Research in Economics 64 (2010) 81–96

Contents lists available at ScienceDirect

Research in Economics

journal homepage: www.elsevier.com/locate/rie

How to measure innovation? New evidence of the technology–growth linkage☆

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ARTICLE INFO

Article history:
Received 18 February 2009
Accepted 28 October 2009

Keywords:
Growth
Innovation
Patents
Intellectual property rights
Fixed effects
GMM

ABSTRACT

It is an undoubtful fact that economic growth depends, ultima ratio, on the production of new ideas. This article aims to contribute to the long-standing debate on the choice of the best proxy to measure innovation and technological diffusion, by offering alternative variables which are tested empirically by means of a panel dataset of 73 countries between 1980 and 2005. Two different proxies of technological progress (patents and a Intellectual Property Rights Index) are used to explain different growth rates of income per capita and, after controlling for endogeneity, our results suggest that both have a positive effect on innovation (and economic growth).

1. Introduction

It is an unquestionable fact that economic growth depends, ultima ratio, on the production of new ideas and innovation; nevertheless, competitive markets do not provide appropriate incentives for such activities: if consumers were to pay only the transmission costs of new ideas, then the revenue obtained would be insufficient to cover the production costs. Historically, societies have used a variety of mechanisms to foster the production of new ideas. Some of them, like copyrights and patents, ensure the innovator the monopoly in the production of the goods that uses those new ideas. Others may include direct subsidies to Research and Development (R&D). One is able to find a large literature dealing with the correct measurement of the innovation process and technological diffusion, however, no consensus has yet been found. We expect to contribute with an additional approach to this ongoing literature and, therefore, help the decision making process with (potential) growth-enhancing policies.

This article aims to contribute to the long-standing debate on the choice of the best proxy to measure innovation and technological diffusion, by offering alternative variables which are tested empirically by means of panel data – fixed effects, two-stage least squares (2SLS) and generalized method of moments – estimation procedures. The contribution of innovation and technological progress, evaluated through two different proxies – patents per 100,000 inhabitants and an Intellectual Property Rights Index a la Ginarte and Park (1997) – is assessed in explaining different growth rates of income per capita around the world. For that purpose we use a panel dataset of 73 countries between 1980 and 2005, divided into 5 years averages.

In addition to this introduction the article has 4 other sections, organized as follows. In the next section, an exposition and literature review of the different types of incentives that can be provided to foster innovation and the production of new

☆ I thank informal conversations at the Faculty of Economics, University of Cambridge for helpful comments and suggestions, as well as the National Science Foundation (Portugal) for the financial support. I would also like to thank an anonymous referee for helpful comments on an earlier version of this article. Any remaining errors are the author's responsibility.

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1090-9443/$ – see front matter
doi:10.1016/j.rie.2009.10.007

ideas are presented together with a clear assessment of the main advantages and disadvantages of each incentive measure. Particular emphasis is given to patents and intellectual property rights schemes. Section 3 describes the methodology, data, variables choice and the econometric model to be estimated using a fixed effects specification. Then, the main results are presented and discussed, and in the light of some findings, we go on to Section 4 which deals with endogeneity issues by means of application of Two-Stage Least Squares and Generalized Method of Moments techniques. The last section concludes and presents some ideas for further research.

2. Economics of ideas, intellectual property and incentive mechanisms to innovation

Innovation and, ultimately, the adoption of new ideas are essential to economic progress. The term intellectual property rights refers to a cluster of legal sub-terms such as patents, copyright, trademark, inter alia that differ in their scope, structure and application. However, they share the common feature of granting ownership rights over the economic use of an idea (Fawcett and Torremans, 2001). These rights are exclusive, meaning their owner is given a legal monopoly over a period of time. One should note that the intellectual property rights' history is older than its economic analysis, as it is a direct descendant of the "labour-mixing and property" formulated by John Locke (Ulmer, 1987). The economic analysis of intellectual property rights appeared first in the seminal works of Arrow (1962) and Nordhaus (1969).

Ramello (2005) summarizes the economics and legal aspects related to intellectual property rights and goes beyond the traditional thesis which relies on incentives to create new ideas and the corresponding public goods provision problem, to consider instead the dynamic effect of intellectual property rights on the market structure and the emergence of social economic behaviours related to peer-to-peer systems and open source movements. With this review, the author aims to present a different overall balance of the intellectual property rights-welfare relation leading to alternative regulatory and policy recommendations.

It is central to understanding the market for ideas on how these are different from other goods (non-rival character of knowledge) and which incentives for adoption might exist. It is a commonly accepted idea that competitive markets are not suitable for the creation of new ideas. However, innovations may or may not arise in such markets depending on the size of the initial indivisibility or fixed costs associated, the speed at which capacity is built up, the size of the market and the elasticity of demand (Boldrin and Levine, 1999, 2002, 2004, 2005). In this context, the creation of monopolies or the attribution of R&D subsidies bring about serious problems.

Economic theory takes patents as important instruments to foster innovation, adoption and diffusion processes and its study is not new, especially regarding its implications to economic growth. According to Hardin (1968) and Heller and Eisenberg (1998), in practice, there exist as many variants of a definition as there are nations that recognise them, hence the problem in using "patents" as a universally accepted variable to proxy innovation or technical progress. Nevertheless, Encaoua et al. (2006) emphasize the major virtues and drawbacks of the patenting systems and they also point out three implications on the ground of current policy debates: (1) patents may not be an effective means of protection for inventors when there are imitation risks (Bester and Petrakis, 1998; Hellwig and Irmen, 2000; Quah, 2002) or first-mover advantage issues involves; (2) the problems with patentability requirements; and (3) the trade-off between the patents policy instruments of length and breadth. In short, copyrights and patents do create insufficient incentives to original R&D as inventors are not able to fully appropriate the consumer surplus or knowledge spillovers to other researchers. Romer (1990) suggested that because after the fixed cost is incurred without legal protection sales take place at marginal cost, leaving no profit to recoup that initial cost, then competitive markets provide inadequate incentives to innovation. For example, according to Kremer (1998), Michael Milken (an important philanthropist) would pay millions of dollars for an effective drug against prostate cancer, while pharmaceutical industries would not take that into account when defining their research budget, as they are not able to fully extract their surplus. Static distortions appear when people that value a good above its marginal cost do not consume it at the monopolist price. For instance, AZT high price makes its use by HIV pregnant women in developing countries difficult and this fact increases the number of infected children (Cf. Kremer (1998)).

In the presence of complete and symmetric information between agents as well as total commitment in some economy, R&D subsidies can actually be more beneficial than creating a new set of distorted monopoly prices, coming from a system of patents (Spence, 1984). However, before research is realized, governments may not know its exact costs and expected benefits and so this creates big distortions when the time comes to pay the inventor — moral hazard problems. One can refer to many other problems such as first-mover advantages (see Herrera and Schroth (2000) for an empirical application in the banking sector), the issue of sequential innovation, rent-seeking behaviour and the optimal duration of intellectual monopoly. According to Kremer (1998), in 1839 the French government combined a patent system with direct governmental support to R&D through the acquisition of the Daguerreotype photography patent and then by making it available to the public domain. After this, the technique was spread all over the world and it was subject to substantial improvements. The acquisition of patents has the potential of not only to eliminate distortions in the monopoly price but also decrease the incentive to non-productive spending in "reverse engineering". Furthermore, it encourages original research. The fact that ideas are non-rival goods suggest that research should be financed through public resources. However, public efforts to finance innovative research are impeded by asymmetric information between the researcher and the public planner. When the government pays for the research production factors instead of paying for its final output, then it is harder to monitor the researcher's effort. Nadiri (1993) suggests that the return rate of private financed innovations is much larger than the public financed ones. Another problem with the direct subsidy from governments to R&D activities is the lobbying pressures that distort both potential benefits and costs of innovations (Romer, 1993).

