On the Problem of Endogenous Unobserved Effects in the Estimation of Gravity Models

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Abstract

We propose to estimate gravity models by a Hausman & Taylor (1981) 2SLS error components approach. First, this allows to account for possible correlations of some of the regressors with the unobserved effects, which has been ignored in previous research. Secondly, in contrast to the Within estimator one obtains estimates for the time-invariant variables also in a two-way formulation with bilateral effects. We show that distance and country size are important sources of correlation. The properly estimated parameter for distance is about twice as high as its biased GLS counterpart and markedly higher than most of the previous estimates.

Key words: gravity equation, panel econometrics
JEL: C33, F14

1 Introduction[1]

Since a couple of years it is convenient to use panel econometric methods in the empirical analysis of trade flows (and more recently also of multinational sales, FDI, and migration), and it is now common knowledge that simple OLS estimates provide only limited information and oftenly deviate to a large extent from their panel econometric counterparts.

Mátyás (1997) mentioned that the correct econometric representation of a gravity equation takes the form of a three-way model with fixed or random exporter, importer, and time effects. However, Egger & Pfaffermayr (2000) have shown that a two-way set-up with time and bilateral effects is even more general from an analysis of variance point

[1] I am indebted in Wilhelm Kohler and Michael Pfaffermayr for helpful suggestions and discussions. I should like to thank Hartmut Egger, Robert Kunst, and Peter Steiner for helpful comments.

of view.[2] The latter approach also gives more support to the random effects model than a framework with both exporter and importer effects. However, in this more general framework, the coefficients of variables, which vary only in the cross-section dimension (most prominently distance, but also common borders, language, etc.) cannot be estimated by a Within regression.

The present paper argues that simple GLS estimation of a random effects model is also of only limited value giving biased estimates if there is some correlation of the explanatory variables with the unobserved bilateral effects, which should be interpreted as unobserved bilateral propensity to trade. In a sensitivity analysis, we identify the sources of correlation and propose to estimate the two-way gravity model with a Hausman & Taylor (1981) two-stage least squares (2SLS) error components model. For our data, the coefficient for transport costs (distance) is about twice as high in absolute value for the consistent Hausman & Taylor approach as for biased GLS.

2 The Empirical Model: A Hausman & Taylor (1981) Approach

We follow a specification closely related to New Trade Theory (see Helpman, 1987; Hummels & Levinsohn, 1995; Egger, 2000; and others). Coinciding with the traditional gravity equation in terms of general model structures, the basic specification reads:

$$\begin{aligned} Y_{ijt} &= X_{ijt}\beta + Z_{ij}\gamma + \epsilon_{ijt} \\ \epsilon_{ijt} &= \mu_{ij} + \lambda_t + \nu_{ijt} \ , \end{aligned} \tag{1}$$

where Y_{ijt} in our case represents real bilateral exports $(LREX_{ijt})$[3], X_{ijt} and Z_{ij} denote $NT \times k$ and $NT \times g$ matrices, where the former vary not only in the cross-section (either over exporters, i; importers, j; or bilateral relationships, ij) but also in the time dimension (t) and the latter are time-invariant with distance as the most prominent example. N denotes the number of cross-sections and T the number of observations per cross-section (i.e. time periods). The specification only includes distance between two countries' capitals in Z_{ij} ($LDIST_{ijt}^{(-)}$, hence, $g =$

[2] Of course, one would exhaust full variance information if modelling all types of interaction effects: exporter-time, importer-time, and exporter-importer (i.e. bilateral effects). However, we will focus only on the latter, as one typically is interested in parameter estimates of traditional time-variant gravity variables which account for the major part of the variance in the other dimensions (see Egger & Pfaffermayr, 2000).

[3] The first letter "L" indicates that variables are expressed in *logs*.

