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Aggregation and the Long Run Behaviour of Economic Time Series

Monte Carlo experiments

by

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Preliminary version

Abstract

The aggregation problem is a well-known difficulty in macroeconometric modelling. It is frequently assumed in these models that the behaviour of economic agents is uniform. Thus the behaviour of a single agent characterizes the aggregate behaviour of the agents (representative agent). However, there may always be some "outliers", some uncharacteristically behaving agents. Such outliers may well determine the time dynamics of the aggregate time series. The paper presents different Monte Carlo experiments to demonstrate this feature. This phenomenon may have an utmost significance in models assuming the cointegration of the variables.

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Introduction

Perron and Phillips (and earlier *Stock and Watson* [1986]) in their 1987 paper asked the important question "Does GNP have a unit root?" (*Perron and Phillips* [1987]). The answer was: it "depends upon the series used and the sample period analyzed" (p. 144). In this paper we try to give a different answer to this question.

It has become evident in the last 10–15 years that several macroeconomic issues depend heavily on the characteristics of macroeconomic data. The existence of cycles, the analysis of consumers' behaviour, labour demand, money supply, etc. depend on whether or not the aggregate variables involved in the study have unit roots or not (or whether they are cointegrated or not). Obviously, the time series characteristics of any data set are strongly affected by the way the data is collected and manipulated. While most of the economic decisions are made by individual agents, the available data usually reflect the behaviour of some group of individuals. So we are forced to observe the economic reality through a cross sectional "aggregation window" (*Granger* [1992]).

The effects of aggregation have been studied extensively in the literature. However, little has been done (*e.g., Rossana and Seater* [1992]) to analyse the effects of this aggregation on the nature of time series.

Macroeconometric models frequently assume that the behaviour of economic agents is uniform, and thus the behaviour of a single agent characterizes the aggregate behaviour of the agents. This assumption of the existence of a *representative agent* renders modelling simpler, and frequently feasible. It was always recognized there may be some outliers, some agents who, for any particular reason, may behave differently. Nevertheless, the maintained hypothesis is that the effects of these perturbations cancel each other, and hence they can be ignored. There is an abundance of papers on the long–run characteristics of the behaviour of representative agents.

In this paper we demonstrate that the above mentioned two concepts, the assumption of representative agents and of (co)integration may frequently be incompatible.

The problem is all too significant as the majority of empirical studies of (co)integration explicitly or implicitly assume the existence of representative agents.

Theory

Definition: Two time series x_t and y_t are cointegrated: $x_t,\ y_t \sim \mathrm{CI}(d, b))$ if

— both variables are integrated to the same order d: $x_t,\ y_t \sim \mathrm{I}(d)$,

— there is a $z_t = y_t - \beta x_t$ linear combination which is integrated to a lower order: $z_t \sim \mathrm{I}(d-b)$, $b > 0$. The $(1, -\beta)$ vector is called the cointegrating vector.

There are n agents in an economy measured over T time periods. Their behaviour is represented by two time series, x_{it} and y_{it} $(i = 1, \ldots, n;\ t = 1, \ldots, T)$. Their relation is characterized by the $y_{it} = \beta_i x_{it} + u_{it}$ regression. x_t and y_t $(t = 1, \ldots, T)$ denote the aggregate time series: $x_t = \sum x_{it}$ and $y_t = \sum y_{it}$.

Property 1: If time series x_{1t} is integrated to order 1, but all other time series x_{it} $(i = 2, \ldots, n)$ are stationary, the aggregate time series x_t is integrated to order one. More generally, if $x_{it} \sim \mathrm{I}(d_i)$, and $d = \max d_i$, then $x_t \sim \mathrm{I}(d)$.

This means that an aggregated time series "inherits" the integration of the single individual with the integration of the highest order.

Property 2: If time series x_{1t} and y_{1t} are cointegrated to order 1, *i.e.*, $x_{1t},\ y_{1t} \sim \mathrm{CI}(1,1)$ with cointegrating vector $(1, \beta_1)$, and all other x_{it} and y_{it} $(i = 2, \ldots, n)$ are stationary, the x_t and y_t aggregate time series are cointegrated to order 1, and their cointegrating vector is $(1, -\beta_1)$ as well, regardless of all other β_i coefficients. More generally, if $x_{1t},\ y_{1t} \sim \mathrm{CI}(d, b)$, and for all other agents $x_{it},\ y_{it} \sim \mathrm{I}(d_i)$ where $d_i \leq (d - b)$, then the two aggregated time series $x_t,\ y_t \sim \mathrm{CI}(d, b)$.

This means that an aggregate time series may be cointegrated even if the variables are cointegrated for only one individual agent, but for all the other agents they are not.

Property 3: If $x_{1t},\ x_{2t} \sim \mathrm{CI}(2,1)$ and all other x_{it} $(i = 3, \ldots, n)$ are stationary, the aggregate time series x_t is integrated to order one. More generally, if $x_{1t},\ x_{2t} \sim \mathrm{CI}(d, b)$ and all other $x_{it} \sim \mathrm{I}(d_i)$ $(i = 3, \ldots, n)$ where $d_i \leq (d - b)$, then $x_t \sim \mathrm{I}(d - b)$.

This means that an aggregate time series may be integrated to an order different from the order of the integration of any of its components.

Property 4: If $x_{it},\ y_{it} \sim \mathrm{CI}(1,1)$ with cointegrating vector $(1, \beta_i)$ $(i = 1, \ldots, n)$, and $\beta_i \neq \beta_j$ for any i and j, then time series x_t and y_t are not necessarily cointegrated. (As a matter of fact they need not be integrated, *c.f.*, property 3.)

This means that aggregate time series may not be cointegrated even if the variables are cointegrated for all individual agents.

Monte Carlo experiments

The outcome of a (co)integration testing procedure on aggregate time series data (from the point of view of our study) and therefore the results of the analysis depend on three factors:

— the presence and characteristics of individual time (trend) heterogeneity among the individual time series that make up the aggregate series;

— the effect of aggregation on this heterogeneity; and

— the size and the power of the (co)integration tests.

The joint effects of these factors can properly be analysed by Monte Carlo experiments.

Five different types of individual behaviour are assumed for the simulation which are characterized by different time series properties. The time series models used in this study are: $y_1 \sim$ IMA(0,0), $y_2 \sim$ IMA(0,1), $y_3 \sim$ IMA(1,0), $y_4 \sim$ IMA(1,1) and $y_5 \sim$ IMA(2,0). The coefficient of the moving average process is 0.8. The disturbance term is $\mathcal{N}(0,1)$, and the drift is 2 for all series. Five different time series lengths were used: 25, 50 100, 250 and 500 observations.

First, we tested the time series properties of aggregate variables, where each aggregate variable is a sum of 20 individuals. Seven aggregate variables were generated:

$$x_1 = \sum_{i=1}^{20} y_{2,i}$$

$$x_2 = y_3 + \sum_{i=1}^{19} y_{1,i}$$

$$x_3 = y_3 + \sum_{i=1}^{19} y_{2,i}$$

$$x_4 = y_4 + \sum_{i=1}^{19} y_{1,i}$$

$$x_5 = y_4 + \sum_{i=1}^{19} y_{2,i}$$

$$x_6 = y_5 + \sum_{i=1}^{19} y_{1,i}$$

$$x_7 = y_5 + \sum_{i=1}^{4} y_{3,i} + \sum_{i=1}^{15} y_{1,i}$$

Integration of these aggregate series was tested by several variants of three different tests: the Dickey–Fuller [1981] test and its augmented version (Said and Dickey [1984]), the Phillips–Perron [1988] test and the Kwiatkowski–Phillips–Schmidt–Shin [1992] test. We computed all tests without and with deterministic trend. Although none of the aggregated time series models has a deterministic trend component, the general practice in applied work is to assume its existence.

Establishing the level of integration of the variables is the first step of the cointegration analysis. Only variables, integrated to the same order, can be cointegrated.

Results of the Monte Carlo experiments

Tables 1–7 summarize the results of the experiments[1] with the seven above defined aggregated time series models. All results are based on 1000 replications of the experiments.

Model 1 is the sum of stationary moving average processes, so this experiment indicates the size of the KPSS test, as it should maintain the null of stationarity. The other tests should reject the null of non–stationarity, so the experiments indicate the power of these tests.

