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CIDE

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SIZE DISTORTIONS OF TESTS FOR HETEROSKEDASTICITY, CROSS-SECTIONAL CORRELATION AND AUTOCORRELATION IN DYNAMIC PANEL DATA MODELS

Abstract

This paper investigates the extent to which different error covariance structures can be identified in finite samples in a dynamic panel data context. Specifically, the size of several known tests for heteroskedasticity, cross-sectional correlation and autocorrelation is evaluated using a dynamic fixed-effects model. Except in a few cases, the size of the tests is found to be seriously distorted. The problem of groupwise heteroskedasticity can be reasonably identified for AR parameter values of 0.5 and 0.7 as the size of the tests is quite close to nominal values. For the same AR values, the size of the tests for cross-sectional and autocorrelation is appreciably distorted towards the over rejection of the null hypothesis, the exception being Baltagi's (1995) test for autocorrelation in the case where $\beta = 0.5, N = 15, T = 100$. For $\beta = 0.9$ the size of all tests is greatly distorted.

Key words: Dynamic Panel Data Models; Instrumental Variables; Size of the Test; Heteroskedasticity; Cross Sectional Correlation; Autocorrelation; Monte Carlo simulations.

JEL classification: C15, C23.

Introduction

The goal of this research is to investigate the extent to which different error covariance structures are identifiable in small samples in dynamic panel data models with AR processes that could rank from moderate to highly persistent. Specifically, the size of various known tests for groupwise heteroskedasticity, cross-sectional correlation and autocorrelation is evaluated using a panel data dynamic fixed effects specification.

Since these tests are implemented on estimated residuals from a preliminary consistent estimator, it seems relevant to investigate the extent to which their performance (size and power) may be affected in contexts in which biases are likely to arise. This research is limited to a few cases only, mainly relevant for macro applications.

In the following section a brief description of each test presented. Section 3 evaluates, via Monte Carlo simulations the size of the tests and reports the most relevant findings. Finally, Section 4 summarizes.

2. *Brief Description of the Tests*

The starting point is the Balestra and Nerlove (1966) dynamic model:

$$y_{it} = \mu_i + \beta y_{it-1} + v_{it} \tag{1}$$

where: μ_i are the individual-specific effects, assumed fixed, and $v_{it} \sim iid(0,\sigma_v^2)$. This will be called individual effects model (IEM): In addition, the following pooled regression model (PRM) specification is considered:[1]

$$y_{it} = \mu + \beta y_{it-1} + v_{it} \tag{2}$$

In this case there are no individual-specific effects and both intercept and slope coefficients are the same for all cross-sections.

First of all, it is possible to have significant variation in the scale of variables across individual cross-sections. This will result in the well known case of groupwise heteroskedasticity . In this case the variance of the error term will be different for each cross-section, i.e. $v_{it} \sim (0,\sigma_{vi}^2)$, that is the errors are still

[1] This model is used for comparison only. Since pooling will result in a large number of observations, no size distortions are expected in this case.

independent but not identically distributed. The covariance matrix of the disturbances will be block-diagonal, with blocks $\sigma^2_{vi}\mathbf{I}_T$ where σ^2_{vi} is the variance of the error term for cross-section i. The off-diagonal blocks are in this case $\mathbf{0}_T$, that is, matrices of zeros of order TxT.

The following three general tests for heteroskedasticity are used here: Breusch-Pagan, Bartlett, and White's tests. The Breusch-Pagan test needs to be adapted to panel data with groupwise heteroskedasticity. Bartlett's test is used by Baltagi and Griffin (1988) to test for heteroskedasticity in a one-way error component panel data model with exogenous regressors, so no adaptation of this test is necessary beyond estimating the errors consistently in a context of lagged dependent variable regressors.

A natural extension of the Breusch-Pagan (1979) test to panel data will consider the alternative hypothesis of groupwise heteroskedasticity as

$$\sigma^2_{vit} = h(\mathbf{z}_{it}'\alpha) = \mathbf{z}_{it}'\alpha \qquad (3)$$