The greatest challenge to the patents acquisition system is price determination. Kremer (1998) suggests a mechanism in which the patent private value would be determined in auction. The government would offer itself to buy the patent for that private value multiplied by a fixed mark-up, the latter being just enough to cover the difference between the private and social value of the invention. Aiming at selling at the real price, a small number of patents randomly selected would be sold at the highest bid. Researchers would then decide whether to keep the patent or sell it at the given price and furthermore any patents acquired by the government would be made available to the public domain. Guell and Fischbaum (1995) suggested that the government should use its power to buy pharmaceutical drugs and that judges should decide the price of the patent. Meanwhile, this method would discourage any inventor to innovate as the final price could be much lower than the real one. So, this scheme – of patents acquisition by governments – should be used together with the traditional patent system. In this way, inventors would receive an additional mark-up above the market value and this would keep the incentives to keep on innovating.

The leading article on alternatives schemes to patents is Wright (1983), which focuses on the racing or common pool problem that occurs when a large number of competitive researchers are trying to achieve identical innovations. Hopenhayn et al. (2006) extend Wright's analysis, focusing on the problem of sequential innovation and compare prizes and patents. Moreover, Shavell and Ypserle (2001) presented a system in which the inventor could choose between the patent and some premium. Their main conclusion is that copyright and patent systems do not possess any fundamental advantage over the reward scheme. Comparing both systems, on the one hand the reward scheme is better than the patent scheme as it avoids deadweight loss coming from exercising monopoly power. On the other hand, incentives to invest in research are imperfect in both the systems. In the case of patents, the incentive to invest is always inappropriate as the monopoly profit is lower than the social surplus. As far the reward scheme is concerned, incentives are governed from the reward itself which are not linked to any social welfare measure. The optimal system, in which the inventor chooses between the patent or the reward, is better than the patent system by itself. The reason is that the expected social welfare is improved as there is no deadweight loss when the inventor chooses the reward. However, it is worth pointing out that in the copyright and patent systems, later innovations might be blocked by patent owners who do not allow improvements in existing technologies (Fullerton and McAfee, 1999).

Scotchmer (1999) states that the use of a reward system is limited as there is scarce information on the real benefits generated by the invention before it is created. Furthermore, patents also distort the direction of future research due to the excessive incentive to develop patented goods instead of substitute or complementary ones (Mansfield et al., 1981). Another way to stimulate innovation is through tournaments. These tournaments have had an important in the world's economic development. Fullerton and McAfee (1999) cite the example of an English railway in 1829. According to the authors, tournaments continue to attract financial resources and they are more effective than traditional contracts as they avoid moral hazard issues. Using a simple model of innovation, Hollis (2007) compares patents, research grants, targeted prizes and ex-post prices as well as explores their interaction. He introduces a new incentive mechanism for innovation, labelled "option broad rewards" and then examines its characteristics and advantages vis-a-vis other existing schemes. Lastly, one should refer that ultimately creativity and innovation should be followed by adoption and diffusion, so that transition to commercially viable products is a sine qua non stage and this requires the midwifery of many services and entrepreneurial skills taking place (Yusuf, 2007).

In this section, we were able to present different, but equally liable, innovation incentive methods, in addition to the patent system and which may have even better results as far as social welfare is concerned. Nevertheless, a lot of controversy remains. In the next section, we describe the main methodologies used throughout the article together with a description of the data set and main variables.

3. Data description and panel data methodology

First, we aim to relate innovation and technological progress with income per capita growth by using a panel data set, which presents, as one of its main advantages, the complete revelation of individual heterogeneity. Panel data sets suggest the existence of differentiating characteristics between individuals which may be or not constant through time.[1]

On the other hand, according to Hsiao (1986) panel data sets provide a larger amount of information, larger data variability, less collinearity between variables, higher number of degrees of freedom and increased estimation efficiency. Including a sectional component into a time series study allows for greater variability in the data and this fact reduces eventual collinearity problems between variables, especially in models with distributed lags.

Additionally, Baltagi (1996) argues that studies that use panel datasets make it easier a more efficient analysis of adjustment dynamics, whereas cross-section sets transmit a false idea of stability. Therefore, panel data allow to join individual behaviour diversity with the existence of adjustment dynamics, even if they are potentially distinct. A larger availability of information increases the estimation efficiency properties, that is, panel datasets allow to identify and measure effects which are not pure and simply identifiable in studies using solely cross-section or time series datasets.

1 In this sense, pure time series or cross-section analysis that do not take this fact into account will always produce biased estimates.

According to Wooldridge (2001), one can distinguish between fixed and random effects when using a panel data specification. The former is more appropriate for the cases where we have an exhaustive sample from a given population or when we want to forecast individual behaviour. When referring to fixed effects, we should be dealing with models whose coefficients can vary between individuals or through time, even if they remain fixed, i.e. non-random, constants. In the following section, we will use fixed effects due to two main determinants: (1) panel data increase the total number of available observations and (2) the intention to control our model in terms of business cycles through annual dummies included as explanatory variables. Random effect models assume that some of the individual and time periods specific behaviour is neither known, not observable nor measurable. Hence, in large panel samples we can always represent these individual specific effects as a random variable.

3.1. Econometric model

The proposed model to discuss the impact of innovation and technological progress on income per capita growth is the following:

$$y_{it} = \gamma + \sum_{t=i}^{5} \alpha_{ot} + \alpha_{1it}X_{1it} + \alpha_{2it}X_{2it} + \sum_{j=2}^{n} \alpha_j X_{jit} + \varepsilon_{it} \tag{1}$$

where,
$\gamma =$ constant
$\alpha_{ot} =$ time constant dummies coefficient
$X_{1it} =$ innovation proxy 1
$X_{2it} =$ innovation proxy 2
$X_{jit} =$ control variables
$\varepsilon_{it} \sim N(0, \sigma)$
and y_{it} is the income per capita growth rate for the selected countries under scrutiny (source: Summers and Heston Penn World Table 6.2). The sample is composed by 73 countries[2] (random selection based on data availability for all variables of interest), where i represents the country and t the time for the period 1980–2005 (subdivided into five periods of 5 years each). It is also our purpose to compare the performance of the full dataset vis-a-vis the OECD group. From Table 1, one can observe that a random sample of countries (from the entire dataset) presents a positive average GDP growth rate for the period under scrutiny. One can notice that poor countries in this table (e.g. Cyprus, Latvia, Lithuania, or Slovenia) had a much larger standard deviation than the rest, therefore, implying a more volatile behaviour over the period 1980–2005.

The final objective is to capture the effect of innovation on per capita income growth, therefore, we will use as a proxy the ratio of total number of patents to 100,000 inhabitants registered in the US market,[3] as well as the Intellectual Property Rights Index (ab hinc IPR, as in Ginarte and Park (1997)). In Table 2, we present the same descriptive statistics for the same selection of countries as before for the period 1980–2005. The aim is to test if the coefficient on the two proxies for innovation is statistically greater than zero, i.e., the higher the number of patents/100.000 inhabitants in the US market (and/or the IPR index), the larger the growth rate of real GDP per capita.

Data concerning the number of patents are obtained through the United States Patent and Trademark Office websitem which divides patents into six categories: *Utility Patent, Design Patent, Plant Patent, Reissue Patent, Defensive Publication and Statutory Invention Registration.* Utility Patent, also called "patents for invention" is the category chosen for the purpose (full definition available in http://www.uspto.gov).

