen an unrestricted dynamic model has motivated us to consider whether it is possible to further simplify the model by imposing restrictions on the lag structure. In particular, we ask whether it is possible to use the Koyck lag scheme. This restriction is tested for using a standard F-test. The restriction implied by the Koyck lag structure is not rejected for any country. By using the Durbin-h test for autocorrelation in the Koyck model, we do not reject the hypothesis of no autocorrelation. This means that we can apply the OLS procedures to the data without having to transform them, in spite of the presence of lagged dependent variable among the regressors.

This conclusion of uncorrelated error terms in Koyck models represnts an interesting interpretation of the so-called data generating process (DGP). It is possible to see some lagged dependent variable models that do not reveal any tendency in error terms to show autocorrelation, although such models should show that tendency by construction[10]. It is easy to interpret this result here. If a lagged dependent variable model does not show autocorrelation in the error term, then the lagged dependent variable in the right hand side does not reflect an exponentially declining wights on the explanatory variables. It rather reflects a valid restriction on a general dynamic specification of the static model, and, therefore, can be interpreted as a partial adjustment mechanism in the dependent variable. Therefore, if a lagged dependent variable model does show autocorrelation, one should test for the validity of the lag structure imposed on the model. This test is a standard F-test on the significance of lagged explanatory variables.

In summary, the suggested procedures to deal with autocorrelation which were adopted to select the best (parsimonious) model for OPEC behavior are:

1. Autocorrelation Test: Test for the degree of autocorrelation. This is achieved by the Wallis and Breusch-Godfrey tests. The result is AR(1) process.
2. Variable Exclusion Tests: Test for the exclusion of relevant variable(s) in the maintained model. This is achieved by the RESET test. The result does not indicate an omitted variable problem.
3. Dynamic Specification Test: Specify an unrestricted dynamic model and test for the optimal number of lags. This is achieved by the MSE criteria. The result is a one-period lag model.
4. Model Reduction Test: See if it is possible to reduce (impose restrictions on) the general unrestricted dynamic model. This is achieved by a standard F-test. The result is a simple Koyck lag model.

The selected model for each OPEC country in the sample is[11]:

$$\ln q_t = a + b \ln P_t + c \ln Q_t + d \ln q_{t-1} + e_t \quad (11)$$

[10] This result is proved in Johnston [1: p. 347].

[11] All test statistics mentioned in this section are available upon request.

In this model, all variables measure the same behavior as in model (4), with the coefficient on q_{t-1} measuring the speed of adjustment in production levels to their current levels. That is, (d) in (10) is the speed of adjustment coefficient.

A Re-examination of OPEC Behavior

Table 2 reports the OLS estimates of model (10). By comparing the estimates reported in Table 2 with those reported in Table 1 and in Griffin [7], the effects of autocorrelation on testing procedures make it impossible to infer anything about OPEC behavior based on the estimates of Table 1 and Griffin's study, where

Table 2. OLS estimates of OPEC market-sharing models $\ln q_{it} = a + b \ln P_{it} + c \ln Q_{it} + d \ln q_{it-1}$.

Country	a	b	c	d	$\bar{R}^2$
Algeria	0.57 (0.50)	-0.03 (0.02)	0.17 (0.07)	0.68 (0.09)	0.78
Indonesia	0.93 (0.50)	0.05 (0.02)	0.12 (0.04)	0.70 (0.08)	0.81
Iran	1.59 (1.49)	−0.09 (0.06)	0.01 (0.17)	0.81 (0.08)	0.76
Iraq	−0.15 (1.73)	−0.03 (0.06)	0.30 (0.19)	0.63 (0.10)	0.51
Kuwait	−2.83 (0.90)	−0.26 (0.04)	0.85 (0.15)	0.31 (0.10)	0.91
Libya	−0.68 (0.86)	−0.06 (0.04)	0.31 (0.12)	0.69 (0.08)	0.83
Nigeria	0.68 (0.75)	−0.01 (0.03)	0.32 (0.10)	0.48 (0.11)	0.60
Qatar	−1.34 (0.68)	−0.02 (0.02)	0.54 (0.10)	0.34 (0.11)	0.74
Saudi Arabia	1.50 (1.72)	0.06 (0.03)	0.33 (0.09)	0.80 (0.06)	0.87
UAE	0.08 (0.50)	0.02 (0.02)	0.20 (0.08)	0.71 (0.09)	0.81
Venezuela	0.78 (0.43)	−0.05 (0.02)	0.11 (0.05)	0.77 (0.06)	0.91

