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SOME PROPERTIES OF THE DURBIN-WATSON TEST AFTER A PRELIMINARY t-TEST

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Abstract

We consider the common situation in which the application of the Durbin-Watson test for serial correlation in the errors of a regression model is preceded by a preliminary t-test for the significance of one of the coefficients. The effect of such pre-testing on the size and power of the Durbin-Watson test is examined in a Monte Carlo experiment.

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I. Introduction

The Durbin-Watson (DW) test for the serial independence of the errors in a regression model is widely used by applied econometricians. It is undoubtedly the best known such test, and its properties have been explored intensively. However, it is frequently applied in contexts which violate the assumptions which ensure its usual properties. The robustness of the DW test to certain departures from these assumptions has been explored in several studies, a useful summary being given by King (1987).

One common but non-standard way in which the DW test is applied is in a "pre-test" situation. Aspects of this problem have been considered by Judge and Bock (1978, pp.143-176), Fomby and Guilkey (1978), King and Giles (1984), Griffiths and Beesley (1984), and Giles and Beattie (1987), all of whom consider preliminary-test estimators in which the choice between Ordinary Least Squares (OLS), and some estimator which "corrects" for autocorrelation, is based on the DW (or some other) test. The DW statistic is also often used in a pre-test testing (rather than estimation) context. Nakamura and Nakamura (1978) and King and Giles (1984) consider the effect of a preliminary test for autocorrelation, using the DW statistic, on the properties of a subsequent t-test involving one of the coefficients. As with other pre-test testing situations, size and power distortions occur at the second testing stage as a consequence of the sequential analysis.

In practice, pre-test testing involving the DW and t-tests usually proceeds in the opposite order to that described above. The significance of the regressors is tested, the model is simplified accordingly, and then any remaining autocorrelation is assessed and perhaps allowed for in the final choice of estimator. The properties of this pre-test testing strategy have not been investigated previously. In this paper we compare the (true) size and power of the DW test after such pre-testing, with its size and power in the absence of a preliminary t-test.

As in the earlier autocorrelation pre-testing literature, we use Monte Carlo analysis. The nature of this pre-test problem precludes exact analytical treatment. The experimental design is outlined in the next section; Section III discusses the results; and Section IV concludes the paper.

II. The Experiment

The model used in our study is

$$y_t = \beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + u_t \tag{1}$$

$$u_t = \rho u_{t-1} + \varepsilon_t \qquad ; 0 < \rho < 1$$

$$\varepsilon_t \sim IN(0,\sigma^2) \qquad ; t = 1,\ldots,T.$$

The SHAZAM package (White et al. (1990)) is used to conduct our experiment. This package incorporates the Normal random number generator algorithm of Brent (1974). Having generated the y_t data, the parameters are estimated by OLS and we test

$$H_0^1 : \beta_2 = 0 \ \underline{vs} \ H_A^1 : \beta_2 \neq 0$$

using the usual t-test and the appropriate Student-t critical values. While this choice of critical value[1] is appropriate only if $\rho = 0$, it is consistent with conventional practice in the situation considered here. If H_0^1 is rejected, the (unrestricted) model (1) is retained. Otherwise, we estimate the (restricted) model,[2]

$$y_t = \beta_0 + \beta_1 x_{1t} + \nu_t , \tag{2}$$

by OLS.

Next, the (exact) DW test is applied to

$$H_0^2 : \rho = 0 \ \underline{vs} \ H_A^2 : \rho > 0 .$$

Exact critical values (which depend on the exogenous variables and which of (1) or (2) is being used at this stage) are calculated by Davies' (1980) algorithm.

This application of the DW test constitutes a "pre-test testing" strategy: the model, and hence residuals, used to construct the DW statistic depends on the outcome of the prior t-test of H_0^1. The experiment is replicated 4,000 times and the appropriate rejection proportions are used to construct empirical measures of the power and true size of the test. The pre-test DW test (DWP) is also compared with the standard DW test applied (without pre-testing) to the unrestricted (DWU) and restricted (DWR) models (1) and (2).

