Small Sample Properties and Pretest Estimation of a Spatial Hausman-Taylor Model

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Abstract: This paper considers a Hausman and Taylor (1981) panel data model that exhibits a Cliff and Ord (1973) spatial error structure. We analyze the small sample properties of a Generalized Moments estimation approach for that model. This spatial Hausman-Taylor estimator allows for endogeneity of the time-varying and time-invariant variables with the individual effects. For this model, the spatial fixed effects estimator is known to be consistent, but its disadvantage is that it wipes out the effects of time-invariant variables which are important for most empirical studies. Monte Carlo results show that this spatial Hausman Taylor estimator performs well in small samples.

Key Words: Hausman-Taylor estimator; Spatial random effects; Small sample properties

JEL Classification: C23; C31

1 Introduction

Hausman and Taylor (1981) proposed a random effects panel data model which allows for endogeneity of time-varying and time-invariant variables with the individual effects. For this model, fixed effects (FE) is known to be consistent, but its disadvantage is that it wipes out the effects of time-invariant variables which are important for most empirical studies. In an earnings equation, the time-invariant variable could be schooling and this is correlated with the unobservable individual effect, see Cornwell and Rupert (1988). In this case, FE would not deliver an estimate of the returns to schooling, but the alternative Hausman and Taylor estimator will provide an asymptotically efficient estimator of this effect. The order condition of identification requires that there are as many exogenous time-variant regressors as there are endogenous time-invariant regressors. Other applications of this estimator include the effect of an individual's birth year on wages (see Light and Ureta, 1995); the effect of health on wages (Contoyannis and Rice, 2001); the effect of distance on bilateral trade (Egger, 2004) or foreign direct investment (Egger and Pfaffermayr, 2004); the effect of common language on bilateral trade (Serlenga and Shin, 2007); the effect of public ownership of firms on productivity (Baltagi, Egger, and Kesina, 2011). The last paper introduces spatial spillovers in total factor productivity by allowing the error term across firms to be spatially interdependent. This model is estimated by extending the Hausman and Taylor (1981) estimator to allow for spatial correlation in the error term. Baltagi, Egger, and Kesina (2011) find evidence of positive spillovers across firms and a large and significant detrimental effect of public ownership on total factor productivity.

This is a follow up paper that studies the small sample performance of various estimators applied to this *spatial* Hausman-Taylor model using Monte Carlo experiments. We will refer to the spatial Hausman-Taylor model by the acronym SHT. This paper also studies the small sample performance of a pretest estimator which is based on two Hausman tests usually carried out by the empirical researcher in practice. It is well known, that the choice between fixed effects (FE) and random effects (RE) estimators is based on the Hausman (1978) test. Baltagi, Bresson, and Pirotte (2003) suggest an alternative pretest estimator based on the Hausman and Taylor model. This pretest estimator reverts to the RE estimator if the standard Hausman test based on the FE versus the RE estimators is not rejected. It reverts to the HT estimator if the choice of strictly exogenous regressors is not rejected by a second Hausman over-identification test based on the difference between the FE and HT estimators, see Baltagi (2008) for a textbook treatment of this subject. This paper generalizes this pretest estimator to account for spatial correlation. In the first step, a standard Hausman (1978) test is performed based on the contrast between spatial fixed effects (SFE) and spatial random effects (SRE),[1] and in the second step a Hausman-Taylor over-identification test is performed based on the contrast between SFE and the SHT estimator. The pretest estimator becomes the SRE estimator if the Hausman test is not rejected in the first step. It becomes the SHT estimator if the first Hausman test is rejected but the second Hausman-Taylor over-identification test is not rejected. If both tests are rejected, then the pretest estimator reverts to the SFE estimator.

This paper performs Monte Carlo experiments to compare the performance of this spatial pretest estimator with the spatial panel data estima-

[1]See Mutl and Pfaffermayr (2011) for the large and small sample properties of the Hausman test statistic in a Cliff and Ord type spatial panel data model.

tors under various designs. The estimators considered are: Spatial OLS (SOLS), spatial fixed effects (SFE), spatial random effects (SRE), and spatial Hausman–Taylor (SHT), respectively.

In one design we let some regressors be correlated with the individual effects and the error to be spatially correlated, i.e. a spatial Hausman–Taylor world. In another design, the regressors are not allowed to be correlated with the individual effects, but the error is allowed to be spatially correlated,i.e., a SRE world. Our results show that the spatial pretest estimator is a viable estimator and performs reasonably well in RMSE but should not be used for simple test of hypothesis. The SFE estimator is a consistent estimator under both designs but its disadvantage is that it does not allow the estimation of the coefficients of the time invariant regressors. When there is endogeneity among the regressors, we show that there is substantial bias in spatial OLS and SRE estimators and both yield misleading inference.

The remainder of the paper is organized as follows. Section 2 briefly reviews the estimators for the spatial Hausman-Taylor model which will be employed in the Monte Carlo analysis. Section 3 introduces the Monte Carlo design and discuss the results. The last section concludes with a brief summary of our main findings.

2 Econometric model

In this section, we briefly review the Hausman and Taylor (1981) model with spatial correlation. Let $i = 1, ..., N$ refer to individual units and $t = 1, ..., T$ refer to time periods. In what follows, we are interested in analyzing a Cliff and Ord (1973) spatial model for period t of the form

$$\mathbf{y}_t = \mathbf{X}_t\beta + \mathbf{Z}\gamma + \mathbf{u}_t = \mathfrak{Z}_t\delta + \mathbf{u}_t \tag{1}$$

$$\mathbf{u}_t = \rho\mathbf{W}\mathbf{u}_t + \varepsilon_t, \quad \varepsilon_t = \mu + \nu_t \tag{2}$$

where $\mathfrak{Z}_t = [\mathbf{X}_t, \mathbf{Z}]$, and $\delta = [\beta', \gamma']'$. Here, $\mathbf{y}_t = (y_{1t}, ..., y_{Nt})'$ is an $N \times 1$ vector of observations on the dependent variable at time t, $\mathbf{X}_t$ is an $N \times K$ matrix of time-varying regressors for period t, $\mathbf{Z}$ is an $N \times R$ matrix of time-invariant regressors. The regressors may be decomposed into $\mathbf{X}_t = [\mathbf{X}_{Ut}, \mathbf{X}_{Ct}]$ and $\mathbf{Z} = [\mathbf{Z}_U, \mathbf{Z}_C]$, where subindex C denotes regressors which are *correlated* with μ while subindex U indicates regressors which are *uncorrelated* with μ. $\mathbf{W}$ is an $N \times N$ observed non-stochastic spatial weights matrix. $\mathbf{u}_t = (u_{1t}, ..., u_{Nt})'$ is the $N \times 1$ vector of disturbances, and $\varepsilon_t = (\varepsilon_{1t}, ..., \varepsilon_{Nt})'$ is an $N \times 1$ vector of innovations which consists of two components: a time-invariant $\mu = (\mu_1, ..., \mu_N)'$ and a time-variant $\nu_t = (\nu_{1t}, ..., \nu_{Nt})'$ component, where $\mu \sim i.i.d.(0, \sigma_\mu^2)$ and $\nu \sim i.i.d.(0, \sigma_\nu^2)$. The vector $\mathbf{W}\mathbf{u}_t$ represents a spatial lag of $\mathbf{u}_t$. The scalar ρ denotes the spatial auto-regressive parameter, while β and γ are $K \times 1$ and $R \times 1$ vectors of regression parameters.