where $\mathbf{z}_{1t}' = [1,0,\ldots\ldots,0]$, $\mathbf{z}_{2t}' = [1,1,0,\ldots\ldots,0]$, $\mathbf{z}_{3t}' = [1,0,1,0,\ldots,0],\ldots,\mathbf{z}_{Nt}' = [1,0,\ldots\ldots,1]$ are $1xN$ vectors, for $t = 1,\ldots,T$; and $\alpha' = [\alpha_1, \alpha^*_1, \alpha^*_2, \ldots, \alpha^*_{N-1}]$ is an $1xN$ vector. Thus, for individual 1, $\sigma^2_{v1t} = \alpha_1$; for individual 2, $\sigma^2_{v2t} = \alpha_1 + \alpha^*_1$; and for individual N, $\sigma^2_{vNt} = \alpha_1 + \alpha^*_{N-1}$. Under the null hypothesis $\mathbf{H}_0 : \alpha^*_1 = \alpha^*_2 = \ldots = \alpha^*_{N-1} = 0$, all the disturbances v_{it} will have a constant variance equal to α_1, which corresponds to the case of homoskedasticity. Assuming that the disturbances are normally distributed the Lagrange Multiplier statistic proposed by Breusch and Pagan is, under the null,

$$h_1 = \left[\mathbf{q}'\mathbf{Z}(\mathbf{Z}'\mathbf{Z})^{-1}\mathbf{Z}'\mathbf{q}\right] / 2\hat{\sigma}^4 \qquad (4)$$

where $\mathbf{Z} = [\mathbf{z}_1, \mathbf{z}_2, \ldots, \mathbf{z}_N]$, $\mathbf{q} = \mathbf{e}^2 - \hat{\sigma}^2\mathbf{i}_{NT}$, $\mathbf{e}^2$ is a $TNx1$ vector of squared residuals, $\mathbf{i}_{NT}$ a $NTx1$ vector of ones, and $\hat{\sigma}^2 = (TN)^{-1}\sum_{i=1}^{N}\sum_{t=1}^{T} e^2_{it}$. Under $\mathbf{H}_0, h_1$ is asymptotically distributed as χ^2_{N-1}. It should be noticed that the statistic h_1 is derived under the assumption that the error terms are normally distributed and its performance is quite poor when this assumption is not met. A modified version of this test which is still valid if the errors are not normally distributed will replace the denominator in (4) by $(NT)^{-1}\sum_{t=1}^{T}\sum_{i=1}^{N}(e^2_{it} - \hat{\sigma}^2)^2$ which is the sample variance of e^2_{it} [See Judge et al.(1988)].

The Bartlett test is a modification of the likelihood ratio test statistic for testing the equality of variances among N independent normal random samples each one consisting of T_i observations [Judge et al. (1985)]. Under the assumption of normally distributed disturbances the Bartlett test statistic can be reformulated as

$$h_2 = C / D \tag{5}$$

where $C = N(T-1)\ln\hat{\sigma}^2 - \sum_{i=1}^{N}(T-1)\ln\hat{\sigma}_i^2$; $D = 1 + (1/3)(N+1)/[N(T-1)]$, $\hat{\sigma}_i^2 = [\sum_{t=1}^{T}(e_{it} - \bar{e}_i)^2]/(T-1)$; and $\hat{\sigma}^2 = [\sum_{i=1}^{N}(T-1)\hat{\sigma}_i^2]/[N(T-1)]$. Notice that here $T_i = T$ is used, that is, the number of observations for each cross-section is identical. The denominator of this test is a scaling constant which makes the distribution of this test approximately χ^2_{N-1}.

White's test statistic can be computed as

$$h_3 = NT\mathbf{R}^2 \tag{6}$$

where $\mathbf{R}^2$ is the squared multiple correlation coefficient from the auxiliary regression of the estimated squared residuals, e_{it}^2, on a constant term, y_{it-2} and y_{it-2}^2. The statistic h_3 has an asymptotic χ^2_2 distribution. Since White's test is in fact a general test for misspecification and is likely to pick up other specification errors or correlation between the explanatory variables and the error term, the instrumental variable y_{it-2} is used instead of y_{it-1} in the auxiliary regression.

In addition to groupwise heteroskedasticity, cross-sectional correlation can also be found in the data. Under cross-sectional correlation the off-diagonal blocks of the covariance matrix of disturbances will take the form $\sigma_{uij}\mathbf{I}_T$ for all $i \neq j$, where σ_{uij} is the covariance between the disturbances of individuals i and j. The null hypothesis that the off-diagonal elements of the covariance matrix of the disturbances are zero can be tested using with the Lagrange Multiplier statistic developed by Breusch-Pagan (1980), which takes the form

$$c_1 = T\sum_{i=2}^{N}\sum_{j=1}^{i-1} r_{ij}^2 \tag{7}$$

where r_{ij} is the correlation coefficient of the residuals between cross-sections i and j. Asymptotically, this statistic is distributed as chi-squared with $N(N-1)/2$ degrees of freedom.