The power of the (augmented) Dickey–Fuller test clearly increases with the sample size. The test in its original form is believed to be sensitive to the error autocorrelation. However, our experiments suggest that it is slightly more powerful than the ADF test. Both versions are rather powerful in case of the differences, where the error autocorrelation is less important. The Phillips–Perron test does not seem to be more powerful than the Dickey–Fuller test. The first version of the KPSS test which is not corrected for autocorrelation is clearly very sensitive to strong error autocorrelation, and its effect increases with the sample size.

Model 2 is the sum of one random walk process and white noise processes. The tests without deterministic trend clearly indicate that the aggregate variable is not stationary. The (augmented) DF and PP tests with deterministic trends suggest that it is a trend–stationary process by rejecting the correct null hypothesis of difference–stationarity in the majority of cases. In large samples the situation is even worse for

[1] Legend to the tables: DF denotes Dickey–Fuller test, ADF is its augmented version assuming first order autocorrelation of the errors. $\hat{\tau}_\mu$ is the t–value from the regression without trend and $\hat{\tau}_\tau$ is the t–value assuming trend. PP denotes the Phillips–Perron test. All four alternative tests are computed under the assumption of first order autocorrelation. KPSS stands for the Kwiatkowski–Phillips–Schmidt–Shin test, KPSS1 assumes first order autocorrelation. x indicates that the test is for the stationarity of the level of the variable, while dx indicates that the stationarity of the first differences was tested. Cr 1% and Cr 5% are the appropriate critical values at the 0.01 and the 0.05 levels of significance. S 1% and S 5% are the share of the experiments in which the test was significant at the 0.01 and 0.05 level of significance.

the tests based on the t-value than in small ones. The Phillips–Perron test based on the estimated coefficient improves with larger samples, but the size is far too large. The KPSS test has a similar problem in distinguishing between the deterministic and the stochastic trends in the small samples, but the power of the test improves markedly with the sample size. The size of the KPSS tests is surprisingly small for the differences in large samples.

These results question the general practice of including deterministic trend when the test is performed. Especially in large samples the stochastic trends are highly correlated, and the emerging multicollinearity strongly influences the outcome of the test. In this clear case of random walk with a drift the deterministic trend tends to dominate the stochastic one, according to the computed tests.

Model 3 is similar to model 2, but stationary moving average processes are added to the random walk. Results are similar to the ones obtained for the previous model. There is little difference in the size of the DF, ADF and PP tests for the levels, although the aggregate variable is mostly composed of moving average processes. The power of the DF test is actually larger when the stationarity of the differences is tested than that of the ADF test, especially in small samples.

Model 4 is the sum of an integrated moving average process and white noise time series. Tests assuming autocorrelated errors give clearly better results than for the previous two models. The size of ADF and PP(t) tests for the levels and of the KPSS tests for the differences is not far from the correct one in the large samples. The power of the KPSS test against trend–stationarity is only affected by small samples.

Model 5 is the sum of an integrated moving average process and stationary moving average processes. The size of the (A)DF and PP tests without trend is usually too low. KPSS is weak in small samples when the null hypothesis is trend–stationarity against the difference–stationary alternative. However, the overall picture emerging from this experiment is close to the expected one: the general conclusion is that the aggregate time series is integrated to order one.

Model 6 is the sum of an integrated process to order two and white noise variables. The positive $\hat{\tau}_\mu$, $t_{\hat{\alpha}}$ and $T(\hat{\alpha}-1)$ values for the levels are a clear indication: there is something wrong with testing the I(1) null against I(0) alternative. The size of DF and ADF tests against the stationarity of differences is wrong again. ADF tests reject the correct null of difference–stationarity against the trend–stationary alternative in most cases. KPSS proved to be powerful in rejecting stationarity both for levels and for differences.

Model 7 is the sum of I(2), I(1) and I(0) processes, without autocorrelation in the disturbances. Results are largely similar to Model 6. All tests indicate that the levels are non–stationary, and all but the $\hat{\tau}_\tau$ tests indicate that differences are not stationary either.

The studied test clearly detected the characteristics expected from the theoretical models in most cases. Tests for stationarity almost always properly indicate the derived dominant characteristics even for relatively small samples. The very frequently applied tests where the null hypothesis is the stochastic trend against a (probably non-significant) deterministic trend, however, point regularly to a deterministic trend if the aggregated time series are strongly autocorrelated moving average processes.

It is clear that aggregation does not dissipate the effect of the outliers: the presence of the non–stationary component is prominent even in very small samples. Taking into account that there was only one non–stationary outlier in all but one model, there are obvious problems with "real" macro–economic time series, if one single individual agent may influence the dynamics of this aggregate variable. In practice, there may be thousands of such outliers. Therefore, the long–run behaviour of the macro time series may, in effect, reflect the individual behaviour of one or a handful of agents.

On a further note, however, it is clear that the properties of these tests are also influenced by the aggregation of many different stationary processes, especially when they are strongly autocorrelated. Thus aggregation does not even "average out" those discrepancies which have no long–run effects.

Conclusion

Returning to our original question whether GNP has a unit root or not, our answer is: it does not matter because this neither reflects the real long run behaviour of the economic agents nor the data generating process.

If a macroeconometric model is based on microeconomic theory and the data generating process is dynamic, even one single outlier may change the characteristics of the aggregate model. The assumed microeconomic behaviour may not be observed in the aggregate time series, and the dynamic characteristics of the aggregate time series may reflect the behaviour of one single extreme agent. If there are several agents with extreme behaviour, the characteristics of the aggregate series may not correspond to any of its components. In such cases any inference from the aggregate time series may be severely biased, and thus useless. Therefore results of (co)integration analysis of aggregate time series should be interpreted with very strong reservation and caution.

In practice these strange characteristics may not always be apparent because of the limited length of the time series: the behaviour of the extreme agent(s) may not dominate the characteristics of a relatively short observation period. However, by obtaining more observations, so increasing the reliability of measurement, the model may actually become worse rather than better: the formerly unrecognized behaviour may become dominant.

Our results also indicate that the conclusion strongly depends on the tests used. The most commonly used tests may give very misleading results if the aggregate time series is a sum of many such individual series which all have highly autocorrelated stationary components.

The only real solution of the problem seems to be the use of micro data (*e.g.*, panel data) which facilitates the identification of outliers, instead of aggregation.

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Table 1 Monte Carlo results for Model 1

	Sample size: 25					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.75	−3.00	−2.1478	0.7475	0.122	0.026
DF x, $\hat{\tau}_\tau$	−4.38	−3.60	−2.4832	0.7783	0.081	0.019
ADF x, $\hat{\tau}_\mu$	−3.75	−3.00	−2.0744	0.7937	0.110	0.032
ADF x, $\hat{\tau}_\tau$	−4.38	−3.60	−2.4251	0.8388	0.092	0.018
DF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−5.2477	1.0745	0.992	0.940
DF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−5.2325	1.0822	0.957	0.781
ADF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−3.8192	0.9193	0.828	0.473
ADF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−3.8641	0.9471	0.574	0.240
PP x, $t_{\hat{\alpha}}$	−3.75	−3.00	−2.2809	0.7769	0.170	0.035
PP x, $t_{\tilde{\alpha}}$	−4.38	−3.60	−2.7003	0.8152	0.123	0.031
PP x, $T(\hat{\alpha}-1)$	−17.2	−12.5	−9.0742	4.3653	0.369	0.115
PP x, $T(\tilde{\alpha}-1)$	−22.5	−17.9	−11.4329	4.5949	0.038	0.005
KPSS x, η_μ	0.739	0.463	0.6550	0.4432	0.562	0.355
KPSS x, η_τ	0.216	0.146	0.2050	0.1004	0.671	0.399
KPSS dx, η_μ	0.739	0.463	0.1149	0.0699	0.002	0.000
KPSS1 dx, η_μ	0.739	0.463	0.1272	0.0703	0.003	0.000
KPSS dx, η_τ	0.216	0.146	0.0684	0.0271	0.020	0.000
KPSS1 dx, η_τ	0.216	0.146	0.0778	0.0248	0.022	0.000