When stacking the model for all time periods $t = 1, .., T$, it reads

$$\mathbf{y} = \mathbf{X}\beta + (\iota_T \otimes \mathbf{Z})\gamma + \mathbf{u} = \mathfrak{Z}\delta + \mathbf{u} \tag{3}$$

$$\mathbf{u} = \rho(\mathbf{I}_T \otimes \mathbf{W})\mathbf{u} + \varepsilon, \quad \varepsilon = \mathbf{Z}_\mu\mu + \nu, \tag{4}$$

where $\mathbf{X} = [\mathbf{x}_1', ..., \mathbf{x}_T']'$, $\mathfrak{Z}_t = [\mathfrak{Z}_1', .., \mathfrak{Z}_T']'$, $\mathbf{u} = [\mathbf{u}_1', .., \mathbf{u}_T']'$ and $\varepsilon = [\varepsilon_1', .., \varepsilon_T']'$. ι_T denotes a $T \times 1$ vector of ones and $\mathbf{I}_T$ denotes a $T \times T$ identity matrix. $\mathbf{Z}_\mu = \iota_T \otimes \mathbf{I}_N$ is an $NT \times N$ selector matrix of ones and zeroes.

For estimation, we employ moment conditions derived in Kapoor, Kelejian, and Prucha (2007) for the SRE model. These moment conditions are given by $\frac{1}{N(T-1)}\varepsilon'\mathbf{Q}\varepsilon = \sigma_\nu^2$, $\frac{1}{N(T-1)}\overline{\varepsilon}'\mathbf{Q}\overline{\varepsilon} = \sigma_\nu^2\frac{1}{N}tr(\mathbf{W}'\mathbf{W})$, $\frac{1}{N(T-1)}\overline{\varepsilon}'\mathbf{Q}\varepsilon = 0$, $\frac{1}{N}\varepsilon'\mathbf{P}\varepsilon = \sigma_1^2$, where $\overline{\varepsilon} \equiv (\mathbf{I}_T \otimes \mathbf{W})\varepsilon$ and $\sigma_1^2 = T\sigma_\mu^2 + \sigma_\nu^2$. $\mathbf{Q}$ denotes the sweeping (within transformation) matrix and $\mathbf{P}$ the (between) projection matrix. The moment conditions can be rewritten in terms of $\mathbf{u}$ using the fact that $\varepsilon = (\mathbf{I}_T \otimes [\mathbf{I}_N - \rho\mathbf{W}])\mathbf{u} = \mathbf{u} - \rho\overline{\mathbf{u}}$ whereby $\overline{\mathbf{u}} \equiv (\mathbf{I}_T \otimes \mathbf{W})\mathbf{u}$ and $\overline{\varepsilon} \equiv (\mathbf{I}_T \otimes \mathbf{W})(\mathbf{I}_T \otimes [\mathbf{I}_N - \rho\mathbf{W}])\mathbf{u} = \overline{\mathbf{u}} - \rho\overline{\overline{\mathbf{u}}}$ with $\overline{\overline{\mathbf{u}}} \equiv (\mathbf{I}_T \otimes \mathbf{W})\overline{\mathbf{u}}$.

The resulting moment conditions are then stacked and solved as a solution to the system of four equations in three unknowns. More formally, $\gamma - \mathbf{\Gamma}\alpha = \mathbf{0}$, where $\alpha = (\rho, \rho^2, \sigma_\nu^2, \sigma_1^2)'$ and

$$\gamma = \begin{pmatrix} \frac{1}{N(T-1)}\mathbf{u}'\mathbf{Q}\mathbf{u} \\ \frac{1}{N(T-1)}\overline{\mathbf{u}}'\mathbf{Q}\overline{\mathbf{u}} \\ \frac{1}{N(T-1)}\mathbf{u}'\mathbf{Q}\overline{\mathbf{u}} \\ \frac{1}{N}\mathbf{u}'\mathbf{P}\mathbf{u} \end{pmatrix}, \quad \mathbf{\Gamma} = \begin{pmatrix} \frac{2}{N(T-1)}\mathbf{u}'\mathbf{Q}\overline{\mathbf{u}} & \frac{-1}{N(T-1)}\overline{\mathbf{u}}'\mathbf{Q}\overline{\mathbf{u}} & 1 & 0 \\ \frac{2}{N(T-1)}\overline{\overline{\mathbf{u}}}'\mathbf{Q}\overline{\mathbf{u}} & \frac{-1}{N(T-1)}\overline{\overline{\mathbf{u}}}'\mathbf{Q}\overline{\overline{\mathbf{u}}} & \frac{1}{N}tr\mathbf{W}'\mathbf{W} & 0 \\ \frac{1}{N(T-1)}(\mathbf{u}'\mathbf{Q}\overline{\overline{\mathbf{u}}} + \overline{\mathbf{u}}'\mathbf{Q}\overline{\mathbf{u}}) & \frac{-1}{N(T-1)}\overline{\mathbf{u}}'\mathbf{Q}\overline{\overline{\mathbf{u}}} & 0 & 0 \\ \frac{2}{N}\mathbf{u}'\mathbf{P}\overline{\mathbf{u}} & \frac{-1}{N}\overline{\mathbf{u}}'\mathbf{P}\overline{\mathbf{u}} & 0 & 1 \end{pmatrix}. \tag{5}$$

As Kapoor, Kelejian, and Prucha (2007) indicate, there are further moment conditions, but it may not be optimal to use them. In practice – especially with large data-sets – it may even be advisable to proceed as follows. First, replace $\mathbf{u}$, $\overline{\mathbf{u}}$, and $\overline{\overline{\mathbf{u}}}$ by their corresponding consistent estimates $\hat{\mathbf{u}}$, $\overline{\hat{\mathbf{u}}}$, and $\overline{\overline{\hat{\mathbf{u}}}}$. Then, define γ_3 and α_3 as the 3×1 subvectors containing the first three elements of γ and α, respectively, and $\mathbf{\Gamma}_3$ as the 3×3 submatrix containing the upper left bloc of elements of $\mathbf{\Gamma}$. Now, solve the first three of the above moment conditions for

$$\hat{\rho} = \arg \min_{\sigma_\nu^2 \in S_\nu, \rho \in S_\rho} \left[\left(\hat{\gamma}_3 - \hat{\mathbf{\Gamma}}_3\hat{\alpha}_3\right)' \hat{\mathfrak{J}}_3 \left(\hat{\gamma}_3 - \hat{\mathbf{\Gamma}}_3\hat{\alpha}_3\right) \right], \tag{6}$$