In the latter two cases the DW sizes and powers are calculated exactly[3] by the method of Koerts and Abrahamse (1969), using Davies' (1980) algorithm. Let the (T×3) regressor matrix be $X = (\underset{\sim}{1}, \underset{\sim}{x}_1, \underset{\sim}{x}_2)$, and let x_{33} be the third leading diagonal element of $(X'X)^{-1}$. Then, for the unrestricted model (1) it is easily shown that these results are independent of $\lambda = \beta_2^2/(2\sigma^2 x_{33})$, the non-centrality parameter associated with the t-test of H_0^1. For the restricted model (2), these evaluations depend on λ. In this case the model is misspecified if $\lambda \neq 0$ ($\beta_2 \neq 0$) and non-central rather than central, Chi square variates enter the probability calculations. Further details of this situation are discussed by Giles et al. (1991). In contrast, including extraneous regressors affects the DW power only through the data matrix on which the standard calculations are based. If the choice of the DW critical value reflects the number of regressors actually included in the model, no size or power distortions arise if some regressors are extraneous.[4]

The dependence of the power of the DW test on the data is well known. We consider several X matrices:

X1 (CPI Data): x_1 and x_2 are current and lagged values of the quarterly Australian Consumers Price Index (seasonally unadjusted), commencing 1959(1).

X2 (Uniform/Trend Data): x_1 is uniform over (10,20) and x_2 is a linear time trend.

X3 (Eigenvector Data): x_1 and x_2 are the eigenvectors corresponding to the two smallest (non-zero) eigenvalues of the[5] "differencing matrix", A.

X4 (Watson's Data): $x_1 = (a_2 + a_T)/\sqrt{2}$, $x_2 = (a_3 + a_{T-1})/\sqrt{2}$, where the a_i's are the eigenvectors corresponding to the roots of A, sorted in increasing order.

These, or similar, data sets have been used in other autocorrelation studies.[6] They exhibit a range of characteristics with respect to trend, collinearity and seasonality, as summarised in Table 1.

TABLE 1.- SAMPLE CORRELATIONS AMONG REGRESSORS AND WITH TREND (t)

	X1	X2	X3	X4
corr.(x_1,x_2)	0.977	0.235	0.000	0.000
corr.(x_1,t)	0.981	0.235	0.000	-0.703
corr.(x_2,t)	0.977	1.000	-0.993	0.000

Values of $\sigma = \beta_0 = \beta_1 = 1$ and $\rho = 0.0(0.1)0.9$ are considered.[7] The value of β_2 is varied to determine values of $\lambda = 0,0.5,2,10$. Non-zero λ and ρ values measure departures from H_0^1 and H_0^2 on scales used conventionally in the pre-test literature. Generally, all tests are conducted at a nominal 5% ($\alpha = 0.05$) level, though in view of the results of Fomby and Guilkey (1978), the effect of assigning $\alpha = 0.5$ for the DW test is also considered.

Generally, T = 20, though the sensitivity of the results to setting T = 60 is explored.

III. Results

The basic results appear in Tables 2 and 3. When $\rho = 0$ the powers are the true sizes of the three variants of the DW test. In this case, when $\lambda = 0$ the true sizes of DWU and DWR equal their nominal sizes (by construction) so the true size of DWP is also actually 5%. The entries for DWP in these tables reflect a small degree of sampling error, the extent of which is easily ascertained by considering the binomial nature of the empirical rejections. For example, for X1 the reported size of DWP when $\lambda = 0$ is 0.055, but its standard error is $\sqrt{0.055(1-0.055)/4000} = 0.0036$, so the reported figure is within two standard errors of 0.05. This is also true for the other data sets.