	Sample size: 50					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.58	−2.93	−2.6655	0.6482	0.313	0.086
DF x, $\hat{\tau}_\tau$	−4.15	−3.50	−2.9299	0.6769	0.191	0.045
ADF x, $\hat{\tau}_\mu$	−3.58	−2.93	−2.5487	0.6770	0.257	0.080
ADF x, $\hat{\tau}_\tau$	−4.15	−3.50	−2.8215	0.7009	0.145	0.040
DF dx, $\hat{\tau}_\mu$	−3.58	−2.93	−7.5930	1.0644	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−4.15	−3.50	−7.5453	1.0584	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.58	−2.93	−5.5808	0.8438	1.000	0.996
ADF dx, $\hat{\tau}_\tau$	−4.15	−3.50	−5.5603	0.8497	0.997	0.968
PP x, $t_{\hat{\alpha}}$	−3.58	−2.93	−2.7504	0.6678	0.372	0.117
PP x, $t_{\tilde{\alpha}}$	−4.15	−3.50	−3.0654	0.7007	0.254	0.066
PP x, $T(\hat{\alpha}-1)$	−18.9	−13.3	−13.7678	5.2656	0.673	0.289
PP x, $T(\tilde{\alpha}-1)$	−25.7	−19.8	−16.2898	5.7481	0.137	0.024
KPSS x, η_μ	0.739	0.463	0.9637	0.7047	0.736	0.503
KPSS x, η_τ	0.216	0.146	0.3181	0.1670	0.865	0.680
KPSS dx, η_μ	0.739	0.463	0.0691	0.0386	0.000	0.000
KPSS1 dx, η_μ	0.739	0.463	0.0768	0.0420	0.000	0.000
KPSS dx, η_τ	0.216	0.146	0.0468	0.0191	0.003	0.000
KPSS1 dx, η_τ	0.216	0.146	0.0521	0.0192	0.002	0.000

	Sample size: 100					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.51	−2.89	−3.5684	0.6073	0.879	0.501
DF x, $\hat{\tau}_\tau$	−4.04	−3.45	−3.7250	0.6125	0.641	0.283
ADF x, $\hat{\tau}_\mu$	−3.51	−2.89	−3.3981	0.6307	0.772	0.402
ADF x, $\hat{\tau}_\tau$	−4.04	−3.45	−3.5606	0.6418	0.530	0.229
DF dx, $\hat{\tau}_\mu$	−3.51	−2.89	−10.9099	1.0721	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−4.04	−3.45	−10.8645	1.0677	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.51	−2.89	−7.9957	0.8560	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−4.04	−3.45	−7.9670	0.8537	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.51	−2.89	−3.6268	0.6230	0.897	0.543
PP x, $t_{\tilde{\alpha}}$	−4.04	−3.45	−3.8146	0.6285	0.705	0.335
PP x, $T(\hat{\alpha}-1)$	−19.8	−13.7	−23.9096	7.0594	0.977	0.810
PP x, $T(\tilde{\alpha}-1)$	−27.4	−20.7	−26.0366	7.3138	0.637	0.287
KPSS x, η_μ	0.739	0.463	1.1417	0.8950	0.791	0.575
KPSS x, η_τ	0.216	0.146	0.4302	0.2440	0.960	0.824
KPSS dx, η_μ	0.739	0.463	0.0369	0.0173	0.000	0.000
KPSS1 dx, η_μ	0.739	0.463	0.0409	0.0187	0.000	0.000
KPSS dx, η_τ	0.216	0.146	0.0276	0.0090	0.000	0.000
KPSS1 dx, η_τ	0.216	0.146	0.0307	0.0097	0.000	0.000

	Sample size: 250					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.46	−2.88	−5.4288	0.5721	1.000	1.000
DF x, $\hat{\tau}_\tau$	−3.99	−3.43	−5.5322	0.5815	1.000	0.997
ADF x, $\hat{\tau}_\mu$	−3.46	−2.88	−5.1452	0.5786	1.000	0.999
ADF x, $\hat{\tau}_\tau$	−3.99	−3.43	−5.2553	0.5924	0.999	0.992
DF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−17.4177	1.0495	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−17.3853	1.0478	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−12.7898	0.8302	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−12.7671	0.8291	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.46	−2.88	−5.4612	0.5814	1.000	1.000
PP x, $t_{\tilde{\alpha}}$	−3.99	−3.43	−5.5834	0.5929	1.000	0.998
PP x, $T(\hat{\alpha}-1)$	−20.3	−14.0	−53.9681	10.2165	1.000	1.000
PP x, $T(\tilde{\alpha}-1)$	−28.4	−21.3	−56.1247	10.5425	1.000	0.998
KPSS x, η_μ	0.739	0.463	1.3765	1.1211	0.846	0.663
KPSS x, η_τ	0.216	0.146	0.5190	0.3171	0.966	0.892
KPSS dx, η_μ	0.739	0.463	0.0156	0.0063	0.000	0.000
KPSS1 dx, η_μ	0.739	0.463	0.0173	0.0071	0.000	0.000
KPSS dx, η_τ	0.216	0.146	0.0122	0.0030	0.000	0.000
KPSS1 dx, η_τ	0.216	0.146	0.0135	0.0034	0.000	0.000

	Sample size: 500					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.44	−2.87	−7.5370	0.5667	1.000	1.000
DF x, $\hat{\tau}_\tau$	−3.98	−3.42	−7.6041	0.5699	1.000	1.000
ADF x, $\hat{\tau}_\mu$	−3.44	−2.87	−7.1450	0.5726	1.000	1.000
ADF x, $\hat{\tau}_\tau$	−3.98	−3.42	−7.2159	0.5795	1.000	1.000
DF dx, $\hat{\tau}_\mu$	−3.44	−2.87	−24.6721	1.0345	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−3.98	−3.42	−24.6482	1.0335	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.44	−2.87	−18.1040	0.8073	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−3.98	−3.42	−18.0869	0.8066	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.44	−2.87	−7.5581	0.5765	1.000	1.000
PP x, $t_{\tilde{\alpha}}$	−3.98	−3.42	−7.6378	0.5811	1.000	1.000
PP x, $T(\hat{\alpha}-1)$	−20.5	−14.0	−103.212	14.1926	1.000	1.000
PP x, $T(\tilde{\alpha}-1)$	−28.9	−21.5	−105.183	14.3968	1.000	1.000
KPSS x, η_μ	0.739	0.463	1.4142	1.1910	0.848	0.662
KPSS x, η_τ	0.216	0.146	0.5514	0.3321	0.986	0.918
KPSS dx, η_μ	0.739	0.463	0.0080	0.0031	0.000	0.000
KPSS1 dx, η_μ	0.739	0.463	0.0089	0.0035	0.000	0.000
KPSS dx, η_τ	0.216	0.146	0.0064	0.0014	0.000	0.000
KPSS1 dx, η_τ	0.216	0.146	0.0070	0.0015	0.000	0.000