This article differs from the majority of the literature in this subject as far as the choice for the innovation proxies and the use of recent data (up to 2005). While other studies take the R&D spending (production factor in the process), ours takes the patent (outcome of that process). According to Crosby (2000), testing empirically new models of economic growth is extremely difficult as usual measures to quantify the impact of innovation on growth are imperfect in its conception. Commonly, one uses the R&D spending or some labour statistics variable in this sector. However, R&D data measure factors in the production process, while the patent quantifies the output of the process. Additionally, one is able to find a large database on patents allowing the use of time series. On the other hand, when one takes patents as the "ideal" measure, it is best to be aware of the difficulty of quantifying its value. That is, some patents are very important, while others are not. According to Jones (1995), the problem in using patents is the fact that not all innovations are patented.

Devinney (1994) estimated the relation between patent and economic growth using a panel data set and he found a positive and statistically significant relation between them. On the same line of reasoning, Crosby (2000) argued that the number of registered patents in Australia has a positive correlation with this country's labour productivity and economic growth between 1901 and 1997. Park (1999) constructs a panel using a sample of 60 countries between 1960 and 1990, and states that R&D did not explain per capita growth rate.

In addition to this technological variable, it is necessary to account for a variety of control variables as other factors also influence income per capita growth rate. These variables are:

[2] In the Appendix B, we present the complete list of countries considered in our analysis together with summary statistics and correlation matrices.

[3] We use the US market as a way of eliminating differences in legislation across countries in our sample.

Table 1
GDP average growth rate between 1980 and 2005 for selected countries.

Country	Average	Stand. Dev	Max	Min
Australia	3.293	1.811	5.325	−2.371
Austria	2.880	3.593	19.470	−0.149
Belgium	2.060	1.424	4.723	−0.962
Cyprus	4.861	2.459	9.400	0.700
Czech Republic	1.510	4304	6.493	−11.612
Denmark	2.048	1.739	5.525	−0.887
Estonia	2.199	6.942	11.098	−21.16
Finland	2.640	2.789	6.091	−6.244
France	2.069	1.185	4.598	−0.914
Germany	1.890	1.524	5.255	−0.802
Greece	2.015	2.242	4.853	−2.259
Hungary	1.631	3.647	5.192	−11.89
Ireland	5.290	3.147	11.680	−0.428
Italy	1.807	1.309	4.194	−0.888
Japan	2.364	1.939	6.765	−2.049
Latvia	2.004	8.688	10.596	−32.119
Lithuania	0.712	9.648	10.316	−21.25
Luxembourg	4.497	3.024	9.983	−0.550
Malta	3867	2.637	8.414	−1.610
The Netherlands	2.384	1.558	4.684	−1.283
Poland	3.611	3.416	7.086	−7.000
Portugal	2.594	2.500	7.489	−2.043
Slovak Republic	1.862	5.202	8.029	−14.57
Slovenia	2.441	4.050	5.410	−8.900
Spain	2.923	1.603	5.547	−1.031
Sweden	2.124	1.779	4.525	−1.995
United Kingdom	2.347	1.812	4.969	−2.097
United States	2.984	1.862	7.198	−1.974

Source: World Development Indicators 2006, World Bank and authors' calculations.

Table 2
Average number of patents registered in the US market between 1980 and 2005 for selected countries.

Country	Average	Stand. Dev	Max	Min
Australia	522.58	225.82	953	237
Austria	382.35	103.26	592	229
Belgium	419.50	178.00	722	205
Cyprus	1.15	1.41	6	0
Czech Republic	9.27	13.44	41	0
Denmark	264.88	129.49	529	121
Estonia	0.88	1.48	5	0
Finland	406.81	249.54	918	116
France	2939.54	642.30	4 041	1 895
Germany	7908.12	1839.02	11 444	5 468
Greece	12.23	6.20	26	3
Hungary	76.65	32.37	131	25
Ireland	68.46	49.95	186	16
Italy	1228.38	322.38	1 751	625
Japan	21 541.31	9154.2	35 515	7 124
Latvia	0.54	1.07	4	0
Lithuania	0.69	1.16	4	0
Luxembourg	27.73	7.77	44	13
Malta	0.69	0.79	3	0
The Netherlands	939.81	245.75	1 391	619
Poland	15.62	8.10	38	5
Portugal	6.58	4.23	17	1
Slovak Republic	1.35	2.31	8	0
Slovenia	6.23	7.71	21	0
Spain	161.27	82.73	309	49
Sweden	978.12	346.85	1 741	623
United Kingdom	2827.38	584.05	3 967	1 930
United States	57 803.69	19 402.77	87 892	32 871

Source: United States Patent and Trademark Office — USPTO and authors' calculations.

- *level of income per capita (at the beginning of the period)*: within the discussion on economic growth, it is of great importance to assess whether convergence is taking place among the selected countries in income per capita. Source: Summers and Heston Penn World Table 6.2

- *gross fixed capital formation (% GDP):* technology is incorporated in capital goods. Therefore, one should expect physical capital to positively affect some economy's growth rate. The relation between technology and investment may occur in two ways: on the one hand, investments do create incentives to improve technology; on the other hand, technological progress generates a higher productivity gain and it consequently increases the return on physical capital investment. Grossman and Helpman (1993) show that the total factor productivity is higher in countries with high investment rates. This variable consists of improvements in the efficient use of land, acquisition of new machinery, construction of new roads, schools, hospitals, etc., together with the net change in the stock of goods firms hold to face unexpected fluctuations in production or sales. Source: World Bank Development Indicator 2008
- *Intellectual Property Index*: innovations are non-rival goods with low marginal cost and they are easily reproduced or copied through "reverse engineering", so intellectual property rights are vital in ensuring profitability and incentive to new innovations. This index goes from one to five, the latter revealing a high patent protection. This index is constructed through a variety of characteristics of countries' regimes and it covers five factors: coverage, participation in international agreements, loss of protection, legal support mechanisms and duration. Source: Ginarte and Park (1997)
- *Schooling*: due to its scientific nature, R&D processes are intensive in the use of human capital. Secondary schooling usually requires a minimum threshold for admission. This variable consists in the average number of years of secondary education of total population and it will be used to capture the direct effect of education in GDP per capita growth. Source: Barro and Lee (2000)
- *Openness (% GDP):* measured as the sum of exports and imports, it has two effects in R&D spending: (1) countries with competitive disadvantage in producing new technology will be induced to leave behind R&D activities; and (2) R&D transference has a positive impact on domestic R&D. Source: World Bank Development Indicator 2008
- *Foreign Direct Investment (FDI)*: FDI inflows have an ambiguous effect on economic growth. On the one hand, FDI can create positive externalities through import of new techniques and capital goods. On the other hand, firms receiving FDI will, most likely, compete with domestic producers which have less technological ability. We use both total inflows and a measure scaled by real GDP for each country. Source: World Bank Development Indicator 2008
- *Fertility Rate*: it represents the number of children born in some period of time. Source: World Bank Development Indicator 2008
- *Life Expectancy at birth*: it indicates the number of years a new born will live. Source: World Bank Development Indicator 2008
- *Mortality Rate< 1y.o.*: it represents the number of children that die before completing one year old (per 1000 children born each year). Inclusion of this variable, as well as fertility rate and life expectancy, will depend on the potential correlation problem. Like expectancy and mortality rate will be used as a proxy to human capital. Source: World Bank Development Indicator 2008
- *Urban Population (%)*: share of population living in urban areas in each country, according to UN definition. Urbanization ratio measures potential effect of geographical clustering in economic growth. Source: World Bank Development Indicator 2008
- *Population Growth Rate:* it includes at residents independently of legal status, with exception of refugees. Source: World Bank Development Indicator 2008
- *Population Density:* total population divided by the country's area. Source: World Bank Development Indicator 2008.