where S_ν, and S_ρ denote the respective admissible parameter spaces of σ_ν^2, and ρ, and $\hat{\mathfrak{J}}_3$ is the 3×3 weighting matrix of the moment vector. Setting $\hat{\mathfrak{J}} = \mathbf{I}_3$ allows estimating ρ and σ_ν^2 consistently by nonlinear least squares. Kapoor, Kelejian, and Prucha (2007) suggested also other options for $\hat{\mathfrak{J}}_3$ and for moments weighting matrices based on all six moment conditions, but these will be difficult to implement with large data-sets. When splitting the set of moment conditions as outlined and with estimates of ρ and σ_ν^2 at hand, σ_1^2 can be solved explicitly from the fourth moment condition as $\hat{\sigma}_1^2 = \frac{1}{N}\hat{\mathbf{u}}'\mathbf{P}\hat{\mathbf{u}} - \frac{2\hat{\rho}}{N}\hat{\mathbf{u}}'\mathbf{P}\hat{\bar{\mathbf{u}}} + \frac{\hat{\rho}^2}{N}\hat{\bar{\mathbf{u}}}'\mathbf{P}\hat{\bar{\mathbf{u}}}$. All of the subsequent Monte Carlo simulations are based on the latter procedure. Cliff and Ord type spatial panel data estimators– such as the aforementioned SFE, SHT, SRE, and SOLS – apply the Cochrane-Orcutt transformation $\mathbf{v}_* = (\mathbf{I}_T \otimes [\mathbf{I}_N - \hat{\rho}\mathbf{W}])\mathbf{v}$ to any variable $\mathbf{v}$ of size $NT \times 1$ in the model in order to avoid efficiency losses from spatial autocorrelation in the disturbances. Moreover, error components type spatial estimators such as SHT or SRE then transform $\mathbf{v}_*$ to obtain $\mathbf{v}_{**} = \hat{\sigma}_\nu \hat{\mathbf{\Omega}}^{-1/2}\mathbf{v}_*$ with $\mathbf{\Omega} = E(\varepsilon\varepsilon')$ and $\hat{\sigma}_\nu \hat{\mathbf{\Omega}}^{-1/2} = \mathbf{Q} + \frac{\hat{\sigma}_\nu}{\hat{\sigma}_1}\mathbf{P}$. Notice that the within counterpart to the SFE estimator replaces $\hat{\sigma}_\nu \hat{\mathbf{\Omega}}^{-1/2}$ by $\mathbf{Q}$ to obtain $\mathbf{v}_{**}$.

Besides the aforementioned estimators, we additionally consider the performance of a spatial pretest estimator that decides between SFE, SRE, and SHT in the spirit of Baltagi, Bresson, and Pirotte (2003) but allowing for spatial correlation. This estimator is based on two Hausman test statistics. In the first step, a standard Hausman (1978) test is performed based on the contrast between spatial fixed effects (SFE) and spatial random effects (SRE), and in the second step a Hausman-Taylor over-identification test is performed based on the contrast between SFE and the SHT estimator. The spatial pretest estimator becomes the SRE estimator if the Hausman test is not rejected in the first step. It becomes the SHT estimator if the first Hausman test is rejected but the second Hausman-Taylor over-identification test is not rejected. If both tests are rejected, then the pretest estimator reverts to the SFE estimator.

3 Monte Carlo analysis

3.1 Design

For an assessment of the various estimators of the SHT model including the pretest estimator in small samples, we follow the design used by Baltagi, Bresson, and Pirotte (2003) but we allow for spatial correlation:

$$\mathbf{y}_t = \mathbf{X}_{U1t}\beta_1 + \mathbf{X}_{U2t}\beta_2 + \mathbf{X}_{Ct}\beta_3 + \mathbf{Z}_U\gamma_1 + \mathbf{Z}_C\gamma_2 + \mathbf{u}_t \quad (7)$$

$$\mathbf{u}_t = \rho\mathbf{W}\mathbf{u}_t + \varepsilon_t, \quad \varepsilon_t = \mu + \nu_t \quad (8)$$

where $\mu \sim i.i.d.(0, \sigma_\mu^2)$, $\nu \sim i.i.d.(0, \sigma_\nu^2)$, and $\mathbf{W}$ is specified as an $N \times N$ nonstochastic, row-normalized spatial weights matrix which is based on the unnormalized counterpart $\mathbf{W}_0$. The latter exhibits zero diagonal elements and otherwise a three-before-and-three-behind neighborhood structure as specified in the Appendix. Here, $\mathbf{y}_t = (y_{1t}, ..., y_{Nt})'$ is an $N \times 1$ vector of observations on the dependent variable at time t, $\mathbf{X}_{U1t}$ and $\mathbf{X}_{U2t}$ are two $N \times 1$ vectors of time-varying regressors which are *uncorrelated* with $\mathbf{Z}_C$, the $N \times 1$ vector $\mathbf{X}_{Ct}$ is *correlated* with $\mathbf{Z}_C$, and $\mathbf{Z}_U$ is an $N \times 1$ vector which is uncorrelated with the other covariates.

We specify the covariates as follows:

- $\mathbf{X}_{U1t} = 0.7\mathbf{X}_{U1,t-1} + \delta + \zeta_t$, where δ is time-invariant and uniform on

$[-2,2]$ and ζ_t is time-variant and uniform on $[-2,2]$; the initial value $\mathbf{X}_{U1,1}$ is defined as $\mathbf{X}_{U1,1}$=$\zeta_1/(1-0.2^2)^{1/2}+\delta/(1-0.7)$.

- $\mathbf{X}_{U2t} = 0.7\mathbf{X}_{U2,t-1} + \eta + \kappa_t$, where η is time-invariant and uniform on $[-2,2]$ and κ_t is time-variant and uniform on $[-2,2]$; the initial value $\mathbf{X}_{U2,1}$ is defined as $\mathbf{X}_{U2,1}$=$\kappa_1/(1-0.2^2)^{1/2}+\eta/(1-0.7)$.

- $\mathbf{Z}_U = \iota_N$, and, hence, it is a constant as in Baltagi, Bresson, and Pirotte (2003).

Regarding the regression coefficients, we assume $\beta_1 = \beta_2 = \beta_3 = \gamma_1 = \gamma_2 = 1$ and $\rho \in \{0; 0.2; 0.4; 0.6; 0.8\}$.

We consider $N \in \{100; 200; 300\}$ and $T \in \{3; 5\}$ and generally set $\sigma^2_\mu + \sigma^2_\nu = 3$ but assume $\phi \equiv \frac{\sigma^2_\mu}{\sigma^2_\mu+\sigma^2_\nu} \in \{0; 0.25; 0.50; 0.75\}$.

In general, we use $1,000$ draws for the stochastic variables to estimate parameters for each of the $3 \cdot 2 \cdot 5 \cdot 4 = 120$ experiments.

For pretest estimation, we consider two alternative states with regard to the true data generating process – an (S)HT world and an (S)RE world – depending on the correlation of $\mathbf{X}_{Ct}$ and $\mathbf{Z}_C$ with the individual effect μ. This is reflected in the construction of these two variables.

Case 1 - (S)HT world:

In the (S)HT world, both $\mathbf{X}_{Ct}$ and $\mathbf{Z}_C$ are correlated with the individual effect μ.

- $\mathbf{X}_{Ct} = 0.7\mathbf{X}_{C,t-1} + \mu + \lambda_t$, where λ_t is time-variant and uniform on $[-2,2]$ and μ is uniform on $[-2,2]$ the initial value $\mathbf{X}_{C,1}$ is defined as $\mathbf{X}_{C,1}$=$\lambda_1/(1-0.2^2)^{1/2}+\mu/(1-0.7)$.