Finally, the assumption of no autocorrelation of the disturbances can also be relaxed. For example, the disturbances of each individual cross-section may follow the AR(1) process

$$v_{it} = \rho_i v_{it-1} + \varepsilon_{it} \; ; \; t = 1,\ldots,T \tag{8}$$

where ε_{it} is assumed i.i.d. with zero mean and variance $\sigma^2_{\varepsilon i}$. If this process is stationary, $\mathrm{Var}[v_{it}] = \sigma^2_{vi} = \sigma^2_{\varepsilon i} / (1-\rho_i^2)$. In addition, cross-sectional correlation can also be allowed by assuming $\mathrm{Cov}[\varepsilon_{it}, \varepsilon_{jt}] = \sigma_{\varepsilon ij}$.

Under groupwise heteroskedasticity, cross-sectional correlation and autocorrelation, each diagonal block of the covariance matrix of disturbances will take the following form:

$$\Omega_{ii} = \frac{\sigma^2_{\varepsilon i}}{1-\rho_i^2}\begin{bmatrix} 1 & \rho_i & \rho_i^2 & \ldots\rho_i^{T-1} \\ \rho_i & 1 & \rho_i & \ldots\rho_i^{T-2} \\ \ldots & \ldots & \ldots & \ldots\;\ldots \\ \rho_i^{T-1} & \rho_i^{T-2} & \ldots & \ldots\;\;1 \end{bmatrix} \tag{9}$$

Similarly, each off-diagonal block will be

$$\Omega_{ij} = \frac{\sigma_{\varepsilon ij}}{1-\rho_i\rho_j}\begin{bmatrix} 1 & \rho_j & \rho_j^2 & \ldots\rho_j^{T-1} \\ \rho_i & 1 & \rho_j & \ldots\rho_j^{T-2} \\ \ldots & \ldots & \ldots & \ldots\;\ldots \\ \rho_i^{T-1} & \rho_i^{T-2} & \ldots & \ldots\;\;1 \end{bmatrix} \tag{10}$$

Three testing procedures for autocorrelation are used here, under the assumption that the autocorrelation coefficient is the same for all individual cross-sections. A Lagrange multiplier test suggested by Baltagi (1995), the Breusch (1978)-Godfrey (1978) Lagrange multiplier test, and an adapted version of the Q test statistic due to Box and Pierce (1970). Baltagi (1995) shows that for testing the null hypothesis, $\rho = 0$, in a fixed effects model the Lagrange multiplier test statistic can be expressed as

$$a_1 = [NT^2 / (T-1)](\tilde{v}'\tilde{v}_{-1} / \tilde{v}'\tilde{v})^2 \tag{11}$$

where $\tilde{v}$ is the NxT vector of the Within residuals.[2] Under the null hypothesis of no autocorrelation a_1 is asymptotically distributed as χ^2_1. This test applies directly to the model given by equation (1).

The Lagrange multiplier test statistic due to Breusch (1978) and Godfrey (1978) can be computed as

$$a_2 = TN\mathbf{R}^2 \tag{12}$$

where $\mathbf{R}^2$ is the squared multiple correlation coefficient from the auxiliary regression of the estimated residuals, e_{it}, on y_{it-2} and e_{it-1}. The statistic a_2 has an

[2] Since the Within estimator of the AR parameter is biased in a dynamic fixed effects model and inconsistent for a given T, estimation of this parameter will be done by IV methods.

asymptotic χ_1^2 distribution. Notice that the instrumental variable y_{it-2} is used instead of y_{it-1} to make sure that if any fit is found in the auxiliary regression it is mainly due to correlation between the current and lagged residuals. Greene (1993) suggests the following modified version of this test. Regress the estimated residuals e_{it} on $y_{it-1},\ldots,e_{t-1}$, and any additional lags, and then test for the joint significance of the coefficients on the lagged residuals with the standard F test. Since here first order autocorrelation is being tested, only one lagged residual needs to be included and its significance is to be tested with the standard t test.

The Q test statistic due to Box and Pierce (1970) takes the form

$$Q = TN\sum_{j=1}^{L} r_j^2 \tag{13}$$

where $r_j = (\sum_{t=j+1}^{T}\sum_{i=1}^{N} e_{it}e_{it-j})/(\sum_{t=1}^{T}\sum_{i=1}^{N} e_{it}^2)$. Q is asymptotically distributed as χ_L^2, with L equal to the number of lags considered. For the case of first order autocorrelation of the disturbances $L=1$ and this test statistic becomes $Q = TN\mathbf{d}^2$, where $\mathbf{d}$ is the well known Durbin-Watson test statistic. In this particular case, Q is asymptotically distributed as χ_1^2. Notice that this test is identical to the one given by Baltagi if T in (13) is replaced by $T^2/(T-1)$. Thus, both tests are equivalent asymptotically.

