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# **PERSISTENCE IN SOME ENERGY FUTURES MARKETS\***

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## **Abstract**

In this paper, we examine the possibility of long range dependence in some energy futures markets for different maturities. In order to test for persistence, we use a variety of techniques based on non-parametric, semiparametric and parametric methods. The results indicate that there is little or no evidence of long memory in gasoline, propane, oil and heating oil at different maturities. However, when we focus on the volatility process, proxied by the absolute returns, we find strong evidence of long memory in all the variables at different contracts.

*Key words:* Persistence; Long memory; Futures; Energy prices; Volatility.

*JEL classification:* C32; C59; Q40.

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## **1. Introduction**

It is commonly accepted that the dynamics of energy prices explain some of the main economic indicators. For example, Hamilton (2008) in a recent survey of the literature on the macroeconomic effects of oil shocks documented that nine out of ten of the US recessions were preceded by increases in the oil price, suggesting then its role as an explanatory variable of economic recessions. Many empirical papers show evidence that energy prices affect macroeconomic variables (e.g., Hamilton, 1983; Hooker, 1996; Kilian, 2008a,b; Tatom, 1988 and Mork, 1989 among many others). Other studies not only consider the change in oil price as a main determinant of inflation and economic activity but also the oil price volatility as a proxy variable of the level of uncertainty about future oil prices. Papers analysing the relevance of the relationship between oil price volatility and the macroeconomy are Hamilton (1996, 2003) and Guo and Kliesen (2005). Thus, for example, Guo and Kliesen (2005) find that a volatility measure constructed using daily crude oil future prices has a negative and significant effect on GDP growth over the period 1984-2004.

As we have shown in the preceding paragraph, it is relevant to understand the dynamic behavior of energy prices. In this paper we focus on the persistence in both energy price returns and their associated volatility processes. Starting with the level of the series, a number of papers have analyzed mean reversion in energy prices (see, e.g., Serletis, 1992; Gil-Alana, 2001 and Postali and Picchetti, 2006). Serletis (1992) using daily crude oil, heating oil and unleaded gasoline tests for unit roots using standard methods. His results support the unit root hypothesis when a structural break is taken into account. More recently, Postali and Picchetti (2006) argue against the existence of unit roots when a period longer than a century is considered. However, if structural

breaks are taken into account, unit roots remain in shorter periods. Other authors focus the interest on the volatility processes (see, for example, Sadorsky, 2006; Tabak and Cajueiro, 2007 and Elder and Serletis, 2007, 2008 among others). Sadorsky (2006) use univariate and multivariate models to estimate and forecast daily volatility in energy futures prices. Tabak and Cajueiro (2007) also analyze volatility in crude oil markets using long range dependence techniques, based on the rescaled range (R/S) statistic (Hurst, 1951). In another recent paper, Elder and Serletis (2008) test for fractional integration in energy futures markets using semiparametric wavelet estimation methods. Studies on volatility in futures markets use absolute returns (see, for example, Elder and Jin, 2007) or alternative statistical models (i.e., the family of GARCH models) (see, for example, Sadorsky, 2006).

In a similar vein to the above papers, we also examine the degree of persistence in some energy future markets, using various procedures for estimating and testing long range dependence. We use alternative methods, based on non-parametric (i.e., Lo, 1991, Giraitis et al., 2003), semiparametric (i.e., Robinson, 1995) and parametric (i.e., Sowell, 1992, Robinson, 1994) techniques.

The paper embraces two principal contributions. First, we focus on futures of energy analyzing persistence in both levels and volatility processes. Previous studies only focus on prices or volatility. Second, we use three alternative approaches to document the persistence in futures markets, based on non-parametric, semiparametric and parametric techniques. It is well known that the results on persistence can substantially vary depending on the methodology employed. In this respect, the use of a variety of methods with different distributional assumptions may contribute to achieving a better overall picture of the degree of persistence of the series.

The structure of the paper is as follows. Section 2 briefly describes the methods of long range dependence that will be employed in the paper. In Section 3, the procedures presented in Section 2 are applied in both the returns and their associated volatility processes. Section 4 contains some concluding comments.

## 2. Methodology

In this section we present a brief description of the methods employed in Section 3 for estimating and testing long range dependence in some energy futures markets. In all cases we consider the possibility that the underlying model is long memory.

We can provide two definitions of long memory, one in the time domain and the other in the frequency domain. Let us consider a zero-mean process  $\{x_t, t = 0, \pm 1, \dots\}$  with  $\gamma_u = E(x_t x_{t+u})$ . The time domain definition of long memory states that:

$$\sum_{u=-\infty}^{\infty} |\gamma_u| = \infty.$$

Now, assuming that  $x_t$  has an absolutely continuous spectral distribution, so that it has spectral density function

$$f(\lambda) = \frac{1}{2\pi} \left( \gamma_0 + 2 \sum_{u=1}^{\infty} \gamma_u \cos(\lambda u) \right),$$

the frequency domain definition of long memory states that the spectral density function is unbounded at some frequency in the interval  $[0, \pi)$ . Most of the empirical work carried out so far has concentrated on the case where the singularity or pole in the spectrum takes place at the zero frequency. This is the standard case of  $I(d)$  models of the form:

$$(1 - L)^d x_t = u_t, \quad t = 0, \pm 1, \dots, \quad (1)$$

with  $d > 0$ , where  $L$  is the lag-operator ( $Lx_t = x_{t-1}$ ) and  $u_t$  is  $I(0)$ . Note that the polynomial in the left-hand-side in (1) can be expressed in terms of its Binomial expansion, such that, for all real  $d$ ,

$$(1 - L)^d = \sum_{j=0}^{\infty} \psi_j L^j = \sum_{j=0}^{\infty} \binom{d}{j} (-1)^j L^j = 1 - d L + \frac{d(d-1)}{2} L^2 - \dots,$$

and (1) can be written as:

$$x_t = d x_{t-1} - \frac{d(d-1)}{2} x_{t-2} + \dots + u_t.$$

If  $d$  is an integer value,  $x_t$  will be a function of a finite number of past observations, while if  $d$  is not an integer,  $x_t$  depends strongly upon values of the time series far away in the past. (See, e.g., Granger and Ding, 1996; Dueker and Startz, 1998). Moreover, the higher the  $d$  is, the higher the level of association will be between the observations. Thus,  $d$  is an indicator of the degree of persistence of the series.<sup>1</sup>

The parameter  $d$  also plays a crucial role from the statistical viewpoint. Thus, if  $d = 0$ ,  $x_t$  is stationary  $I(0)$  and is commonly denoted as “short memory”; on the contrary, if  $d > 0$ ,  $x_t$  is said to be “long memory” so-named because of the strong degree of association between observations in the far distant past, and if  $0 < d < 0.5$ , the series is still covariance stationary; however, if  $d \geq 0.5$ , the series is no longer stationary and as  $d$  increases beyond 0.5 and through 1 the series is becoming “more nonstationary” in the sense, for example, that the partial sums increase in magnitude with  $d$  being non-summable. In the following we describe some methods for testing long memory (and fractional integration) in univariate time series.

