



UNITED NATIONS  
UNIVERSITY

**UNU-MERIT**

## Working Paper Series

**#2008-039**

Further results on bias in dynamic unbalanced panel data models with  
an application to firm R&D investment

Boris Lokshin



# Further results on bias in dynamic unbalanced panel data models with an application to firm R&D investment

Boris Lokshin

*Faculty of Economics and Business Administration  
Maastricht University and UNU-MERIT  
PO Box 616, 6200 MD Maastricht, The Netherlands*

## **Abstract**

This paper extends the LSDV bias-corrected estimator in [Bun, M., Carree, M.A. 2005. Bias-corrected estimation in dynamic panel data models, *Journal of Business and Economic Statistics*, 23(2): 200-10] to unbalanced panels and discusses the analytic method of obtaining the solution. Using a Monte Carlo approach the paper compares the performance of this estimator with three other available techniques for dynamic panel data models. Simulation reveals that LSDV-bc estimator is a good choice except for samples with small T, where it may be unpractical. The methodology is applied to examine the impact of internal and external R&D on labor productivity in an unbalanced panel of innovating firms.

**Key words:** Bias correction, unbalanced panel data, GMM; dynamic model

**JEL codes:** C23

**UNU-MERIT Working Papers**  
ISSN 1871-9872

Maastricht Economic and social Research and training centre on Innovation and Technology, UNU-MERIT

*UNU-MERIT Working Papers intend to disseminate preliminary results of research carried out at the Centre to stimulate discussion on the issues raised.*



## 1. Introduction

As is well-known, the within estimator (LSDV) is not consistent for large  $N$  and finite  $T$  in dynamic panel data models. Bun and Kiviet (2003) and Bruno (2005) derive the infeasible bias approximations of this estimator. The bias approximations can be estimated using an initial consistent estimator such as Anderson-Hsiao or GMM estimator. This proposed correction thus depends on initial consistent estimates. In a recent contribution, Bun and Carree (2005) proposed an alternative correction to the bias that directly uses LSDV estimator, obviating the need to resort to initial consistent estimates.

The purpose of this paper is to extend the method to implement the Bun and Carree (2005) estimator for unbalanced panels. An analytic solution is derived which allows to avoid the iterative methods. In the second part of the paper, Monte Carlo experiments are carried out to assess the performance of the LSDV-bias corrected estimator in the designs with various degrees of unbalancedness. The performance of LSDV-bias corrected is also compared to difference and system GMM estimators (Blundell and Bond, 1998) and to the additive bias-corrected estimator (Bruno, 2005; Bun and Kiviet, 2003).

The rest of the paper is organized as follows. Section 2 presents the model and discusses the analytic method of obtaining the solution. Section 3 reviews the results of the Monte Carlo experiments that assess the performance of the estimator. The methodology is applied to examine the impact of internal and external R&D on labor productivity in an empirical illustration in Section 4, finally, Section 5 concludes.

## 2. The model

We consider the dynamic fixed effects model

$$y_{it} = \gamma y_{i,t-1} + x'_{it} \beta + \eta_i + \varepsilon_{it}, \quad i = 1, \dots, N; t = 1, \dots, T \quad (1)$$

The dependent variable,  $y_{it}$ , is determined by the one-period own lag  $y_{i,t-1}$ , the  $((k-1) \times 1)$  vector of strictly exogenous explanatory variables,  $x_{it}$ , an unobserved individual effect  $\eta_i$ , and a random disturbance  $\varepsilon_{i,t} \sim N(0, \sigma_\varepsilon^2), \sigma_\varepsilon^2 > 0$ . We assume that  $x_{it}$  is not correlated with the general disturbance term, but could be correlated with the individual-specific term,  $\eta_i$ .

Bun and Carree (2005) formulate the expressions for the case of a balanced panel to correct the bias of the inconsistent LSDV estimator, reproduced for convenience here:

$$\gamma_{lsdv} = \gamma - (\sigma_\varepsilon^2 h(\gamma, T)) / ((1 - \rho_{x, y_{-1}}^2) \sigma_{y_{-1}}^2) \quad (2)$$

$$\beta_{k, lsdv} = \beta_k - \zeta_k (\gamma_{lsdv} - \gamma), \quad k = 1, \dots, K \quad (3)$$

$$\sigma_\varepsilon^2(\gamma, \beta) = (y - \mathcal{Y}_{-1} - X\beta)' A (y - \mathcal{Y}_{-1} - X\beta) / (N(T-1)) \quad (4)$$

where  $h(\gamma, T) = (T-1 - T\gamma + \gamma^T) / (T(T-1)(1-\gamma)^2)$ ,  $\rho_{xy_{-1}}^2 = \sigma_{xy_{-1}} / \sigma_x \sigma_{y_{-1}}^2$  and  $\zeta = \sigma_{xy_{-1}} / \sigma_x^2$ . Bun and Carree (2005) use iterative methods on (2)-(4) to find the bias-corrected estimates. In our experiments the iterative method showed to be imprecise. In what follows we propose to solve the system of equations analytically with respect to  $\gamma$  and  $\beta = (\beta_1, \dots, \beta_k)'$  as explained here.