3. *Evaluating the Size of the Tests*

The size of the tests is evaluated using Monte Carlo simulations, which are designed as follows. The AR parameter values of interest are: 0.5, 0.7, 0.9. The sample sizes considered are: $N = 15, T = 100$; $N = 40, T = 50$; and $N = 100, T = 30$. The specifications considered are given by equations (1) and (2) respectively. In each case, the data is generated under the null hypothesis of no heteroskedasticity, no cross-sectional correlation and no autocorrelation. The error terms are drawn from a standard normal distribution. In order to get the estimated residuals, OLS estimation is used in the case of the PRM, and Anderson-Hsiao IV estimation is implemented in the case of the IEM.[3]

[3] This estimator uses the two-period lagged level of y as instrumental variable and is preferred to the one-period lagged difference of y which has been reported to behave quite poorly. See Arellano (1989) and Baltagi (1995).

The size of each test is computed as the number of times the null hypothesis is rejected (the null is true by construction) divided by the total number of replications in the experiment. The nominal sizes considered are 0.01, 0.05 and 0.10. The number of replications in each experiment is 10000 with the exception of the Breusch-Pagan test for heteroskedasticity where it was set to 500 only. All programs were written in GAUSS. The results are presented in Tables 1 through 6.

Consider first the results for the PRM. In this case, the size of all tests for heteroskedasticity and cross-sectional correlation is approximately correct. However, as the value of the autoregressive parameter is increased, in general these tests tend to reject the null more frequently than their nominal values. Concerning autocorrelation, the size of Baltagi's LM test, is found to be significantly less than its nominal value. The two versions of the Breusch-Godfrey test give size values close to their nominal values, with a very small tendency to over reject the null as the autoregressive parameter increases. Overall, this research does not find any significant size distortion in the case of the PRM. This result was anticipated since the pooled samples have a very large number of observations which ensures consistent and unbiased estimation of the residuals.

In the case of the IEM, and concerning heteroskedasticity, White and Bartlett's tests have sizes close to their nominal values when β is equal to 0.5 or 0.7, with a slight tendency to over reject the true null hypothesis as N is increased and T is reduced. The Breusch-Pagan test rejects the null more frequently than the previous two tests, but is not appreciably different from their nominal values. For $\beta = 0.9$ all tests over reject the null significantly. For the cases of cross-sectional correlation and autocorrelation in the IEM model, with exception of Baltagi's test for the case when $\beta = 0.5$ and $N = 15, T = 100$, the size of all tests appears to be strongly distorted towards over rejection of the null hypothesis. This tendency is greater the higher β, the higher N and the lower T.

Table 1: Size of tests in pooled regression model (AR=0.5)

Sample	**N=15**	**, T=**	**100**	**N=50**	**, T=**	**40**	**N=**	**100,T**	**=30**
Nom. Size	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**
HETER.									
White	0.011	0.050	0.098	0.009	0.045	0.091	0.011	0.047	0.095
Bartlett	0.008	0.048	0.098	0.008	0.044	0.096	0.010	0.049	0.097
B-P	0.012	0.042	0.084	0.004	0.046	0.086	0.006	0.040	0.072
C. S. C.									
B-P	0.009	0.046	0.093	0.009	0.047	0.094	0.009	0.045	0.090
AUTOC.									
Baltagi	0.000	0.000	0.001	0.000	0.001	0.003	0.000	0.001	0.004
B-G (1)	0.009	0.049	0.098	0.010	0.051	0.101	0.010	0.053	0.103
B-G (2)	0.009	0.049	0.098	0.010	0.051	0.101	0.010	0.053	0.103

Table 2: Size of tests in pooled regression model (AR=0.7)

Sample	**N=15**	**, T=**	**100**	**N=50**	**, T=**	**40**	**N=**	**100,T**	**=30**
Nom. Size	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**
HETER.									
White	0.009	0.048	0.099	0.010	0.050	0.010	0.012	0.048	0.093
Bartlett	0.010	0.047	0.098	0.009	0.051	0.103	0.011	0.051	0.099
B-P	0.010	0.040	0.094	0.006	0.046	0.084	0.020	0.056	0.102
C. S. C.									
B-P	0.010	0.049	0.091	0.009	0.046	0.092	0.008	0.044	0.086
AUTOC.									
Baltagi	0.000	0.006	0.018	0.001	0.008	0.028	0.001	0.011	0.031
B-G (1)	0.009	0.049	0.100	0.010	0.050	0.105	0.011	0.050	0.098
B-G (2)	0.009	0.049	0.100	0.010	0.050	0.105	0.011	0.050	0.098