- $\mathbf{Z}_C = \delta + \eta + \mu + \xi$, where ξ is uniform on $[-2, 2]$.

Case 2 - (S)RE world:
In the SRE world, both $\mathbf{X}_{Ct}$ and $\mathbf{Z}_C$ are uncorrelated with the individual effect μ.

- $\mathbf{X}_{Ct} = 0.7\mathbf{X}_{C,t-1} + \tau + \lambda_t$, where τ is time-invariant an uniform on $[-2, 2]$; the initial value $\mathbf{X}_{C,1}$ is defined as $\mathbf{X}_{C,1}$=$\lambda_1/(1 - 0.2^2)^{1/2} + \tau/(1 - 0.7)$.

- $\mathbf{Z}_C = \delta + \eta + \xi$.

In the next section, we focus on the bias, the root mean squared error (RMSE), and the size of tests for $H_0^a : \beta_3 = 1$, and $H_0^b : \gamma_2 = 1$ at the 5% significance level. We focus on β_3 and γ_2, since they are the coefficients of the endogenous time-variant regressor, and the endogenous time-invariant regressor, respectively.

3.2 Results for bias and RMSE

Table 1 gives the bias, RMSE, and size of tests for $H_0^a : \beta_3 = 1$, and $H_0^b : \gamma_2 = 1$ at the 5% significance level. This is done for $(N = 100, T = 3)$ for Case 1, where the data generating process complies with the Hausman-Taylor world. Consider the configuration where $\rho = 0$ and $\phi \in \{0; 0.25; 0.50; 0.75\}$ in Table 1, which does not involve any spatial correlation. Obviously, the Spatial OLS estimator is consistent only if $\phi = 0$, i.e., in the absence of correlation between the individual-effects and the regressors. If $\phi > 0$, the endogeneity of $\mathbf{X}_{Ct}$ and $\mathbf{Z}_C$ will lead to parameter bias. Note that the bias and RMSE for SOLS increases with ϕ and the size of the tests is unacceptable, rejecting the null when true 100% of the time. This confirms the results in Baltagi, Bresson, and Pirotte (2003). The same holds true for the SRE estimator since it does not deal with endogeneity of the regressors and only handles spatial correlation. SFE performs well for β_3, but does not yield estimates for γ_2. The SHT estimator yields low RMSE for both β_3 and γ_2. If $\rho > 0$, i.e., there is spatial correlation, SOLS is consistent but not efficient if $\phi = 0$, but otherwise biased and inconsistent if $\phi > 0$. SHT delivers consistent and asymptotically efficient estimates of both β_3 and γ_2, while SFE yields consistent estimates for β_3 only. For example, for $\rho = 0.6$ and $\phi = 0.75$, the RMSE for SOLS for β_3 is 0.765 compared to 0.114 for SFE, 0.673 for SRE and 0.111 for SHT. The corresponding RMSE for SOLS for γ_2 is 0.427 compared to 0.430 for SRE and 0.135 for SHT. Test of hypotheses is misleading with SOLS and SRE but it is properly sized for SFE and SHT except when $\phi = 0$, where it is oversized, of the order of 10-11% rather than 5%, due to the fact that we are correcting for spatial correlation when there is not any.

Table 2 reports the the bias, RMSE, and size of tests for Case 2, i.e., the spatial RE world. For this case, there is no endogeneity and SHT applies an instrumental variable estimator when there is no need for it. SRE gives the best performance in terms of RMSE for both coefficients. However, SHT's performance is not far behind.

Tables 3 and 4 run the same experiments but now tripling N holding T constant ($N = 300, T = 3$). By and large we observe the same results as in Tables 1 and 2, but with different bias and RMSE magnitudes. The size of the tests for $H_0^a : \beta_3 = 1$, and $H_0^b : \gamma_2 = 1$ for the SFE estimator improve.

3.3 The Spatial Pretest Estimator

Table 5 shows the choice of the spatial pretest estimator for various values of ρ and ϕ. The first panel gives these results for $(N = 100, T = 3)$ for Case 1, i.e., a spatial HT world. For example, for $\rho = 0.6$, and $\phi = 0.75$, out of 1,000 replications, the spatial pretest estimator is an SHT estimator in 909 replications and a SFE estimator in 80 replications and a SRE estimator in the remaining 11 replications. The performance of the spatial pretest (SPT) estimator, reported in Table 1, is better in RMSE sense than SOLS or SRE but not as well as SHT.

The second panel in Table 5 shows Case 2, which is a spatial RE world. For $\rho = 0.6$, and $\phi = 0.75$, out of 1,000 replications, the spatial pretest estimator is a SRE estimator in 910 replications, a SHT estimator in 53 replications and a SFE estimator in the remaining 37 replications. The performance of the spatial pretest (SPT) estimator, reported in Table 2, is better in RMSE sense than SOLS or SHT but not as well as SRE. This performance improves dramatically as N grows larger, see Tables 3 and 4 with $N = 300$ and $T = 3$. The size of tests for $H_0^a : \beta_3 = 1$, and $H_0^b : \gamma_2 = 1$ for SPT are obviously affected by the pretesting and are not recpmmended in practice.[2]

For Case 2 – the spatial random effects world – as summarized in Tables 2 and 4, the preferred estimator is SRE. Here the SHT and SPT should not do well, but their performance seems to be satisfactory despite the instru-

[2]It is well known that the pretest estimator (based on the Hausman test in the first step and a simple hypothesis test in the second step) display poor size and power properties, see Guggenberger (2010). This is confirmed by Baltagi, Bresson and Pirotte (2003) using standard panel data Monte Carlo experiments and by our results here for their spatial counterparts. In fact, Guggenberger's (2010) recommendation of using a (one-step) t-test procedure based on the fixed effects estimator instead of a two-step procedure is a good idea even under the presence of spatial correlation. In this case, the researcher would use the t-test based on the SFE estimator instead of the two-stage procedure.

mental variable estimation that is not needed, and the Hausman tests that are performed. Of course, test of hypotheses using SPT suffer from poor size and power for some of the experiments and using the t-test from the one-step SFE is recommended. Unfortunately, this recommendation applies to the time-varying regressor coefficients only.

4 Conclusions

This paper provides Monte Carlo evidence on the small sample performance of Cliff and Ord (1973) type spatial panel data estimators. We focus in particular on Hausman and Taylor (1981) type panel data models with spatial disturbances. We find that the spatial Hausman and Taylor type estimator performs well in RMSE sense in comparison to the spatial fixed effects, the spatial random effects, and the spatial OLS estimators. An added advantage of the spatial Hausman-Taylor estimator is that it delivers estimates of endogenous time-invariant variables, unlike the spatial fixed effects model. Moreover, unlike the spatial random effects or the spatial pooled OLS model it allows regressors in the model to be correlated with the individual-specific effects.

We also investigate the performance of a spatial pretest estimator based on two Hausman tests. We find that the spatial pretest estimators perform particularly well if the heterogeneity due to the individual effects is relatively important and the associated problem of endogeneity of the regressors with the individual effects become more pertinent. The spatial pretest estimator guards against a possible misspecified choice of estimator and its RMSE performance is satisfactory, but test of hypotheses using the SHT estimator is not recommended. Instead one should use the one-step SFE in practice, but this applies to the time-varying regressor coefficients only.