The expressions (2) – (4) can be used to solve analytically for the bias-corrected estimates of  $\gamma$  and  $\beta = (\beta_1, \dots, \beta_k)$  as follows. Using (3) we can express  $\beta_1, \dots, \beta_k$  as a function of  $\gamma$  and insert the resulting expression in (4). The resulting expression is a quadratic polynomial with respect to  $\gamma$  of the form  $\sigma_\varepsilon^2 = c_0 + c_1\gamma + c_2\gamma^2$ , where  $c_0$ ,  $c_1$ , and  $c_2$  are known constants. These constants have the following expressions:  $c_0 = (y - X(\beta_{lsdv} + \zeta\gamma_{lsdv}))' A (y - X(\beta_{lsdv} + \zeta\gamma_{lsdv})) / (N(T-1))$ ,  $c_1 = (y - X(\beta_{lsdv} + \zeta\gamma_{lsdv}))' A (X\zeta - y_{-1}) + (X\zeta - y_{-1})' A (y - X(\beta_{lsdv} + \zeta\gamma_{lsdv})) / (N(T-1))$ , and  $c_2 = (X\zeta - y_{-1})' A (X\zeta - y_{-1}) / (N(T-1))$ .

The computed  $\sigma_\varepsilon^2 = c_0 + c_1\gamma + c_2\gamma^2$  is inserted back to (2). The resulting expression is a polynomial of power T with respect to  $\gamma$ :

$$a_0 + a_1\gamma + a_2\gamma^2 + \dots + a_T\gamma^T = 0 \quad (5)$$

where  $a_0, \dots, a_T$  are some known constants. For example, when  $T=3$ , these constants have the following expressions:

$a_0 = \gamma_{lsdv} + c_0 / (3\xi)$ ,  $a_1 = (c_0 + 2c_1) / (6\xi) - 1$ ,  $a_2 = (c_1 + 2c_2) / (6\xi)$ ,  $a_3 = c_2 / (6\xi)$ , where  $\xi = (1 - \rho_{x,y_{-1}}^2) \sigma_{y_{-1}}^2$  is the conditional variance of  $\tilde{y}_{it} = y_{it} - \bar{y}_i$  given  $\tilde{x}_{it} = x_{it} - \bar{x}_i$ .

The advantage of an analytical solution is in extra precision. When  $T$  is odd the polynomial (5) always has at least one real root, when  $T$  is even, it may have zero real roots and  $T$  complex roots. Having solved for  $\gamma$ , we use (3) to obtain the bias-corrected  $\beta_1, \dots, \beta_k$ .

The expressions (2) – (5) can be generalized to the case of unbalanced panel, when there are missing observations in the interval  $[0, T]$  for some individuals. The individuals can be ordered in terms of the length of their time period,  $T_i - B_i + 1$ ,  $B_i$  denotes the beginning of the period and  $T_i$  the final time period for an individual  $i$  ( $1 \leq B_i \leq T_i \leq T$ ). The resulting unbalanced panel consists of at most  $T-1$  balanced panels, with the number of observations  $n_p$ , with maximum length equal to  $T$  and the minimum possible length 2. Following Bun and Carree (2005) we introduce the  $\varphi(p)$ , the fraction of observations in each of the balanced sub-panels, i.e.  $\varphi(p) = (p-1) \cdot n_p / \sum_{p=2}^T (p-1)n_p$ . The bias-corrected estimates of  $\gamma$  and  $\beta_1, \dots, \beta_k$  can then be obtained by solving the following system of equations:

$$\gamma_{lsdv} = \gamma - (\sigma_\varepsilon^2 h_u(\gamma, T)) / ((1 - \rho_{x,y_{-1}}^2) \sigma_{y_{-1}}^2) \quad (6)$$

$$\sigma_\varepsilon^2(\gamma, T) = \sum_{p=2}^T \varphi(p) \sigma_\varepsilon^2(p) \quad (7)$$

where  $h_u(\gamma, T) = \sum_{p=2}^T \varphi(p) (p-1 - p\gamma + \gamma^p) / (p(p-1)(1-\gamma)^2)$ . It can be shown that the last expression can be also written as  $h_u(\gamma) = \sum_{p=2}^T \varphi_{2,p} ((p-1) - p\gamma + \gamma^p) / p(1-\gamma)^2 / (\bar{T} - 1)$ , where  $\varphi_{2,p} = n_p / N$ .

The expression for  $\sigma_\varepsilon^2(p)$  becomes  $\sigma_\varepsilon^2(p) = (y - \gamma y_{-1} - X\beta)' A_s (y - \gamma y_{-1} - X\beta) / (n_p(p-1))$ . Idempotent matrix  $A_s$  wipes out the individual means and selects usable observations and is defined

as  $A_s = S(I - D(D'SD)^{-1}D')S$ , where  $D = I_N \otimes i_p$  ( $Np \times N$ ) is matrix of individual dummies ( $i_p$  is the  $(p \times 1)$  vector of unity elements), matrix  $S = \text{diag}(S_i)$ , ( $Np \times Np$ ) block-diagonal, and  $S_i = \text{diag}(s_{it})$ , ( $p \times p$ ) diagonal matrix for each  $i$  are such that  $s_{it}=1$  if  $(\text{obs}_{i,t}$  and  $\text{obs}_{i,t-1})=(1,1)$ . Finally, vector  $\beta = (\beta_1, \dots, \beta_k)'$  is solved for as explained in (2)-(4). To increase the precision of the estimates, this system and the polynomial of power  $T$  with respect to  $\gamma$  in (5) is solved analytically with respect to  $\gamma$  and  $\beta = (\beta_1, \dots, \beta_k)'$ .