3.2. Empirical results and discussion

The main purpose of this article is to verify whether the innovation process has a direct effect on GDP per capita growth rate. In order to do that we use panel data with fixed effects.[4] Before presenting our main results, it is worth noticing how Total Factor Productivity (TFP) – the Solow Residual or the "measure of our ignorance" – is explained by variables such as Patents per 100.000 inhabitants, Patents per capita and the IPR index. In Table 3, we present the estimation output for the three common alternatives when dealing with panel data sets, i.e., pooling, fixed and random effects.[5] In all cases, all variables are positive and significant at the 1% level, implying that indeed they are important in determining the TFP (in levels) for the sample at hands.[6] It is also interesting to report that the correlation coefficients TFP-Patents and TFP-IPR were both positive and increased their value between 1980 and 2000 from 0.29 and 0.67 to 0.30 and 0.75, respectively (Appendix B).

The main results are presented in Table 4 which is composed of five columns.[7] The first one shows all explanatory variables as described before; on the second and third columns, the model is estimated with all variables for the entire set

4 One should notice that it is not our purpose to evaluate all channels through which technological progress can affect GDP per capita growth rate.

5 Through a Hausman Test to compare the models using fixed and random effects, we concluded that the former provides better estimates in this case at a 1% significance level.

6 TFP series were computed following the methodology described in the Appendix A.

7 We also performed the same analysis taking "Patents per capita" as our technological proxy. This change did not altered the non-significance associated with this variable (and its variants). Moreover, even if one thinks of possible multicollinearity problems associated in having "Patents per 100.000 inhabitants" and "IPR" both in the estimation procedure, this possibility was disregarded through individual estimation with either one variable or the other.

Table 3
The direct effect of patents/100,000 inhab. and IPR on Total Factor Productivity (whole sample).

Independent variables	Pooling		Fixed effects		Random effects	
	(1)	(2)	(3)	(4)	(5)	(6)
Patents/100,000 inhab.	456.3418***		540.3334***		669.3838***	
Patents per capita		1715176***		1487113***		1982948***
IPR index	183.7429***	152.6144***	35.92384***	29.99651***	52.25933***	40.80119***
Number of obs.	321	321	321	321	321	321
F(2, 318)	165.03	185.73				
F(2, 246)			19.77	27.55		
Wald chi2(2)					73.42	108.32
Prob>F	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: All specifications include the estimate of a constant coefficient, not presented in this table for reasons of parsimony. Robust t-ratios using heteroskedastic-consistent standard errors were computed and are available upon request. Dependent Variable: Total Factor Productivity. Significance levels are interpreted as follows: Not significant.
*** Significant at 1%.

Table 4
The direct effect of patents/100,000 inhab. and IPR on real GDP growth per capita.

Independent variables	Direct effect of patents/100,000 inhab. and IPR			
	All variables		Parsimonious model	
	All countries (1)	OECD (2)	All countries (3)	OECD (4)
Ln GDPpc (init)	−1.746563	−2.784356	−1.650589*	−2.438451***
Patents/100,000	−4.66835	−6.658456		
GFCF (%GDP)	−4.66835	−0.4005757***		−0.3131396***
IPR index	1.3016*	1.057992	1.286681**	1.947802***
Schooling	1.216751	0.8719826	1.653716*	
Openness	0.0674783**	0.0987682	0.0662146**	
Fertility rate	1.177178	0.1499363	1.210162*	
Life expectancy	−0.1341499	−0.2662508		
Mortality rate	0.0012936	−0.150981		
Urban population	0.1761584	−0.2698781		−0.2422245**
Population density	0.0328195*	0.0920222	0.0314534*	
Population growth	0.5817492	−0.4205907		
FDI inflows	9.09e−12	3.12e−11		3.18e−11**
Number of obs.	257	77	257	77
F(13, 177)	2.17			
F(13, 44)		3.33		
F(6, 187)			4.26	
F(5, 79)				5.87
Prob>F	0.0127	0.0014	0.0005	0.0001

Note: All specifications include the estimate of a constant coefficient, not presented in this table for reasons of parsimony. Robust t-ratios using heteroskedastic-consistent standard errors were computed and are available upon request. Dependent variable: Growth rate of real GDP per capita. The parsimonious model is obtained through stepwise estimation procedure, that is, successive elimination of non-significant variables and ex-post analysis of the resulting ones. Significance levels are interpreted as follows: Not significant.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

of countries under scrutiny whether or not they are significant at usual significance levels. Fourth and fifth columns present the estimates of the model with only variables which are significant at a 10% level. This result is obtained through a stepwise estimation procedure — successive elimination of non-significant variables and ex-post analysis of the resulting ones.

The results from the estimated models with the two technological proxies have some similarity – which signals some robustness – together with the signs of the remaining variables reflecting standard economic theory. Taking into account the parsimonious models, one can note the presence of conditional beta convergence on income per capita for the period under scrutiny. A reduction of 1% in initial GDP produces an increase of 1.7% (2.4%) on the GDP per capita growth rate for the entire sample (OECD), i.e., countries which begin the period with a smaller income per capita did grow faster to their steady-state level. Due to a high degree of similarity of countries within the OECD group, it is also possible that they present absolute convergence — without controlling for the steady-state.

Our first proxy – patents/100,000 inhabitants – is used to capture the effect of technological progress on income per capita growth rate and it presents a negative sign, however, it is not significant in none of the models. One possible justification for the negative sign (as one would expect ex-ante a positive effect) can be the fact that the impact of patents on innovation and economic performance is complex and it can actually hamper further innovation, especially when it reduces access to basic knowledge, as may happen in the case in emerging technological areas when innovation has a cumulative character and patents protect foundation inventions (Bar-Shalom and Cook-Deegan, 2002; Shapiro, 2002). Several weaknesses lie in using patents as an economic indicator.[8] One problem with patent data is that the process of patenting is not harmonized across countries, i.e., different countries follow different procedures to grant patents. Moreover, not all inventions are patented and institutional factors, including aspects of patent law and procedures which can vary from one country to another, influence the data. Furthermore, the weakness lies in the particular role of patenting in the complex process of invention and innovation, and its role in firms' strategies. Finally, the quality and value of patents varies greatly, due to ''home advantage'' bias as countries take more patents in their domestic market than in other regions. It is important to note that propensity to patent varies from technology-to-technology and comparisons of patent counts should be made only within similar technology areas (Kurtossy, 2004).

The same does not happen with the second proxy – IPR index – which presents a positive sign and it is significant at usual levels. This fact supports the prediction of theoretical models with technological progress, that is, the country which has a high level of intellectual property rights enforcement presents a larger income per capita growth for the period 1980–2005 — direct effect. It is relevant to note that the model with solely OECD countries obtained a higher R-square as the one for the entire sample and also when one drops the technological term (IPR) the R-square reduces drastically — which leads us to conclude that a great share of the dependent variable is explained by this last proxy.

As far as schooling is concerned, we do find the usual positive effect of education on income growth — direct effect. The higher the educational level the larger income per capita growth will be. This variable is only significant in the parsimonious model (with the entire sample) at a 10% level and one reason being the fact that these countries are largely affected, in recent years, by tertiary rather than secondary education for the period under scrutiny. The term referring to openness – the sum of exports and imports – is positive and significant at 5% level when we consider the entire sample in both the models. Therefore, a country with a more consistent trading relation will grow faster. An increase of 1% in this variable will increase the GDP growth rate in 0,1% — parsimonious model with the entire sample. Fertility rate has a positive effect on growth as it is significant at a 10% level in the parsimonious model. This translates the fact that younger societies have a greater scope to grow as a function of their larger active working force (older societies cannot succeed in producing as much output). This fact is related with the negative effect associated with too much urbanization as presented in the parsimonious model for OECD countries. A high urbanization ratio may have adverse effects on growth at a national level as it creates a big income and development gap between cities and rural areas, with decreasing living conditions in this highly clustering urban spaces. The two variables that capture the human development level – life expectancy at birth and mortality rate – are not significant at usual confidence levels.

