Intellectual Property Rights and Innovation in Developing Countries: Evidence from Panel Data

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Introduction

In industrialized countries, intellectual property rights (IPR) are part of the infrastructure supporting investments in research and development (R&D) leading to innovation. By granting temporary exclusive rights on inventions, IPR allow right-holders to price their products above marginal cost, and hence recoup their initial research investment. Such exclusive right creates incentives for the conduct of R&D. However, by granting monopoly rights on an invention, IPR impede its dissemination. The resulting under-provision of protected goods and monopoly distortions are usually considered acceptable costs for the creation of new knowledge and the increase in social welfare that it entails.

In general, IPR are perceived as contributing to the promotion of technological innovation and to the transfer and dissemination of technology, in a manner conducive to social and economic welfare (WTO-TRIPs Agreement, Art. 7). Still, growing numbers of experts question these affirmations for developing countries (LDCs) and argue that IPR "do little to stimulate innovation in developing countries" (CIPR, 2002: 1). IPR may provide an incentive for innovation but there is limited local capacity in LDCs to make use of it. Similarly, even if stronger IP protection supports an increase in technology transfer, limited local absorptive capability may constrain the potential to use it. Finally, the environment in which IPR exist, for example the quality of the legal system and the importance of transaction costs, might severely constrain the incentive effect, as has been concluded for Mexico (Léger, 2005). In these countries, the balance between dynamic benefits and static costs might not be positive. Still, IPR is an important issue in bilateral, regional and multilateral trade negotiations. Pressure is put on LDCs to sign up for stronger standards of IP protection without having a clear picture of the impacts IPR have in these economies (Fink and Maskus, 2005).

This study hence investigates the role IPR play for innovation using a novel panel dataset of LDCs and industrialized countries. In doing so it contributes to the innovation literature by comparing the determinants of innovation in developing and industrialized countries, and takes into account the cumulative nature of innovation by using dynamic panel estimation methods. Furthermore, it investigates the performances of different estimators for samples with small N and small T.

We find that past R&D investments have a positive and significant impact on current innovation, demand-pull factors are also important in all country groups, and the structure of the economy has a negative (positive) impact in developing (industrialized) countries. Intellectual property protection is only significant (at a low level) for developing countries. The least-square dummy variable corrected estimator (Kiviet, 1995; Bruno, 2005a) is found to be the most appropriate for small, unbalanced datasets.

The rest of the paper is organized as follows. Section 2 review the theoretical and empirical literature on IPR and innovation. Section 3 presents the methodology and the data used, and section 4 presents and discusses the results of the estimations. Section 5 concludes.

Innovation

Nature and Determinants

The result of the innovation process is a new product (or process) as well as new information, which has public good characteristics, i.e., non-rivalry and non-excludability. These two properties of information make the gains from innovation uncertain and difficult to appropriate, which implies that R&D opportunities that would be socially profitable are not exploited because they are privately unprofitable. In order for innovation to be undertaken, incentives need to be given. IPR is suggested as one possible government intervention to correct for this market failure[1].

Three main reasons exist for innovation. First, the possibility of increased profits and market share, secured by IPR or other mechanisms (e.g. first-mover advantage, secrecy) motivates investments in innovative activity. Second, innovation would react to "demand-pull" factors (Schmookler, 1966), i.e., the perceived demand for new products and processes. Conversely, "technology-push" factors, that are related to advancements in technology and science, would also play an important role (Cohen and Klepper, 1996).

The environment in which a firm operates affects its innovative performance. At the macroeconomic level, economic and political stability (Lall, 1992) provides an environment supportive of innovation. Competition and openness to trade also affect incentives to innovate, as does the structure of the economy, however these impacts are theoretically not clear (Grossman and Helpman, 1991). At the firm level, given that R&D is an expensive endeavor, cost of, and access to capital are important aspects. Finally, qualified scientists and workers are essential inputs into the innovation process, hence the level of human capital in the country is another important factor (Crespo *et al*, 2004).