### 3. Monte Carlo experiments

In our Monte-Carlo experiments we follow Bun and Kiviet (2003) and Bruno (2005). Data for  $y_{it}$  are generated by model (2.1) and the data for  $x_{it}$  by

$$x_{it} = \rho x_{i,t-1} + \xi_{it}, \quad \xi_{it} \sim N(0, \sigma_\xi^2), \quad i = 1, \dots, N \text{ and } t = 1, \dots, T \quad (8)$$

Initial observations  $y_{i0}$  and  $x_{i0}$  are generated using a procedure that allows to avoid small sample non-stationary problems<sup>1</sup> (Kiviet, 1995). The individual effects  $\eta_i$  are generated by assuming  $\eta_i \sim N(0, \sigma_\eta^2)$  and  $\sigma_\eta = \sigma_\varepsilon(1-\gamma)$ , while  $\sigma_\varepsilon^2$  is normalized to unity. In addition to  $\beta$  and  $\sigma_\xi^2$ ,  $\rho$  also determines the correlation between  $y_{it}$  and  $x_{it}$  and is set at values 0.8 and 0.2. In Kiviet (1995) it is argued that the relative bias of the estimators is significantly influenced by  $\sigma_s^2$ , the signal-to-noise ratio of the regression. In our experiments we use a combination of relatively high  $\sigma_s^2=9$  with high and low correlation and relatively low  $\sigma_s^2=2$  with high and low  $\rho$ . The parameter  $\gamma$  is set at values 0.8 and 0.2. We also choose  $\beta=1-\gamma$  so that a change in  $\gamma$  impacts the short-run and not the long-run dynamic relationship between  $x$  and  $y$ .

To investigate how the bias-corrected estimator performs for unbalanced data, we select for the Monte Carlo experiments T-patterns ranging from slightly to badly unbalanced. Following

---

<sup>1</sup> We implemented a Fortran code for the LSDV-bc estimator, available upon request. For the additive LSDV bias corrected estimator we used `xtlsdvc` module for Stata discussed in Bruno (2005) and for GMM routine `xtabond2` written by David Roodman, Center for Global Development, Washington, DC. To generate the data we used Stata 9.0 program `xtarsim` developed by G. Bruno, and described in Bruno, 2005. We performed 10000 replications with a fixed seed.



Baltagi and Chang (1995) we control for the extent of unbalancedness as measured by the Ahrens and Pincus (1981) index:  $\omega = N / [\bar{T} \sum_{t=2}^T (n(t)/t)]$ , where  $\bar{T} = \sum_{t=2}^T [n(t)t] / N$ ,  $N = \sum_{t=2}^T n(t)$ , and  $n(t)$  is the number of observations in a sub-panel  $t$ . Note that  $0 \leq \omega \leq 1$  and  $\omega = 1$  when the panel is balanced.

We vary  $n(t)$  from 20 to 160 for the different T-patterns (4, 10, 15, 20). For each of the T-patterns we consider three cases from mild unbalancedness ( $\omega = 0.9$ ) to medium ( $\omega = 0.6$ ) and severe unbalancedness ( $\omega = 0.3$ ).

The results for the Monte Carlo experiments for T-patterns (4, 10, 20) are summarized in tables 1 and 2. As expected, the bias for both  $\gamma$  and  $\beta$  decreases in  $\bar{T}$ . The bias of  $\gamma$  slightly decreases in unbalancedness for additive bias-corrected estimator and increases for GMM estimators. With respect to  $\sigma_s^2$ ,  $\gamma$ , and  $\rho$  the patterns reported by Bruno (2005) and Bun and Kiviet (2003) are confirmed. Last column reports the number of no-solution cases for the LSDV-bias corrected estimator. When  $T$  is odd the polynomial in (5) always has at least one real root, when  $T$  is even, it may have zero real roots and  $T$  complex roots. In our Monte Carlo experiments, for the designs we count the number of cases when the polynomial has no real roots, and when there is at least one real root, we count as non-convergence those solutions that are smaller than  $\gamma$ -LSDV. While the bias-corrected estimator may produce superior results in terms of bias, it is not always practical. When the signal-to-noise ratio  $\sigma_s^2$  is low and the  $\bar{T}$  is relatively small (designs 1, 2, 5, 6) there is a large percentage of cases with no solution for high values of  $\gamma$ . Overall, LSDV-bc has the smallest bias, but the advantage over the additive bias-corrected estimator becomes negligible as  $\bar{T}$  increases. For relatively small  $\bar{T}$ , high values of  $\gamma$  GMM-system is the preferred choice.