Finally, FDI has a very small, but significant at a 5% level, positive effect on growth. However, there is no consensus on the present literature about the exact effect of FDI on growth in a panel set of countries, reflecting the need for further research. As a matter of robustness, the same exercise was conducted with an alternative measure taking instead the FDI to real GDP ratio. Our results show no major differences vis-a-vis Table 4, except the fact that now the FDI/GDP coefficient has a larger positive magnitude, despite being insignificant in both the entire sample and the OECD sub-sample.[9] Despite these results, FDI is by no means an exogenous variable, i.e., there is a known and strong effect of IPRs on FDI and this implies the need to use instrumental variables to account for endogeneity (which is addressed in Section 4).

However, before addressing the endogeneity problem it is worth making two comments: Firstly, it is important to add to our previous set of regressors a measure of market size since if IPRs are to affect growth in any given country, a larger domestic market will generally give stronger incentives to innovate. In order to avoid a spurious regression problem, we have included a proxy for internal market size given by Gross National Income in logarithms – lnGNI – (collected from the Penn World Table 6.2).[10] In Table 5,[11] second row, we can observe that not only is the GNI coefficient positive and statistically significant in all the different specifications, with a particular high value for the OECD sub-sample regressions, but also the R-squared increased, therefore indicating a better fit of the model.

The second comment is, most likely, more relevant since our results on the IPR proxy raise the question of whether this variable's strength relies on institutional-related indicators, such as the ''rule of law'' (lacto sensu) within some country.[12] The idea behind this omitted variable bias is that countries for which the IPR index is positive and highly significant could have better contract enforcement policies, more effective regulatory systems or less corrupt agents/politicians, and this effect is being captured by such index. Previous empirical studies on the role of institutions in growth[13] measure institutional

8 Some surveys available on this topic are: Basberg (1987), ''Patents and the measurement of technological change: a survey of the literature'', Research Policy; Pavitt (1988), ''Uses and abuses of patent statistics'', A.F.J. van Raan (ed.) Handbook of Quantitative Studies of Science and Technology, Amesterdam - Elsevier; and Griliches (1990), ''Patent statistics as economic indicators: a survey'', Journal of Economic Literature.

9 For economy of space, these results are available from the authors upon request.

10 The market-size hypothesis is additionally correlated with FDI inflows (see e.g. Ajami and Barniv (1984) and Grosse and Trevino (1996)) and with appropriate caveats, GDP frequently has been used as a proxy for market size in manufacturing literature (see e.g., Grubaugh (1987) and Culem (1998)).

11 For now, the reader should focus his attention on specifications (1)–(4) only.

12 We thank an anonymous referee for raising this issue.

13 There is a long-standing tradition in the empirical growth literature to incorporate various measures of the quality of institutions as determinants of economic growth across countries. In the seminal study by Acemoglu et al. (2001), a serious attempt was made to control for the possibility of reverse causality in establishing a causal role for institutions in economic development.

Table 5
The direct effect of patents/100,000 inhab. and IPR on real GDP growth per capita (inclusion of market size and "rule of law" proxies).

Independent variables	Direct effect of patents/100,000 inhab. and IPR								
	All variables		Parsimonious model		All variables (1996–2005)				
	All countries (1)	OECD (2)	All countries (3)	OECD (4)	All countries (5)	(6)	(7)	(8)	(9)
Ln GDPpc (init)	−1.910*	−2.735*	−1.650*	−1.664*	−1.719**	−1.337*	−1.146*	−1.528*	−1.624**
Ln GNI	3.172*	29.975***	3.031**	21.036***	2.856**	2.221*	1.904*	2.538*	2.697**
Patents/100,000	−30.674	−58.896			(−)	(−)	(−)	(−)	(−)
GFCF (%GDP)	0.179	0.767*		0.623*	0.162*	0.126	0.108	0.144	0.153**
IPR index	2.090*	12.980**	1.339*	9.392***	1.482*	1.063*	0.854*	1.272*	1.377**
Schooling	1.135	2.294	2.104*		1.022*	0.795	0.681	0.909	0.965*
Openness	0.0245	0.097	0.002*		0.022	0.017	0.015*	0.020	0.021*
Fertility rate	−.726	−4.121			−0.654	−0.508	−0.436	−0.581	−0.617
Life expectancy	0.723*	0.629			0.651	0.506	0.434	0.579	0.615
Mortality rate	0.0224	0.158			0.020	0.016	0.013	0.018	0.019
Population density	−.043	−1.534**		−.395**	−0.039	−0.030	−0.026	−0.035	−0.037
Population growth	−.827	−6.503*		−3.208*	−0.745*	−0.579	−0.496*	−0.662	−0.703*
FDI/GDP	50.433*	7.361	39.033*	6.347*	20.391*	10.304*	5.260*	15.347*	17.869*
Rule of law					0.711**				
Government effect						0.331			
Regulatory quality							0.620*		
Control for corruption								0.247	
Kaufmann index									0.403**
AIC					79.802	112.644	89.796	134.305	75.662
Number of obs.	259	77	262	77	84	84	84	84	84

Note: All specifications include the estimate of a constant coefficient, not presented in this table for reasons of parsimony. Robust t-ratios using heteroskedastic-consistent standard errors were computed and are available upon request. AIC is the Akaike Information Criteria used for model selection. Dependent Variable: Growth rate of real GDP per capita. The parsimonious model is obtained through stepwise estimation procedure, that is, successive elimination of non-significant variables and ex-post analysis of the resulting ones. Significance levels are interpreted as follows: Not significant.

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

quality by: the rule of law index (Knack and Keefer, 1995; Sachs and Warner, 1997), the risk of expropriation (Acemoglu et al., 2001), government repudiation of contracts (Knack and Keefer, 1995; Sachs and Warner, 1997), bureaucratic quality (Knack and Keefer, 1995; Sachs and Warner, 1997); incidence of corruption (Mauro, 1995), and constraints on the executive (Glaeser et al., 2004). Several of these measures principally capture the state's ability in protecting property rights. The problem of measuring the strength of IP protection can be partially ameliorated by also developing measures of the extent to which laws are generally enforced in the country. Assuming that IPR laws are then enforced to the same extent as other laws, one could obtain a better measure of the strength of IPR protection by interacting the Ginarte–Park index with an index of overall law enforcement, such as the one developed by Kaufmann et al. (2009).[14]

In addition to testing individual variables, our measure of general institutional quality is a composite index ("Kaufmann index") defined as the average of four indices on rule of law, government effectiveness, regulatory quality[15] and control for corruption[16] from Kaufmann et al. (2009). Kaufmann et al. (2009) constructed some clusters of indicators to measure a society's perception of government quality. For our analysis, a particularly interesting cluster refers to the "rule of law" and it measures the perceptions of the citizens about the incidence of crime, the effectiveness and predictability of the judiciary system, and the enforcement of contracts. In other words, it reflects the degree to which citizens of a country are willing to accept the established institutions to make and implement laws and adjucate disputes. These indices are increasingly common in the literature to measure institutional quality and we adopt their measures for the years, 1996–2000 and 2000–2005.[17] Their dataset includes the values of these indicators for a small number of years starting from 1996, thus,

14 An additional problem, namely that it is not clear why there are systematic differences across countries in the strength of IPR protection, is harder to deal with and goes beyond the scope of the present article. This requires identifying a source of variation in the strength of patent protection that is not correlated with the unmeasured influences that condition technology transfer, such as the demand for technology. In econometric terms, one needs a source of exogenous variation. This problem is more acute in empirically assessing the role of IPR protection on technology imports. Developing a systematic approach to solve the problem requires an entirely new line of research on what factors determine the strength of IPR protection in a country.

15 The latter two variables measure the autonomy from political pressure, the strength and expertise to govern without drastic changes in policy or interruptions in government services.