For $\lambda \neq 0$, Size(DWU) < Size(DWP) < Size(DWR). There is one exception in the case of Watson's X matrix, but this is again within sampling error. As λ increases, the restriction $\beta_2 = 0$ becomes increasingly false, and the true size of DWR increases monotonically at a rate which is highly data-dependent. At the same time, the true size of DWP increases and then decreases, ultimately to the true 5% size of DWU (and therefore to its own nominal size). This is intuitively plausible - when λ is small there is a reasonable probability that the preliminary t-test will lead to the restricted model, so DWP is drawn towards DWR. As λ increases, the power of the t-test tends to unity, the restricted model is increasingly rejected, and DWP tends to DWU. Again, the rate of convergence varies with the form of X. The greatest size distortion (which is always upwards) for DWP arises with the eigenvector data (X3), where the true size can be at least three times as great as the nominal 5%. This is consistent with the results of

King and Giles (1984, pp.41-43) for the converse situation involving the size of the t-test after a preliminary DW test. Also consistent with their results is the relatively low distortion which arises with the CPI data (X1). The least size distortion occurs with Watson's X matrix (X4). Referring back to Table 1, it is clear that the degree of size distortion for DWP is not merely a function of the collinearity of the regressors.

The power of the pre-test DW test exhibits the same pattern noted above for its size as λ increases, for the same reason. In some cases (e.g., X1) an extreme form of this pattern arises for large ρ, with a monotonic decrease in power with increasing λ, ceteris paribus. The powers of all three variants of the DW test increase with ρ, regardless of the value of λ, as expected. In the case of X4 it is known (King (1985, p.31)) that the power of the DW test falls for sufficiently large ρ, at a rate depending on the values of T and k. Our results confirm that this result still holds after pre-testing.[8]

Power comparisons across the three versions of the DW test and/or across data sets are complicated by the size differences. The values in Tables 2 and 3 are rejection probabilities. If size differences are ignored, the apparent powers follow the same ranking noted above for sizes. At least when $\lambda = 0$ it is clear that Power (DWU) < Power(DWP) < Power(DWR), within sampling error, and the power of the pre-test test is of similar magnitude to that of the standard DW test applied to the restricted model. In this same case, comparing across data sets, the power of DWP is virtually the same for X1 and X2, slightly lower for X3, and lower still for X4. Again, from Table 1, there seems to be no simple explanation for this ranking in terms of the degree of trend or collinearity of the regressors.

If one test has smaller Type I and Type II error probabilities than a second test, then the first test unambiguously has the higher power. With this in mind we see that when $\lambda \neq 0$, DWP can still be more powerful than the standard (no pre-test) DW test in certain circumstances. Examples occur relative to DWR with the CPI data (X1) for $\lambda = 0.5$ or 2, and small ρ values; and with Watson's data (X4) for $\rho \geq 0.5$, when $\lambda = 2$, or $\rho \geq 0.2$ when $\lambda = 10$. The size orderings generally preclude such conclusions relative to DWU when $\lambda \neq 0$ in the cases we have studied, but an exception is when $\lambda = 10$ with X4. In this case, DWP is more powerful than DWU for all ρ. Finally, we have no evidence that the pre-test DW test can have higher power simultaneously than both the DW test applied to the unrestricted model and that applied to the restricted model, neither do our results show that DWP can have the lowest power among the three DW tests considered.

Some illustrative results relating to the effects of altering the sample size or the nominal size of the DW test of H_0^2 appear in Table 4. When $T = 60$, the results accord with those described above for $T = 20$. Of course, as the DW test is consistent, its power increases with T. This holds for DWP as well as for DWU and DWR, as may be seen by comparing the appropriate entries in Tables 2 and 4. Related to this, the degree of (upward) size distortion as a result of pre-testing is reduced as T increases. For example, for X2 in Table 2 the maximum such distortion is 174%, but it is only 92% in Table 4. The pre-test size distortion can also be reduced by increasing the nominal size of the DW test of H_0^2. For example, the 174% distortion noted above for X2 when $\alpha = 0.05$ is reduced to 25.4% when $\alpha = 0.5$.