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<sup>1</sup> For recent surveys of fractional integration see the papers of Robinson (2003), Doukhan et al. (2003) and more recently, Gil-Alana and Hualde (2008).

## 2.1 A non-parametric approach

We start with the non-parametric procedures. The two methods presented here test the null hypothesis of short memory (i.e.  $d = 0$  in (1)) against long memory ( $d > 0$ ) and/or anti-persistence ( $d < 0$ ). First we describe a procedure developed by Lo (1991). The modified R/S statistic (Lo, 1991) is:

$$Q_T(q) = \frac{1}{\hat{\sigma}_T(q)} \left( \max_{1 \leq k \leq T} \sum_{j=1}^k (x_j - \bar{x}) - \min_{1 \leq k \leq T} \sum_{j=1}^k (x_j - \bar{x}) \right),$$

where  $\hat{\sigma}_T^2(q) = \hat{\sigma}_x^2 + 2 \sum_{j=1}^q \omega_j(q) \hat{\gamma}_j$ , and  $\omega_j(q) = 1 - \frac{j}{q+1}$ ,  $1 \leq j < T$ ,

and  $x_t$  is a stationary series ( $-0.5 < d < 0.5$ ) of sample size  $T$ , with sample mean  $\bar{x}$ , sample variance  $\hat{\sigma}_x^2$ , and sample autocovariance at lag  $j$  given by  $\hat{\gamma}_j$ . This statistic was further normalized as:

$$V_T(q) = \frac{Q_T(q)}{\sqrt{T}}. \quad (2)$$

The null hypothesis of  $I(0)$  includes ARMA models, though as pointed out by Haubrich and Lo (2001) does not contain a trend-stationary model. The limiting distribution of  $V_T(q)$  is derived in Lo (1991) and the 95% confidence interval with equal probabilities in both tails is [0.809, 1.862]. Several Monte Carlo experiments conducted by Teverovsky et al. (1999) and Willinger et al. (1999) show that this method is biased in favor of accepting the null of no long memory as the bandwidth parameter  $q$  increases. Therefore, these authors were cautionary about using Lo's modified method in isolation.

Another recent non-parametric approach is the rescaled-variance V/S statistic proposed by Giraitis, Kokoszka, Leipus and Teysiere (2003), which is given by



$$M_T(q) = \frac{\text{Var}(S_1^*, S_2^*, \dots, S_T^*)}{T \hat{\sigma}_T^2(q)}, \quad (3)$$

where  $S_k^* = \sum_{j=1}^k (x_j - \bar{x})$ , and  $\text{Var}(S_1^*, S_2^*, \dots, S_T^*) = \frac{1}{T} \sum_{j=1}^T (S_j^* - \bar{S}^*)^2$  is their sample

variance. According to Giraitis et al. (2003) the V/S test is more suitable for series that exhibit high volatility, and various Monte Carlo experiments conducted by these authors show that the V/S test is shown to be less sensitive to the choice of the bandwidth number  $q$ . The asymptotic distribution of  $M_T(q)$  coincides with the limiting distribution of the standard Kolmogorov statistic.

A final comment is worthy of mention at this point and it is related with the choice of the optimal bandwidth number  $q(q^*)$  in the two methods described above:  $q = 0$  correspond to the classic Hurst-Mandelbrot R/S statistic. Haubrich and Lo (2001) suggested using Andrew's (1991) data-dependent procedure to determine the optimal bandwidth, which is given by

$$q^* = \left( \frac{3a^* T}{2} \right)^{\frac{1}{3}}, \quad (4)$$

with

$$a^* = \frac{4\hat{\rho}^2}{(1 - \hat{\rho}^2)^2},$$

where  $\hat{\rho}$  is the first order AR coefficient.

## 2.2 A semi-parametric approach

The method presented here is based on equation (1), where  $u_t$  is simply supposed to be  $I(0)$ . We describe a procedure developed by Robinson (1995), which is essentially a

local ‘Whittle estimator’ in the frequency domain, using a band of frequencies that degenerates to zero. The estimator is implicitly defined by:

$$\hat{d} = \arg \min_d \left( \log \overline{C(d)} - 2d \frac{1}{m} \sum_{s=1}^m \log \lambda_s \right), \quad (5)$$

$$\overline{C(d)} = \frac{1}{m} \sum_{s=1}^m I(\lambda_s) \lambda_s^{2d}, \quad \lambda_s = \frac{2\pi s}{T}, \quad \frac{m}{T} \rightarrow 0,$$

where  $I(\lambda_s)$  is the periodogram of the raw time series,  $x_t$ , given by:

$$I(\lambda_s) = \frac{1}{2\pi T} \left| \sum_{t=1}^T x_t e^{i\lambda_s t} \right|^2,$$

and  $d \in (-0.5, 0.5)$ . Under finiteness of the fourth moment and other mild conditions, Robinson (1995) proved that:

$$\sqrt{m} (\hat{d} - d_o) \rightarrow_d N(0, 1/4) \quad \text{as } T \rightarrow \infty,$$

where  $d_o$  is the true value of  $d$ .

Though there exist further refinements of this procedure, (Velasco, 1999, Phillips and Shimotsu, 2004, 2005; etc.), these methods require additional user-chosen parameters and then, the results concerning the estimation of  $d$  may be very sensitive to the choice of these parameters. In this respect, the method of Robinson (1995) seems computationally simpler.

### 2.3 A parametric approach

There exist several methods for estimating and testing the fractional differencing parameter in parametric contexts (e.g., Sowell, 1992; Beran, 1993; Tanaka, 1999; etc.). In this paper we perform a suitable method suggested by Robinson (1994). There are several reasons for using this method. First, it permits us to include deterministic terms

such as an intercept or a linear time trend unlike what happens with other methods such as Lo's (1991) non-parametric approach. Another advantage of this method is that it is valid for any real value of  $d$ , therefore encompassing stationary ( $d < 0.5$ ) and nonstationary ( $d \geq 0.5$ ) hypotheses, unlike the methods described in Section 2.1 and 2.2 that require first differencing to render the series stationary prior to the estimation of  $d$ . We employ here the following model,

$$y_t = \beta_0 + x_t, \quad t = 1, 2, \dots \quad (6)$$

$$(1 - L)^d x_t = u_t, \quad t = 1, 2, \dots, \quad (7)$$

where  $u_t$  is assumed to be  $I(0)$ , and given the parametric nature of this method,  $u_t$  has to have a parametric form, that may be a white noise process, or more generally, allowing some type of weak autocorrelation (i.e, ARMA) structure. In this approach we test the null hypothesis:

$$H_o : d = d_o,$$

for any real value  $d_o$  in (6) and (7), and the limit distribution is standard  $N(0, 1)$ . The functional form of the test statistic can be found in any of the numerous empirical applications of his tests (e.g. Gil-Alana and Robinson, 1997, Gil-Alana, 2000, etc.).