Appendix

All of the Monte Carlo runs are based on the following unnormalized weights matrix based on a three-before-and-three-behind design of neighborhood

$$\mathbf{W_0} = \begin{pmatrix} 0 & 1 & 1 & 1 & 0 & \cdots & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 & \cdots & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 & 1 & 0 & \cdots & 0 & 1 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & \cdots & 0 \\ 0 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & 0 & \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & \cdots & 0 & 1 & 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & \cdots & 0 & 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 & \cdots & 0 & 1 & 1 & 1 & 0 \\ & & & & & & & & & \end{pmatrix}. \qquad (9)$$

Each row of this matrix exhibits a row-sum of 6. Hence, the row-normalized as well as the maximum row-sum normalized counterpart of that matrix is

$$\mathbf{W} = \begin{pmatrix} 0 & 1/6 & 1/6 & 1/6 & 0 & \cdots & 0 & 1/6 & 1/6 & 1/6 \\ 1/6 & 0 & 1/6 & 1/6 & 1/6 & 0 & \cdots & 0 & 1/6 & 1/6 \\ 1/6 & 1/6 & 0 & 1/6 & 1/6 & 1/6 & 0 & \cdots & 0 & 1/6 \\ 1/6 & 1/6 & 1/6 & 0 & 1/6 & 1/6 & 1/6 & 0 & \cdots & 0 \\ 0 & 1/6 & 1/6 & 1/6 & 0 & 1/6 & 1/6 & 1/6 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & 0 & \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & 0 & 1/6 & 1/6 & 1/6 & 0 & 1/6 & 1/6 & 1/6 \\ 1/6 & 1/6 & \cdots & 0 & 1/6 & 1/6 & 1/6 & 0 & 1/6 & 1/6 \\ 1/6 & 1/6 & 0 & \cdots & 0 & 1/6 & 1/6 & 1/6 & 0 & 1/6 \\ 1/6 & 1/6 & 1/6 & 0 & \cdots & 0 & 1/6 & 1/6 & 1/6 & 0 \\ \end{pmatrix}. \quad (10)$$

The latter is employed in all experiments in that paper.

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Table 1 - Case 1: HT World - Bias, RMSE and 5% size test, N=100 and T=3

								Spatial models																				
		SOLS						Fixed effects (SFE)			Random effects (SRE)						Hausman-Taylor (SHT)						Pretest (SPT)					
		β_3			γ_2			β_3			β_3			γ_2			β_3			γ_2			β_3			γ_2		
ρ	ϕ	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size
0	0	-0.004	0.132	8.4	0.006	0.114	9.2	-0.001	0.139	8.2	-0.004	0.128	8.5	0.006	0.114	8.9	0.000	0.141	9.8	-0.006	0.095	9.3	-0.005	0.092	10.1	0.010	0.080	11
0	0.25	0.190	0.435	93.9	0.097	0.171	20.5	-0.014	0.140	9.8	0.188	0.425	92.3	0.098	0.171	19.4	-0.012	0.140	10.9	0.020	0.121	7	0.093	0.172	73	0.059	0.092	16.9
0	0.5	0.240	1.000	100	0.117	0.246	43.6	-0.001	0.152	9.6	0.238	1.015	100	0.121	0.252	42.3	0.003	0.171	10.2	0.004	0.132	6.7	0.059	0.262	44.8	0.031	0.120	21.5
0	0.75	0.253	2.010	100	0.117	0.361	84	0.000	0.139	10.3	0.246	2.052	100	0.133	0.412	86	0.005	0.140	11.1	0.001	0.100	6.4	0.004	0.126	10.7	-0.010	0.101	5.5
0.2	0	0.007	0.101	6.6	0.000	0.106	6.2	0.005	0.115	7.7	0.007	0.101	6.5	0.000	0.109	5.9	0.004	0.118	8.3	-0.027	0.085	5.6	0.007	0.116	8.8	-0.014	0.068	7.9
0.2	0.25	0.195	0.383	95.6	0.090	0.117	16	0.005	0.135	7.3	0.192	0.353	94.4	0.091	0.116	14.9	0.006	0.134	7.4	-0.012	0.120	5.2	0.101	0.175	72.1	0.047	0.105	14.7
0.2	0.5	0.244	0.634	100	0.114	0.133	38.8	0.000	0.110	6.2	0.241	0.634	100	0.119	0.138	36.8	0.003	0.111	6.7	0.008	0.090	5.1	0.064	0.169	45	0.030	0.081	18.9
0.2	0.75	0.258	1.691	100	0.115	0.287	81.4	0.001	0.100	7.3	0.249	1.608	100	0.135	0.335	83.9	0.005	0.104	7.8	0.001	0.091	5.7	0.005	0.109	8	-0.006	0.091	5.5
0.4	0	-0.001	0.091	5.1	-0.001	0.108	4.3	-0.005	0.106	5.3	-0.001	0.091	4.8	-0.001	0.108	3.7	-0.006	0.112	5.9	-0.003	0.092	3.9	0.002	0.098	7	-0.007	0.074	5
0.4	0.25	0.194	0.537	95.5	0.091	0.129	15.3	0.000	0.149	5.6	0.192	0.537	94.2	0.092	0.136	14.8	0.001	0.148	6.7	-0.004	0.137	5.4	0.103	0.180	73.9	0.051	0.107	13.8
0.4	0.5	0.242	1.197	100	0.107	0.270	36.3	0.000	0.088	3.6	0.239	1.256	100	0.113	0.281	33.1	0.004	0.091	3.7	-0.023	0.120	3.9	0.073	0.154	46.4	0.020	0.106	16.8
0.4	0.75	0.257	0.834	100	0.113	0.194	74.6	0.001	0.095	4.7	0.243	0.780	100	0.143	0.220	81.3	0.006	0.091	5.9	-0.006	0.077	5.3	0.005	0.093	5.8	-0.014	0.078	5.1
0.6	0	0.003	0.142	4.7	0.002	0.093	5.2	0.004	0.156	4.3	0.003	0.144	5.1	0.002	0.104	5	0.004	0.156	5.1	-0.016	0.159	4.1	0.003	0.115	5.7	0.011	0.076	6.3
0.6	0.25	0.185	0.583	95.8	0.084	0.228	13.3	0.003	0.145	6.3	0.183	0.569	94.1	0.085	0.229	12.1	0.004	0.148	6.3	-0.014	0.149	4.2	0.108	0.175	74.7	0.062	0.098	12.2
0.6	0.5	0.236	1.356	100	0.106	0.277	34.7	0.002	0.143	3.6	0.232	1.371	100	0.113	0.289	30.9	0.005	0.143	4	0.010	0.109	3.2	0.084	0.258	49.4	0.053	0.094	17.4
0.6	0.75	0.246	0.765	100	0.113	0.427	70.1	-0.004	0.114	4.7	0.225	0.673	100	0.159	0.430	81.8	0.002	0.111	5.2	0.011	0.135	5.7	0.003	0.130	6.8	0.005	0.147	6.4
0.8	0	0.000	0.151	4.7	0.001	0.132	3.3	0.002	0.147	3.3	0.001	0.150	4.4	0.001	0.132	3	0.002	0.147	4	0.011	0.155	4.8	0.002	0.097	4.6	-0.007	0.065	3.3
0.8	0.25	0.178	0.574	94.4	0.082	0.209	12.8	-0.003	0.157	3.9	0.176	0.561	92.3	0.083	0.213	11.8	-0.001	0.156	4.1	0.026	0.138	3.2	0.126	0.184	75.4	0.070	0.079	10.4
0.8	0.5	0.225	1.337	100	0.106	0.302	32.3	-0.002	0.155	5.3	0.219	1.353	100	0.116	0.320	28.6	0.000	0.152	5.9	0.004	0.163	3.3	0.099	0.258	58.1	0.059	0.129	18.5
0.8	0.75	0.237	1.809	100	0.105	0.305	58.4	0.003	0.175	3.5	0.208	1.641	100	0.166	0.482	78	0.007	0.172	4.4	0.001	0.115	3.8	0.027	0.214	16.1	0.018	0.124	13.6