TABLE 2.-EXACT POWERS OF THE DW TEST
(T = 20; α = 0.05)

λ	Test	ρ = 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
		X1 : CPI Data									
0	DWU	0.050	0.097	0.171	0.274	0.396	0.523	0.638	0.731	0.799	0.844
	DWP	0.055	0.106	0.172	0.286	0.411	0.548	0.664	0.757	0.824	0.875
	DWR	0.050	0.100	0.180	0.291	0.424	0.560	0.681	0.774	0.840	0.880
0.5	DWU	0.050	0.097	0.171	0.274	0.396	0.523	0.638	0.731	0.799	0.844
	DWP	0.061	0.114	0.186	0.302	0.423	0.552	0.671	0.752	0.817	0.865
	DWR	0.062	0.107	0.181	0.293	0.437	0.594	0.736	0.847	0.921	0.969
2	DWU	0.050	0.097	0.171	0.274	0.396	0.523	0.638	0.731	0.799	0.844
	DWP	0.084	0.132	0.207	0.334	0.429	0.551	0.669	0.743	0.808	0.858
	DWR	0.098	0.127	0.186	0.299	0.474	0.680	0.852	0.952	0.991	0.999
10	DWU	0.050	0.097	0.171	0.274	0.396	0.523	0.638	0.731	0.799	0.844
	DWP	0.056	0.102	0.168	0.283	0.391	0.518	0.648	0.729	0.792	0.836
	DWR	0.270	0.213	0.206	0.324	0.627	0.908	0.993	1.000	1.000	1.000
		X2 : Uniform/Trend Data									
0	DWU	0.050	0.094	0.164	0.259	0.375	0.498	0.615	0.713	0.788	0.837
	DWP	0.047	0.099	0.169	0.275	0.402	0.549	0.665	0.754	0.827	0.874
	DWR	0.050	0.096	0.178	0.291	0.429	0.574	0.706	0.811	0.886	0.933
0.5	DWU	0.050	0.094	0.164	0.259	0.375	0.498	0.615	0.713	0.788	0.837
	DWP	0.081	0.139	0.216	0.318	0.442	0.562	0.673	0.759	0.829	0.875
	DWR	0.086	0.147	0.235	0.349	0.480	0.612	0.730	0.824	0.891	0.935
2	DWU	0.050	0.094	0.164	0.259	0.375	0.498	0.615	0.713	0.788	0.837
	DWP	0.137	0.203	0.282	0.378	0.487	0.593	0.690	0.765	0.831	0.873
	DWR	0.213	0.297	0.397	0.505	0.611	0.708	0.791	0.857	0.906	0.940
10	DWU	0.050	0.094	0.164	0.259	0.375	0.498	0.615	0.713	0.788	0.837
	DWP	0.064	0.113	0.180	0.282	0.405	0.531	0.646	0.741	0.817	0.866
	DWR	0.795	0.843	0.881	0.909	0.928	0.940	0.948	0.953	0.957	0.961
		X3 : Eigenvector Data									
0	DWU	0.050	0.095	0.165	0.258	0.367	0.479	0.579	0.660	0.718	0.753
	DWP	0.050	0.102	0.175	0.281	0.410	0.535	0.642	0.725	0.777	0.807
	DWR	0.050	0.100	0.182	0.297	0.434	0.575	0.701	0.799	0.869	0.916
0.5	DWU	0.050	0.095	0.165	0.258	0.367	0.479	0.579	0.660	0.718	0.753
	DWP	0.079	0.138	0.226	0.334	0.445	0.554	0.651	0.729	0.779	0.807
	DWR	0.090	0.157	0.251	0.369	0.499	0.625	0.734	0.819	0.880	0.921
2	DWU	0.050	0.095	0.165	0.258	0.367	0.479	0.579	0.660	0.718	0.753
	DWP	0.151	0.218	0.298	0.395	0.492	0.585	0.667	0.735	0.780	0.806
	DWR	0.237	0.332	0.440	0.552	0.655	0.744	0.814	0.867	0.906	0.934
10	DWU	0.050	0.095	0.165	0.258	0.367	0.479	0.579	0.660	0.718	0.753
	DWP	0.066	0.111	0.184	0.288	0.399	0.512	0.613	0.701	0.757	0.794
	DWR	0.844	0.890	0.924	0.946	0.960	0.969	0.973	0.975	0.975	0.974

TABLE 3.-EXACT POWERS OF THE DW TEST
(T = 20; α = 0.05)