### **3 Evidence of persistence in energy futures markets**

The time series data analysed in this section correspond to the log-transformation of daily energy futures prices. All data are obtained from the Energy Information Agency . The sample period for each of the variables is described in Appendix 1.

We use four alternative energy futures prices: crude oil, gasoline, heating oil and propane. For each variable we have four different maturity contracts. Contract 1 is defined as a futures contract specifying the earliest delivery date. Contracts 2 to 4

represent the successive delivery months following Contract 1. For detailed information relating to future energy contracts see the Energy Information Agency web site. Contracts for gasoline, heating oil, and propane expire on the last business day of the month preceding the delivery month. Thus, the delivery month for Contract 1 is the calendar month following the trade date. For crude oil, each contract expires on the third business day prior to the 25<sup>th</sup> calendar day of the month preceding the delivery month. If the 25<sup>th</sup> calendar day of the month is a non-business day, trading ceases on the third business day prior to the business day preceding the 25<sup>th</sup> calendar day. After a contract expires, Contract 1 for the remainder of that calendar month is the second following month.

In this section we examine the possibility of long memory in both the returns and their associated volatility processes in the oil futures with different maturities using alternative methods.

### **3.1 Persistence in energy future returns**

Initially, we implement the test of Lo (1991) described in Section 2.1 to the returns of the four futures of energy prices. Table 1 reports the modified R/S statistic for gasoline, propane, oil and heating oil at different contracts. All futures returns present evidence of  $I(0)$  suggesting that the four series are stationary at all contracts. This result holds for all values of the bandwidth number  $q$ , including the one based on Andrews's (1991) procedure in (4). However, using the V/S statistic proposed by Giraitis et al. (2003), (see, Table 2), the results reject the null hypothesis of  $I(0)$  processes in all cases.<sup>2</sup>

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<sup>2</sup> The rejection of the null in the Giraitis et al.'s (2003) procedure may be related with the existence of long memory volatility in the underlying processes. See Section 3.2.

The disparity of the results based on the non-parametric methods suggest that we should try with other approaches. Next we implement the Whittle semiparametric method of Robinson (1995). Figure 1 presents the estimates of  $d$  based on Robinson (1995) (see equation (5)) using the whole range of values of the bandwidth number  $m$  (displayed in the horizontal axe).<sup>3</sup> We also display in the plots the 95% confidence interval corresponding to the  $I(0)$  case. We find mixed evidence. First, we only find evidence of  $I(d > 0)$  for propane in contracts 1 and 2 for some bandwidth numbers. Second, we obtain some evidence of  $I(d < 0)$  (i.e., anti-persistence) in the following cases: contracts 1 and 4 of gasoline, and contract 1 of oil and heating oil. A similar result of anti-persistence is found by Elder and Serletis (2008), showing that the variance of energy futures prices may be dominated by high frequency components. Finally, for the remaining cases, the estimated values of  $d$  are within the  $I(0)$  interval.

Finally, we use Robinson's (1994) parametric tests to determine the degree of persistence in the future energy markets. Table 3 reports the results based on white noise, AR(1) and Bloomfield disturbances. The latter is a non-parametric approach of modelling the  $I(0)$  disturbances that produce autocorrelations decaying exponentially as in the AR case. Using this method, the first thing we observe is that the results are consistent across the three types of disturbances. We report in the table the estimates of  $d$  along with the 95% confidence intervals of the non-rejection values of  $d$ .<sup>4</sup> The  $I(0)$  null hypothesis cannot be rejected in many cases and some estimates of  $d$  are above 0

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<sup>3</sup> In case of the Whittle estimator of Robinson (1995), the use of optimal values has not been theoretically justified. Some authors, such as Lobato and Savin (1998) use an interval of values for  $m$ . We have preferred to report the results for the whole range of values of  $m$ .

<sup>4</sup> The confidence intervals were constructed using the following strategy. First, choose a value of  $d$  from a grid. Then, form the test statistic testing the null for this value. If the null is rejected at the 95% level, discard this value of  $d$ . Otherwise, keep it. An interval is then obtained after considering all the values of  $d$  in the grid.

while others are below 0. The main results can be summarized as follows. Firstly, for gasoline, the  $I(0)$  hypothesis cannot be rejected in the cases of contracts 1, 2 and 3 if the disturbances are white noise. However, this hypothesis is rejected in favor of a negative  $d$  for contract 4 with white noise  $u_t$ , and for the four gasoline series if the disturbances are autocorrelated. Secondly, for the propane, the estimated  $d$ 's are in all cases positive though the  $I(0)$  case cannot be rejected in the majority of cases. The exceptions are contracts 1, 2 and 3 with uncorrelated (white noise) errors. Third, for oil prices, we observe negative values of  $d$  in practically all cases, and, if  $u_t$  is autocorrelated the  $I(0)$  hypothesis is always rejected in favor of  $d < 0$ . Finally, for heating oil, we also obtain negative values of  $d$ , but now the  $I(0)$  hypothesis is practically never rejected. The exceptions are contract 1 in all cases, and contracts 2 and 4 with white noise  $u_t$ . Thus, the overall picture in this table indicates that the order of differencing is negative or zero in the majority of the cases.

### **3.2. Evidence of persistence in volatility**

In this sub-section we conduct the same type of analysis as in Section 3.1 but now we focus on the volatility measured as the absolute returns of energy futures prices.<sup>5</sup>

We start again with the non-parametric methods. Using the modified R/S statistic of Lo (1991) the results for the four series reject the null of  $I(0)$  in favour of long memory behaviour. (see Table 4). Table 5 present the results using the V/S statistic (Giraitis et al., 2003) and, in this case, the results also support the long memory hypothesis ( $I(d, d > 0)$ ) in all series for different maturities.

Figure 2 reports the results based on the Whittle semiparametric method of Robinson (1995). We see that for all the variables and contracts, the value of  $d$  is found to be statistically significantly above 0, suggesting once more long memory in the volatility process.

Finally, we perform the parametric procedure of Robinson (1994). For all the energy variables and contracts, the estimates are positive and the intervals exclude the  $I(0)$  hypothesis. The lowest degree of persistence in the volatility processes seems to take place for gasoline (contracts 2 and 4) and heating oil (contracts 2 and 4) especially if the disturbances are uncorrelated. On the other extreme, the highest values occur in propane and oil for all different contracts, with values above 0.250 if the disturbances are autocorrelated. The same happens for heating and oil in contract 1.

When we observe the impact of maturity, the results are not very conclusive. Comparing contracts 1 and 4 across series and types of disturbances, in Table 6, it is observed that the estimated orders of integration in contract 1 are higher than in contract 4 in ten out of the twelve cases presented, however, the overlapping confidence intervals indicate that the results are inconclusive.

#### **4. Conclusions and comments**

The dynamic behavior in energy prices is one of the most relevant issues in the global economy. In this paper we have documented evidence of the persistence on futures price returns and volatility in several energy markets (crude oil, gasoline, heating oil and propane) for different maturities. To test this hypothesis we used various alternative

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<sup>5</sup> Previous studies on volatility in futures markets also use absolute returns (see, for example, Elder and Jin, 2007).

long-range dependence procedures based on non-parametric, semiparametric and parametric techniques.