Notes: Numbers in parentheses are standard errors. $\bar{R}^2$ is the adjusted coefficient of determination. Variables are defined in the text.

autocorrelation has biased the estimated variance downward and, hence, invalidated the testing procedures. Table 2 provides more accurate estimates to evaluate the behavior of OPEC countries in the world oil market.

From Table 2, we see that the estimates of d, the coefficient of adjustment, are significant and have the expected sign for all countries. The estimates of the coefficients on other members' production (Q_t) also have the expected signs; however, the estimates are significant for ten out of the eleven countries considered in this study. This country, Iraq, is the one that has the wrong sign and insignificant estimate of c in Griffin's study. The estimates of the price coefficients have mixed signs. However, we note that in the market-sharing and partial market-sharing models, the price coefficient is free to take any sign. Only in the competitive model do we expect the price coefficient to be positive. Therefore, the sign of price estimates is part of the market behavior hypothesis tests which will be provided shortly. Nonetheless, the significantly negative price coefficients can be interpreted as an evidence of the revenue model discussed in the previous section. That is, for a given level of desired investment, an increase in price decreases output, since the additional revenue would be more than needed [23].

The fact that the finally selected model contains a lagged dependent variable makes it possible to distinguish between the short and long run behavior of OPEC. For the short run, alternative hypothesis of OPEC behavior are tested by applying the appropriate F-statistics.

First, the assumption of constant market-sharing cartel (that is, $b = d = 0$ and $c = 1$) is rejected for all countries. Therefore, the hypothesis that changes in OPEC members production are the sole determinant of the behavior of any other member does not provide an acceptable explanation of OPEC behavior. Griffin rejected this hypothesis for ten out of the eleven countries considered.

The market-sharing cartel model ($c = 1$) is also rejected for all countries in the short run. The static specification of Griffin led to the rejection of such a model for only six countries. This indicates that changes in oil supply from OPEC countries do not correspond exactly to changes in market shares in the short run; rather, supply is affected by other factors, such as the level of production in the previous period and prices.

The partial market-sharing model ($b \neq 0$, c and d are > 0) provided the best explanation. It is not possible to reject this model for ten countries. Iraq is the only country for which the partial market-sharing model is rejected. It is this country that Griffin noticed to have been "long noted for independent behavior"[12]. The frequent significant coefficients on price suggest that market-shares are affected by price levels.

The short run competitive explanation of OPEC behavior ($b > 0$ and $c = 0$) is rejected for all countries.

The above conclusion suggests that, at least in the short run, OPEC members are involved in effective output coordination. It should be emphasized that, although our conclusion seems to confirm that of Griffin, we believe that our conclusion is based on more accurate estimating and testing procedures.

The remaining part of this selection is devoted to long run elasticities of prices and other members' production, which are shown in Table 3.

Table 3. Mean lags and long run elasticities of OPEC members.

Country	Mean lag	P_t	Q_t
Algeria	2.13	−0.09	0.53
Indonesia	2.33	0.17	0.57
Iran	0.69	0.03	1.02
Iraq	2.57	0.29	1.36
Kuwait	0.45	−0.38	1.23
Libya	2.23	−0.19	1.00
Nigeria	0.92	−0.02	0.62
Qatar	0.52	−0.03	0.82
Saudi Arabia	4.00	0.30	1.65
UAE	2.45	0.07	0.69
Venezuela	3.35	−0.22	0.48

Notice: Mean lags are calculated from the estimates of Table 2 as d/(1-d). Long run price elasticities are calculated as b/(1-d). Long run elasticities with respect to others' production are calculated as c/(1-d).