Though innovation could play a crucial role for economic development in LDCs, most of the literature so far has focused on industrialized countries. However, a different treatment could be warranted given that LDC characteristics differ from the usual models. Demand-pull factors could have a limited impact in LDCs, given the generally lower purchasing power of inhabitants. Markets are often incomplete, weak or non-

[1] Others can include tax breaks on the performance of R&D, contests, R&D, or public performance of R&D.

existent (Lall, 1992), which has important implications for the conduct of innovative activities, especially in areas such as capital (financial and human) and information. The institutional environment is characterized by the presence of high transaction costs, which often include corruption (Collier, 1998), and by weak institutions. These could affect the functioning of the market and the transmission of signals – e.g. demand for certain goods – to the innovators. Furthermore, the performance of IPR, a market-based tool, in malfunctioning markets, still has to be investigated.

IPR in a North-South setting

In a North-South setting, where only the North can innovate and the South has lower labor costs, Deardorff (1992) finds that stronger IPR hurt the South and benefit the North. Another study (Chin and Grossman, 1990) reaches similar conclusions, except for the case of highly productive R&D, for which international IP protection increases global welfare. There is however always a conflict of interest between the North and the South. Zigic (1998) extends this model to allow for different levels of IP protection and finds that this conflict holds when R&D efficiency is low, but that the interests could be in congruence for higher R&D efficiency levels. Similarly, in a model assuming different preferences in the North and the South, strong IP protection in the South provides incentives for Northern innovation addressing Southern needs, hence benefiting both regions (Diwan and Rodrik, 1991). However purchasing power is not taken into account: Anecdotic evidence from the case of essential medicines in least-developed countries shows that strong IPR might not be enough for Northern R&D to take place. In a dynamic general equilibrium framework including imitation and technology transfer, Helpman (1993) finds that strengthening IPR spurs innovation in the North in the short-run but slows it in the long run. The South also loses from stronger IPR, through a deterioration of its terms of trade, reallocation of production and a global slowdown of innovation. Conversely, a dynamic endogenous growth model (Saint-Paul, 2004) reveals that the South might lose more than the North from **weak** IPR, depending on the relative comparative advantages and the growth potential of the goods concerned. In general, the impact of stronger IPR on innovation is still unclear theoretically and heavily depends on the models used and their underlying assumptions.

Empirical Evidence

A few studies examine the link between IP protection and innovation for panels of countries. Alfranca and Huffman (2003) use a panel of EU countries to estimate the effects of economic incentives and institutions on private innovation in agriculture, and find the level of IP protection, institutional quality, economic openness and the lagged value of agricultural production to be positive and significant factors. Conversely, interest rate and the lagged value of crop production have (significant) negative impacts. Kanwar and Evenson (2003) investigate the determinants of innovation and technological change, proxied by total R&D investments as a proportion of GNP. They obtain similar results: IP protection, credit availability, demand-pull factors, trade openness and human capital positively affect innovation, while political instability and interest rate would have a negative effect. They however do not consider the impact of past innovative activity, which is done by Lederman and Maloney (2003), who use a dynamic GMM estimator. They find that interest rate and risk negatively affect aggregate private and public R&D investments, while past R&D investments, credit market depth, IP protection, complementary institutions and the quality of research institutions are positive and significant explanatory factors. However, GMM estimators rely on asymptotic properties, hence estimates can be biased for small samples like their. Furthermore, they do not control explicitly for the level of development of the countries.

A recent article (Higino Schneider, 2005) investigates the role of trade, FDI and IPR in explaining innovation and finds that, while IPR play a significant and positive role in industrialized countries, it is negative and not significant for LDCs, and is positive and significant for the whole sample. Contrary to the other studies, she uses the number of patent applications in the USA as a proxy for innovation. Since IP protection systems are relatively recent in LDCs, and that not all innovations qualify for patent protection, this measure might be imperfect for the study of innovation in LDCs. Furthermore, patenting activity might be closely related to the structure of the economy, which is not controlled for. Finally, past innovative activity is not taken into account.

The impact of IPR on innovation in LDCs is theoretically not clear, and the empirical evidence available indicates that it might be different for industrialized and developing countries. This article hence tests the propositions that:

- IPR protection is a significant factor affecting innovation;
- The determinants of innovation are different for developing and industrialized countries.

It does so by using a new dataset of industrialized and developing countries. Finally, the paper also compares the performances of different econometric estimators for small samples.

Methodology

Data

I constructed a new panel dataset comprising 24 industrialized and 44 developing countries. I use average annual data for six 5-year sub-periods (1970-1995). Table 1 presents the variables used in the estimations, along with the expected signs of the parameters, and their sources.