1), reflecting a proxy for transport costs.[4]

X_{ijt} comprises the following columns (variables). Sum of the bilateral real GDP of a country pair

$$LGDT_{ijt}^{(+)} = \ln(GDP_{it} + GDP_{jt}), \tag{2}$$

similarity in country size in terms of GDP

$$LSIM_{ijt}^{(+)} = \ln\left[1 - \left(\frac{GDP_{it}}{GDP_{it} + GDP_{jt}}\right)^2 - \left(\frac{GDP_{jt}}{GDP_{it} + GDP_{jt}}\right)^2\right], \tag{3}$$

with $-\infty \leq LSIM \leq \ln[0.5]$, which takes its maximum when two countries are identical in size, and a distance measure for relative factor endowments in terms of GDP per capita (GDP/POP)

$$LRLF_{ijt}^{(+)} = \left| \ln\frac{GDP_{it}}{POP_{it}} - \ln\frac{GDP_{jt}}{POP_{jt}} \right|, \tag{4}$$

with $0 \leq LRLF$, which takes its minimum for countries with identical relative factor endowments.

As in traditional gravity applications, other determinants are included, which - besides time - vary either in the exporter or the importer dimension and are reflecting export enhancing or impeding factors. These variables are measures for the observable propensity to trade which in theoretical contexts is represented by trade costs in a broad sense. Since they do not vary in the bilateral but only the country-specific dimension of the cross-section, they are assumed to be uncorrelated with the unobserved bilateral effects. This set of data contains exporter and importer viability of contracts $(LFV_{it}^{(+)}, LFV_{jt}^{(+)})$, and exporter and importer rule of law $(LFR_{it}^{(+)}, LFR_{jt}^{(+)})$, which are expected to have a positive impact on bilateral trade (exports). Finally, exporter and importer taxes on trade as a percentage of a country's overall trade $(LFT_{it}^{(-)}, LFT_{jt}^{(+)})$ are likely to impede exports if they are high in the sending country or low in the receiving country. This is also a standard outcome in models of trade and multinationals if taxes are modelled similarly to iceberg transport costs. However, the expected effect is less clear-cut if one has to think about taxes as affecting government expenditures as well.[5]

[4] Superscripts denote the theoretically expected sign of the impact of the respective variable on bilateral exports. See also the next section for more details on the explanatory variables.

[5] Governments could e.g. spend the respective tax earnings in order to assure risky export contracts or to subsidize certain export activities. However, from the perspective of an individual firm's profit maximization problem, it may be justified to treat trade taxes like iceberg costs.

μ_{ij} are unobserved (random) bilateral effects and λ_t are time effects, which we propose to treat as fixed (see also Egger, 2000, for a detailed reasoning).

Of course, in spite of the correlation between some explanatory variables with the unobserved effects, the fixed effects approach is consistent for β but it will not give an estimate for γ. In contrast, the random effects approach is more efficient, but has to assume that all elements of both Z and X are uncorrelated with μ_{ij} in order to give consistent parameter estimates. Regarding the interpretation of μ_{ij} as time invariant bilateral propensity to trade, we propose to account for the possible lack of this required independence. First, distance ($LDIST$) may be one source of correlation. Secondly, part of the X (called X_2) may represent another one. Possible candidates of the latter are size related variables like bilateral sum of GDP ($LGDT$) and relative country size ($LSIM$). Only part of the time-variant regressors ($X_1 = n \times k_1$) might be uncorrelated with the unobserved bilateral effects. Ignoring the mentioned sources of correlation and running a traditional GLS regression - depending on the size of correlation - yields inconsistent estimates.

In order to overcome this problem, Hausman & Taylor (1981), henceforth HT, suggest to premultiply the model by $\widehat{\Omega}^{-1/2}$

$$\widehat{\Omega}^{-1/2} y_{ijt} = \widehat{\Omega}^{-1/2} X_{ijt}\beta + \widehat{\Omega}^{-1/2} Z_{ij}\gamma + \widehat{\Omega}^{-1/2}\epsilon_{ijt}, \tag{5}$$

where $\widehat{\Omega}^{-1/2}$ has a typical element $y_{ijt} - \widehat{\theta}_{ij}\overline{y}_{ij.}$ for Y_{ijt}, and similarly for X_{ijt} and Z_{ij} with $\widehat{\theta}_{ij} = 1 - \widehat{\sigma}_\nu/\widehat{\sigma}_{1ij}$. $\widehat{\sigma}_\nu$ is derived from the Within estimation of (1), and $\widehat{\sigma}_{1ij} = \sqrt{T_{ij}\widehat{\sigma}_\mu + \widehat{\sigma}_\nu}$ stems from a 2SLS (between) regression of the bilateral averages of the Within residuals of (1) on Z (i.e. $LDIST$) with X_1 as the instruments.[6]