The main findings of the paper can be summarized as follows: We found little or no evidence of long memory in the energy future prices returns, and this was observed across different maturity rates. However, we found strong evidence of long memory in the volatility processes (measured as absolute returns) in all the four variables. These results are consistent with other financial variables where long range dependence is found exclusively on the volatility processes. When we examine persistence in levels, the estimated values of  $d$  are positive for propane and negative for the rest of the variables. We found the highest values of  $d$  in contract 1 for propane and oil. If we focus on the volatility processes, the estimated values of  $d$  are in all cases positive, and higher for contract 1 in propane and heating oil. In addition, for propane, the persistence decays as the maturity of the contract increases. Finally, the degree of persistence seems to be higher in contract 1 for gasoline, propane and heating oil compared with contract 4.

Long memory is a relevant feature for energy future markets because its presence can be interpreted as evidence of predictable behavior. Energy price and volatility persistence are key variables for risk and portfolio managers. Some degree of predictability would be interpreted as there existing a possibility of exploiting the dependence in order to generate some extraordinary profits. In this context we find evidence of some degree of volatility persistence in all energy futures markets. For example, it seems to be the case that the degree of volatility persistence is higher in the oil market than in the gasoline market. This result would suggest that there exists more profit opportunities for investors in oil than in gasoline markets, because there is more time to respond to changes in volatility in oil than in gasoline.



This paper can be extended in several directions. Thus, longer periods of time can be examined and the possibility of structural breaks should be incorporated into the models. Asymmetric behaviour in energy futures prices is another interesting issue, and models combining fractional integration with non-linearities should be elaborated. Finally, multivariate models including all future contracts in a single framework will also be examined in future papers.

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**Table 1: Lo's (1991) modified R/S statistic results ( $V_T(q)$ )**

Series / q	0	1	2	3	4	5	10	50	100	500	$q^*$
GASOC1	0.988	0.971	0.967	0.973	0.980	0.987	1.034	1.079	1.190	1.553	0.973
GASOC2	0.945	0.939	0.944	0.947	0.953	0.960	0.991	1.030	1.123	1.390	0.939
GASOC3	1.103	1.086	1.080	1.081	1.085	1.089	1.128	1.106	1.180	1.416	1.081
GASOC4	0.998	1.022	1.037	1.045	1.054	1.061	1.097	1.163	1.257	1.349	1.045
PROPC1	1.323	1.275	1.245	1.237	1.237	1.235	1.240	1.194	1.258	1.503	1.235
PROPC2	1.339	1.305	1.287	1.281	1.282	1.279	1.282	1.214	1.257	1.495	1.282
PROPC3	1.292	1.261	1.245	1.234	1.237	1.235	1.250	1.185	1.213	1.447	1.237
PROPC4	1.241	1.225	1.216	1.206	1.207	1.201	1.224	1.145	1.164	1.396	1.216
OILC1	0.942	0.943	0.961	0.981	0.989	1.001	1.057	1.043	1.081	1.330	0.943
OILC2	1.05	1.043	1.050	1.063	1.068	1.076	1.114	1.078	1.106	1.373	1.050
OILC3	1.127	1.117	1.124	1.136	1.139	1.147	1.183	1.128	1.149	1.338	1.117
OILC4	1.120	1.120	1.130	1.144	1.149	1.157	1.195	1.129	1.142	1.349	1.120
HEATC1	0.981	0.987	0.991	1.004	1.015	1.027	1.096	1.126	1.166	1.423	0.991
HEATC2	1.043	1.061	1.068	1.074	1.081	1.088	1.127	1.183	1.236	1.354	1.074
HEATC3	1.189	1.184	1.184	1.191	1.196	1.206	1.248	1.138	1.150	1.463	1.184
HEATC4	1.127	1.153	1.163	1.166	1.171	1.175	1.205	1.208	1.230	1.378	1.166

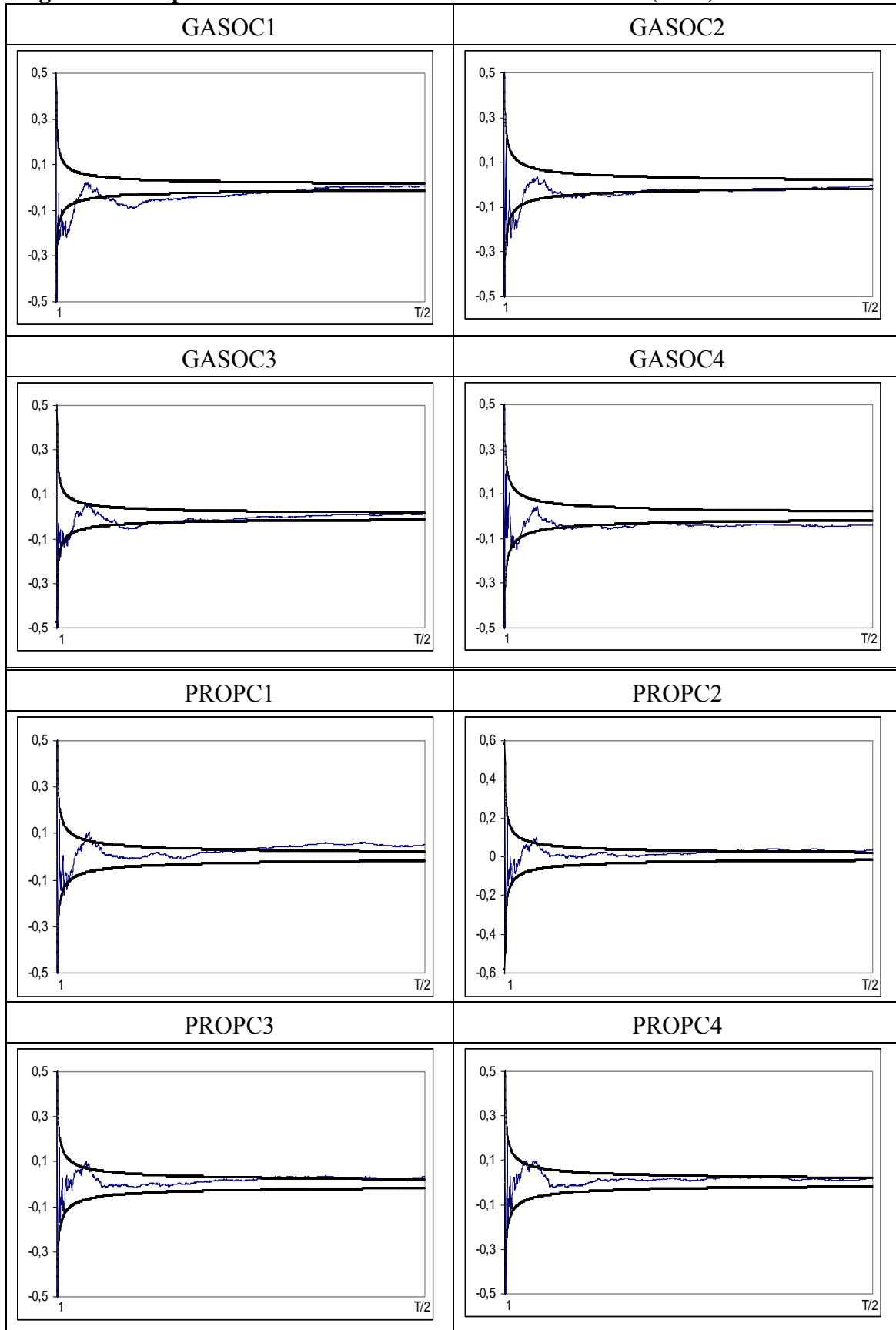
The 95% confidence interval for the  $I(0)$  null hypothesis is [0.809, 1.862].