16 It measures whether illegal payments are generally expected throughout government in the form of bribes connected with import and export licenses, exchange controls, tax assessments, police protection, or loans. Alternatively, one could use the Transparency International's Corruption Perception Index (CPI) that is widely employed in the literature as a measure of corruption. This CPI is a composite index based on seven international surveys of the perception business people and country experts have regarding corruption in over hundred countries.

17 We have also used a measure of risk of expropriation from La Porta et al. that was used in the Acemoglu et al. (2001) and subsequent articles. However, the use of the previous variable limited our sample size considerably without providing any extra explanatory power.

many observations are missing. As we are covering the period from 1980–2005, in order to solve this problem, for the remainder of the article starting from the next section, we use other indicators (based on the Freedom House and Polity IV Projects) that exhibit a very high correlation with the indicators proposed by Kaufmann et al. (2009).

In Table 5, specifications (5)–(9) address this second comment. We have taken the entire set of variables for the whole country sample and then we redid the regression represented in specification (1) (solely considering the IPR index[18]) by adding one new institutional-based variable individually at each time, that is, specification (5), (6), (7), (8), and (9) include "rule of law", "government effectiveness", "regulatory quality", "control for corruption" and the "Kaufmann index", respectively. Our new results confirm our initial suspicion that not only are the five measures positive and three of them statistically significant at usual levels, but also the IPR index has decreased its overall magnitude throughout the different specifications (even though it remained significant). Not only has the IPR index magnitude decrease, but also other variables such as the FDI/GDP, openness and investment (GFCF) have seen their coefficients to decrease their absolute values, translating the importance of institutionally-based measures to explain these dimensions (such that it should be left unmodelled in the residuals). The fact that for both "Government Effectiveness" and "Control for Corruption" we found statistically insignificant coefficients (despite their ex-ante expected signs) could be interpreted as a sign that the importance of IPR for innovation is not simply as a proxy for good overall institutional environment as captured by these variables. This confirms that we were facing an omitted variable bias and, furthermore, these new specifications are associated with a higher explanatory power for cross-country differences, as evidenced by increased R-squares vis-a-vis specification (1). Furthermore, the AIC allows to select specification (9) has the preferred model. The remaining variables have kept their signs and statistical power as before and as predicted from standard economic theory.

4. Endogeneity

The correlation coefficients were examined for all of the possible explanatory variables to check for endogeneity.[19] For instance, infant mortality and schooling showed high correlation so there was a need to suspect endogeneity. The use of these variables can be justified as, although they may show similar trends, it is unlikely that they affect each other directly and it would be difficult to identify a variable to instrument for them. The omission of one of the variables did not significantly change the main results. Moreover, both are popular variables within the endogenous growth literature.

As far as FDI is concerned, we have used institutional proxies as instrumental variables (IV),[20] more precisely, we have collected data for Property Rights (PR) and Civil Liberties (CL) from Freedom House, and Democ (number of democratic features), Autoc and Polity2-index (capturing the initial level of democracy) from the Polity IV-Project. The Polity IV data set allows us to capture the data for the needed 25 years period and it now contains a new variable Polity2.[21] The Polity2 is a score given to the countries based on the annual coding of the existing regimes and it follows five indicators.[22]

A fundamental assumption of regression analysis is that the right-hand side variables are uncorrelated with the disturbance term. If this assumption is violated, both OLS and weighted least squares are biased and inconsistent. There are a number of situations where some of the right-hand side variables are correlated with disturbances. Some classic examples occur when: (1) there are endogenously determined variables; (2) right-hand side variables are measured with error. The standard approach in such cases is to estimate the equation using instruments. The idea behind these instruments is to find a set of variables, that are both correlated with the explanatory variables in the equation and uncorrelated with the disturbance term. In this context, in order to correct for the FDI endogeneity we estimate an equation with dependent variable the growth rate of GDP per capita and with independent variables the IPR and Patents per capita,[23] using a 2SLS approach and taking as instruments the different institutional proxies. Table 6 presents four columns, divided between "all sample" and "OECD", each of these instrumented by the set "PR + CL" or "Democ + Autoc".[24] As one can see, both IPRs and patents per capita are positive and statistically significant at usual levels, except the case of "pat_pc" using the entire sample and the set of "PR + CL" instruments.

IV identification test results were also conducted. The underidentification test consists of a LM test for which the null hypothesis that the equation is underidentified is tested; the rejection of the null hypothesis indicates that the model is

18 Similar regressions with "Patents/100,000" instead of the "IPR index" were performed, however, the associated coefficient has remained statistically insignificant and it did not add much explanatory power.

19 We thank an anonymous referee for important suggestions on how to address the FDI endogeneity problem.

20 Several proxies were used for robustness since each of them measure a different aspect of institutional quality — see correlation matrix in the Appendix, Table 10 (Appendix B).

21 POLITY2: The POLITY2 score is computed by subtracting the AUTOC score from the DEMOC score and the resulting unified polity scale ranges from +10 (strongly democratic) to −10 (strongly autocratic). DEMOC: Democracy index, 0 = least democratic, 10 = most democratic. AUTOC: Autocracy index, 0 = least autocratic, 10 = most autocratic.

22 Refer to Polity IV manual for further information.

23 We only use these two explanatory variables given their central importance in our analysis and also for simplicity due to econometric limitations. In fact, in order to calculate 2SLS estimates, the econometric specification must satisfy the order condition for identification, which says that there must be at least as many instruments as there are coefficients in the equation. See Davidson and Mackinnon (2004) for additional discussion. The inclusion of additional control variables does not alter our main results and insights.

24 The Polity2 proxy yielded similar results and so it was not included for economy of space.

Table 6
Two-stage least squares regressions.

Independent variables	All (1)	All (2)	OECD (3)	OECD (4)
Pat_pc	82010.28**	39079.31	224590.3*	225836.8***
IPR	0.705304*	1.038866***	−2.128371*	−2.118237***
N	261	261	80	80
Inst	*Autoc+Democ*	*PR+CL*	*Autoc+Democ*	*PR+CL*

Note: All specifications include the estimate of a constant coefficient, not presented in this table for reasons of parsimony. Robust t-ratios using heteroskedastic-consistent standard errors were computed and are available upon request. Dependent variable growth rate of real GDP per capita. Instruments are indicated in the last row of the table, using Freedom House and Polity IV proxies for institutional quality. Significance levels are interpreted as follows: Not significant.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table 7a
OLS regression of GRGDP pc and TFP on R&D expenditure.

Independent variables	GRGDP pc		TFP	
	All (1)	OECD (2)	All (3)	OECD (4)
rd	3.62803***	1.128087	59.81875***	203.1383***
c	−21.97179**	5.3674	487.0252***	535.4563
F(1, 84)	9.76			
F(42, 54)		0.62		
F(1, 83)			10.01	
F(39, 45)				20.52
Prob > F	0.0024	0.9451	0.0022	0.0000

Note: All specifications include the estimate of a constant coefficient, not presented in this table for reasons of parsimony. Robust t-ratios using heteroskedastic-consistent standard errors were computed and are available upon request. Dependent variables: Growth rate of real GDP per capita (columns 1 and 2) and TFP (columns 3 and 4). Significance levels are interpreted as follows: Not significant.
** Significant at 5%.
*** Significant at 1%.

identified. For all regressions of Table 6, the null hypothesis of the underidentification test is rejected at the usual significance levels. The Sargan statistic from the Sargan–Hansen test of overidentified restrictions provided additional robustness, for which the joint null hypothesis that the instruments are valid instruments is tested; the results show that for all regressions, the reported p-values conclude a non-rejection of the null at the 10% level, hence the instruments are valid ones. It can be concluded that the IV estimation is rich and meaningful.