(5) is estimated by 2SLS using a proper set of instruments (called A_{HT}) in order to overcome this bias. Following Breusch et al. (1989), we use a feasible set of instruments, which is equivalent to the idea of HT and consists of the Within transformed X (i.e. $\widetilde{X} = [\widetilde{X_1}, \widetilde{X_2}]$) and the means of X_1 in the bilateral dimension (i.e. $\overline{X_1}$), hence, in our case $A_{HT} = [\widetilde{X}, \overline{X}_1]$.[7] 2SLS is only identified if $k_1 \geq g$, and the HT estimator is over-identified and more efficient than the Within estimator, if $k_1 > g$. Subscript ij indicates that the panel may be unbalanced.

[6] Amemiya & MaCurdy (1986) and Breusch et al. (1989) suggest even more efficient sets of instruments than Hausman & Taylor (1981). However, as compared to Hausman & Taylor, their models require more exogeneity assumptions and they are less suited for the analysis of unbalanced panel data.

[7] Note that we do not consider any time-invariant effects which are uncorrelated with μ_{ij}.

Summing up, the 2SLS error components model has two possible advantages with respect to the Within regression: First, it is possibly more efficient without any loss in consistency, if $k_1 > g$, and the instruments are legitimate. Secondly, if trade (or FDI, etc.) potentials are to be projected, which is a conventional method e.g. in the area of integration research (see Wang & Winters, 1991; Baldwin, 1994; etc.) it is more appropriate, as an adjustment of the fixed effects conceptually contradicts the idea of the Within estimator.

3 Data and Estimation Results

We run regressions on bilateral exports from OECD countries to other economies (including OECD and non-OECD countries) covering the period 1986-1997. Nominal exports in current USD (from OECD, Monthly Statistics of International Trade; IMF, Direction of Foreign Trade; and the Vienna Institute of Comparative Economic Studies, hereafter WIIW) are converted by export price (IMF, International Financial Statistics; OECD, Economic Outlook; and WIIW) and exchange rate indices (IMF, International Financial Statistics; and WIIW) to obtain real values with 1995 as the base year. Nominal GDP in USD (OECD, Economic Outlook and National Accounts Volume 1; IMF, International Financial Statistics; and WIIW) are also converted to real numbers using GDP deflators (same sources as GDP) and exchange rate indices. Population numbers are collected from OECD (Economic Outlook and National Accounts Volume 1), IMF (International Financial Statistics) and WIIW.

Three economic freedom variables are included for the exporters and the importers each, which are provided by Economic Freedom Network (Economic Freedom of the World) and account for legal structure and property rights (Area V of the database) and international exchange (part of Area VI of the respective database). These variables are partly based on (zero-to-ten) ratings and partly on continuous data. They measure a country's economic freedom in several respects and can be interpreted as export impeding or enforcing determinants controlling for observed propensity to trade. The corresponding variables are viability of contracts (LFV_{it}, LFV_{jt}), rule of law (LFR_{it}, LFR_{jt}), and taxes on trade as a percentage of exports and imports (LFT_{it}, LFT_{jt}).

$>$ Table 1$<$

All variables are in logs. The data base only contains bilateral trade relations which cover a period of at least 5 years within 1986 and 1997. After removing a couple of outliers exhibiting excess studentized residuals with an absolute value larger than 3.5 in the Within regression of

(1), we come up with 7337 observations. All regressions include time dummies.

In a first step we run the Within regression which treats bilateral effects (μ_{ij}) as fixed and gives consistent parameter estimates independent of the possible correlation between μ_{ij} and some of the regressors. We find a significantly positive effect of each of the three Heckscher-Ohlin variables ($LGDT$, $LSIM$, $LRLF$) on bilateral exports, being in accordance with the New Trade Theory (compare Helpman & Krugman, 1985). As one would have expected, the viability of contracts in both the exporting and the importing country (LFV) positively affects trade relations. The same holds true for higher levels of the rule of law in the importer country (LFR_{jt}). Contrary to our expectations, higher taxes in the exporter country are positively related to trade activity. The remaining parameters cannot be estimated precisely.