X4 : Watson's Data

λ	Test	ρ = 0	0.1	0.2	0.3	0.4	0.5	0.6
	DWU	0.050	0.088	0.142	0.212	0.291	0.366	0.424
0	DWP	0.055	0.103	0.176	0.264	0.373	0.488	0.573
	DWR	0.050	0.096	0.167	0.266	0.383	0.501	0.602
	DWU	0.050	0.088	0.142	0.212	0.291	0.366	0.424
0.5	DWP	0.065	0.110	0.166	0.248	0.347	0.443	0.526
	DWR	0.060	0.104	0.171	0.258	0.358	0.457	0.539
	DWU	0.050	0.088	0.142	0.212	0.291	0.366	0.424
2	DWP	0.072	0.111	0.160	0.223	0.300	0.377	0.445
	DWR	0.079	0.119	0.172	0.236	0.305	0.369	0.416
	DWU	0.050	0.088	0.142	0.212	0.291	0.366	0.424
10	DWP	0.055	0.094	0.151	0.211	0.286	0.357	0.407
	DWR	0.088	0.107	0.131	0.158	0.185	0.206	0.210

λ	Test	ρ = 0.7	0.8	0.9	0.92	0.94	0.96	0.98
	DWU	0.452	0.440	0.386	0.372	0.356	0.340	0.324
0	DWP	0.636	0.668	0.651	0.639	0.626	0.600	0.568
	DWR	0.672	0.701	0.680	0.668	0.654	0.637	0.617
	DWU	0.452	0.440	0.386	0.372	0.356	0.340	0.324
0.5	DWP	0.589	0.619	0.606	0.596	0.580	0.560	0.531
	DWR	0.590	0.592	0.496	0.450	0.385	0.285	0.124
	DWU	0.452	0.440	0.386	0.372	0.356	0.340	0.324
2	DWP	0.497	0.527	0.518	0.506	0.494	0.476	0.450
	DWR	0.429	0.383	0.221	0.167	0.106	0.044	0.004
	DWU	0.452	0.440	0.386	0.372	0.356	0.340	0.324
10	DWP	0.438	0.443	0.407	0.392	0.377	0.359	0.334
	DWR	0.185	0.117	0.019	0.007	0.001	0.000	0.000

TABLE 4.-EXACT POWERS OF THE DW TEST

X2 : T = 60; α = 0.05

λ	Test	ρ = 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	DWU	0.050	0.176	0.417	0.694	0.886	0.970	0.994	0.999	1.000	1.000
0	DWP	0.054	0.186	0.437	0.716	0.895	0.973	0.995	0.999	1.000	1.000
	DWR	0.050	0.179	0.428	0.711	0.900	0.977	0.996	1.000	1.000	1.000
	DWU	0.050	0.176	0.417	0.694	0.886	0.970	0.994	0.999	1.000	1.000
0.5	DWP	0.065	0.217	0.468	0.727	0.900	0.976	0.995	0.999	1.000	1.000
	DWR	0.068	0.214	0.469	0.739	0.911	0.979	0.997	1.000	1.000	1.000
	DWU	0.050	0.176	0.417	0.694	0.886	0.970	0.994	0.999	1.000	1.000
2	DWP	0.096	0.257	0.511	0.753	0.907	0.977	0.996	0.999	1.000	1.000
	DWR	0.135	0.324	0.581	0.808	0.937	0.985	0.997	1.000	1.000	1.000
	DWU	0.050	0.176	0.417	0.694	0.886	0.970	0.994	0.999	1.000	1.000
10	DWP	0.054	0.191	0.441	0.709	0.890	0.973	0.995	0.999	1.000	1.000
	DWR	0.624	0.798	0.911	0.968	0.990	0.998	0.999	1.000	1.000	1.000