Innovation is proxied by total R&D expenditures as a proportion of GDP. IPR are expected to provide incentives for private R&D, but the classification of R&D tends to be between productive and non-productive sectors and these series are not stable over time. Moreover, working with aggregate R&D expenditures allows including more LDCs in the sample. Intellectual property protection is proxied by a time-varying index of IP protection that covers 5 categories of patent law: extent of coverage, membership in international agreements, provisions for loss of protection, enforcement mechanisms and the duration of protection[2] (see Park and Ginarte, 1997).

Table 1. Description of Variables

	Expected Sign	Variable	Source
Dependent variable			
Innovation		Total R&D expenditures as a proportion of GDP (5-year average) (RDGDP)	UNESCO statistical yearbooks (various years), RICYT
Explanatory variables			
Demand-pull factors	+ +	Gross domestic product (GDP) per capita (constant 2000 US$) (GDPPC) Population (latest year) (POP)	World Development Indicators (WDI) (World Bank, 2005)
Technology-push factors	+	Lagged R&D expenditures as a proportion of GDP (L_RDGDP)	UNESCO statistical yearbooks, RICYT
Macroeconomic instability	-	Inflation (INF)	WDI 2005
Political instability	-	State failure events dummy (POL)	Constructed from State failure task force
Access to capital	+	Saving as a proportion of GDP (SAV)	WDI (2005)
Cost of capital	-	Real interest rate (INTRATE)	WDI (2005)
Competition Structure of the economy	+/- +/-	Openness to trade (OPEN) Value-added in manufacturing as a pro portion of GDP (MAN)	Penn World Table 6.1 WDI (2005)
Intellectual property protection	+/-	Index of IP protection (IP)	Park and Ginarte (1997), Park (2002)
Human capital	+	Years of schooling, above 15 (EDU)	Barro-Lee data set (2000)

Estimations are performed on three sub-samples: industrialized countries, developing countries and the whole sample (see table 2). Least-developed countries are underrepre-

[2] I would like to thank Walter Park for kindly making his dataset available.

sented in this dataset: data are not available for the periods covered, which could bias the results. Table 3 presents the summary statistics.

Table 2. Countries

Developing Countries	Industrialized Countries
Argentina, Bolivia, Brazil, Central African Republic, Chile, Columbia, Costa Rica, Cyprus, Ecuador, Egypt, El Salvador, Guatemala, Guyana, India, Indonesia, Iran, Jamaica, Jordan, Mauritius, Mexico, Nicaragua, Niger, Pakistan, Panama, Peru, Philippines, Singapore, Sri Lanka, Sudan, Thailand, Trinidad & Tobago, Turkey, Uruguay, Venezuela, Zambia	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, USA

Table 3. Summary Statistics

Variables	Developing Countries (44)		Industrialized Countries (22)		Total Sample (66)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
RDGDP	0,104	0,347	1,451	0,749	0,666	0,865
GDPPC	2450,12	2815,74	15 291	6 865	4 585,63	6 744,68
POP	38 715	108 934	33 338	50 611	35 912	90 567
INF	74,79	391,03	7,611	6,631	48,260	305,639
POL	0,291	0,455	0,028	0,166	0,203	0,403
SAV	17,546	10,411	24,259	5,253	19,898	10,237
INTRATE	5,816	22,151	3,932	4,113	5,023	16,053
OPEN	65,84	59,31	44,338	24,165	58,873	49,937
MANUF	17,646	9,331	21,671	5,298	18,218	8,823
IP	2,159	0,727	3,201	0,659	2,523	0,844
EDU	4,347	2,035	7,897	2,104	4,617	2,776

Estimation

Given the theoretical importance of technology-push factors, the past investments in R&D as a proportion of GDP, i.e., the lagged dependent variable, is used as a regressor. This introduction generates a dynamic relationship for countries (i) over time (t) of the type $y_{it} = \alpha y_{i,t-1} + \beta x_{it}^{'} + u_{it}$, $i = 1, \ldots, N$ and $t = 2, \ldots, T$ where α is a scalar, $x_{it}^{'}$ is 1 x K and β is K x 1. The error component is $u_{it} = \eta_i + v_{it}$ where $E[\eta_i] = 0, E[v_{it}]$, $E[v_{it}\eta_i] = 0$ for $i = 1, \ldots, N$ and $t = 2, \ldots, T$. The v_{it} are assumed to be serially uncorrelated $E[v_{it}\, v_{is}] = 0$ for $i = 1, \ldots, N$ and $s \neq t$.