#### 4. Empirical Application

In this section we apply the estimators discussed in this paper to a dynamic model of firm productivity and R&D investment. The empirical illustration makes use of the data from the annual R&D surveys in the Netherlands in combination with the data from the Netherlands census of manufacturers, both provided by Statistics Netherlands. The R&D surveys contain

information on type and amount of R&D expenditures, and the census data contain information on value added, labor, and fixed capital investments. These merged establishment level databases provided us with an unbalanced panel of firms covering the years 1996-2001.

Our empirical model of firm productivity is derived from an augmented Cobb-Douglas production function that allows estimating labor productivity as a function of internal and external R&D. A semi-translog approximation of the production function with a second-order polynomial in R&D investment is used. Such a specification allows for decreasing returns to scale in internal and external R&D with a non-linear approximation of changes in the knowledge stock. There are a priori strong reasons to allow for (dis)economies of scale at the same time as (dis)economies of scope in R&D investment if the process of augmentation of the knowledge capital stock is characterized by declining returns to scale and if high R&D intensive firms engage in both internal and external R&D. Cohen and Klepper (1996) among others argued that R&D productivity is to decline with firm size.

The dependent variable, firm labor productivity, is net value added per employee at constant prices. Internal R&D is defined as a firm's expenditure on intramural R&D while external R&D is the expenditure on contracted R&D. Investment growth is the percentage growth in gross fixed capital investments between  $t-1$  and  $t$ , and employment growth is the percentage growth in employment.

Table 3 provides descriptive statistics on the variables used in estimation. The results of the dynamic panel estimation using difference and system GMM as well as two bias-corrected estimators are reported in Table 4. The four consistent estimators agree on the signs and magnitudes of most of the coefficients, while the system GMM estimator generates a higher F-value than difference GMM.<sup>2</sup> The Hansen test of over-identifying restrictions does not reject at 1% the validity of the instruments for the GMM models, with the exception of the system GMM model in column (2). Arellano-Bond AR tests also indicate that there are no problems relating to serial correlation of the error terms.

---

<sup>2</sup> GMM results are from the two-step variant of the estimator, which is more efficient than the one-step. The two-step estimates of the standard errors tend to be downward biased (Arellano and Bond 1991; Blundell and Bond 1998). The standard errors are corrected via a finite-sample correction to the two-step covariance matrix derived by Windmeijer (2005).

Overall the results clearly suggest that there are diseconomies of scale in both internal and external R&D with the squares term of both internal and external R&D negative and significant. Allowing for diseconomies of scale leads to a positive, although insignificant estimate for the coefficient of the interaction term between internal and external R&D.

## 5. Conclusion

In this paper we enlarged on the results obtained in Bun and Carree (2005) on the bias of LSDV-corrected estimator for dynamic panel data models. We considered the analytical formulas to derive the bias, which obviate the need to resort to the iterative methods of obtaining the solution. We have extended the formulas to include the unbalanced panels and assessed the performance of the estimator using a Monte Carlo approach. Simulation reveals that LSDV-bc estimator is a good choice compared to difference and system GMM as well as the additive bias-corrected estimator except for samples with small  $T$ , where it may be unpractical.

Our main conclusion is that for samples with  $T > 5$  the LSDV-bias corrected estimator performs well in terms of bias relative to all other estimators, including the LSDV additive bias-corrected technique. This finding effectively updates an earlier recommendation by Judson and Owen (1999) in favor of the new bias-corrected estimator. For samples with  $T < 5$  the LSDV-bias corrected estimator relatively often does not have a solution, especially around the unity circle (cf. Hahn, Hausman and Kuersteiner, 2001).

It is useful to note a number of caveats in the proposed results. The LSDV inconsistency derived in the paper is not robust to the presence of gaps in the data because of the function  $h$  which is derived on the assumption of balanced sub-panels. This is, however, immaterial for the Monte Carlo designs considered in the paper, but may be of importance in the applications with real-life data sets. The exogeneity of the selection rule  $S$  is a required assumption in the proposed results. Situations when the unbalanced nature of the data is caused by self-selection or attrition are not considered in this extension and are left for future work.

When applying the estimator to the dynamic model of firm productivity and R&D investment we find a convergence parameter of  $-0.27$ , implying that about a fourth of the productivity

lead is neutralized by the next period. The implied by LDVC-bias corrected estimator convergence in productivity in Dutch firms is much faster than that implied by the additive bias-corrected or difference GMM estimators.

**Acknowledgment:**

I thank Martin Carree and for useful comments

## References

Ahrens, H and R. Pincus, 1981, On two measures of unbalancedness in a one-way model and their relation to efficiency, *Biometric Journal*, 23, 227-235.

Anderson, T. and C. Hsiao, 1981, Estimation of dynamic models with error components, *Journal of American Statistical Association*, 76, 598-606.

Arellano, Manuel and Olympia Bover, 1995, Another look at the instrumental variable estimation of error-components models, *Journal of Econometrics*, 68, 29-51.