As the channel through which we expect IPRs to influence growth is through innovation, we would expect R&D expenditure to be important.[25] In this sense, if we first run a simple OLS regression of the growth rate of GDP per capita on R&D expenditure as percentage of GDP (retrieved from the World Development Indicators) we obtain positive and significant coefficients for both the entire sample and the OECD sub-sample — see Table 7a.[26] If we then regress the R&D variable on the GNI (to account for the market size) and the IPR index we get positive and significant coefficients for both of them, which means that the larger the internal domestic market and enforcement of property rights, the higher the fraction of GDP attributed to R&D. These findings are in accordance with standard theories which predict that IPR protection stimulates innovation because protection raises incentives to create innovations by enabling innovators to reap the benefits of innovation (through monopoly profits) and recoup the costs of R&D investments — see Table 7b.

Perhaps, a more informative way to address this issue is to estimate a two equation system in which only R&D expenditure changes growth, and R&D expenditure (in the second equation) is determined by variables such as the strength of IPRs and market size (together with some institutional/political instruments to account for FDI, among others). We will use the GMM approach which estimates parameters directly from moment conditions imposed by the model. To enable identification, the number of moment conditions should be at least as large as the number of unknown parameters. Consider a model that is characterised by a set of R moment conditions as $E\{f(w_t, z_t, \theta)\} = 0$, where f is a vector function with R elements, θ is a K-dimensional vector containing all unknown parameters, w_t is a vector of observable variables, z_t is a vector of instruments and W_n is the optimal weighting matrix which may depend on θ. The GMM estimator chooses θ to minimise:

$$Q_n(\theta) = \left[\frac{1}{n}\sum_{t=1}^{n} f(w_t, z_t, \theta)\right]' W_n \left[\frac{1}{n}\sum_{t=1}^{n} f(w_t, z_t, \theta)\right]. \tag{2}$$

[25] According to Scherer (1998), this input measure (in contrast to patents which account for innovation output) may not always lead to the same conclusions, as before.

[26] Table 7a also presents the same regression taking TFP as the dependent variable and similar results are obtained.

Table 7b
OLS regression of R&D expenditure on GNI and IPR index.

Independent variables	All	OECD
	(1)	(2)
GNI	0.2532441*	0.0000237**
IPR	0.6512492***	0.105492*
c	−1.565542	0.4688203*
F(2, 83)	70.98	
F(42, 53)		18.37
Prob > F	0.0000	0.0000
N	107	94

Note: All specifications include the estimate of a constant coefficient, not presented in this table for reasons of parsimony. Robust t-ratios using heteroskedastic-consistent standard errors were computed and are available upon request. Dependent variable: Growth rate of real GDP per capita. Significance levels are interpreted as follows: Not significant.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table 8
System-GMM estimation.

Independent variables	All	All	OECD	OECD
	(1)	(2)	(3)	(4)
C(1)	9.281897***	8.459781***	−12.43925***	−10.81683**
C(2)	2.749825**	2.116039**	2.235917***	1.995515***
C(3)	−12.28948**	−184.2797	−15.24043	−11.82670
C(4)	0.375885**	−4.707217	2.311488**	2.689506***
C(5)	0.469741**	7.856586	0.529949	0.344068
Inst	*Autoc+Democ*	*PR+CL*	*Autoc+Democ*	*PR+CL*

Note: All specifications include the estimate of a constant coefficient, not presented in this table for reasons of parsimony. The dependent variable is GRGDP pc for period t. Equation 1: GRGDPPC = C(1) + C(2)*R_D; Equation 2: R_D = C(3) + C(4)*IPR + C(5)*LOG(GNI). Significance levels are interpreted as follows: Not significant;
** Significant at 5%.
*** Significant at 1%.

The number of instruments is potentially enormous since the disturbances at time t are uncorrelated with the exogenous variables at time t, but they are also uncorrelated with the same variables at time $t-1$ and $t-2$ and so on. The efficiency gains to be made are, therefore, large. The amount of information gained depends on the correlation of the instruments with the included exogenous variables (Green, 2003). The GMM specification, additionally, does not require strong distributional assumptions like normality, it can allow for heteroskedasticity of unknown form and can estimate parameters even if the model cannot be solved analytically from the first order conditions.

After this brief theoretical exposition, we are now in a condition to estimate the above two equations by system-GMM using as instruments Freedom House and Polity-IV proxies. The results are presented in Table 8. Coefficient C(2) shows, as before, the larger the R&D share, the higher the GDP growth and this positive value is significant at 5% and 1% levels in both "All" and "OECD". The coefficient on the market size (C(5)) variable is positive but insignificant in 3 out of 4 columns. The most interesting results is given by the coefficient C(4), i.e., the IPR index in the second equation. This coefficient appears to be positive in 3 out of 4 regressions. Moreover, the latter is significant at 5% and 1% levels in the OECD sub-sample, meaning that the stricter the property rights enforcement, the higher the level of R&D expenditure, hence more innovation.[27] This finding is somewhat in disaccordance with some recent studies, e.g. Jaffe and Lerner (2004) and Bessen and Maskin (2006), which argue that patents may be counterproductive because they incur additional application costs, discourage attempts to invent around patents, and delay spillover to sequential innovations.[28] Furthermore, Lerner (2002) examines the impacts on innovation by 177 IPR policy changes across sixty countries and over a 150-year period. He finds that strengthening patent protection has few positive effects on patents applications by entities in the country undertaking the policy change. One justification for our results comes from data limitations on the R&D variable, which was only available for a reduced number of countries and years, and this naturally constrains our research. Moreover, Lerner (2002) examines IPR policy changes, something we do not control for in our analysis and his time period is much larger than ours.

Even though after surveying the empirical literature, Jaffe (1999) makes a disquieting conclusion that there is little empirical evidence to support the widely accepted theory that strengthening IPR protection has significant impact on

27 To further test the robustness of the results, a number of diagnostic tests are conducted. To correct for heteroscedasticity, robust standard errors are used in all the specifications. Wald tests are used to test for the significance of the group variables. The Sargan test, asymptotically distributed as χ^2, with as many degrees of freedom as overriding restrictions, tests the validity of the instruments under GMM specifications. To test for serial correlation AR(1) and AR(2) tests are conducted.

28 Another difficulty is that invention and innovation may be incremental processes, with each step building on prior knowledge. If patents and trade secrets are excessively strong, this incremental innovation can be impeded (Jaffe and Lerner, 2004).

innovation,[29] unfortunately, the actual (empirical) effects of IPR protection on innovation have been generally found to be inconclusive. Researchers continue to search for evidence and answers with regard to the efficacy of IPR protection on innovation. This article has shed light on this ongoing debate with additional and new empirical evidence.

5. Final remarks and further extensions

This article offered further economic evidence on the effect of technological progress in affecting income per capita growth for a panel of different countries between 1980–2005. We used two alternative proxies, the number of patents registered in the US market and the Intellectual Property Rights Index a la Ginarte and Park, together with several control variables. Intangibles, which include IPR and innovation parameters such as patents or R&D, also including variables as reputation, confidence or trust, are now widely recognised as a major possible explanation to GDP growth. Our main results show that ideas/innovation/technology affect positively income per capita growth rate, even after controlling for endogeneity. These results indicate that countries with a higher degree of IPR, which reflects protection on the market for new ideas, leads to a larger level of income per capita, compared with countries with low property rights enforcement mechanisms. It is worth pointing that IP protection, as proxied by "rule of law" (lacto sensu), should be independently included and taken into account, as attested by its positive and significant coefficient, translating the importance of good institutional and governance quality in explaining cross-country differences.