Table 2 Monte Carlo results for Model 2

	Sample size: 25						Sample size: 50						Sample size: 100					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.75	−3.00	−1.0282	0.4546	0.000	0.000	−3.58	−2.93	−0.7648	0.3071	0.000	0.000	−3.51	−2.89	−0.5308	0.2537	0.000	0.000
DF x, $\hat{\tau}_\tau$	−4.38	−3.60	−4.8143	1.0674	0.896	0.638	−4.15	−3.50	−6.2906	1.1008	0.998	0.983	−4.04	−3.45	−8.0290	1.2866	1.000	1.000
ADF x, $\hat{\tau}_\mu$	−3.75	−3.00	−0.6256	0.5338	0.000	0.000	−3.58	−2.93	−0.4503	0.4101	0.000	0.000	−3.51	−2.89	−0.3068	0.3667	0.000	0.000
ADF x, $\hat{\tau}_\tau$	−4.38	−3.60	−3.5253	0.9454	0.421	0.167	−4.15	−3.50	−4.4209	0.9285	0.840	0.612	−4.04	−3.45	−5.3972	1.0282	0.973	0.903
DF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−7.8743	1.6113	1.000	1.000	−3.58	−2.93	−11.5688	1.6449	1.000	1.000	−3.51	−2.89	−16.7441	1.5991	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−7.7297	1.5898	1.000	0.998	−4.15	−3.50	−11.4647	1.6342	1.000	1.000	−4.04	−3.45	−16.6700	1.5935	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−5.5255	1.1678	0.997	0.960	−3.58	−2.93	−8.1642	1.1776	1.000	1.000	−3.51	−2.89	−11.7383	1.1093	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−5.4519	1.1694	0.972	0.833	−4.15	−3.50	−8.1058	1.1686	1.000	1.000	−4.04	−3.45	−11.6959	1.1061	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.75	−3.00	−0.8543	0.5874	0.000	0.000	−3.58	−2.93	−0.5871	0.4124	0.000	0.000	−3.51	−2.89	−0.3830	0.3489	0.000	0.000
PP x, $t_{\tilde{\alpha}}$	−4.38	−3.60	−5.1626	1.1579	0.936	0.745	−4.15	−3.50	−6.4868	1.1496	0.998	0.987	−4.04	−3.45	−8.1123	1.3526	1.000	1.000
PP x, $T(\hat{\alpha}-1)$	−17.2	−12.5	−1.4059	1.0470	0.994	0.944	−18.9	−13.3	−0.6662	0.4796	1.000	0.998	−19.8	−13.7	−0.3039	0.2796	1.000	1.000
PP x, $T(\tilde{\alpha}-1)$	−22.5	−17.9	−24.5206	4.7457	0.000	0.000	−25.7	−19.8	−44.4074	8.4782	0.000	0.000	−27.4	−20.7	−77.1464	16.4207	0.000	0.000
KPSS x, η_μ	0.739	0.463	2.2019	0.0825	1.000	1.000	0.739	0.463	4.7781	0.0504	1.000	1.000	0.739	0.463	9.8269	0.0486	1.000	1.000
KPSS x, η_τ	0.216	0.146	0.0837	0.0496	0.121	0.022	0.216	0.146	0.1485	0.1064	0.393	0.198	0.216	0.146	0.3569	0.2719	0.769	0.612
KPSS dx, η_μ	0.739	0.463	0.0703	0.0370	0.000	0.000	0.739	0.463	0.0398	0.0214	0.000	0.000	0.739	0.463	0.0250	0.0151	0.000	0.000
KPSS1 dx, η_μ	0.739	0.463	0.0991	0.0468	0.000	0.000	0.739	0.463	0.0572	0.0285	0.000	0.000	0.739	0.463	0.0363	0.0214	0.000	0.000
KPSS dx, η_τ	0.216	0.146	0.0488	0.0150	0.000	0.000	0.216	0.146	0.0268	0.0081	0.000	0.000	0.216	0.146	0.0153	0.0044	0.000	0.000
KPSS1 dx, η_τ	0.216	0.146	0.0701	0.0172	0.001	0.000	0.216	0.146	0.0388	0.0102	0.000	0.000	0.216	0.146	0.0223	0.0061	0.000	0.000

	Sample size: 250						Sample size: 500					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.46	−2.88	−0.3400	0.1949	0.000	0.000	−3.44	−2.87	−0.2396	0.1757	0.000	0.000
DF x, $\hat{\tau}_\tau$	−3.99	−3.43	−10.0821	1.7756	1.000	1.000	−3.98	−3.42	−11.5564	2.3834	1.000	1.000
ADF x, $\hat{\tau}_\mu$	−3.46	−2.88	−0.1920	0.3098	0.000	0.000	−3.44	−2.87	−0.1379	0.2859	0.000	0.000
ADF x, $\hat{\tau}_\tau$	−3.99	−3.43	−6.4486	1.3205	0.992	0.980	−3.98	−3.42	−7.1547	1.6411	0.998	0.987
DF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−26.7061	1.5450	1.000	1.000	−3.44	−2.87	−38.0079	1.6641	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−26.6582	1.5422	1.000	1.000	−3.98	−3.42	−37.9735	1.6627	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−18.6924	1.1468	1.000	1.000	−3.44	−2.87	−26.4747	1.1072	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−18.6644	1.1446	1.000	1.000	−3.98	−3.42	−26.4547	1.1062	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.46	−2.88	−0.2442	0.2714	0.000	0.000	−3.44	−2.87	−0.1707	0.2452	0.000	0.000
PP x, $t_{\tilde{\alpha}}$	−3.99	−3.43	−9.8834	1.9553	1.000	0.999	−3.98	−3.42	−10.9212	2.6544	1.000	1.000
PP x, $T(\hat{\alpha}-1)$	−20.3	−14.0	−0.1208	0.1346	1.000	1.000	−20.5	−14.0	−0.0593	0.0850	1.000	1.000
PP x, $T(\tilde{\alpha}-1)$	−28.4	−21.3	−133.991	39.6813	0.000	0.000	−28.9	−21.5	−182.372	71.5314	0.000	0.000
KPSS x, η_μ	0.739	0.463	24.8594	0.0664	1.000	1.000	0.739	0.463	49.8688	0.0900	1.000	1.000
KPSS x, η_τ	0.216	0.146	1.3656	0.9157	0.988	0.962	0.216	0.146	3.3418	2.1217	1.000	0.998
KPSS dx, η_μ	0.739	0.463	0.0147	0.0101	0.000	0.000	0.739	0.463	0.0112	0.0086	0.000	0.000
KPSS1 dx, η_μ	0.739	0.463	0.0214	0.0146	0.000	0.000	0.739	0.463	0.0163	0.0123	0.000	0.000
KPSS dx, η_τ	0.216	0.146	0.0082	0.0028	0.000	0.000	0.216	0.146	0.0056	0.0023	0.000	0.000
KPSS1 dx, η_τ	0.216	0.146	0.0119	0.0040	0.000	0.000	0.216	0.146	0.0082	0.0033	0.000	0.000

Table 3 Monte Carlo results for Model 3

	Sample size: 25						Sample size: 50						Sample size: 100					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.75	−3.00	−0.7256	0.7323	0.003	0.000	−3.58	−2.93	−0.5627	0.5174	0.000	0.000	−3.51	−2.89	−0.4156	0.3956	0.000	0.000
DF x, $\hat{\tau}_\tau$	−4.38	−3.60	−2.4751	0.7952	0.083	0.015	−4.15	−3.50	−2.8567	0.7189	0.183	0.043	−4.04	−3.45	−3.5382	0.6354	0.534	0.209
ADF x, $\hat{\tau}_\mu$	−3.75	−3.00	−0.6720	0.8339	0.007	0.002	−3.58	−2.93	−0.5039	0.5941	0.000	0.000	−3.51	−2.89	−0.3848	0.4412	0.000	0.000
ADF x, $\hat{\tau}_\tau$	−4.38	−3.60	−2.4293	0.8319	0.092	0.019	−4.15	−3.50	−2.7584	0.7043	0.148	0.036	−4.04	−3.45	−3.3963	0.6626	0.433	0.169
DF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−5.2524	1.0727	0.992	0.937	−3.58	−2.93	−7.5706	1.0867	1.000	1.000	−3.51	−2.89	−10.8249	1.0680	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−5.2491	1.0874	0.953	0.791	−4.15	−3.50	−7.5317	1.0838	1.000	1.000	−4.04	−3.45	−10.7858	1.0656	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−3.8312	0.8584	0.832	0.499	−3.58	−2.93	−5.5711	0.8585	0.999	0.996	−3.51	−2.89	−7.9243	0.8085	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−3.8805	0.8877	0.589	0.266	−4.15	−3.50	−5.5635	0.8668	0.998	0.963	−4.04	−3.45	−7.9023	0.8097	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.75	−3.00	−0.7175	0.8231	0.007	0.002	−3.58	−2.93	−0.5434	0.5603	0.000	0.000	−3.51	−2.89	−0.4012	0.4217	0.000	0.000
PP x, $t_{\tilde{\alpha}}$	−4.38	−3.60	−2.6859	0.8371	0.143	0.026	−4.15	−3.50	−2.9901	0.7337	0.227	0.065	−4.04	−3.45	−3.6178	0.6562	0.571	0.249
PP x, $T(\hat{\alpha}-1)$	−17.2	−12.5	−1.0875	1.3037	0.354	0.125	−18.9	−13.3	−0.6037	0.6301	0.622	0.268	−19.8	−13.7	−0.3109	0.3265	0.937	0.675
PP x, $T(\tilde{\alpha}-1)$	−22.5	−17.9	−11.3151	4.7185	0.000	0.000	−25.7	−19.8	−15.7226	5.9458	0.000	0.000	−27.4	−20.7	−23.7251	7.3795	0.000	0.000
KPSS x, η_μ	0.739	0.463	2.1360	0.2007	1.000	0.999	0.739	0.463	4.6901	0.1305	1.000	1.000	0.739	0.463	9.7594	0.0950	1.000	1.000
KPSS x, η_τ	0.216	0.146	0.2119	0.1046	0.679	0.437	0.216	0.146	0.3361	0.1782	0.880	0.691	0.216	0.146	0.5190	0.3024	0.964	0.868
KPSS dx, η_μ	0.739	0.463	0.1174	0.0735	0.004	0.000	0.739	0.463	0.0732	0.0417	0.000	0.000	0.739	0.463	0.0442	0.0256	0.000	0.000
KPSS1 dx, η_μ	0.739	0.463	0.1306	0.0745	0.005	0.000	0.739	0.463	0.0813	0.0445	0.000	0.000	0.739	0.463	0.0487	0.0280	0.000	0.000
KPSS dx, η_τ	0.216	0.146	0.0684	0.0275	0.022	0.001	0.216	0.146	0.0478	0.0203	0.003	0.000	0.216	0.146	0.0296	0.0105	0.000	0.000
KPSS1 dx, η_τ	0.216	0.146	0.0783	0.0253	0.023	0.000	0.216	0.146	0.0533	0.0206	0.004	0.000	0.216	0.146	0.0326	0.0112	0.000	0.000