Table 2 - Case 2: RE World - Bias, RMSE and 5% size test, N=100 and T=3

								Spatial models																				
		SOLS						Fixed effects (SFE)			Random effects (SRE)						Hausman-Taylor (SHT)						Pretest (SPT)					
		β_3			γ_2			β_3			β_3			γ_2			β_3			γ_2			β_3			γ_2		
ρ	ϕ	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size
0	0	0.000	0.102	7.1	-0.001	0.136	8.5	0.007	0.106	7.9	0.000	0.102	6.7	0.000	0.138	7.5	0.006	0.130	8.5	0.031	0.134	8.7	0.007	0.065	9.2	0.009	0.064	8.9
0	0.25	0.000	0.099	10.3	0.002	0.131	9	0.011	0.124	9.8	0.000	0.101	7.2	0.002	0.120	7.7	0.011	0.124	10.2	0.004	0.128	7.8	0.002	0.071	10.6	-0.006	0.069	8.8
0	0.5	0.000	0.148	20.9	0.003	0.118	21.4	0.001	0.123	8	0.000	0.166	8.2	0.000	0.120	9.6	0.000	0.129	9	-0.012	0.125	7.5	0.002	0.090	10.3	-0.002	0.096	10.5
0	0.75	0.001	0.131	27.9	-0.006	0.151	29.9	0.001	0.153	8	0.001	0.166	9.1	-0.007	0.138	8.6	0.001	0.149	7.7	-0.008	0.129	7.7	0.001	0.129	10.1	-0.004	0.101	9.3
0.2	0	0.000	0.097	6.3	0.001	0.106	6.9	-0.008	0.131	6.7	0.000	0.098	6.2	0.001	0.105	6.3	-0.009	0.133	7.8	0.018	0.140	5.4	-0.001	0.079	9.1	0.013	0.081	8.6
0.2	0.25	-0.001	0.105	9.9	-0.003	0.146	6.6	-0.005	0.109	5.7	-0.001	0.102	7.2	-0.003	0.144	5	-0.004	0.109	5.8	0.005	0.093	8.4	-0.001	0.086	8.7	0.003	0.079	7.7
0.2	0.5	0.001	0.089	18.1	0.009	0.107	17.1	-0.005	0.115	6.6	0.000	0.101	5.8	0.010	0.112	6.3	-0.005	0.116	6.7	0.013	0.116	5.8	-0.001	0.085	7.9	0.002	0.085	7.1
0.2	0.75	-0.001	0.125	26.9	-0.005	0.100	23.7	0.001	0.120	7.3	0.000	0.152	6.4	0.000	0.113	4.9	0.001	0.126	7.4	0.011	0.092	5.3	0.000	0.138	8.2	0.003	0.074	6.1
0.4	0	0.002	0.084	5.3	-0.001	0.117	4.5	0.009	0.114	5.1	0.002	0.084	4.8	-0.001	0.121	4.1	0.008	0.124	5.5	0.005	0.121	4	0.005	0.094	7.6	0.002	0.070	5.1
0.4	0.25	0.002	0.105	6.2	0.003	0.138	8.5	-0.005	0.086	5	0.002	0.103	4.4	0.003	0.140	6.2	-0.004	0.094	5.1	-0.030	0.147	5.3	0.001	0.087	6.8	-0.011	0.084	8.2
0.4	0.5	-0.001	0.111	15.5	0.005	0.131	15.6	-0.002	0.158	5.1	-0.001	0.116	4.1	0.007	0.167	4.2	-0.001	0.158	5.3	0.021	0.119	4.1	0.000	0.099	7.2	0.017	0.075	5.3
0.4	0.75	-0.001	0.086	25.4	0.003	0.122	25.8	0.003	0.083	4.7	0.001	0.106	6.3	0.005	0.085	6.2	0.003	0.085	5.2	0.008	0.087	5	0.001	0.105	7.3	0.003	0.093	6.8
0.6	0	-0.001	0.168	3.8	0.002	0.156	3.7	-0.001	0.147	3.9	-0.001	0.168	3.4	0.002	0.158	3.7	-0.002	0.144	4.2	-0.004	0.133	5	0.005	0.079	5.2	0.010	0.075	5.7
0.6	0.25	0.000	0.152	5.7	0.003	0.166	3.9	-0.008	0.142	3.7	-0.001	0.152	4	0.003	0.163	2.9	-0.009	0.140	4.1	-0.002	0.136	3	-0.003	0.069	5.3	0.014	0.068	3.9
0.6	0.5	-0.001	0.143	13.4	0.005	0.113	14.1	-0.003	0.155	3.3	-0.001	0.156	5.6	0.002	0.109	4.6	-0.003	0.155	3.6	-0.022	0.120	4	-0.001	0.095	6.5	0.003	0.069	5.5
0.6	0.75	-0.004	0.159	21.3	-0.001	0.141	22	-0.001	0.147	4.4	-0.002	0.164	3.4	0.005	0.136	5.6	-0.001	0.148	4.4	0.011	0.116	4.2	-0.002	0.131	4.6	0.003	0.114	6.8
0.8	0	0.000	0.133	3.6	-0.002	0.133	3.5	-0.005	0.150	4.4	0.000	0.133	3.5	-0.002	0.135	3.2	-0.005	0.149	4.6	0.010	0.135	3.5	0.003	0.072	4.9	0.005	0.065	3.8
0.8	0.25	0.001	0.148	6.1	0.005	0.166	6.8	0.005	0.174	4.3	0.001	0.148	4.3	0.005	0.170	4.8	0.003	0.172	4.7	0.018	0.140	3.8	0.001	0.082	5	0.005	0.067	4.8
0.8	0.5	-0.001	0.164	12.1	0.001	0.150	13.7	-0.005	0.155	4.8	-0.001	0.172	4.1	0.000	0.145	4.3	-0.006	0.160	5.3	-0.006	0.142	3.7	-0.003	0.096	5.7	-0.003	0.082	4.6
0.8	0.75	-0.002	0.147	21.7	0.005	0.151	21.8	-0.001	0.159	3.8	-0.002	0.166	4.1	0.006	0.142	4.1	-0.001	0.160	4	0.007	0.157	3.6	-0.001	0.122	4.4	0.007	0.141	4.1