Secondly, we estimate the GLS (random effects) model to obtain an estimate for distance ($LDIST$) and find that the coefficients for the remaining variables deviate to a large extent from their fixed effects counterparts, which is an indication for correlation of some of the explanatory variables with the unobserved bilateral effects. This leads to biased estimates not only for these parameters (reflected by the highly significant Hausman test statistics) but also for distance.

To give a sensitivity analysis, we estimate four regressions in the spirit of Hausman & Taylor (1981). Once, we treat distance ($LDIST$) and bilateral sum of GDP ($LGDT$) as only *singly exogenous* (this terminology was introduced by Cornwell et al., 1992, and is due to X_2), which is labeled as HT I in Table 2. In the next column of Table 2 (HT II), similarity in country size ($LSIM$) was treated as *singly exogenous* in addition to $LDIST$ and $LGDT$. We should remember that we considered a possible relation between these size-related variables and μ_{ij}, as they also reflect some information on time-invariant trade-cost-like factors as distance.

$>$ Table 2 $<$

HT III enlarges the set of possible *singly exogenous* variables by bilateral distance in relative factor endowments ($LRLF$), and HT IV excludes all time-variant variables from that set treating only $LDIST$ as *singly exogenous.*

On the one hand, from the HT IV estimates we can see that distance indeed seems to be related to μ_{ij}, which shows up in parameter estimates which are lying in between the Within and the GLS estimates.

On the other hand, The HT test for over-identification[8] together with the remaining relatively large deviations from the Within parameters reveal that there are additional sources of correlation of other explanatory variables with the μ_{ij}. From HT I we see that $LGDT$ indeed seems to exhibit an important correlation with μ_{ij}, and the respective estimation results are far closer to the Within estimator than HT IV. Moreover, the corresponding test for over-identification in contrast to HT IV does not reject the hypothesis of the legitimacy of our set of instruments, and the geometric mean of canonical correlations shows a closer average relation between the *singly exogenous* variables and the corresponding instruments (i.e. A_{HT}) than in HT IV.[9] As country size in terms of bilateral GDP (LGDT) faces some correlation, we extend the set of *singly exogenous* variables by relative country size ($LSIM$) as well and find our supposition confirmed: Specification HT II comes rather close to our Within estimates; it works well in terms of average canonical correlation, and the test of over-identification again fails to reject the hypothesis of the instrument relevance. Hereafter, the treatment of distance in relative factor endowments ($LRLF$) in HT III as *singly exogenous* cannot yield more improvement of the results.

The estimated parameter values from regressions HT I to HT III are very close both to each other and to the Within estimates being practically identical at the first digit numbers after the comma. We may conclude from this analysis that distance and country size are the most important sources of correlation with the unobserved bilateral effects.[10] Accounting for this relation and applying 2SLS techniques in the spirit of HT allows us to consistently estimate the impact of distance on bilateral exports and this approach is more efficient than the Within framework. The coefficient for distance amounts to about -1.7, which in absolute value is about doubly as high as its biased GLS counterpart and markedly

[8] This test is based on the squared standard error of the Within regression ($\widehat{\sigma}_{\nu}^2$) and the difference between the estimates and the variance-covariance matrices (VC) of the parameters between the Within and the 2SLS regression ($\widehat{m} = \widehat{q}'[VC(\widehat{q})]^{-1}\widehat{q}$, where $\widehat{q} = [\widehat{\beta}_{Within} - \widehat{\beta}_{2SLS}]$. Under the null hypothesis $\widehat{\sigma}_{\nu}^2\widehat{m}$ is distributed as χ_d^2, with $d = k_1 - g$.

[9] Canonical variate analysis is a standard tool of dimensionality reduction in multivariate statistics. The geometric mean of canonical correlations is a compact information of the association between two sets of variables (see e.g. Baltagi & Khanti-Akom, 1990).

[10] Regarding the $\widehat{\theta}_{ij}$ values this result is not so surprising. As compared to the GLS approach, the $\widehat{\theta}_{ij}$ are larger and exhibit smaller variance in the HT models. This drives the random transformed variables closer to the Within transformed ones. Hence, the resulting estimates are also more close to the Within model than to the traditional random effects (GLS) approach.