	Sample size: 250						Sample size: 500					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.46	−2.88	−0.2478	0.2877	0.000	0.000	−3.44	−2.87	−0.2042	0.2584	0.000	0.000
DF x, $\hat{\tau}_\tau$	−3.99	−3.43	−4.9245	0.7028	0.985	0.911	−3.98	−3.42	−6.0699	0.8552	0.999	0.988
ADF x, $\hat{\tau}_\mu$	−3.46	−2.88	−0.2273	0.3218	0.000	0.000	−3.44	−2.87	−0.1908	0.2843	0.000	0.000
ADF x, $\hat{\tau}_\tau$	−3.99	−3.43	−4.6581	0.7189	0.961	0.817	−3.98	−3.42	−5.6934	0.8462	0.995	0.966
DF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−17.3346	1.0517	1.000	1.000	−3.44	−2.87	−24.5331	1.0393	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−17.3053	1.0499	1.000	1.000	−3.98	−3.42	−24.5118	1.0383	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−12.7174	0.8338	1.000	1.000	−3.44	−2.87	−18.0013	0.8132	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−12.6984	0.8330	1.000	1.000	−3.98	−3.42	−17.9874	0.8127	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.46	−2.88	−0.2353	0.3043	0.000	0.000	−3.44	−2.87	−0.1969	0.2720	0.000	0.000
PP x, $t_{\tilde{\alpha}}$	−3.99	−3.43	−4.9426	0.7287	0.983	0.915	−3.98	−3.42	−6.0285	0.8814	0.998	0.985
PP x, $T(\hat{\alpha}-1)$	−20.3	−14.0	−0.1152	0.1487	0.998	0.992	−20.5	−14.0	−0.0682	0.0940	1.000	1.000
PP x, $T(\tilde{\alpha}-1)$	−28.4	−21.3	−45.2385	11.9121	0.000	0.000	−28.9	−21.5	−68.7376	18.1821	0.000	0.000
KPSS x, η_μ	0.739	0.463	24.8324	0.0808	1.000	1.000	0.739	0.463	49.8540	0.0968	1.000	1.000
KPSS x, η_τ	0.216	0.146	1.0485	0.7068	0.996	0.977	0.216	0.146	2.5245	1.7838	1.000	0.999
KPSS dx, η_μ	0.739	0.463	0.0227	0.0128	0.000	0.000	0.739	0.463	0.0161	0.0106	0.000	0.000
KPSS1 dx, η_μ	0.739	0.463	0.0251	0.0142	0.000	0.000	0.739	0.463	0.0178	0.0116	0.000	0.000
KPSS dx, η_τ	0.216	0.146	0.0147	0.0046	0.000	0.000	0.216	0.146	0.0094	0.0031	0.000	0.000
KPSS1 dx, η_τ	0.216	0.146	0.0162	0.0050	0.000	0.000	0.216	0.146	0.0104	0.0034	0.000	0.000

Table 4 Monte Carlo results for Model 4

	Sample size: 25						Sample size: 50						Sample size: 100					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.75	−3.00	−1.1656	0.9721	0.055	0.016	−3.58	−2.93	−0.8538	0.7921	0.009	0.002	−3.51	−2.89	−0.5753	0.7609	0.003	0.000
DF x, $\hat{\tau}_\tau$	−4.38	−3.60	−3.6022	1.1370	0.457	0.235	−4.15	−3.50	−3.4908	1.2600	0.449	0.297	−4.04	−3.45	−3.1987	1.1177	0.373	0.205
ADF x, $\hat{\tau}_\mu$	−3.75	−3.00	−0.7182	1.0579	0.022	0.008	−3.58	−2.93	−0.5401	1.0535	0.013	0.002	−3.51	−2.89	−0.3626	1.1326	0.016	0.004
ADF x, $\hat{\tau}_\tau$	−4.38	−3.60	−2.5241	0.9960	0.133	0.037	−4.15	−3.50	−2.3285	0.9950	0.120	0.045	−4.04	−3.45	−2.0440	0.8694	0.062	0.019
DF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−7.4021	1.5027	1.000	0.997	−3.58	−2.93	−10.7183	1.4825	1.000	1.000	−3.51	−2.89	−15.4425	1.5226	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−7.4173	1.5028	0.999	0.992	−4.15	−3.50	−10.7799	1.4831	1.000	1.000	−4.04	−3.45	−15.5071	1.5173	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−4.8490	1.0866	0.976	0.854	−3.58	−2.93	−6.9283	1.0951	1.000	1.000	−3.51	−2.89	−9.7972	1.0659	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−4.9958	1.1246	0.912	0.687	−4.15	−3.50	−7.0851	1.0753	1.000	0.999	−4.04	−3.45	−9.9316	1.0608	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.75	−3.00	−1.0340	1.1604	0.066	0.022	−3.58	−2.93	−0.6904	0.9672	0.012	0.003	−3.51	−2.89	−0.4418	0.9890	0.008	0.003
PP x, $t_{\tilde{\alpha}}$	−4.38	−3.60	−3.8259	1.2561	0.534	0.313	−4.15	−3.50	−3.4359	1.3947	0.441	0.303	−4.04	−3.45	−2.8764	1.1923	0.270	0.148
PP x, $T(\hat{\alpha}-1)$	−17.2	−12.5	−2.6094	4.1631	0.741	0.490	−18.9	−13.3	−1.1639	2.1850	0.601	0.419	−19.8	−13.7	−0.4323	0.9941	0.473	0.262
PP x, $T(\tilde{\alpha}-1)$	−22.5	−17.9	−17.3771	6.7080	0.017	0.006	−25.7	−19.8	−18.7721	11.3060	0.001	0.001	−27.4	−20.7	−15.5245	10.7790	0.000	0.000
KPSS x, η_μ	0.739	0.463	1.9651	0.4976	0.971	0.949	0.739	0.463	4.4395	0.5866	0.999	0.999	0.739	0.463	9.4484	0.5833	1.000	1.000
KPSS x, η_τ	0.216	0.146	0.1881	0.1068	0.594	0.364	0.216	0.146	0.5071	0.2646	0.931	0.844	0.216	0.146	1.1628	0.5289	0.998	0.989
KPSS dx, η_μ	0.739	0.463	0.1229	0.0845	0.006	0.000	0.739	0.463	0.1314	0.1142	0.023	0.002	0.739	0.463	0.1521	0.1313	0.034	0.004
KPSS1 dx, η_μ	0.739	0.463	0.1538	0.0937	0.012	0.000	0.739	0.463	0.1598	0.1268	0.039	0.004	0.739	0.463	0.1849	0.1518	0.063	0.010
KPSS dx, η_τ	0.216	0.146	0.0613	0.0235	0.008	0.000	0.216	0.146	0.0525	0.0276	0.011	0.000	0.216	0.146	0.0575	0.0363	0.037	0.006
KPSS1 dx, η_τ	0.216	0.146	0.0814	0.0248	0.023	0.000	0.216	0.146	0.0666	0.0298	0.025	0.000	0.216	0.146	0.0712	0.0416	0.058	0.012