Baltagi, B. and Y-J. Chang, 1994, Incomplete panels: a comparative study of alternative estimators for the unbalanced one-way error component regression model, *Journal of Econometrics*, 62, 67-89.

Blundell, R. and S. Bond (1998) Initial conditions and moment restrictions in dynamic panel data models, *Journal of Econometrics*, 87, 115-143.

Bruno, G., 2005, Approximating the bias of the LSDV estimator for dynamic unbalanced panel data models, *Economics Letters*, 87, 361-366.

Bruno, G., 2005b, Estimation and inference in dynamic unbalanced panel-data models with a small number of individuals, *Stata Journal*, 5(4), 473-500.

Bun, M. and M. Carree, 2005, Bias-corrected estimation in dynamic panel data models, *Journal of Business and Economic Statistics*, 23(2), 200-209.

Bun, M. and J. Kiviet, 2003, On the diminishing returns of higher order terms in asymptotic expansions of bias, *Economics Letters*, 79, 145-152.

Cohen, W. and S. Klepper, 1996, A reprise of size and R&D, *Economic Journal* 106, 925-951.

Hahn, J, Hausman, G. Kuersteiner, 2001, Bias-corrected instrumental variable estimation for dynamic panel models with fixed effects, MIT working paper 01-24.

Judson R. and L. Owen, 1999, Estimating dynamic panel data models: a guide for macroeconomists, *Economics Letters*, 65, 9-15.

Kiviet, J., 1995, On bias, inconsistency and efficiency of various estimators in dynamic panel data models, *Journal of Econometrics*, 68, 53-78.

Roodman, D., 2006, How to Do xtabond2: An introduction to “difference” and “system” GMM in Stata, Working paper 103, Center for Global Development, Washington.

Windmeijer, Frank, 2005, A finite sample correction for the variance of linear efficient two-step GMM estimators, *Journal of Econometrics*, 126, 25-51.

Table 1 Bias Results,  $\sigma_s^2=2$

$\bar{T}$	$\omega$	$\gamma$	$\rho$	$\gamma$ LSDV-BC	$\gamma$ LSDV-AD	$\gamma$ GMM-SYS	$\gamma$ GMM-DIF	$\beta$ LSDV-BC	$\beta$ LSDV-AD	$\beta$ GMM-SYS	$\beta$ GMM-DIF	non con- verged cases, %	
4	0.9	0.8	0.8	-0.0560	-0.1132	-0.0126	-0.1132	0.0003	-0.0001	0.0004	-0.0046	30.0	
			0.2	-0.0468	-0.1049	-0.0128	-0.1051	-0.0025	-0.0080	-0.0011	-0.0098	27.0	
	0.6	0.8	0.8	-0.0023	-0.0105	0.0181	-0.0264	-0.0014	0.0015	-0.0105	-0.0008		
			0.2	-0.0014	-0.0040	0.0080	-0.0095	-0.0008	-0.0009	-0.0009	-0.0027		
	10	0.9	0.8	0.8	-0.0279	-0.0583	0.0111	-0.1559	-0.0021	0.0080	-0.0076	0.0201	16.2
				0.2	-0.0207	-0.0482	0.0125	-0.1421	0.0003	-0.0010	-0.0001	-0.0077	13.9
0.6		0.8	0.8	-0.0024	-0.0077	0.1438	-0.0489	-0.0012	0.0015	-0.0935	0.0172		
			0.2	-0.0009	-0.0024	0.0808	-0.0212	-0.0005	-0.0005	-0.0054	-0.0014		
20	0.9	0.8	0.8	-0.0029	-0.0255	-0.0008	-0.0504	-0.0005	0.0038	-0.0006	0.0097	1.7	
			0.2	-0.0013	-0.0228	-0.0008	-0.0456	0.0001	-0.0006	-0.0000	-0.0025	1.0	
	0.6	0.8	0.8	-0.0013	-0.0018	0.0298	-0.0146	0.0004	0.0009	-0.0185	0.0056		
			0.2	-0.0005	-0.0006	0.0133	-0.0058	-0.0000	-0.0000	-0.0011	-0.0002		
	0.3	0.8	0.8	-0.0054	-0.0195	0.0039	-0.0606	0.0040	0.0071	-0.0011	0.0189	1.0	
			0.2	-0.0033	-0.0170	0.0040	-0.0551	0.0003	-0.0001	-0.0002	-0.0024	0.6	
40	0.9	0.8	0.8	-0.0014	-0.0019	0.0609	-0.0182	0.0024	0.0028	-0.0404	0.0095		
			0.2	-0.0004	-0.0005	0.0289	-0.0079	0.0003	0.0003	-0.0031	-0.0005		
	0.6	0.8	0.8	-0.0024	-0.0061	0.0231	-0.0658	-0.0021	0.0004	-0.0129	0.0214		
			0.2	-0.0016	-0.0045	0.0225	-0.0612	-0.0005	-0.0001	-0.0012	-0.0016		
	0.3	0.8	0.8	-0.0015	-0.0019	0.1554	-0.0258	-0.0001	0.0002	-0.1080	0.0151		
			0.2	-0.0011	-0.0012	0.0898	-0.0129	-0.0003	-0.0003	-0.0101	0.0003		
80	0.9	0.8	0.8	-0.0005	-0.0049	0.0025	-0.0383	0.0009	0.0022	0.0003	0.0166		
			0.2	0.0002	-0.0039	0.0024	-0.0348	0.0005	0.0005	0.0004	-0.0008		
	0.6	0.8	0.8	-0.0002	-0.0003	0.0444	-0.0126	0.0008	0.0009	-0.0289	0.0083		
			0.2	0.0002	0.0002	0.0211	-0.0051	0.0004	0.0004	-0.0019	0.0004		
	0.3	0.8	0.8	-0.0050	-0.0035	0.0067	-0.0214	0.0051	0.0009	-0.0040	0.0103		
			0.2	-0.0040	-0.0027	0.0064	-0.0195	0.0009	-0.0002	-0.0005	-0.0006		
160	0.9	0.8	0.8	0.0108	0.0004	0.0476	-0.0070	-0.0058	-0.0001	-0.0328	0.0053		
			0.2	0.0071	0.0003	0.0227	-0.0030	-0.0008	-0.0002	-0.0026	0.0002		
	0.6	0.8	0.8	-0.0020	-0.0040	0.0135	-0.0333	-0.0018	-0.0010	-0.0077	0.0155		
			0.2	-0.0018	-0.0035	0.0129	-0.0307	-0.0007	-0.0006	-0.0010	-0.0009		
	0.3	0.8	0.8	-0.0009	-0.0009	0.0909	-0.0132	-0.0003	-0.0002	-0.0644	0.0087		
			0.2	-0.0007	-0.0008	0.0469	-0.0062	-0.0004	-0.0004	-0.0062	-0.0001		