**Table 2: Giraitis et al. (2003) V/S statistic results ( $M_T(q)$ )**

Series / q	0	1	2	3	4	5	10	50	100	500	$q^*$
GASOC1	0.0254	0.0245	0.0243	0.0246	0.0250	0.0253	0.0278	0.0303	0.0368	0.0628	0.0246
GASOC2	0.0342	0.0337	0.0342	0.0344	0.0348	0.0353	0.0376	0.0407	0.0483	0.0740	0.0337
GASOC3	0.0395	0.0383	0.0379	0.0379	0.0382	0.0385	0.0413	0.0398	0.0453	0.0652	0.0379
GASOC4	0.0430	0.0451	0.0464	0.0472	0.0480	0.0486	0.0520	0.0584	0.0682	0.0786	0.0472
PROPC1	0.0510	0.0474	0.0452	0.0446	0.0446	0.0445	0.0448	0.0415	0.0461	0.0659	0.0445
PROPC2	0.0516	0.0490	0.0477	0.0472	0.0473	0.0471	0.0473	0.0424	0.0455	0.0643	0.0473
PROPC3	0.0557	0.0530	0.0516	0.0508	0.0510	0.0509	0.0521	0.0468	0.0491	0.0698	0.0510
PROPC4	0.0579	0.0564	0.0556	0.0547	0.0548	0.0542	0.0564	0.0493	0.0510	0.0733	0.0556
OILC1	0.0389	0.0381	0.0404	0.0422	0.0428	0.0440	0.0489	0.0477	0.0511	0.0775	0.0381
OILC2	0.0408	0.0401	0.0407	0.0417	0.0421	0.0428	0.0455	0.0429	0.0452	0.0696	0.0407
OILC3	0.0593	0.0582	0.0590	0.0603	0.0606	0.0615	0.0654	0.0594	0.0616	0.0836	0.0582
OILC4	0.0514	0.0513	0.0523	0.0536	0.0540	0.0548	0.0584	0.0522	0.0534	0.0746	0.0513
HEATC1	0.0459	0.0465	0.0460	0.0481	0.0492	0.0503	0.0573	0.0605	0.0649	0.0966	0.0460
HEATC2	0.0436	0.0451	0.0458	0.0462	0.0468	0.0474	0.0509	0.0561	0.0613	0.0735	0.0462
HEATC3	0.0697	0.0691	0.0691	0.0699	0.0705	0.0712	0.0767	0.0638	0.0652	0.1054	0.0691
HEATC4	0.0556	0.0582	0.0591	0.0595	0.0600	0.0604	0.0635	0.0638	0.0662	0.0831	0.0595

The critical value at the 95% level is  $1.36/\sqrt{T}$ , that is, 0.0183 for GASOC1; 0.0239 for GASOC2; 0.0183 for GASOC3; and 0.0241 for GASOC4. 0.0231 for PROPC1; 0.0232 for PROPC3; and 0.0231 for PROPC4. 0.0173 for OILC1; 0.0180 for OILC2; and 0.0180 for OILC4. 0.0163 for HEATC1; 0.0232 for HEATC2; 0.0163 for HEATC3; and 0.0232 for HEATC4.

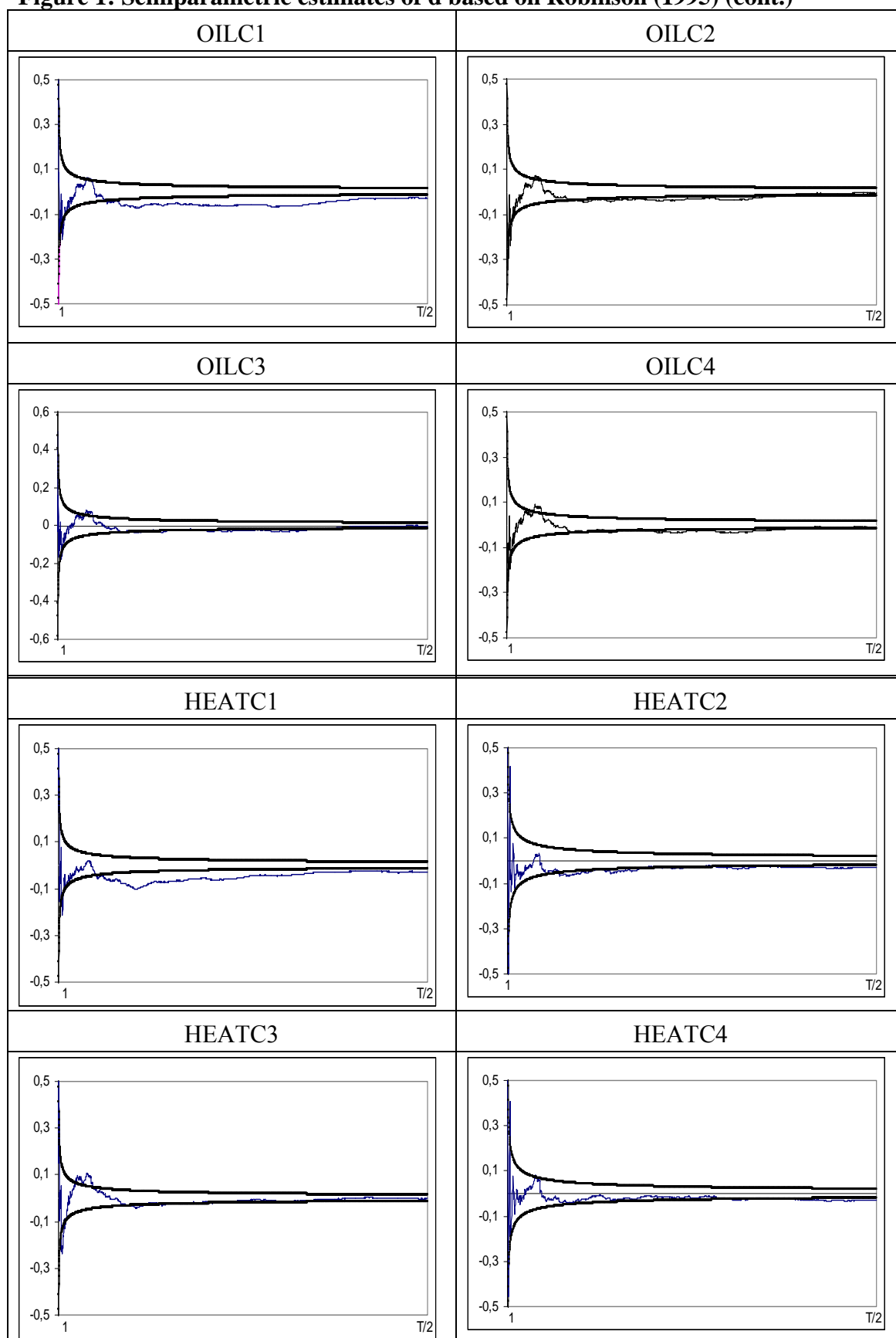
**Figure 1: Semiparametric estimates of  $d$  based on Robinson (1995)**



(cont.)