(on the average about 2-3 times) higher than the estimate found by other authors (see Oguledo & MacPhee, 1994, for an overview about the majority of cross-section estimates; and Baldwin, 1994; and Egger, 2000; for panel estimates). The difference between our and other panel data studies is supposed to have two main sources: first, previous research did not account for the fact of the superiority of a two-way framework vis-à-vis a three-way one. Secondly, possible correlation between the explanatory variables and the unobserved effects has been ignored.[11]

4 Conclusions

A generalized gravity panel data model accounts for two rather than three ways: time and bilateral effects. Such a framework does not allow for a direct Within estimation of the parameters of time-invariant variables where distance is the most prominent example of.

We propose to estimate gravity panel models by a 2SLS error components approach in the spirit of Hausman & Taylor (1981). This set-up is possibly more efficient than a fixed effects approach and - in contrast - it is more appropriate if trade (FDI, etc.) potentials are to be projected. Moreover, it has two important additional advantages:

1. It allows to account for possible correlations of some of the explanatory variables with the unobserved effects, which in contrast to traditional GLS gives consistent parameter estimates.

2. Secondly and in contrast to the Within estimator, it is able to derive parameter estimates for the time-invariant variables if a (generally more proper) two-way approach is applied.

We show for a large panel of OECD and non-OECD countries that correlation between explanatory variables and unobserved bilateral effects matters a lot and gives heavily biased GLS estimates. Our Hausman & Taylor-type estimates lead us to the conclusion that country size and distance are the most important sources of this correlation, which has been ignored in previous research. With a value of -1.7, the properly estimated parameter for distance is about twice as high in absolute value as its biased GLS counterpart and between about twice and triple as high as most of the estimates found by other authors.

[11] This argument holds true, independently of whether a three-way or a two-way model is estimated. The two-way approach only generates the additional problem of the estimation of time-invariant effects.

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Table 1: Descriptive Statistics: All Variables in Logs (7337 Observations)

Variables:	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Real Exports ($LREX_{ijt}$)	19.97	2.26	10.78	25.75
Distance ($LDIST_{ij}$)	7.94	1.13	4.89	9.41
Bilateral Sum of GDP ($LGDT_{ijt}$)	27.47	1.29	22.23	30.33
Similarity in Size ($LSIM_{ijt}$)	-1.72	1.17	-9.62	-0.69
Distance in Relative Factor Endowments ($LRLF_{ijt}$)	1.51	1.53	0.00	8.99
Exporter Viability of Contracts (LFV_{it})	2.17	0.19	1.25	2.30
Importer Viability of Contracts (LFV_{jt})	2.06	0.30	0.41	2.30
Exporter Rule of Law (LFR_{it})	2.20	0.19	1.19	2.30
Importer Rule of Law (LFR_{jt})	2.00	0.48	-1.20	2.30
Exporter Taxes in Percent of Trade (LFT_{it})	2.23	0.06	1.99	2.29
Importer Taxes in Percent of Trade (LFT_{jt})	2.14	0.21	0.96	2.29
Year 1986 (λ_1)	0.07	0.25	0.00	1.00
Year 1987 (λ_2)	0.07	0.25	0.00	1.00
Year 1988 (λ_3)	0.07	0.26	0.00	1.00
Year 1989 (λ_4)	0.07	0.26	0.00	1.00
Year 1990 (λ_5)	0.11	0.31	0.00	1.00
Year 1991 (λ_6)	0.11	0.31	0.00	1.00
Year 1992 (λ_7)	0.11	0.31	0.00	1.00
Year 1993 (λ_8)	0.11	0.31	0.00	1.00
Year 1994 (λ_9)	0.11	0.31	0.00	1.00
Year 1995 (λ_{10})	0.10	0.30	0.00	1.00
Year 1996 (λ_{11})	0.05	0.21	0.00	1.00
Year 1997 (λ_{12})	0.05	0.21	0.00	1.00

Table 2: Two-way Gravity Estimation Results. Dependent Variable: Log of Bilateral Exports