Some problems arise from the introduction of the lagged variable on the right-hand-side. Since y_{it} is a function of η_i, $y_{i\,t-1}$ is also a function of η_i, causing a correlation between a regressor and the error term. This renders the OLS estimator inconsistent and biased (upwards). Estimation using fixed effects (FE) eliminates the inconsistency by eliminating η_i. However, for panels with small T, this induces a correlation between the transformed lagged dependent variable and the transformed error term, which causes the fixed effects estimator to be biased (downwards). The estimates of α obtained with these two methods can however be used as boundaries to control for misspecification or inconsistency in other models.

Arellano and Bond (1991) proposed a generalized method of moments (GMM) procedure where they use orthogonality conditions between $y_{i,\,t-1}$ and the disturbance v_{it} to obtain supplementary instruments, which yields a consistent estimator. Other authors (eg. Blundell and Bond, 1998, hereafter BB) have since found that weak instruments could cause large finite sample biases, especially when time series are persistent and the number of series observations is small. They proposed a system GMM estimator using equations in differences and in levels to bring additional moment conditions and increase efficiency. Such estimation procedure is adequate for panels with large N and small T since it relies on asymptotic properties. Windmeijer (2005) hence developed a correction for the two-step covariance matrix that significantly increases the efficiency of these GMM estimators, that is implemented here.

Comparing these different estimators, Judson and Owen (1999) and Adolph *et al* (2005) found the Least-Squares Dummy Variable Corrected estimator (LSDVC), originally proposed by Kiviet (1995) and recently extended by Bruno (2005a, 2005b) to the case of unbalanced panels, to be the most efficient and less biased. However, while taking care of the endogeneity of the lagged dependent variable, the LSDVC estimator assumes strict exogeneity of the other regressors. Another possible estimator to deal with small sample bias is the limited information maximum likelihood estimator (LIML), which has been found in such conditions to be superior to GMM estimators (Alvarez and Arellano, 2003). It is robust to the presence of heteroskedasticity and, contrary to LSDVC, it allows for the presence of right-hand-side endogenous variables.

Results and Analysis

Estimation Results

Estimations are performed using Stata8, and all variables are estimated in logs[3]. Tests indicate the presence of first-order autocorrelation and heteroskedasticity: The GMM regressions are hence estimated using the two-step estimator. Given the small T, tests for equality of slopes across groups could not be performed. Table 4 presents the estimation results for the different models and sub-samples.

As was already mentioned, OLS produces an estimate of α that is biased upwards, and α_{FE} is biased downwards, hence an unbiased estimate should lie in this interval. α_{BB} is however consistently outside these boundaries: the GMM system estimator relies on asymptotic properties and even though the Windmeijer finite sample correction adjusts the variance-covariance matrix for small samples, it does not correct the bias of the estimates. Similarly, α_{LIML} is very small in comparison with the other estimates. Even though it has been found less biased than FE and GMM estimators in simulations, its performance for unbalanced datasets appears to be poor. Even though the bias of LSDVC estimates also tends to increase with the degree of unbalancedness of the dataset (Bruno, 2005b), these results are theoretically more reliable. Hence the results of the different estimations are presented but only the LSDVC results will be discussed for interpretative purposes.

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[3] Different user-developed programs are used: Roodman (2005) for the GMM estimations, Bruno (2005b) for the LSDVC estimations, and Schaffer (2006) for LIML.