Table 3: Size of tests in pooled regression model (AR=0.9)

Sample	**N=15**	**, T=**	**100**	**N=50**	**, T=**	**40**	**N=**	**100,T**	**=30**
Nom. Size	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**
HETER.									
White	0.009	0.044	0.092	0.012	0.049	0.097	0.011	0.052	0.104
Bartlett	0.009	0.050	0.097	0.011	0.048	0.103	0.009	0.047	0.099
B-P	0.014	0.058	0.102	0.020	0.058	0.112	0.018	0.058	0.104
C. S. C.									
B-P	0.010	0.049	0.096	0.008	0.043	0.093	0.010	0.043	0.090
AUTOC.									
Baltagi	0.005	0.034	0.079	0.007	0.040	0.084	0.008	0.044	0.091
B-G (1)	0.010	0.050	0.102	0.010	0.051	0.101	0.010	0.053	0.103
B-G (2)	0.010	0.050	0.103	0.010	0.051	0.101	0.010	0.053	0.103

Table 4: Size of tests in individual fixed-effects model (AR=0.5)

Sample	**N=15**	**, T=**	**100**	**N=50**	**, T=**	**40**	**N=**	**100,T**	**=30**
Nom. Size	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**
HETER.									
White	0.011	0.050	0.105	0.012	0.052	0.101	0.015	0.058	0.108
Bartlett	0.010	0.050	0.100	0.008	0.046	0.098	0.010	0.052	0.103
B-P	0.010	0.042	0.084	0.008	0.066	0.104	0.010	0.062	0.130
C.S.C.									
B-P	0.012	0.059	0.112	0.056	0.176	0.284	0.316	0.585	0.724
AUTOC.									
Baltagi	0.012	0.063	0.126	0.098	0.247	0.355	0.274	0.491	0.601
B-G (1)	0.034	0.116	0.187	0.142	0.304	0.408	0.358	0.560	0.659
B-G (2)	0.025	0.101	0.178	0.129	0.290	0.396	0.336	0.545	0.643

Table 5: Size of tests in individual fixed-effects model (AR=0.7)

Sample	**N=15**	**, T=**	**100**	**N=50**	**, T=**	**40**	**N=**	**100,T**	**=30**
Nom. Size	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**
HETER.									
White	0.011	0.049	0.098	0.013	0.058	0.110	0.014	0.060	0.113
Bartlett	0.011	0.059	0.103	0.010	0.058	0.110	0.013	0.054	0.104
B-P	0.014	0.052	0.108	0.016	0.060	0.108	0.036	0.088	0.148
C.S.C.									
B-P	0.014	0.063	0.120	0.074	0.206	0.324	0.362	0.624	0.754
AUTOC.									
Baltagi	0.021	0.084	0.159	0.177	0.341	0.438	0.343	0.523	0.610
B-G (1)	0.074	0.188	0.282	0.267	0.423	0.515	0.465	0.614	0.686
B-G (2)	0.027	0.098	0.180	0.185	0.350	0.449	0.356	0.532	0.617

Table 6: Size of tests in individual fixed-effects model (AR=0.9)

Sample	**N=15**	**, T=**	**100**	**N=50**	**, T=**	**40**	**N=**	**100,T**	**=30**
Nom. Size	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**
HETER.									
White	0.025	0.078	0.137	0.234	0.333	0.400	0.392	0.482	0.546
Bartlett	0.073	0.142	0.207	0.498	0.560	0.606	0.593	0.646	0.682
B-P	0.092	0.164	0.232	0.574	0.626	0.662	0.604	0.652	0.686
C.S.C.									
B-P	0.169	0.247	0.316	0.692	0.752	0.797	0.855	0.919	0.949
AUTOC.									
Baltagi	0.300	0.375	0.436	0.663	0.729	0.770	0.755	0.817	0.849
B-G (1)	0.515	0.640	0.705	0.842	0.887	0.908	0.901	0.929	0.942
B-G (2)	0.300	0.374	0.436	0.661	0.727	0.767	0.750	0.814	0.847

4. Conclusion

With a few exceptions, this research finds serious size distortions of the tests for non sphericalnesses in panel data dynamic fixed effects models. The problem of groupwise heteroskedasticity could reasonably be identified for AR values of 0.5 and 0.7, as the size of the tests is quite close to nominal values. For the same AR values, the size of the tests for cross-sectional and autocorrelation is appreciably distorted towards over rejection of the null hypothesis, with exception of Baltagi's (1995) test for auto correlation in for the case when $\beta = 0.5, N = 15, T = 100$. For $\beta = 0.9$ the size of all tests is greatly distorted.

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