Further interesting aspects of OPEC behavior can be inferred from Table 3 by looking at the mean lag, which indicates how fast the gap between current and previous production levels is closed, we notice a strong tendency to return quickly to the long run (equilibrium) position. The mean lag varies from 0.45 of a quarter for Kuwait to 4 quarters for Saudi Arabia. This implies that Saudi Arabia stays out of its

(12)Griffin [7; p. 957]. It is obvious from Table 1 of Griffin that the partial market sharing model should have been rejected for Iraq. However, Griffin stated that the model was not rejected for any country (see Table 2 of his study).

long run equilibrium position longer than any other member. On the other hand, given that the long run coefficient on production of other members measures how the market share of a member changes in response to change in others' production, Saudi Arabia seems to expand its market share larger than other members in the long run. Countries which expand their market shares by small amount are those with low reserve levels. The long run price elasticities are consistent with market shares. That is, in general, increasing market shares are observed for countries with large (absolute value) price elasticities which also happen to have large reserves (e.g. Saudi Arabia and Iraq).

Section IV
Conclusion

This study employed a pocedure for dealing with autocorrelation to modify the maintained model in a way that is consistent with the data generating process. The procedure is simple and can be applied whenever autocorrelation appears in a regression model.

We select OPEC behavior as an application to the procedure of dealing with autocorrelation. OPEC behavior has not been thoroughly examined in formal and accurate foundations. A study by James Griffin was an attempt to ascertain OPEC behavior empirically. However, his conclusion can not be fully accepted, due to the strong presence of autocorrelation in his estimations, which hinders the validity of any statistical inference. We reestimated the OPEC behavior model after dealing with autocorrelation and arrived at the conclusion that partial market sharing model explained OPEC behavior best. While this conclusion seems to coincide with that of Griffin, we believe that the present study lends more support to the usual view of OPEC as well as official announcements of OPEC members of production coordinations. The present study also shed light on long run aspects of OPEC behavior. In general, members with large oil reserves tend to expand their market shares in the long run more than those with low oil reserves.

Further enhancements to econometric modellings, which provide valuable future research potentials, emerge from the present study. To name just few aspects in this area, it would be interesting to examine the consequences of imposing different lag structures upon dynamic models. With regard to OPEC behavior, a better understanding of OPEC behavior should be based on the comprehensive specification of the testable model. A major contribution to the evaluation of OPEC behavior is to start from a model which is explicitly derived from the economic theory of exhaustible resources.

References

[1] Johnston, J. *Econometric Methods*. New York: McGraw-Hill, (1984).

[2] Maddala, G. *Introduction to Econometrics*. New York: Macmillan, (1988).

[3] Hendry, D. and Mizon, G. "Correlation as a Convenient Simplification, Not a Nuisance: A Comment on a Study of the Demand for Money by the Bank of England". *Economic journal*, Vol. 88, No. 351, (September 1978), pp. 549-563.

[4] Thursby, J. "A Test Strategy for Discriminating between Autocorrelation and Misspecification in Regression Analysis". *Review of Economics and Statistics*, Vol. 63, No. 1, (Feb. 1981), pp. 117-123.

[5] Fisher, D.; Gately, D. and Kyle, J. "The Prospects for OPEC: A Critical Survey of Models of the World Oil Market." *Journal of Development Economics*, Vol. 2, No. 4, (December 1975), pp. 363-386.

[6] Gately, D. "A Ten-Year Retrospective: OPEC and the World Oil Market". *Journal of Economic Literature*, Vol. 22, No. 3, (September 1984), pp. 1100-1114.

[7] Griffin, J. "OPEC Behavior: A Test of Alternative hypothsis". *American Economic Review*. Vol. 75, No. 5, (December 1985), pp. 954-963.

[8] Adelman, M. "Scarcity and World Oil Prices". *Review of Economics and Statistics*, Vol. 68, No. 3 (August 1986), pp. 387-397.

[9] Loderer, C. "A Test of the OPEC Cartel Hypothesis: 1973-1983". *Journal of Finance*, Vol 40, No. 3, (July 1985), pp. 991-1006.

[10] Geroski, P.; Phillps, L. and Ulph, A. "Oligopoly, Competition and Welfare: Some Recent Developments". *Journal of Industrial Economics*, Vol. 33, No. 4, (June 1985), pp. 369-386.