**Figure 1: Semiparametric estimates of  $d$  based on Robinson (1995) (cont.)**



**Table 3: Estimates of d and 95% confidence band using Robinson's (1994) approach**

	White noise	AR (1)	Bloomfield (1)
GASOC1	<b>0.002</b> [-0.016, 0.022]	<b>-0.063</b> [-0.094, -0.029]	<b>-0.049</b> [-0.078, -0.018]
GASOC2	<b>-0.010</b> [-0.033, 0.016]	<b>-0.050</b> [-0.086, -0.009]	<b>-0.048</b> [-0.085, -0.008]
GASOC3	<b>0.010</b> [-0.008, 0.029]	<b>-0.031</b> [-0.060, 0.000]	<b>-0.054</b> [-0.083, -0.024]
GASOC4	<b>-0.046</b> [-0.065, -0.023]	<b>-0.042</b> [-0.077, -0.004]	<b>-0.046</b> [-0.077, -0.006]
PROPC1	<b>0.054</b> [0.031, 0.078]	<b>0.008</b> [-0.030, 0.051]	<b>0.015</b> [-0.016, 0.048]
PROPC2	<b>0.036</b> [0.014, 0.061]	<b>0.006</b> [-0.030, 0.045]	<b>0.005</b> [-0.026, 0.038]
PROPC3	<b>0.033</b> [0.011, 0.057]	<b>0.003</b> [-0.033, 0.042]	<b>0.008</b> [-0.029, 0.041]
PROPC4	<b>0.019</b> [-0.002, 0.042]	<b>0.007</b> [-0.027, 0.045]	<b>0.007</b> [-0.030, 0.040]
OILC1	<b>-0.034</b> [-0.050, -0.016]	<b>-0.079</b> [-0.101, -0.052]	<b>-0.082</b> [-0.113, -0.060]
OILC2	<b>-0.010</b> [-0.027, 0.008]	<b>-0.051</b> [-0.076, -0.021]	<b>-0.046</b> [-0.073, -0.023]
OILC3	<b>0.007</b> [-0.022, 0.012]	<b>-0.039</b> [-0.064, -0.015]	<b>-0.041</b> [-0.068, -0.020]
OILC4	<b>-0.016</b> [-0.032, 0.002]	<b>-0.040</b> [-0.064, -0.016]	<b>-0.039</b> [-0.060, -0.010]
HEATC1	<b>-0.033</b> [-0.049, -0.016]	<b>-0.066</b> [-0.091, -0.037]	<b>-0.059</b> [-0.079, -0.034]
HEATC2	<b>-0.035</b> [-0.056, -0.012]	<b>-0.034</b> [-0.069, 0.004]	<b>-0.035</b> [-0.072, 0.005]
HEATC3	<b>-0.003</b> [-0.018, 0.012]	<b>-0.022</b> [-0.045, 0.003]	<b>-0.049</b> [-0.058, 0.039]
HEATC4	<b>-0.034</b> [-0.053, -0.012]	<b>-0.015</b> [-0.048, 0.021]	<b>-0.015</b> [-0.052, 0.018]

**Table 4: Lo's (1991) modified R/S statistic results ( $V_T(q)$ )**

Series / q	0	1	2	3	4	5	10	50	100	500	$q^*$
GASOC1	5.554	5.161	4.857	4.597	4.394	4.219	3.639	2.236	1.774	1.308	4.597
GASOC2	5.323	5.140	5.001	4.853	4.730	4.611	4.201	2.789	2.220	1.270	5.140
GASOC3	6.591	6.109	5.743	5.437	5.188	4.967	4.214	2.520	1.968	1.445	5.437
GASOC4	5.860	5.530	5.317	5.135	4.980	4.830	4.322	2.822	2.283	1.279	5.135
PROPC1	5.294	4.825	4.433	4.119	3.880	3.680	3.046	1.886	1.645	1.277	3.680
PROPC2	5.554	5.043	4.662	4.357	4.104	3.895	3.216	1.978	1.694	1.286	4.104
PROPC3	5.824	5.325	4.925	4.619	4.357	4.140	3.446	2.129	1.799	1.286	4.357
PROPC4	5.993	5.485	5.092	4.797	4.552	4.350	3.689	2.323	1.928	1.306	5.092
OILC1	5.435	4.867	4.475	4.151	3.908	3.705	3.073	1.730	1.337	1.020	4.867
OILC2	5.942	5.431	5.039	4.699	4.436	4.214	3.508	2.026	1.591	1.390	5.039
OILC3	5.271	4.749	4.364	4.056	3.815	3.612	2.968	1.658	1.279	0.965	4.749
OILC4	6.644	6.002	5.541	5.173	4.883	4.634	3.840	2.180	1.703	1.456	6.002
HEATC1	6.922	6.347	5.849	5.456	5.157	4.904	4.086	2.360	1.883	1.290	5.849
HEATC2	5.460	5.340	5.151	4.976	4.822	4.665	4.131	2.682	2.166	1.342	4.976
HEATC3	6.664	6.118	5.677	5.321	5.041	4.795	4.008	2.280	1.777	1.197	6.118
HEATC4	5.888	5.677	5.476	5.291	5.132	4.961	4.399	2.882	2.280	1.300	5.291