Table 2 Results,  $\sigma_s^2=9$

$\bar{T}$	$\omega$	$\gamma$	$\rho$	$\gamma$ LSDV-BC	$\gamma$ LSDV-AD	$\gamma$ GMM-SYS	$\gamma$ GMM-DIF	$\beta$ LSDV-BC	$\beta$ LSDV-AD	$\beta$ GMM-SYS	$\beta$ GMM-DIF	non con- verged cases, %
4	0.9	0.8	0.8	-0.0242	-0.0634	0.0161	-0.1469	-0.0006	0.0011	-0.0081	-0.0039	0.02
			0.2	-0.0140	-0.0318	-0.0103	-0.0674	-0.0013	-0.0029	-0.0000	-0.0059	
	0.6	0.8	0.8	-0.0022	-0.0025	0.0148	-0.0168	-0.0004	-0.0001	-0.0084	-0.0004	
			0.2	-0.0011	-0.0012	0.0022	-0.0032	-0.0005	-0.0005	-0.0003	-0.0011	
	0.3	0.8	0.8	-0.0176	-0.0207	0.0049	-0.1125	0.0011	0.0054	-0.0036	0.0083	
			0.2									

			0.2	-0.0078	-0.0085	0.0035	-0.0508	-0.0004	-0.0006	0.0001	-0.0029	
		0.2	0.8	-0.0021	-0.0018	0.0814	-0.0224	-0.0001	-0.0002	-0.0525	0.0069	
			0.2	-0.0010	-0.0008	0.0277	-0.0063	-0.0003	-0.0003	-0.0017	-0.0004	
10	0.9	0.8	0.8	-0.0147	-0.0183	0.0098	-0.0571	0.0012	0.0018	-0.0040	0.0029	
			0.2	-0.0053	-0.0080	-0.0028	-0.0223	-0.0002	-0.0005	0.0001	-0.0014	
		0.2	0.8	-0.0012	-0.0011	0.0191	-0.0070	0.0005	0.0005	-0.0116	0.0024	
			0.2	-0.0004	-0.0004	0.0042	-0.0017	-0.0000	-0.0000	-0.0004	0.0000	
	0.6	0.8	0.8	-0.0122	-0.0125	0.0050	-0.0503	0.0019	0.0024	-0.0023	0.0059	
			0.2	-0.0038	-0.0055	-0.0004	-0.0201	-0.0001	-0.0002	-0.0000	-0.0011	
		0.2	0.8	-0.0008	-0.0007	0.0343	-0.0079	0.0012	0.0012	-0.0222	0.0037	
			0.2	-0.0001	-0.0001	0.0095	-0.0024	0.0001	0.0001	-0.0010	-0.0002	
	0.3	0.8	0.8	-0.0069	-0.0050	0.0112	-0.0393	0.0009	0.0013	-0.0056	0.0087	
			0.2	-0.0029	-0.0029	0.0069	-0.0202	-0.0001	-0.0002	-0.0002	-0.0005	
		0.2	0.8	-0.0010	-0.0009	0.0799	-0.0115	0.0002	0.0001	-0.0548	0.0064	
			0.2	-0.0007	-0.0006	0.0308	-0.0042	-0.0001	-0.0001	-0.0031	0.0001	
20	0.9	0.8	0.8	-0.0066	-0.0067	0.0033	-0.0322	0.0012	0.0013	-0.0012	0.0052	
			0.2	-0.0019	-0.0024	-0.0007	-0.0134	0.0001	0.0000	0.0001	-0.0004	
		0.2	0.8	-0.0005	-0.0004	0.0239	-0.0058	0.0006	0.0006	-0.0152	0.0032	
			0.2	0.0000	0.0000	0.0069	-0.0016	0.0002	0.0002	-0.0005	0.0001	
	0.6	0.8	0.8	-0.0191	-0.0058	0.0039	-0.0183	0.0098	0.0010	-0.0020	0.0040	
			0.2	-0.0080	-0.0020	0.0011	-0.0075	0.0015	-0.0001	-0.0000	-0.0002	
		0.2	0.8	0.0004	0.0000	0.0249	-0.0032	0.0012	0.0001	-0.0166	0.0021	
			0.2	0.0009	0.0000	0.0074	-0.0010	0.0001	-0.0001	-0.0008	0.0001	
	0.3	0.8	0.8	-0.0054	-0.0052	0.0068	-0.0229	0.0006	0.0007	-0.0035	0.0056	
			0.2	-0.0022	-0.0024	0.0032	-0.0107	-0.0001	-0.0002	-0.0002	-0.0003	
		0.2	0.8	-0.0006	-0.0006	0.0457	-0.0057	0.0000	-0.0000	-0.0315	0.0033	
			0.2	-0.0005	-0.0004	0.0156	-0.0020	-0.0002	-0.0002	-0.0020	-0.0001	