X2 : T = 20 ; α = 0.5

λ	Test	ρ = 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	DWU	0.500	0.630	0.743	0.832	0.894	0.935	0.961	0.976	0.985	0.989
0	DWP	0.491	0.631	0.759	0.849	0.909	0.949	0.970	0.982	0.988	0.992
	DWR	0.500	0.640	0.761	0.854	0.916	0.955	0.976	0.988	0.994	0.997
	DWU	0.500	0.630	0.743	0.832	0.894	0.935	0.961	0.976	0.985	0.989
0.5	DWP	0.560	0.684	0.789	0.863	0.915	0.948	0.969	0.981	0.988	0.992
	DWR	0.580	0.701	0.802	0.877	0.928	0.960	0.979	0.989	0.994	0.997
	DWU	0.500	0.630	0.743	0.832	0.894	0.935	0.961	0.976	0.985	0.989
2	DWP	0.627	0.729	0.815	0.876	0.922	0.951	0.972	0.982	0.988	0.992
	DWR	0.758	0.831	0.887	0.928	0.956	0.974	0.985	0.991	0.995	0.997
	DWU	0.500	0.630	0.743	0.832	0.894	0.935	0.961	0.976	0.985	0.989
10	DWP	0.502	0.633	0.751	0.837	0.900	0.937	0.965	0.979	0.987	0.991
	DWR	0.991	0.994	0.995	0.996	0.997	0.997	0.997	0.998	0.998	0.998

IV. Conclusions

The Durbin-Watson test is often used in a pre-test regression situation similar to that analysed in this paper. As with the converse problem considered by King and Giles (1984), the quantitative implications of pre-test testing can vary considerably with the form of the regressors. However, several general conclusions can be drawn from our results.

First, the application of a preliminary t-test increases the true size of the DW test above its nominal level, unless the restriction being tested holds exactly. The percentage size distortion can be reduced by increasing the nominal size of the DW test. However, an even greater size inflation occurs if the (false) restriction is simply imposed without testing, and then the DW test is applied. There is no distortion in size if the DW test is applied to the unrestricted model without pre-testing.

Second, the implications of pre-testing for the true power of the DW test are less easily determined. If the hypothesis being tested by the t-test is true, then there is a clear DW power advantage in pre-testing rather than ignoring the restriction. If this hypothesis is false then, depending on the data and other factors, it is also possible to gain a power advantage relative to simply imposing the restriction, by pre-testing before applying the DW test.

Third, if size differences are ignored and one considers the raw probabilities of correctly rejecting serial independence, the performance of the pre-test DW test lies between those of the two possible "no pre-test" strategies. Accordingly, the existing results in the autocorrelation testing literature provide a useful guide to the likely performance of the pre-test DW test in various situations.

Further research into this problem would be warranted. Pre-tests of more general restrictions could be considered, though other results in the pre-test literature lead one to conjecture that the results would be qualitatively consistent with those reported here. Of greater interest would be an examination of the effect of using different autocorrelation tests at the second testing stage.

FOOTNOTES

*We are grateful to Judy Giles and John Small for helpful discussions and advice.

1. The results of King and Giles (1984) and Griffiths and Beesley (1984) also support this choice in favour of the (asymptotically justified) alternative of using the standard Normal critical values.
2. The same data-generating process, and the same data, apply in (2) as in (1).
3. As a check on the accuracy of the Monte Carlo experiment, we also simulated these powers in tandem with those for the pre-test DW test, and acceptable results were obtained.
4. Of course, different results would be obtained if the extraneous regressors were deleted and the critical value modified accordingly, but the researcher is unaware that irrelevant regressors are included.
5. A is a (T×T) tri-diagonal matrix whose leading diagonal elements are 2 except for the top left and bottom right elements, whose values are unity. The elements of the leading off-diagonals are all -1. The eigenvector corresponding to the zero root of A has constant elements.
6. For example, King and Giles (1984), King (1985), and Evans (1989).
7. Our results are invariant to the choice of σ, β_0, β_1 and β_2. See Breusch (1980) and King and Giles (1984). Values of $\rho > 0.9$ are considered with X4, for reasons discussed below.
8. Although we do not report results for $\rho > 0.9$ for the other data matrices, we have verified that the powers of all of the DW tests increase for $0.9 < \rho < 1.0$ in those cases.

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