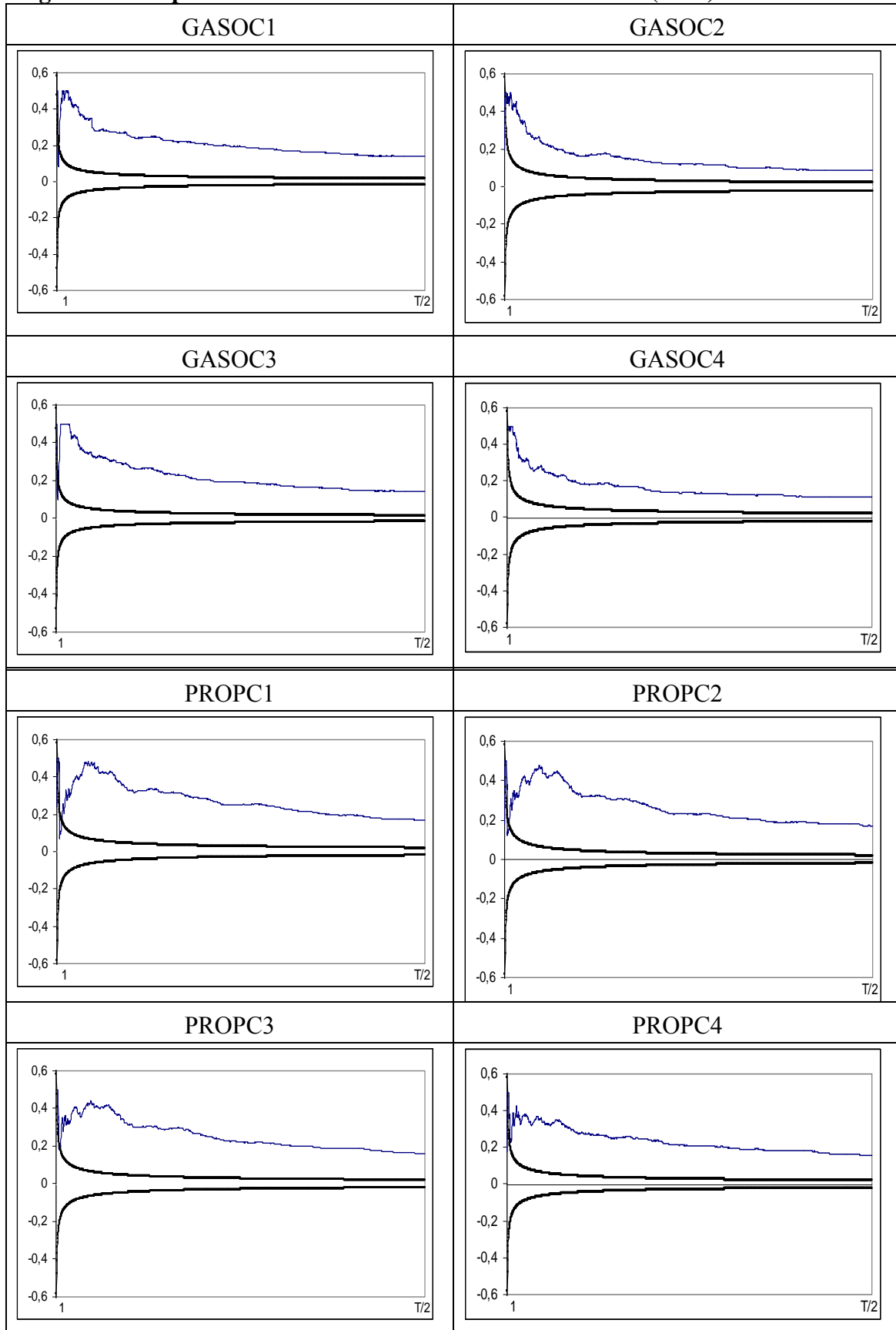
The 95% confidence interval for the  $I(0)$  null hypothesis is [0.809, 1.862].

**Table 5: Giraitis et al. (2003) V/S statistic results ( $M_T(q)$ )**

Series / q	0	1	2	3	4	5	10	50	100	500	$q^*$
GASOC1	2.7801	2.4002	2.1261	1.9045	1.7399	1.6038	1.1937	0.4507	0.2838	0.1542	1.9045
GASOC2	2.5228	2.3517	2.2265	2.0969	1.9923	1.8933	1.5711	0.6928	0.4388	0.1436	2.3517
GASOC3	3.7290	3.2032	2.8316	2.5371	2.3102	2.1179	1.5240	0.5452	0.3324	0.1794	2.5371
GASOC4	2.9574	2.6337	2.4352	2.2709	2.1365	2.0091	1.6089	0.7155	0.4490	0.1410	2.2709
PROPC1	3.1903	2.6505	2.2369	1.9320	1.7138	1.5421	1.0564	0.4051	0.3081	0.1856	1.5421
PROPC2	3.3748	2.7821	2.3771	2.0766	1.8423	1.6592	1.1312	0.4286	0.3144	0.1810	1.8423
PROPC3	3.6527	3.0538	2.6123	2.2973	2.0442	1.8457	1.2788	0.4884	0.3487	0.1783	2.0442
PROPC4	3.6671	3.0721	2.6474	2.3495	2.1159	1.9318	1.3897	0.5511	0.3795	0.1742	2.6474
OILC1	2.1101	1.6922	1.4303	1.2312	1.0909	0.9805	0.6748	0.2139	0.1278	0.0744	1.6922
OILC2	2.0623	1.7227	1.4828	1.2899	1.1494	1.0372	0.7186	0.2399	0.1478	0.1128	1.4828
OILC3	2.2410	1.8190	1.5367	1.3264	1.1749	1.0522	0.7109	0.2213	0.1319	0.0751	1.8190
OILC4	3.0081	2.4546	2.0922	1.8325	1.6248	1.4632	1.0046	0.3239	0.1978	0.1446	2.4546
HEATC1	3.1489	2.6474	2.2481	1.9564	1.7473	1.5806	1.0974	0.3661	0.2331	0.1094	2.2481
HEATC2	2.9301	2.8030	2.6081	2.4335	2.2857	2.1392	1.6774	0.7073	0.4614	0.1772	2.4335
HEATC3	3.1651	2.6684	2.2973	2.0185	1.8113	1.6393	1.1452	0.3705	0.2250	0.1022	2.2973
HEATC4	3.4902	3.2444	3.0182	2.8184	2.6512	2.4779	1.9480	0.8365	0.5234	0.1703	3.0182