Table 4. Estimation Results

Variables	Developing Countries					Industrialized Countries					Total Sample				
	OLS	FE	LSDVC	BB	LIML	OLS	FE	LSDVC	BB	LIML	OLS	FE	LSDVC	BB	LIML
L_RDGDP	0,563***	0,570***	0,596***	0,391***	0,421***	0,735***	0,268*	0,779***	0,747***	0,151**	0,573***	0,570***	0,609***	0,489***	0,406***
	(0,017)	(0,022)	(0,310)	(0,043)	(0,032)	(0,053)	(0,148)	(0,172)	(0,064)	(0,059)	(0,019)	(0,020)	(0,012)	(0,065)	(0,040)
IP	0,404**	0,562	0,662*	1,632	0,929	0,069	0,521*	0,153	0,207	0,355*	0,498**	0,521	0,647	0,459	0,917
	(0,175)	(0,598)	(0,386)	(1,244)	(0,932)	(0,050)	(0,279)	(0,333)	(0,251)	(0,183)	(0,193)	(0,517)	(0,434)	(0,896)	(0,822)
EDU	0,282	-0,298	-0,193	2,305**	0,142	0,157	-0,255	-0,070	0,035	-0,329*	0,256	-0,343	-0,139	1,986**	-0,120
	(0,273)	(0,885)	(0,614)	(0,841)	(1,693)	(0,129)	(0,410)	(0,283)	(0,327)	(0,185)	(0,250)	(0,763)	(0,930)	(0,747)	(1,392)
POP	0,293***	1,973*	1,759*	-0,002	1,575	0,015	-0,859	-1,273	0,029	-0,296	0,306***	2,004**	1,634***	-0,169	1,806
	(0,064)	(1,028)	(0,105)	(0,309)	(2,206)	(0,017)	(1,234)	(2,271)	(0,047)	(0,395)	(0,060)	(0,894)	(0,389)	(0,187)	(1,860)
SAV	-0,194*	0,120	0,148	-0,126	0,104	0,100	-0,255	-0,124	0,155	-0,249*	-0,223*	0,125	0,171	-0,794**	0,074
	(0,012)	(0,265)	(0,192)	(0,334)	(0,143)	(0,112)	(0,342)	(0,634)	(0,241)	(0,133)	(0,118)	(0,234)	(0,287)	(0,364)	(0,149)
MAN	-0,235	-0,944**	-0,871**	-0,166	-0,009	0,008	0,952**	0,991**	-0,233	-	-0,317	-0,885**	-0,782***	-1,103	-0,129
	(0,432)	(0,494)	(0,427)	(1,639)	(0,925)	(0,080)	(0,436)	(0,387)	(0,222)		(0,353)	(0,431)	(0,163)	(0,996)	(0,835)
GDPPC	0,381**	-0,009	-0,099	-0,889	-0,406	0,103	1,403***	1,266***	-0,023	0,813***	0,584***	-0,036	-0,186	0,234	-0,071
	(0,160)	(0,570)	(0,340)	(0,584)	(0,947)	(0,113)	(0,352)	(0,184)	(0,096)	(0,184)	(0,102)	(0,490)	(0,609)	(0,359)	(0,905)
CONSTANT	-7,113***	-	-	-	-	-1,751*	-	-	-	-	-8,278***	-	-	-	-
	(0,876)					(0,956)					(0,854)				
R^2	0,844	0,831	-	-	0,215	0,879	0,659	-	-	0,294	0,894	0,831	-	-	0,214
F- test	262,93	111,97	24,61	113,40	82,44	224,85	9,12	415,07	70,26	11,92	467,88	139,41	18,90	134,41	48,47
(p value)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
F-test instru-ments	-	-	-	-	188,11	-	-	-	-	90,17	-	-	-	-	191,19
					(0,000)					(0,000)					(0,000)
Test overid.	-	-	-	28,42	0,068	-	-	-	14,77	0,194	-	-	-	36,79	0,153
(p value)				(0,443)	(0,9665)				(0,981)	(0,659)				(0,432)	(0,695)
Countries	35	35	35	35	32	21	21	21	21	24	55	55	55	55	47
Observations	201	201	201	181	134	61	61	61	61	110	261	261	261	241	178

Note: Significant at the 1% level:* **, 5%: **, 10%: *. Standard errors in parentheses.

For all models, the F-tests show that the parameters are jointly significant. Following expectations, $\alpha_{OLS} > \alpha_{FE}$ for the full sample as well as for the sub-sample of industrialized countries, but for the developing countries sub-sample $\alpha_{FE} > \alpha_{OLS}$. Even though α_{LSDVC} is not located in the interval for full sample and the developing countries sub-samples, it is slightly above the upper-bound (α_{OLS}) which could indicate an upward bias. For all samples α is positive and strongly significant, which supports the hypothesis of the cumulative nature of innovation.