	Sample size: 250						Sample size: 500					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.46	−2.88	−0.3382	0.7588	0.000	0.000	−3.44	−2.87	−0.3413	0.7805	0.005	0.000
DF x, $\hat{\tau}_\tau$	−3.99	−3.43	−2.9682	0.9856	0.287	0.141	−3.98	−3.42	−2.9100	0.9498	0.264	0.132
ADF x, $\hat{\tau}_\mu$	−3.46	−2.88	−0.1931	1.1663	0.010	0.003	−3.44	−2.87	−0.3066	1.2125	0.017	0.011
ADF x, $\hat{\tau}_\tau$	−3.99	−3.43	−1.8903	0.7862	0.035	0.006	−3.98	−3.42	−1.8853	0.7751	0.021	0.004
DF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−24.4139	1.4665	1.000	1.000	−3.44	−2.87	−34.6248	1.4863	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−24.4600	1.4724	1.000	1.000	−3.98	−3.42	−34.6637	1.4883	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−15.4682	1.0103	1.000	1.000	−3.44	−2.87	−21.8791	1.0551	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−15.5565	1.0173	1.000	1.000	−3.98	−3.42	−21.9497	1.0603	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.46	−2.88	−0.2509	0.9959	0.006	0.001	−3.44	−2.87	−0.3135	1.0229	0.012	0.005
PP x, $t_{\tilde{\alpha}}$	−3.99	−3.43	−2.4381	0.9559	0.126	0.063	−3.98	−3.42	−2.3208	0.8666	0.093	0.034
PP x, $T(\hat{\alpha}-1)$	−20.3	−14.0	−0.1430	0.5597	0.316	0.140	−20.5	−14.0	−0.1187	0.3924	0.276	0.109
PP x, $T(\tilde{\alpha}-1)$	−28.4	−21.3	−12.4207	8.8199	0.000	0.000	−28.9	−21.5	−11.3560	7.5888	0.000	0.000
KPSS x, η_μ	0.739	0.463	24.4519	0.4917	1.000	1.000	0.739	0.463	49.4718	0.5852	1.000	1.000
KPSS x, η_τ	0.216	0.146	2.8695	1.2595	1.000	1.000	0.216	0.146	5.5835	2.6827	1.000	1.000
KPSS dx, η_μ	0.739	0.463	0.1604	0.1388	0.036	0.009	0.739	0.463	0.1728	0.1712	0.060	0.016
KPSS1 dx, η_μ	0.739	0.463	0.1959	0.1667	0.065	0.014	0.739	0.463	0.2111	0.2050	0.090	0.028
KPSS dx, η_τ	0.216	0.146	0.0633	0.0406	0.046	0.011	0.216	0.146	0.0672	0.0425	0.061	0.010
KPSS1 dx, η_τ	0.216	0.146	0.0778	0.0478	0.083	0.023	0.216	0.146	0.0824	0.0511	0.110	0.024

Table 5 Monte Carlo results for Model 5

	Sample size: 25						Sample size: 50						Sample size: 100					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.75	−3.00	−0.8908	1.0148	0.017	0.002	−3.58	−2.93	−0.5827	0.9495	0.005	0.000	−3.51	−2.89	−0.4309	0.9339	0.002	0.000
DF x, $\hat{\tau}_\tau$	−4.38	−3.60	−2.1637	0.8544	0.042	0.008	−4.15	−3.50	−2.1692	0.8184	0.056	0.009	−4.04	−3.45	−2.0981	0.7545	0.035	0.006
ADF x, $\hat{\tau}_\mu$	−3.75	−3.00	−0.8739	1.0738	0.026	0.002	−3.58	−2.93	−0.6069	0.9920	0.006	0.001	−3.51	−2.89	−0.4264	0.9538	0.005	0.001
ADF x, $\hat{\tau}_\tau$	−4.38	−3.60	−2.1696	0.9058	0.060	0.014	−4.15	−3.50	−2.1774	0.8191	0.058	0.007	−4.04	−3.45	−2.1262	0.7709	0.043	0.003
DF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−4.9288	1.0869	0.982	0.878	−3.58	−2.93	−7.0298	1.0315	1.000	1.000	−3.51	−2.89	−9.8870	1.0376	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−5.0168	1.1260	0.924	0.707	−4.15	−3.50	−7.0884	1.0354	1.000	1.000	−4.04	−3.45	−9.9281	1.0478	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−3.5416	0.8816	0.713	0.376	−3.58	−2.93	−5.0566	0.8670	0.997	0.974	−3.51	−2.89	−7.0461	0.7906	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−3.6833	0.9035	0.498	0.202	−4.15	−3.50	−5.1499	0.8696	0.986	0.887	−4.04	−3.45	−7.1115	0.7937	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.75	−3.00	−0.9137	1.1122	0.028	0.005	−3.58	−2.93	−0.5830	0.9934	0.005	0.000	−3.51	−2.89	−0.4312	0.9569	0.005	0.000
PP x, $t_{\tilde{\alpha}}$	−4.38	−3.60	−2.3564	0.9105	0.081	0.012	−4.15	−3.50	−2.2767	0.8516	0.078	0.014	−4.04	−3.45	−2.1592	0.7751	0.045	0.007
PP x, $T(\hat{\alpha}-1)$	−17.2	−12.5	−1.9300	2.8894	0.250	0.055	−18.9	−13.3	−0.9155	1.8031	0.252	0.091	−19.8	−13.7	−0.4259	0.9495	0.212	0.053
PP x, $T(\tilde{\alpha}-1)$	−22.5	−17.9	−9.4088	4.6808	0.000	0.000	−25.7	−19.8	−10.1555	5.7611	0.000	0.000	−27.4	−20.7	−9.7297	5.5856	0.000	0.000
KPSS x, η_μ	0.739	0.463	1.9059	0.5317	0.967	0.939	0.739	0.463	4.3697	0.6842	0.999	0.995	0.739	0.463	9.3763	0.6744	1.000	0.999
KPSS x, η_τ	0.216	0.146	0.2492	0.1178	0.756	0.565	0.216	0.146	0.5120	0.2469	0.969	0.898	0.216	0.146	1.0694	0.5069	1.000	0.996
KPSS dx, η_μ	0.739	0.463	0.1619	0.1135	0.029	0.000	0.739	0.463	0.1545	0.1212	0.032	0.002	0.739	0.463	0.1585	0.1342	0.039	0.005
KPSS1 dx, η_μ	0.739	0.463	0.1682	0.1049	0.020	0.000	0.739	0.463	0.1574	0.1154	0.026	0.002	0.739	0.463	0.1589	0.1312	0.038	0.005
KPSS dx, η_τ	0.216	0.146	0.0770	0.0322	0.041	0.000	0.216	0.146	0.0696	0.0351	0.044	0.003	0.216	0.146	0.0691	0.0389	0.051	0.006
KPSS1 dx, η_τ	0.216	0.146	0.0843	0.0281	0.037	0.001	0.216	0.146	0.0726	0.0328	0.039	0.002	0.216	0.146	0.0700	0.0377	0.053	0.007