**Table 3 Descriptive statistics**

Variable	Mean	S.D.	Description
Productivity	3.88	.52	Net value added divided by employees in constant prices, in logarithm
$\Delta$ Labor	.01	.29	Log growth in the number of employees
$\Delta$ Investment	.03	4.01	Log growth in Fixed Capital Investment in constant prices
R&DINT	.07	.20	Expenditure on in-house R&D divided by net value added
R&DEXT	.01	.06	Expenditure on contracted R&D divided by net value added

**Table 4 Dynamic model of labor productivity**

	GMM (difference)	GMM (system)	Bias- corrected additive	LSDV-bias corrected
	(1)	(2)	(3)	(4)
Productivity <sub>t-1</sub>	0.821*** (0.124)	0.535*** (0.065)	0.566*** (0.035)	0.743*** (0.194)
$\Delta$ Labor	-0.507*** (0.075)	-0.400*** (0.069)	-0.498*** (0.023)	-0.551*** (0.060)
$\Delta$ investment	-0.001 (0.002)	0.005* (0.003)	0.001 (0.002)	0.002 (0.002)
R&DINT	0.943*** (0.266)	0.161 (0.101)	0.293** (0.117)	0.518** (0.207)
R&DINT squared	-0.103*** (0.037)	-0.005 (0.014)	-0.021 (0.016)	-0.046* (0.025)
R&DEXT	1.748*** (0.616)	0.783** (0.340)	0.775*** (0.238)	1.182*** (0.326)
R&DEXT squared	-1.339** (0.634)	-0.739* (0.379)	-0.667*** (0.192)	-0.867*** (0.207)
R&DINT * R&DEXT	0.257 (0.521)	0.228 (0.371)	0.030 (0.059)	0.008 (0.091)
Wald(df)	79.62	161.6		
Hansen test (df), p-value	21.85(21) 0.40	45.34(29) 0.04		
AR(1) test (p-value)	-5.01(0.00)	-5.49(0.00)		
AR(2) test (p-value)	0.14(0.89)	0.45(0.65)		
N. Obs.	1032	1032	1032	1032

Notes: \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. All models include year dummies. Instruments for the difference GMM equations are lagged values of the right hand side variables in levels; Instruments for the level equations are differenced values of the right hand side variables. Robust standard errors are in parentheses. For GMM estimates, the finite-sample correction to the two-step covariance matrix derived by windmeijer (2005) is used.