[11] Geroski, P.; Ulph, A. and Ulph, D. "A Model of Crude Oil Market in which Market Conduct Varies". *Economic Journal (Supplement)*, (1987), pp. 77-86.

[12] MacAvoy, P. *Crude Oil Price as Determined by OPEC and Market Fundamentals*. Cambridge: Ballinger, 1982.

[13] Johany, A. "OPEC and the Price of Oil: Cartelization or Alteration of Property Rights', in El Mallakh, R. (Ed.). *OPEC: Twenty Years and Beyond*. Boulder CO: Westview Press, (1982).

[14] Mead, W. "The Performance of Government Energy Regulation". *American Economic Review Proceedings*, Vol. 60, No. 2, (May 1979), pp. 352-356.

[15] Mead, W. "An Economic Analysis of Crude Oil Price Behavior in the 1970's, in El Mallakh, R. (Ed.), *OPEC: Twenty Years and Beyond*. Boulder, CO: Westview Press, (1982).

[16] Teece, D. "OPEC Behavior: An Alternative View, in Griffin, J. and Teece, D. (Eds.), *OPEC Behavior and World Oil Prices*. London: Allen and Unwin, (1982).

[17] Granger, C. and Newbold, P. *Forecasting Economic Time Series*. New York: Academic Press, (1986).

[18] Davidson, R. and MacKinnon, J. "The Interpretation of Test Statistics'. *Canadian Journal of Economics*, Vol. 2, No. 4, (February 1985), pp. 38-86.

[19] Thursby, J. and Schmidt, P. "Some Properties of Tests for Specification Error in a Linear Regression Model". *Journal of the American Statistical Association*, Vol. 72, No. 397, (September 1977), pp. 635-641.

[20] Godfrey, C. *Misspecification Tests in Econometrics: The Lagrange Multiplier Principles and other Approaches*. Cambridge University Press, (1988).

[21] Hendry, D. and Richard. J. "The Econometric Analysis of Economic Time Series". *International Statistical Review*, Vol. 51, No. 1, (April 1983).

[22] Mizon, G. and Hendry, D. "An Empirical Application and Monte Carlo Analysis of Test of Dynamic Specification. *Review of Economic Studies*, Vol. 47, No. 147, (January 1980), pp. 21-45.

[23] Adelman, M. "OPEC as a Cartel", in Griffin, J. and Teece, D. (Eds.), *OPEC Behavior and World Oil Prices*. London: Allen and Unwin, (1982).

الارتباط الذاتي في النماذج الاقتصادية الساكنة والصياغة الديناميكية لها: تطبيق على سلوك دول الأوبك

سليمان محمد التركي

أستاذ مساعد، قسم الاقتصاد، كلية العلوم الإدارية، جامعة الملك سعود، الرياض، المملكة العربية السعودية

(قدم للنشر في ٢٤/٨/١٤١٣هـ؛ وقبل للنشر في ١/١/١٤١٤هـ)

ملخص البحث. يؤدي وجود الارتباط الذاتي في نموذج الانحدار إلى خلق تحيز في تقدير تباين نموذج الانحدار وتباينات تقديرات المعلمات، وبالتالي إعاقة الاستدلال الإحصائي. لذا فإن الطريقة المتبعة والمقبولة عند وجود ارتباط ذاتي تتمثل في تحويل البيانات للتخلص من الارتباط الذاتي. وعوضا عن محاولة التخلص من الارتباط الذاتي، تستخدم هذه الدراسة أسلوبا عمليا للاستفادة من المعلومات المتضمنة في الارتباط الذاتي لتعديل النموذج وإلقاء مزيد من الضوء على الظاهرة محل الدراسة. ولقد تم تطبيق هذا الأسلوب لدراسة سلوك دول الأوبك في سوق النفط العالمي. واتضح أن النموذج الجزئي لحصة السوق يعد من أفضل النماذج التي تفسر سلوك دول الأوبك في الأجل القصير. وفي الأجل الطويل، فإن حصة أعضاء الأوبك ذوي الاحتياطات العالية من النفط في السوق ترتفع بشكل أكبر عند المقارنة بحصص الأعضاء ذوي الاحتياطات المنخفضة.