Explanatory Variables:	Within	GLS	HT I a)	HT II b)	HT III c)	HT IV d)
Distance ($LDIST_{ij}$)	-	-0.866 **)	-1.623 **)	-1.794 **)	-1.896 **)	-0.991 **)
	-	*0.032*	*0.142*	*0.155*	*0.171*	*0.125*
Bilateral Sum of GDP ($LGDT_{ijt}$)	0.384 **)	0.919 **)	0.435 **)	0.426 **)	0.418 **)	0.603 **)
	0.029	*0.023*	*0.029*	*0.029*	*0.029*	*0.027*
Similarity in Size ($LSIM_{ijt}$)	0.064 **)	0.231 **)	0.066 **)	0.086 **)	0.079 **)	0.127 **)
	0.024	*0.019*	*0.023*	*0.024*	*0.024*	*0.022*
Distance in Relative Factor Endowments ($LRLF_{ijt}$)	0.092 **)	0.214 **)	0.096 **)	0.113 **)	0.106 **)	0.140 **)
	0.021	*0.017*	*0.020*	*0.021*	*0.021*	*0.019*
Exporter Viability of Contracts (LFV_{it})	0.220 **)	0.102 *)	0.246 **)	0.255 **)	0.254 **)	0.170 **)
	0.052	*0.053*	*0.052*	*0.052*	*0.052*	*0.051*
Importer Viability of Contracts (LFV_{jt})	0.573 **)	0.408 **)	0.560 **)	0.564 **)	0.564 **)	0.507 **)
	0.033	*0.035*	*0.033*	*0.033*	*0.033*	*0.033*
Exporter Rule of Law (LFR_{it})	-0.032	0.249 **)	0.018	0.017	0.016	0.068
	0.048	*0.048*	*0.047*	*0.048*	*0.048*	*0.047*
Importer Rule of Law (LFR_{jt})	0.133 **)	0.227 **)	0.130 **)	0.126 **)	0.125 **)	0.163 **)
	0.027	*0.027*	*0.026*	*0.027*	*0.027*	*0.026*
Exporter Taxes in Percent of Trade (LFT_{it})	1.239 **)	0.568 **)	1.158 **)	1.190 **)	1.206 **)	0.864 **)
	0.158	*0.162*	*0.158*	*0.159*	*0.159*	*0.155*
Importer Taxes in Percent of Trade (LFT_{jt})	-0.065	-0.239 **)	-0.088 *)	-0.085 *)	-0.086 *)	-0.152 **)
	0.050	*0.051*	*0.050*	*0.050*	*0.050*	*0.049*
Number of Observations (NT)	7337	7337	7337	7337	7337	7337
Number of Bilateral Relationships (N)	779	779	779	779	779	779
R^2 e)	0.99	0.94	0.94	0.94	0.94	0.95
σ_μ	-	0.89	1.72	1.76	1.78	1.59
σ_ν	0.28	0.28	0.28	0.28	0.28	0.28
average $\theta_{ij} = 1 - \sigma_\nu / \sigma_{1ij}$	-	0.90	0.95	0.95	0.95	0.94
minimum θ_{ij}	-	0.87	0.93	0.93	0.94	0.93
maximum θ_{ij}	-	0.91	0.95	0.95	0.95	0.95
Wald Tests: f)						
Fixed Bilateral Effects (μ_{ij}): F(N = 778)	185.65 **)	-	-	-	-	-
Fixed Time Effects (λ_t): F(T = 11)	84.91 **)	682.44 **)	81.80 **)	81.83 **)	81.20 **)	80.97 **)
Hausman (Fixed versus Random Effects): $\chi^2(22)$	-	1969.46 **)	-	-	-	-
Over-identification: $\chi^2(k_1-1)$ g)	-	-	7.91	8.26	10.32 *)	27.54 **)
Canonical Correlations h)	-	-	0.57	0.66	0.70	0.44

a) LGDT and LDIST are singly exogenous, k_1=8+T. - b) LGDT, LSIM and LDIST are singly exogenous, k_1=7+T. - c) LGDT, LSIM, LRLF and LDIST are singly exogenous, k_1=6+T. - d) Only LDIST is singly exogenous, k_1=9+T. - e) Calculated from ESS/TSS; for GLS and HT I - HT IV from the transformed model. - f) Based on the estimated variance-covariance matrix of the respective estimator; degrees of freedom = 6538 for the Within estimator and 7315 otherwise. - g) Based on Hausman & Taylor (1981), see a), b), c), and d) for information on k_1. - h) Geometric mean of canonical correlations between the endogenous variables and the set of instruments, see Baltagi & Khanti-Akom (1995).

*) significant at 10 percent. - **) significant at 5 percent. - Time dummies and constant not reported in order to save space. Standard errors are emphasized and reported below coefficients.