Table 3 - Case 1: HT World - Bias, RMSE and 5% size test for Case 1, N=300 and T=3

								Spatial models																				
		SOLS						Fixed effects (SFE)			Random effects (SRE)						Hausman-Taylor (SHT)						Pretest (SPT)					
		β_3			γ_2			β_3			β_3			γ_2			β_3			γ_2			β_3			γ_2		
ρ	ϕ	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size
0	0	0.004	0.161	6.8	0.001	0.150	7.5	0.005	0.162	7.3	0.004	0.163	6.7	0.000	0.149	7.1	0.006	0.161	7.9	-0.003	0.135	8.1	0.004	0.111	9	0.009	0.069	9.3
0	0.25	0.194	0.776	100	0.086	0.303	34.5	-0.001	0.156	6.6	0.193	0.788	100	0.087	0.303	32.9	-0.001	0.157	7.1	-0.006	0.157	7.5	0.057	0.242	49.2	0.022	0.145	20.4
0	0.5	0.241	1.821	100	0.112	0.356	82.2	-0.002	0.140	6.1	0.239	1.752	100	0.115	0.353	81.6	-0.001	0.139	6.4	0.013	0.139	6.9	0.002	0.144	7.8	0.016	0.141	8.4
0	0.75	0.254	3.997	100	0.115	0.649	99.9	0.002	0.137	5.5	0.247	3.920	100	0.130	0.726	99.9	0.004	0.134	6	-0.003	0.146	4.7	0.003	0.134	6	-0.007	0.149	3.8
0.2	0	0.000	0.174	5.8	-0.001	0.154	6.7	0.002	0.154	5.4	0.000	0.174	5.9	-0.001	0.154	6.6	0.003	0.154	5.8	-0.003	0.142	5.9	0.002	0.110	8.2	-0.004	0.078	8.9
0.2	0.25	0.195	1.028	100	0.088	0.285	35	-0.002	0.174	4.4	0.193	1.020	100	0.089	0.285	33.5	-0.002	0.171	4.4	0.001	0.152	5.4	0.058	0.271	50.8	0.032	0.131	19.7
0.2	0.5	0.244	2.568	100	0.113	0.468	82.6	-0.001	0.141	5.3	0.242	2.618	100	0.117	0.484	82	0.000	0.140	5.7	0.001	0.129	5.1	0.004	0.155	7.8	0.001	0.160	7.9
0.2	0.75	0.256	4.765	100	0.117	0.652	99.9	-0.002	0.157	5.7	0.248	4.439	100	0.136	0.739	99.9	0.000	0.162	6	0.002	0.159	6.8	-0.001	0.158	6	-0.003	0.160	6.1
0.4	0	-0.002	0.105	5.3	0.001	0.097	4.3	-0.001	0.128	4.5	-0.002	0.104	5.1	0.001	0.097	4	-0.001	0.120	4.8	-0.014	0.107	6.4	0.000	0.106	6.3	0.008	0.087	6.8
0.4	0.25	0.192	0.968	100	0.087	0.245	33.6	-0.005	0.160	5.6	0.190	0.941	100	0.088	0.248	32.9	-0.004	0.159	5.7	0.007	0.157	4.4	0.059	0.285	51	0.036	0.133	18.6
0.4	0.5	0.242	2.148	100	0.110	0.484	79.2	-0.001	0.148	5.6	0.239	2.199	100	0.115	0.503	78.9	0.000	0.148	5.4	0.001	0.146	4.3	0.007	0.158	8.9	0.002	0.146	8.3
0.4	0.75	0.256	1.441	100	0.117	0.403	99.2	-0.001	0.074	5.8	0.243	1.405	100	0.147	0.485	99.9	0.001	0.075	5.6	0.003	0.081	5.9	0.001	0.075	5.7	0.001	0.081	5.2
0.6	0	0.000	0.167	3.6	-0.002	0.160	4.5	0.001	0.170	4.5	0.000	0.168	3.5	-0.002	0.160	4.5	0.001	0.171	4.4	-0.010	0.172	3.7	0.001	0.116	5	-0.007	0.088	5.5
0.6	0.25	0.189	1.091	100	0.083	0.295	29.2	0.004	0.146	3.6	0.187	1.078	100	0.084	0.295	28.3	0.004	0.148	4.2	-0.014	0.147	3.7	0.075	0.267	55.5	0.029	0.119	17.8
0.6	0.5	0.235	2.496	100	0.107	0.403	76.7	-0.002	0.125	4.2	0.231	2.381	100	0.114	0.429	76	-0.001	0.125	4	0.001	0.157	4	0.008	0.179	9.8	0.003	0.157	8.3
0.6	0.75	0.247	3.495	100	0.112	0.501	99	0.001	0.131	4	0.227	3.284	100	0.157	0.813	99.9	0.003	0.134	4.2	0.006	0.132	3.1	0.002	0.134	4.4	0.004	0.133	2.9
0.8	0	-0.001	0.164	4.3	0.003	0.171	3.6	-0.002	0.146	4.3	-0.001	0.165	4.1	0.003	0.171	3.6	-0.002	0.147	4.9	0.001	0.159	3.6	-0.001	0.109	4.5	-0.001	0.071	3.9
0.8	0.25	0.178	0.972	100	0.081	0.298	30.6	-0.003	0.158	3.8	0.176	0.949	100	0.082	0.297	29.1	-0.003	0.158	3.9	-0.002	0.157	4.6	0.088	0.270	62.8	0.047	0.119	21.2
0.8	0.5	0.225	2.188	100	0.102	0.459	73.1	0.001	0.149	4.9	0.219	2.201	100	0.111	0.461	72.5	0.002	0.145	4.7	0.002	0.140	5	0.030	0.220	19.5	0.018	0.136	17.3
0.8	0.75	0.236	3.108	100	0.106	0.587	96.5	0.001	0.150	3.3	0.208	2.975	100	0.166	0.790	100	0.003	0.146	3.5	-0.007	0.149	3.5	0.003	0.146	3.5	-0.008	0.148	2.8