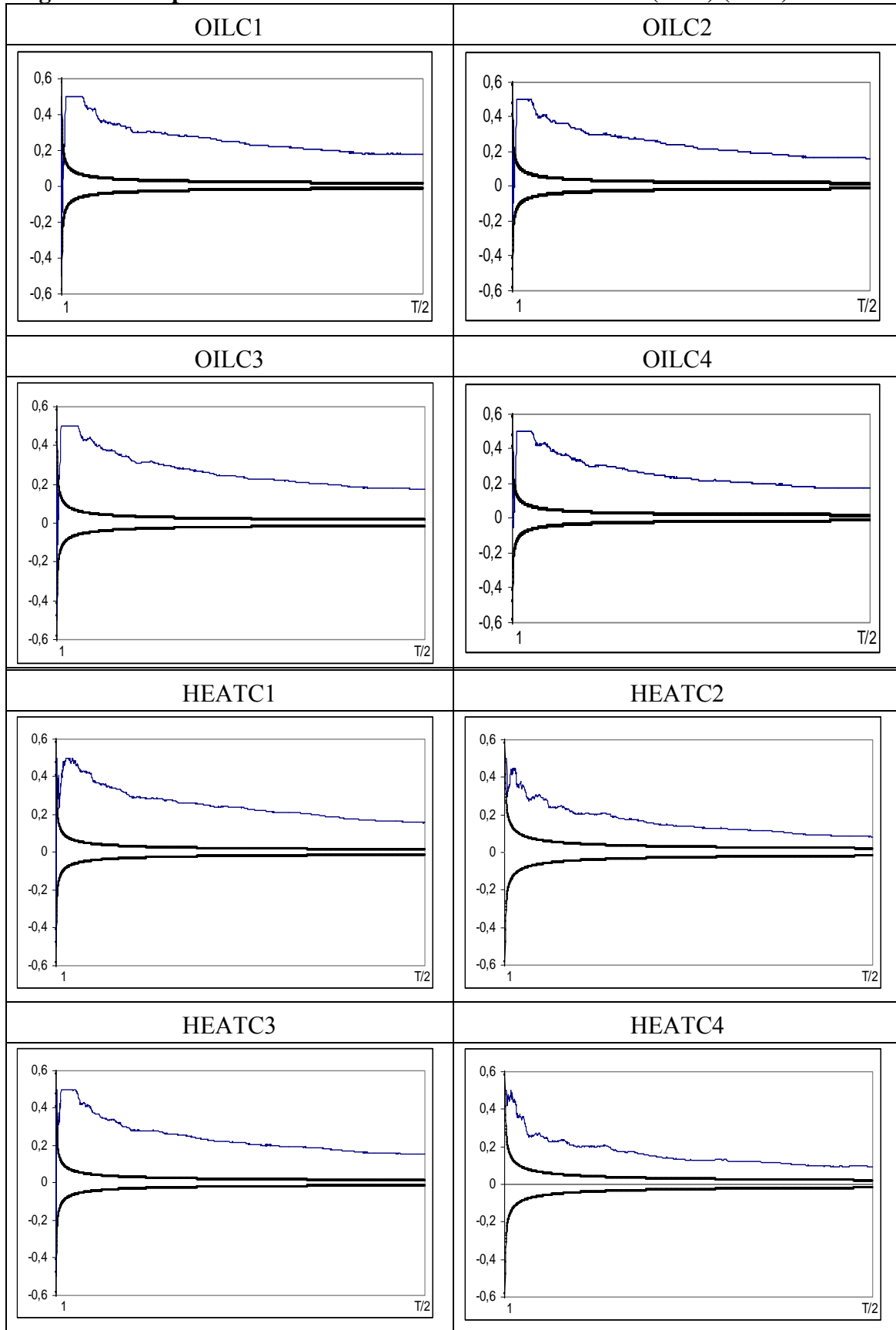
The critical value at the 95% level is  $1.36/\sqrt{T}$ , that is, 0.0183 for GASC1; 0.0239 for GASC2; 0.0183 for GASC3; and 0.0241 for GASC4. 0.0231 for PROC1; 0.0232 for PROC3; and 0.0231 for PROC4. 0.0173 for OILC1; 0.0180 for OILC2; and 0.0180 for OILC4. 0.0163 for HEAC1; 0.0232 for HEAC2; 0.0163 for HEAC3; and 0.0232 for HEAC4.

**Figure 2: Semiparametric estimates of  $d$  based on Robinson (1995)**



(cont.)

**Figure 2: Semiparametric estimates of  $d$  based on Robinson (1995) (cont.)**



**Table 6: Estimates of d and 95% confidence band using Robinson's (1994) approach**

	White noise	AR (1)	Bloomfield (1)
GASOC1	<b>0.143</b> [0.131, 0.157]	<b>0.207</b> [0.189, 0.227]	<b>0.216</b> [0.198, 0.239]
GASOC2	<b>0.075</b> [0.062, 0.091]	<b>0.103</b> [0.084, 0.127]	<b>0.107</b> [0.084, 0.130]
GASOC3	<b>0.156</b> [0.144, 0.168]	<b>0.216</b> [0.199, 0.235]	<b>0.233</b> [0.213, 0.258]
GASOC4	<b>0.099</b> [0.085, 0.117]	<b>0.115</b> [0.096, 0.140]	<b>0.117</b> [0.095, 0.141]
PROC1	<b>0.190</b> [0.175, 0.205]	<b>0.291</b> [0.267, 0.316]	<b>0.321</b> [0.292, 0.346]
PROC2	<b>0.188</b> [0.173, 0.204]	<b>0.267</b> [0.244, 0.291]	<b>0.289</b> [0.256, 0.313]
PROC3	<b>0.177</b> [0.163, 0.194]	<b>0.261</b> [0.237, 0.287]	<b>0.280</b> [0.251, 0.313]
PROC4	<b>0.171</b> [0.156, 0.188]	<b>0.241</b> [0.216, 0.269]	<b>0.254</b> [0.225, 0.285]
OILC1	<b>0.195</b> [0.184, 0.206]	<b>0.259</b> [0.243, 0.277]	<b>0.274</b> [0.255, 0.294]
OILC2	<b>0.182</b> [0.172, 0.194]	<b>0.259</b> [0.243, 0.276]	<b>0.289</b> [0.264, 0.303]
OILC3	<b>0.188</b> [0.178, 0.199]	<b>0.262</b> [0.245, 0.279]	<b>0.281</b> [0.262, 0.301]
OILC4	<b>0.193</b> [0.183, 0.205]	<b>0.262</b> [0.246, 0.278]	<b>0.284</b> [0.260, 0.304]
HEATC1	<b>0.168</b> [0.159, 0.179]	<b>0.257</b> [0.241, 0.275]	<b>0.277</b> [0.258, 0.296]
HEATC2	<b>0.080</b> [0.068, 0.095]	<b>0.149</b> [0.125, 0.175]	<b>0.161</b> [0.133, 0.198]
HEATC3	<b>0.163</b> [0.153, 0.173]	<b>0.237</b> [0.221, 0.251]	<b>0.252</b> [0.233, 0.272]
HEATC4	<b>0.087</b> [0.074, 0.101]	<b>0.132</b> [0.112, 0.157]	<b>0.140</b> [0.114, 0.169]

## Appendix 1.

### Sample period

	Starting date	Ending date	Number of Observations
<b>Gasoline</b>			
Contract 1	January 02, 1985	December 29, 2006	5514
Contract 2	January 20, 1994	November 30, 2006	3218
Contract 3	December 03, 1984	October 31, 2006	5492
Contract 4	January 28, 1994	September 29, 2006	3170
<b>Propane</b>			
Contract 1	December 17, 1993	October 02, 2007	3447
Contract 2	February 02, 1994	October 02, 2007	3416
Contract 3	February 08, 1994	October 02, 2007	3412
Contract 4	December 17, 1993	October 02, 2007	3447
<b>Oil</b>			
Contract 1	April 04, 1983	October 02, 1985	6143
Contract 2	January 02, 1985	October 02, 2007	5705
Contract 3	March 30, 1983	October 02, 2007	6145
Contract 4	January 02, 1985	October 02, 2007	5705
<b>Heating Oil</b>			
Contract 1	January 02, 1980	October 02, 2007	6159
Contract 2	February 02, 1994	October 02, 2007	3418
Contract 3	January 02, 1980	October 02, 2007	6159
Contract 4	January 14, 1994	October 02, 2007	3433



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