	Sample size: 250						Sample size: 500					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.46	−2.88	−0.2736	0.9469	0.003	0.000	−3.44	−2.87	−0.1769	0.9870	0.002	0.000
DF x, $\hat{\tau}_\tau$	−3.99	−3.43	−2.1512	0.7570	0.044	0.009	−3.98	−3.42	−2.1450	0.7516	0.050	0.009
ADF x, $\hat{\tau}_\mu$	−3.46	−2.88	−0.2793	0.9486	0.003	0.000	−3.44	−2.87	−0.1807	0.9885	0.002	0.000
ADF x, $\hat{\tau}_\tau$	−3.99	−3.43	−2.1672	0.7695	0.046	0.007	−3.98	−3.42	−2.1594	0.7510	0.052	0.007
DF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−15.6962	0.9946	1.000	1.000	−3.44	−2.87	−22.2262	0.9976	1.000	1.000
DF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−15.7214	0.9946	1.000	1.000	−3.98	−3.42	−22.2473	1.0001	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−11.0982	0.7888	1.000	1.000	−3.44	−2.87	−15.7361	0.7998	1.000	1.000
ADF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−11.1364	0.7904	1.000	1.000	−3.98	−3.42	−15.7669	0.8030	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.46	−2.88	−0.2742	0.9529	0.003	0.000	−3.44	−2.87	−0.1761	0.9902	0.002	0.000
PP x, $t_{\tilde{\alpha}}$	−3.99	−3.43	−2.1802	0.7684	0.050	0.008	−3.98	−3.42	−2.1620	0.7551	0.052	0.007
PP x, $T(\hat{\alpha}-1)$	−20.3	−14.0	−0.1524	0.5387	0.216	0.054	−20.5	−14.0	−0.0703	0.3828	0.198	0.065
PP x, $T(\tilde{\alpha}-1)$	−28.4	−21.3	−10.0601	5.7776	0.000	0.000	−28.9	−21.5	−9.9619	5.9796	0.000	0.000
KPSS x, η_μ	0.739	0.463	24.4444	0.5557	1.000	1.000	0.739	0.463	49.4415	0.5758	1.000	1.000
KPSS x, η_τ	0.216	0.146	2.6511	1.2756	1.000	1.000	0.216	0.146	5.4850	2.6044	1.000	1.000
KPSS dx, η_μ	0.739	0.463	0.1599	0.1302	0.038	0.006	0.739	0.463	0.1661	0.1441	0.052	0.008
KPSS1 dx, η_μ	0.739	0.463	0.1594	0.1283	0.034	0.004	0.739	0.463	0.1658	0.1436	0.053	0.007
KPSS dx, η_τ	0.216	0.146	0.0697	0.0435	0.057	0.012	0.216	0.146	0.0682	0.0406	0.053	0.009
KPSS1 dx, η_τ	0.216	0.146	0.0698	0.0425	0.058	0.013	0.216	0.146	0.0681	0.0399	0.052	0.008

Table 6 Monte Carlo results for Model 6

	Sample size: 25						Sample size: 50						Sample size: 100					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.75	−3.00	8.8407	1.6762	0.000	0.000	−3.58	−2.93	20.1939	2.0236	0.000	0.000	−3.51	−2.89	35.2673	2.7149	0.000	0.000
DF x, $\hat{\tau}_\tau$	−4.38	−3.60	−0.3169	0.7343	0.000	0.000	−4.15	−3.50	−0.0597	1.2147	0.004	0.000	−4.04	−3.45	−0.1389	2.3178	0.084	0.050
ADF x, $\hat{\tau}_\mu$	−3.75	−3.00	4.6639	1.0584	0.000	0.000	−3.58	−2.93	4.6274	0.9597	0.000	0.000	−3.51	−2.89	3.5425	0.5851	0.000	0.000
ADF x, $\hat{\tau}_\tau$	−4.38	−3.60	−0.1961	1.0248	0.001	0.000	−4.15	−3.50	0.0302	1.8094	0.034	0.014	−4.04	−3.45	−0.1449	3.0846	0.159	0.117
DF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−1.7998	0.5237	0.014	0.001	−3.58	−2.93	−1.3034	0.3085	0.000	0.000	−3.51	−2.89	−0.9355	0.1928	0.000	0.000
DF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−7.4276	1.5115	0.999	0.994	−4.15	−3.50	−10.3429	1.5712	1.000	1.000	−4.04	−3.45	−13.3944	1.9048	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−0.8326	0.4422	0.000	0.000	−3.58	−2.93	−0.5809	0.3248	0.000	0.000	−3.51	−2.89	−0.4318	0.2567	0.000	0.000
ADF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−4.9769	1.0779	0.916	0.694	−4.15	−3.50	−6.4287	1.2046	0.994	0.976	−4.04	−3.45	−7.8822	1.4793	1.000	0.998
PP x, $t_{\hat{\alpha}}$	−3.75	−3.00	10.3533	1.8821	0.000	0.000	−3.58	−2.93	18.3916	2.1704	0.000	0.000	−3.51	−2.89	27.2516	2.3917	0.000	0.000
PP x, $t_{\tilde{\alpha}}$	−4.38	−3.60	−0.2351	1.0507	0.001	0.000	−4.15	−3.50	−0.0120	1.6788	0.027	0.011	−4.04	−3.45	−0.1573	2.9208	0.138	0.103
PP x, $T(\hat{\alpha}-1)$	−17.2	−12.5	1.7445	0.1758	0.000	0.000	−18.9	−13.3	1.8158	0.1139	0.000	0.000	−19.8	−13.7	1.8396	0.0774	0.000	0.000
PP x, $T(\tilde{\alpha}-1)$	−22.5	−17.9	−0.1292	0.5402	0.000	0.000	−25.7	−19.8	−0.0024	0.3077	0.000	0.000	−27.4	−20.7	−0.0106	0.2074	0.000	0.000
KPSS x, η_μ	0.739	0.463	2.3022	0.0228	1.000	1.000	0.739	0.463	4.6817	0.0332	1.000	1.000	0.739	0.463	9.4467	0.0478	1.000	1.000
KPSS x, η_τ	0.216	0.146	0.5470	0.0081	1.000	1.000	0.216	0.146	1.1434	0.0085	1.000	1.000	0.216	0.146	2.3331	0.0120	1.000	1.000
KPSS dx, η_μ	0.739	0.463	1.1969	0.0362	1.000	1.000	0.739	0.463	2.4797	0.0183	1.000	1.000	0.739	0.463	4.9938	0.0194	1.000	1.000
KPSS1 dx, η_μ	0.739	0.463	0.8663	0.0200	1.000	1.000	0.739	0.463	1.7062	0.0106	1.000	1.000	0.739	0.463	3.3753	0.0117	1.000	1.000
KPSS dx, η_τ	0.216	0.146	0.7669	0.3145	1.000	0.999	0.216	0.146	2.7727	0.8009	1.000	1.000	0.216	0.146	9.1130	2.2294	1.000	1.000
KPSS1 dx, η_τ	0.216	0.146	1.0353	0.4519	1.000	1.000	0.216	0.146	3.3676	1.1174	1.000	1.000	0.216	0.146	9.8920	3.1690	1.000	1.000

	Sample size: 250						Sample size: 500					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.46	−2.88	60.3044	3.3035	0.000	0.000	−3.44	−2.87	86.3445	3.3308	0.000	0.000
DF x, $\hat{\tau}_\tau$	−3.99	−3.43	−0.1297	5.5681	0.270	0.241	−3.98	−3.42	0.3080	9.8075	0.358	0.336
ADF x, $\hat{\tau}_\mu$	−3.46	−2.88	2.2692	0.2925	0.000	0.000	−3.44	−2.87	1.6014	0.1910	0.000	0.000
ADF x, $\hat{\tau}_\tau$	−3.99	−3.43	−0.1114	5.9907	0.308	0.284	−3.98	−3.42	0.2704	8.1890	0.345	0.323
DF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−0.5873	0.1370	0.000	0.000	−3.44	−2.87	−0.4131	0.1139	0.000	0.000
DF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−17.3372	2.9695	1.000	1.000	−3.98	−3.42	−19.5379	3.9125	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−0.2734	0.2369	0.000	0.000	−3.44	−2.87	−0.1877	0.2203	0.000	0.000
ADF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−9.2401	2.0468	1.000	1.000	−3.98	−3.42	−9.7476	2.3252	1.000	1.000
PP x, $t_{\hat{\alpha}}$	−3.46	−2.88	43.5003	2.4537	0.000	0.000	−3.44	−2.87	61.4914	2.3942	0.000	0.000
PP x, $t_{\tilde{\alpha}}$	−3.99	−3.43	−0.1247	6.3318	0.297	0.266	−3.98	−3.42	0.3158	9.8949	0.352	0.336
PP x, $T(\hat{\alpha}-1)$	−20.3	−14.0	1.8612	0.0485	0.000	0.000	−20.5	−14.0	1.8700	0.0349	0.000	0.000
PP x, $T(\tilde{\alpha}-1)$	−28.4	−21.3	−0.0027	0.1326	0.000	0.000	−28.9	−21.5	0.0030	0.0909	0.000	0.000
KPSS x, η_μ	0.739	0.463	23.7317	0.0762	1.000	1.000	0.739	0.463	47.5343	0.1107	1.000	1.000
KPSS x, η_τ	0.216	0.146	5.9033	0.0192	1.000	1.000	0.216	0.146	11.8572	0.0282	1.000	1.000
KPSS dx, η_μ	0.739	0.463	12.5016	0.0305	1.000	1.000	0.739	0.463	25.0066	0.0439	1.000	1.000
KPSS1 dx, η_μ	0.739	0.463	8.3762	0.0195	1.000	1.000	0.739	0.463	16.7113	0.0287	1.000	1.000
KPSS dx, η_τ	0.216	0.146	38.3155	11.6405	1.000	1.000	0.216	0.146	98.6568	36.6748	1.000	1.000
KPSS1 dx, η_τ	0.216	0.146	35.0280	13.8983	1.000	1.000	0.216	0.146	80.1149	35.8427	1.000	1.000