We are especially interested in the IP index, however it is significant (at the 10% level) only in the regression for LDCs. This could be explained by the high level of correlation between the IPR index and other variables in the estimations, see table 5 for some of the correlations. The correlation between IPR and lagged R&D is high and significant for industrialized countries and the full sample, however it is low and insignificant for the LDCs sub-sample.

Table 5. Correlations for IPR

IPR and..	LDC	DC	Total sample
L_RD	0,0619	0,6419 *	0,6048 *
EDU	0,3263 *	0,4052 *	0,5904 *
GDPCAP	0,3161 *	0,5473 *	0,6500 *
POP	-0,1837 *	0,4500 *	-0,0633
OPEN	0,2010 *	0,1390	0,0187
MANUF	-0,1099	-0,0032	0,0466

Note: * significant at the 5% level

Looking at the correlation between IPR and openness to trade, that is significant for LDCs but not for the two other samples, could help explaining the strengthening of IPR in these different groups. In industrialized countries, IPR were strengthened to protect inventions, while in LDCs strengthening took place to comply with international trade agreements, as was observed in Latin American countries (Jaffé and van Wijk, 1995). This however raises the question of the possible endogeneity of the IPR variable. Wu-Hausman F-tests of endogeneity however show that none of the regressors (apart from the lagged dependent variable) are endogenous.

Value-added in manufacturing, which is used to account for the structure of the economy, is negative and significant for the full sample as well as for the LDCs sub-sample, while it is also significant but positive for industrialized countries. Theoretically, the sign of the relationship is not clear: as formal R&D mainly leads to technological innovations, that are then used in manufacturing, one would expect that countries where manufacturing is an important sector of the economy would be more innovative, as is the case in the sub-sample of industrialized countries. However, this variable is highly correlated with other variables that could be considered indicators of development (education, GDP per capita, quality of the institutions, and the dummy for developing country status), hence in the case of developing countries the negative sign could relate to this relationship rather than to the impact of the structure of the economy.

Finally, the demand-pull hypothesis, reflected by the variables GDP per capita and population, is supported in all sub-samples: population is positive and significant (at the 10% level) in LDCs and in the full sample (at the 1% level), whereas GDP per capita is positive and strongly significant in industrialized countries. The lower levels of R&D in developing countries appear not to respond to the purchasing power of the local market. Given that we are working with aggregated R&D expenditures, it could also be that most of the R&D expenditures in LDCs come from the government and hence do not respond to perceived market demand but rather to strategic priorities.

Discussion

These results suggest that innovation, in both developing and industrialized countries, strongly depends on past R&D investments, the so-called technology push factors, and more importantly so in industrialized countries. This could be due to the fact that in most industrialized countries, firms and research institutes have a higher level of technological capabilities and hence benefit from advances in science pushing further the technological frontier, i.e., domestic investments and investments from other industrialized countries. Conversely, the level of technological capabilities amongst firms and research institutes in LDCs is in general lower (or more heterogeneous), and these have access to spillovers from the R&D activities in industrialized countries, and the role of domestic investments would hence not be as important. This is supported by empirical evidence that R&D spillovers are especially important when countries are trading with countries with higher technological capabilities (Coe, Helpman and Hoffmaister, 1997).

Similarly, in industrialized countries the demand-pull factors (as proxied by GDP per capita) play an important role, but not in LDCs, where population is positive and significant. In the same line of though as the discussion on the technology-push factors, demand for innovation in LDCs can be satisfied from several sources – domestic and foreign – while the demand for a variety of differentiated products, adapted to the local conditions, is more important in industrialized countries, which might explain this situation. Another explanation would be that the characteristics of the markets in LDCs (high transaction costs) impair the transmission, and hence the impact, of demand for innovation.

These results are consistent with those of previous studies discussed in section 2. However, the number of significant parameters is a lot higher in these other studies, and the estimation methods differ: Kanwar and Evenson use OLS on the equation in logarithmic form, in a static model (not including past R&D investments), ignoring the potential role of technology-push factors on innovation, which are here found to be important. On the other hand, Lederman and Maloney use the GMM system estimator, which is expected to yield consistent estimators for panels with large N and small T, without correcting for the small sample bias, which causes the standard errors to be underestimated (Windmeijer, 2005). Furthermore, they chose to estimate certain variables in logarithmic form where the interpretation of the results becomes problematic and contrary to standard procedures, e.g., estimating most variables in levels but the IP index in logarithmic form. Even though Kanwar and Evenson (2003) look at the determinants of private R&D and Lederman and Maloney (2003) use aggregate R&D, they obtain similar results.