## **The UNU-MERIT WORKING Paper Series**

- 2008-01 *Science, Technology and Development: Emerging concepts and visions* by Luc Soete
- 2008-02 *Reframing technical change: Livestock Fodder Scarcity Revisited as Innovation Capacity Scarcity. Part 1. A Review of Historical and Recent Experiences* by Andy Hall, Rasheed Sulaiman V., Mona Dhamankar, Peter Bezkorowajnyj & Leela Prasad
- 2008-03 *Reframing technical change: Livestock Fodder Scarcity Revisited as Innovation Capacity Scarcity. Part 2. A Framework for Analysis* by Andy Hall, Rasheed Sulaiman, V. and Peter Bezkorowajnyj
- 2008-04 *Reframing technical change: Livestock Fodder Scarcity Revisited as Innovation Capacity Scarcity. Part 3. Tools for Diagnosis and Institutional Change in Innovation Systems* by Andy Hall, Rasheed Sulaiman and Peter Bezkorowajnyj
- 2008-05 *Is Inter-Firm Labor Mobility a Channel of Knowledge Spillovers? Evidence from a Linked Employer-Employee Panel* by Mika Maliranta, Pierre Mohnen & Petri Rouvinen
- 2008-06 *Financial Constraints and Other Obstacles: Are they a Threat to Innovation Activity?* By P. Mohnen, F.C. Palm, S. Schim van der Loeff and A. Tiwari
- 2008-07 *Knowledge-based productivity in 'low-tech' industries: evidence from firms in developing countries* by Micheline Goedhuys, Norbert Janz and Pierre Mohnen
- 2008-08 *The Voyage of the Beagle in Innovation Systems Land. Explorations on Sectors, Innovation, Heterogeneity and Selection* by Martin Srholec & Bart Verspagen
- 2008-09 *Crafting Firm Competencies to Improve Innovative Performance* by Boris Lokshin, Anita van Gils & Eva Bauer
- 2008-10 *The Economics and Psychology of Personality Traits* by Lex Borghans, Angela Lee Duckworth, James J. Heckman & Bas ter Weel
- 2008-11 *Embedding Research in Society: Development Assistance Options for Supporting Agricultural Innovation in a Global Knowledge Economy* by Andy Hall
- 2008-12 *Playing in Invisible Markets: Innovations in the Market for Toilets to Harness the Economic Power of the Poor* by Shyama V. Ramani
- 2008-13 *Explaining Success and Failure in Development* by Adam Szirmai
- 2008-14 *Running The Marathon* by William Cowan, Robin Cowan and Patrick Llerena
- 2008-15 *Productivity effects of innovation, stress and social relations* by Rifka Weehuizen, Bulat Sanditov and Robin Cowan
- 2008-16 *Entrepreneurship and Innovation Strategies in ICT SMEs in Enlarged Europe (EU25)* by Kaushalesh Lal and Theo Dunnewijk
- 2008-17 *Knowledge Transfers between Canadian Business Enterprises and Universities: Does Distance Matter?* By Julio M. Rosa & Pierre Mohnen
- 2008-18 *Multinationals are Multicultural Units: Some Indications from a Cross-Cultural Study* by Nantawan Noi Kwanjai & J. Friso den Hertog

- 2008-19 *The Innovativeness of Foreign Firms in China* by Branka Urem, Ludovico Alcorta and Tongliang An
- 2008-20 *Beyond the emission market: Kyoto and the international expansion of waste management firms* by Ionara Costa, Asel Doranova and Geert-Jan Eenhoorn
- 2008-21 *The ‘making of’ national giants: technology and governments shaping the international expansion of oil companies from Brazil and China* by Flavia Carvalho and Andrea Goldstein
- 2008-22 *If the Alliance Fits . . . : Innovation and Network Dynamics* by Robin Cowan & Nicolas Jonard
- 2008-23 *Facing the Trial of Internationalizing Clinical Trials to Developing Countries: With Some Evidence from Mexico* by Fernando Santiago-Rodriguez
- 2008-24 *Serving low-income markets: Rethinking Multinational Corporations’ Strategies* by Shuan SadreGhazi and Geert Duysters
- 2008-25 *A percolation model of eco-innovation diffusion: the relationship between diffusion, learning economies and subsidies* by Simona Cantono and Gerald Silverberg
- 2008-26 *New Europe’s Promise for Life Sciences* by Sergey Filippov and Kálmán Kalotay
- 2008-27 *A closer look at the relationship between life expectancy and economic growth* by Théophile T. Azomahou, Raouf Boucekkine, Bity Diene
- 2008-28 *Regional Capital Inputs in Chinese Industry and Manufacturing, 1978-2003* by Lili Wang & Adam Szirmai
- 2008-29 *Worker remittances and government behaviour in the receiving countries* by Thomas Ziesemer
- 2008-30 *Strategic motivations for Sino-Western alliances: a comparative analysis of Chinese and Western alliance formation drivers* by Tina Saebi & Qinqin Dong
- 2008-31 *Changing Configuration of Alternative Energy Systems* by Radhika Bhuyan and Lynn Mytelka
- 2008-32 *Promoting clean technologies: The energy market structure crucially matters* by Théophile T. Azomahou, Raouf Boucekkine, Phu Nguyen-Van
- 2008-33 *Local Knowledge Spillovers, Innovation and Economic Performance in Developing Countries: A discussion of alternative specifications* by Effie Kesidou and Adam Szirmai
- 2008-34 *Wage effects of R&D tax incentives: Evidence from the Netherlands* by Boris Lokshin and Pierre Mohnen
- 2008-35 *Cross-border Investment and Economic Integration: The Case of Guangdong Province and Hong Kong SAR* by Naubahar Shari and Can Huang
- 2008-36 *Radical versus non-radical inventions* by Wilfred Schoenmakers, Geert Duysters & Wim Vanhaverbeke
- 2008-37 *Localized Innovation, Localized Diffusion and the Environment: An Analysis of CO<sub>2</sub> Emission Reductions by Passenger Cars, 2000-2007* by Bart Los and Bart Verspagen

- 2008-38 *The economic impact of AIDS in sub-Saharan Africa* by Théophile T. Azomahou, Raouf Boucekine, Bity Diene
- 2008-39 *Further results on bias in dynamic unbalanced panel data models with an application to firm R&D investment* by Boris Lokshin