Table 7 Monte Carlo results for Model 7

	Sample size: 25						Sample size: 50						Sample size: 100					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.75	−3.00	9.9803	1.8000	0.000	0.000	−3.58	−2.93	22.3505	2.4026	0.000	0.000	−3.51	−2.89	38.0889	3.2671	0.000	0.000
DF x, $\hat{\tau}_\tau$	−4.38	−3.60	−0.3201	0.8294	0.002	0.000	−4.15	−3.50	−0.1456	1.2610	0.006	0.002	−4.04	−3.45	−0.0761	2.5131	0.096	0.070
ADF x, $\hat{\tau}_\mu$	−3.75	−3.00	4.9955	1.1853	0.000	0.000	−3.58	−2.93	4.8156	1.0050	0.000	0.000	−3.51	−2.89	3.5341	0.5975	0.000	0.000
ADF x, $\hat{\tau}_\tau$	−4.38	−3.60	−0.2031	1.1362	0.005	0.001	−4.15	−3.50	−0.1157	1.7226	0.025	0.010	−4.04	−3.45	−0.0662	3.1440	0.144	0.108
DF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−1.6623	0.4749	0.002	0.000	−3.58	−2.93	−1.2216	0.3006	0.000	0.000	−3.51	−2.89	−0.8627	0.1986	0.000	0.000
DF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−7.0118	1.4243	0.998	0.987	−4.15	−3.50	−9.7026	1.5208	1.000	1.000	−4.04	−3.45	−12.5182	1.7724	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.75	−3.00	−0.7802	0.4752	0.000	0.000	−3.58	−2.93	−0.5742	0.3331	0.000	0.000	−3.51	−2.89	−0.4002	0.2884	0.000	0.000
ADF dx, $\hat{\tau}_\tau$	−4.38	−3.60	−4.6021	1.1160	0.826	0.539	−4.15	−3.50	−6.0291	1.1143	0.995	0.962	−4.04	−3.45	−7.3012	1.3908	1.000	0.991
PP x, $t_{\hat{\alpha}}$	−3.75	−3.00	11.9549	2.2985	0.000	0.000	−3.58	−2.93	20.5857	2.7371	0.000	0.000	−3.51	−2.89	29.4112	2.8487	0.000	0.000
PP x, $t_{\tilde{\alpha}}$	−4.38	−3.60	−0.2649	1.1628	0.005	0.002	−4.15	−3.50	−0.1395	1.6463	0.024	0.010	−4.04	−3.45	−0.0755	3.0655	0.126	0.101
PP x, $T(\hat{\alpha}-1)$	−17.2	−12.5	1.3640	0.1331	0.000	0.000	−18.9	−13.3	1.5831	0.0920	0.000	0.000	−19.8	−13.7	1.7195	0.0716	0.000	0.000
PP x, $T(\tilde{\alpha}-1)$	−22.5	−17.9	−0.1267	0.5671	0.000	0.000	−25.7	−19.8	−0.0241	0.2997	0.000	0.000	−27.4	−20.7	−0.0067	0.2141	0.000	0.000
KPSS x, η_μ	0.739	0.463	2.3425	0.0145	1.000	1.000	0.739	0.463	4.7369	0.0240	1.000	1.000	0.739	0.463	9.5074	0.0414	1.000	1.000
KPSS x, η_τ	0.216	0.146	0.5465	0.0089	1.000	1.000	0.216	0.146	1.1429	0.0096	1.000	1.000	0.216	0.146	2.3324	0.0127	1.000	1.000
KPSS dx, η_μ	0.739	0.463	1.2019	0.0333	1.000	1.000	0.739	0.463	2.4792	0.0199	1.000	1.000	0.739	0.463	4.9930	0.0211	1.000	1.000
KPSS1 dx, η_μ	0.739	0.463	0.8677	0.0182	1.000	1.000	0.739	0.463	1.7054	0.0112	1.000	1.000	0.739	0.463	3.3743	0.0129	1.000	1.000
KPSS dx, η_τ	0.216	0.146	0.8222	0.3284	1.000	1.000	0.216	0.146	2.8321	0.8331	1.000	1.000	0.216	0.146	9.3335	2.4184	1.000	1.000
KPSS1 dx, η_τ	0.216	0.146	1.0612	0.4591	1.000	1.000	0.216	0.146	3.3051	1.1011	1.000	1.000	0.216	0.146	9.7269	3.2480	1.000	1.000

	Sample size: 250						Sample size: 500					
	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%	Cr 1%	Cr 5%	Mean	std dev	S 5%	S 1%
DF x, $\hat{\tau}_\mu$	−3.46	−2.88	62.3881	3.5006	0.000	0.000	−3.44	−2.87	87.7649	3.6032	0.000	0.000
DF x, $\hat{\tau}_\tau$	−3.99	−3.43	0.1560	5.7630	0.270	0.237	−3.98	−3.42	0.1824	10.8212	0.362	0.344
ADF x, $\hat{\tau}_\mu$	−3.46	−2.88	2.1706	0.2701	0.000	0.000	−3.44	−2.87	1.5163	0.1795	0.000	0.000
ADF x, $\hat{\tau}_\tau$	−3.99	−3.43	0.1789	5.6866	0.291	0.258	−3.98	−3.42	0.1256	8.3267	0.352	0.328
DF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−0.5411	0.1382	0.000	0.000	−3.44	−2.87	−0.3837	0.1251	0.000	0.000
DF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−16.1072	2.7779	1.000	1.000	−3.98	−3.42	−18.1594	3.8098	1.000	1.000
ADF dx, $\hat{\tau}_\mu$	−3.46	−2.88	−0.2519	0.2442	0.000	0.000	−3.44	−2.87	−0.1764	0.2348	0.000	0.000
ADF dx, $\hat{\tau}_\tau$	−3.99	−3.43	−8.6362	1.8769	1.000	0.999	−3.98	−3.42	−9.2012	2.2593	1.000	0.998
PP x, $t_{\hat{\alpha}}$	−3.46	−2.88	44.9591	2.5848	0.000	0.000	−3.44	−2.87	62.4841	2.5843	0.000	0.000
PP x, $t_{\tilde{\alpha}}$	−3.99	−3.43	0.1778	6.2649	0.285	0.255	−3.98	−3.42	0.1386	10.6500	0.359	0.340
PP x, $T(\hat{\alpha}-1)$	−20.3	−14.0	1.8127	0.0469	0.000	0.000	−20.5	−14.0	1.8437	0.0344	0.000	0.000
PP x, $T(\tilde{\alpha}-1)$	−28.4	−21.3	0.0031	0.1313	0.000	0.000	−28.9	−21.5	0.0019	0.0962	0.000	0.000
KPSS x, η_μ	0.739	0.463	23.7950	0.0721	1.000	1.000	0.739	0.463	47.6061	0.1074	1.000	1.000
KPSS x, η_τ	0.216	0.146	5.9039	0.0185	1.000	1.000	0.216	0.146	11.8555	0.0260	1.000	1.000
KPSS dx, η_μ	0.739	0.463	12.5026	0.0289	1.000	1.000	0.739	0.463	25.0044	0.0414	1.000	1.000
KPSS1 dx, η_μ	0.739	0.463	8.3765	0.0186	1.000	1.000	0.739	0.463	16.7098	0.0271	1.000	1.000
KPSS dx, η_τ	0.216	0.146	38.6522	11.8808	1.000	1.000	0.216	0.146	98.7787	37.0341	1.000	1.000
KPSS1 dx, η_τ	0.216	0.146	34.3366	13.4351	1.000	1.000	0.216	0.146	79.0124	35.0242	1.000	1.000