Table 4 - Case 2: RE World - Bias, RMSE and 5% size test, N=300 and T=3

								Spatial models																				
		SOLS						Fixed effects (SFE)			Random effects (SRE)						Hausman-Taylor (SHT)						Pretest (SPT)					
		β_3			γ_2			β_3			β_3			γ_2			β_3			γ_2			β_3			γ_2		
ρ	ϕ	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size	Bias	RMSE	5% size
0	0	-0.001	0.145	7.5	0.000	0.146	7.3	-0.002	0.151	5.9	-0.001	0.145	7.2	0.000	0.146	6.7	-0.002	0.153	6.8	0.013	0.143	6.3	-0.001	0.077	9.2	0.012	0.068	7
0	0.25	0.000	0.156	9.8	0.002	0.152	8.5	-0.001	0.157	7.4	0.000	0.157	7.8	0.002	0.157	6.3	-0.001	0.156	7.6	0.013	0.131	6.2	0.000	0.086	10.2	0.003	0.067	7.7
0	0.5	-0.001	0.153	16.9	-0.001	0.136	18.6	0.002	0.147	7.5	0.000	0.150	5.8	-0.001	0.152	7.2	0.002	0.146	7.5	-0.002	0.155	8.3	-0.001	0.095	9.2	-0.001	0.088	8.4
0	0.75	0.001	0.151	23.5	-0.002	0.151	24.7	-0.002	0.158	7.3	-0.001	0.170	6.9	-0.004	0.157	6.6	-0.002	0.158	7.4	-0.007	0.133	7.6	-0.001	0.126	8.3	-0.005	0.115	7.5
0.2	0	0.000	0.148	5	0.003	0.153	5.1	0.004	0.135	3.8	0.000	0.148	4.9	0.003	0.152	4.9	0.004	0.134	3.6	0.010	0.148	4.3	0.000	0.070	6.6	0.004	0.075	6
0.2	0.25	-0.001	0.167	7.2	0.004	0.135	7.6	0.000	0.162	4.6	-0.001	0.165	5.3	0.004	0.135	6.2	0.000	0.162	4.8	-0.007	0.155	4	-0.001	0.089	7.6	0.002	0.077	7.4
0.2	0.5	0.001	0.162	17.7	0.001	0.135	15.7	-0.002	0.156	4.2	0.001	0.163	4.5	0.001	0.133	5.1	-0.002	0.157	4.1	0.005	0.159	5.3	0.000	0.090	5.5	0.003	0.090	6.3
0.2	0.75	0.000	0.138	20.9	-0.003	0.164	23.4	0.001	0.151	5.5	0.000	0.139	4.8	0.000	0.145	4.6	0.001	0.151	5.2	0.004	0.149	5	0.000	0.118	5.3	0.001	0.115	6
0.4	0	-0.001	0.094	4	0.001	0.093	5.2	-0.003	0.111	5.2	-0.001	0.094	3.8	0.001	0.093	5.2	-0.002	0.101	5.6	-0.006	0.107	3.6	0.000	0.086	6.5	0.001	0.054	6.1
0.4	0.25	-0.001	0.146	6.5	0.001	0.147	7	-0.001	0.127	4.5	-0.001	0.146	5.1	0.001	0.148	4.6	-0.001	0.132	4.4	-0.001	0.164	4.7	-0.001	0.083	7.6	0.001	0.081	6.1
0.4	0.5	-0.001	0.156	16	0.003	0.170	17	-0.005	0.159	4.6	-0.001	0.154	5.1	0.003	0.150	5.4	-0.005	0.161	4.9	0.005	0.146	4.4	-0.002	0.103	7.3	0.004	0.088	6.8
0.4	0.75	0.002	0.089	24.7	-0.004	0.102	24.4	0.001	0.092	5.8	0.001	0.084	6.3	-0.002	0.093	6.5	0.001	0.092	6.1	0.001	0.099	6.6	0.001	0.091	7.3	-0.001	0.104	7.5
0.6	0	0.000	0.166	4.4	-0.001	0.160	4.4	-0.004	0.164	4.6	0.000	0.166	4.3	-0.001	0.159	4.3	-0.004	0.162	4.9	-0.003	0.172	4.9	0.001	0.082	6.2	-0.001	0.082	5.7
0.6	0.25	0.000	0.162	6.4	0.003	0.177	5.8	-0.001	0.159	5	0.000	0.163	4.3	0.003	0.173	4.5	-0.001	0.162	5.4	0.010	0.137	3.6	0.001	0.094	6.4	0.005	0.066	5.4
0.6	0.5	0.000	0.163	13.2	0.001	0.139	15.2	-0.002	0.141	4	0.000	0.160	3.7	0.001	0.141	4	-0.002	0.141	3.7	0.000	0.150	4.5	0.000	0.079	4.8	0.001	0.086	4.6
0.6	0.75	0.001	0.172	21.8	-0.001	0.160	22	0.000	0.147	3.2	0.000	0.147	3.4	-0.002	0.152	3.6	0.000	0.147	3	-0.004	0.141	3.8	0.000	0.117	4.3	-0.002	0.132	4.1
0.8	0	0.000	0.155	5.3	-0.002	0.162	2.9	0.000	0.147	3.9	0.000	0.154	4.6	-0.002	0.163	2.8	0.000	0.147	3.8	0.004	0.155	4.6	-0.001	0.071	4.8	0.002	0.067	3.8
0.8	0.25	0.000	0.184	5	0.002	0.128	5.3	0.000	0.162	4	0.000	0.184	3.2	0.001	0.129	3.6	0.000	0.166	4.4	-0.013	0.150	3.2	0.001	0.080	4.4	0.000	0.074	3.6
0.8	0.5	0.001	0.166	14.5	-0.002	0.158	12.7	-0.003	0.146	4.3	0.000	0.172	4.1	-0.002	0.150	3.7	-0.002	0.149	4.5	-0.002	0.143	4.1	0.000	0.087	5	0.000	0.085	4.4
0.8	0.75	0.000	0.150	20	-0.002	0.147	20	-0.001	0.159	4.1	-0.001	0.158	3.7	0.000	0.144	3.3	-0.001	0.160	4.1	0.003	0.165	3.9	-0.001	0.128	3.8	0.001	0.117	3

Table 5 : Number of times the pretest estimator took on the spatial fixed effects (SFE), spatial random effects (SRE), and spatial Hausman-Taylor (SHT) in 1000 replications

		Spatial models											
		N = 100, T = 3						N = 300, T = 3					
		Hausman-Taylor world Case 1			Random effects world Case 2			Hausman-Taylor world Case 1			Random effects world Case 2		
ρ	ϕ	SFE	SRE	SHT	SFE	SRE	SHT	SFE	SRE	SHT	SFE	SRE	SHT
0	0	82	799	119	65	834	101	57	847	96	60	863	77
0	0.25	107	655	238	70	821	109	94	434	472	60	846	94
0	0.5	131	360	509	75	813	112	118	28	854	75	833	92
0	0.75	119	6	875	92	793	115	104	0	896	69	860	71
0.2	0	51	875	74	57	855	88	41	884	75	45	909	46
0.2	0.25	74	704	222	52	868	80	61	475	464	51	897	52
0.2	0.5	89	411	500	53	881	66	94	47	859	39	905	56
0.2	0.75	90	10	900	52	865	83	100	0	900	37	903	60
0.4	0	47	890	63	32	907	61	45	904	51	56	900	44
0.4	0.25	45	750	205	41	907	52	90	465	445	42	904	54
0.4	0.5	80	442	478	50	894	56	86	55	859	42	902	56
0.4	0.75	99	5	896	36	883	81	100	0	900	50	891	59
0.6	0	28	924	48	51	896	53	26	923	51	30	922	48
0.6	0.25	44	781	175	34	924	42	67	512	421	34	914	52
0.6	0.5	66	459	475	44	912	44	82	42	876	36	922	42
0.6	0.75	80	11	909	37	910	53	81	0	919	38	917	45
0.8	0	30	933	37	34	926	40	45	916	39	28	923	49
0.8	0.25	47	781	172	25	916	59	58	524	418	33	928	39
0.8	0.5	59	495	446	27	920	53	93	62	845	19	934	47
0.8	0.75	78	19	903	29	915	56	88	0	912	33	931	36