Estimation issues

The availability of data is problematic, especially for LDCs, which caused several countries to be excluded from the samples. There might hence be a selection bias, since the countries for which data are available possess a certain level of institutional capacity. This *de facto* eliminates countries with lower levels of institutional capacity and takes away some of the variability, and hence representativity of the sample, which in turn affects the quality of the estimates.

However, data for these countries are not available, to such an extent that taking the bias into account in the estimations, using for example a Heckman selection model, was impossible. It is important to keep this qualification in mind, even though the information obtained on the more advanced LDCs, especially compared with the case of industrialized countries, also provides useful insights for policy-making in countries at lower levels of development.

The empirical analysis of small, unbalanced samples is problematic. While the LIML estimator has been found to have a small bias in Monte Carlo simulations, its performance with the datasets at stake is poor. Test results and statistics of the model were satisfactory[4] but the estimates are obviously biased, for all sub-samples. The LSDVC yields a better performance but is also biased, which is consistent with evidence from simulations (Bruno, 2005b), where the bias was found to increase with the degree of unbalencedness of the dataset.

Another important point relates to the collinearity among right-hand-side regressors. Table 6 shows the pairwise correlations among the variables used in the estimations and makes clear that they are all interdependent. Even though panel estimations reduces the problem of collinearity among regressors, it still affects the quality of the estimates and especially the interpretation of results.

Table 6. Pairwise Correlations – Full Sample

	L_RDGDP	IPR	EDU	GDPCAP	POP	SAV
L_RDGDP	1					
IPR	0,5986*	1				
EDU	0,5975*	0,3928*	1			
GDPCAP	0,7103*	0,5282*	0,7706*	1		
POP	0,2268*	0,0025	-0,0040	-0,0950*	1	
SAV	0,2577*	0,1406*	0,5047*	0,4780*	0,0904	1
MAN	0,2840*	0,0514	0,6041*	0,5355*	0,0445	0,3419*

Note: in logs, *: significant at the 5% level

Finally, innovation is inherently difficult to define and to measure. Definitions vary among sources: the systems of innovation literature stays close to Schumpeter's "new combinations" by defining innovation as "a new use of pre-existing possibilities and

[4] Since the LIML regressions were not discussed, details of the instrumental variables and first-stage statistics are not reported but are available from the author upon request.

components" (Lundvall, 1992, p.8) while the OECD (1997) defines it as all the scientific, technological, organizational, financial, and commercial activities necessary to create, implement, and market new or improved products or processes (1997). Measuring innovation implies focusing on its more technical aspects, and though this issue has been discussed in the literature (see for example Griliches, 1994; Stern et al, 2000) the conclusion is that no perfect measure is available. This problem might be even more relevant for the case of developing countries, where innovation consists more of learning, adaptation and imitation, which again would call for a different treatment. However, given the importance of these issues for economic theory and policy, these qualifications should be kept in mind while more efforts and resources should be directed toward solving data and definition problems.

Conclusion

This paper identifies the determinants of innovation using a panel of developing and industrialized countries, applying different panel estimation methods to the case of panels with small N and T. Previous investments in R&D are found to be an important factor explaining private R&D investments, in both samples, while demand-pull factors (GDP per capita) play a role in industrialized countries but not in developing countries, human capital is positive and significant only in the full sample.

Even though the LSDVC estimator has been found to be most efficient and less biased than other estimators in Monte Carlo simulations, its bias increases with the degree of unbalancedness of the dataset. Another econometric issue relates to the high correlation among regressors, which makes the interpretation of the coefficients difficult and potentially affects the significance of the variables. Finally, the availability of data is problematic, and further efforts should be devoted to the collection of adequate data.

Given the importance of innovation for economic growth and development, the study of the innovation process in developing countries warrants more attention, and the results presented here underline the need to control for the level of development of look more specifically at the case of developing countries, as determinants of innovation could differ according to the level of development.

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