As far as extensions are concerned, measuring the patent applications against the population size does not take into account the resources of each country for being innovative, so that one possible extension would be to replicate the analysis using a deflator measure in total counts of patents (e.g. GDP) to account for this aspect. Alternatively, one could use Patent Citation Indicators, Cites per Patent, the Current Impact Index, the Technology Strength measure, inter alia (Kurtossy, 2004). In addition to this remark, the article also discusses several alternative mechanisms to incentive the innovative activity, concluding that the joint use of these methods can achieve a higher welfare than the solely use of the traditional patents scheme. However, no empirical test has been conducted to conclude this, which leaves the answer to this statement for future research. Another possible extension to this part of the article could be the empirical comparison of several innovation incentive mechanisms and also the study of the channel – e.g. investment rate, physical capital productivity, labour productivity or the joint use of these three – through which innovation affects technical progress.

In summary, the traditional view of patents as a compromise between incentives to innovate and barriers to technology diffusion, if not incorrect, presents a somewhat limited picture, as patents can either encourage or deter innovation and diffusion, depending on certain conditions. In fact, patents affect innovation and diffusion processes depending on particular features of the patent regime. In this respect, our article is another contribution to the long-standing legacy of articles using different measures and methodologies to adjust for variation in the quality of patent-based measures.

Appendix A. TFP growth accounting

TFP computations based on Klenow, Peter J. & Rodriguez-Clare, Andres [2005], "Externalities and Growth," Handbook of Economic Growth, volume 1A, in P. Aghion and S. Durlauf, eds., pp. 817–861 (chapter 11).

All variables are from the Penn World Table 6.2. Years are 1960 through 2004, or a continuous subset. Key sample requirements were availability of rgdpwok (GDP per worker) and att.

- att = attainment of individuals 25 and older. Source: Barro, Robert J., and Jong-Wha Lee (2000), "International Data on Educational Attainment: Updates and Implications", NBER Working Paper 7911.
- ky = estimated ratio of physical capital to output. We set the initial k/y using the methodology described in Klenow, Peter J. & Rodriguez-Clare, Andres [1997], "Economic growth: A review essay", Journal of Monetary Economics, vol. 40(3), pp. 597–617.

Author calculations: standard capital accumulation with delta = 8%. We used alpha = 1/3; phi = 0.085. Source for phi = 0.085: Psacharopoulos, George and Harry Anthony Patrinos [2002], "Returns to Investment in Education: A Further Update", World Bank Policy Research Working Paper 2881.

Formula:

TFP = rgdpwok / [(ky*rgdpwok)^(alpha)*(exp(phi*att))^(1-alpha)].

Appendix B. List of countries and summary statistics

List of Countries: Argentina, Australia, Austria, Bangladesh, Belgium, Benin, Benin, Bolívia, Brazil, Canada, China, Chile, Colombia, Congo, Costa Rica, Cyprus, Denmark, Dominican Rep., Ecuador, Egypt, Finland, France, Gabon, Germany, Ghana, Greece, Guatemala, Guyana, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan,

29 Hall and Ziedonis (2001) also draw the same conclusion with regard to R&D investment when innovation is cumulative, as they put it, "there remains little systematic evidence on how a shift toward stronger patent rights affects the innovative activities of firms in the context of rapidly changing, cumulative technologies".

Table 9
Summary statistics.

	GRGDP	LNGDP	PAT100	PATPC	K	IPR	EDU	OPEN	FERTRATE	LIFEEXP	MORTRATE	URBPOP	POPDENS	POPGR	FDI
Mean	1.88147	7.87878	0.01335	1.86e−05	21.9727	2.66641	1.93073	63.8459	3.42756	67.8037	59.6464	58.2225	116.808	1.60233	3.27e+09
Median	2.15000	7.72024	3.00e−0	2.72e−07	21.6000	2.55833	1.68300	56.0000	3.00000	70.0000	40.0000	59.2000	56.6075	2.00000	2.85e+08
Maximum	22.0000	10.5937	0.68549	0.00025	40.8000	4.87500	5.08000	197.200	7.00000	80.4000	214.000	97.1000	1196.25	5.80000	1.44e+11
Minimum	−12.4000	4.78760	0.00000	0.00000	5.00000	0.58823	0.14700	12.8000	1.00000	41.5000	4.40000	9.90000	1.75078	−0.60000	−2.03e+08
Std. Dev.	4.33600	1.50338	0.06777	4.21e−05	5.87992	1.13628	1.17361	36.9840	1.73220	8.80988	57.7157	21.3037	177.107	1.11838	1.13e+10
Skewness	−0.14919	0.07271	7.19841	3.05676	0.34835	0.23930	0.90759	1.42221	0.64308	−0.79554	1.05399	−0.17674	3.93264	0.23687	8.517604
Kurtosis	5.96922	1.85731	59.3566	12.7367	3.78948	1.84494	3.16896	5.07910	2.29984	2.68989	2.96877	2.12218	21.2603	2.64555	96.60644
Jarque–Bera	95.3610	14.2085	36 229.9	1415.43	11.8723	16.7393	35.5888	132.927	22.9637	28.1386	47.5939	9.58957	4233.02	3.74873	96 935.7
Probability	0.00000	0.00082	0.00000	0.00000	0.00264	0.00023	0.00000	0.00000	0.00001	0.000001	0.00000	0.00827	0.00000	0.15345	0.00000
Sum	483.540	2024.84	3.43209	0.00477	5647.00	685.269	496.200	16 408.4	880.883	17 425.5	15 329.1	14 963.2	30 019.6	411.800	8.41e+11
Sum Sq. Dev.	4813.03	578.604	1.17583	4.55e−07	8850.80	330.533	352.607	350 161.7	768.135	19 869.1	852 764.2	116 185.4	8029 973	320.198	3.28e+22
Observations	257	257	257	257	257	257	257	257	257	257	257	257	257	257	257

Table 10
Correlation matrix: TFP, Patents per 100.000 inhabitants, Patents per capita and IPR index.

	TFP	PAT100	PATPC	IPR
TFP	1			
PAT100	0.3161	1		
PATPC	0.5798	0.6989	1	
IPR	0.7058	0.30593	0.5914	1

Jordan, Luxemgbourg, Madagáscar, Malaysia, Malta, Mauritania, Mexico, Morocco, The Netherlands, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Saudi Arábia, Senegal, South Africa, Spain, Sri Lanka, Swaziland, Sweden, Switzerland, Thailand, Trinidad & Tobago, Tunisia, Uganda, United Kingdom, United States, Uruguay, Zambia, Zimbabwe. See Tables 9 and 10.

References

Acemoglu, D., Johnson, S., Robinson, J., 2001. The colonial origins of comparative development. American Economic Review 91, 1369–1401.
Ajami, K.A., Barniv, R., 1984. Utilising Economic indicators in explaining foreign investment in the US. Management International Review 24 (4), 16–26.
Arrow, K.J., 1962. Economic welfare and the allocation of resources for invention. In: Universities-National Bureau of Economic Research Conference Series, The Rate and Direction of Economic Activities: Economic and Social Factors. Princeton University Press.
Baltagi, B., 1996. Econometric Analysis of Panel Data, 2nd ed. John Wiley & Sons, New York.
Bar-Shalom, A., Cook-Deegan, R.M., 2002. Patents and innovation in cancer therapeutics: Lessons from CellPro. The Milbank Quarterly 80, 637–676.
Barro, R.J., Lee, J.-W., 2000. International Data on Educational Attainment Updates and Implications, NBER Working Papers 7911, National Bureau of Economic Research.
Basberg, B.L., 1987. Patents and the measurement of technological change: A survey of the literature. Research Policy 16 (2–4), 131–141.
Bessen, J., Maskin, E., 2006. Sequential innovation, patents and imitation. Working Paper, Princeton University.
Bester, H., Petrakis, E., 1998. Wage and productivity growth in a competitive industry. CEPR Discussion Paper 2031.
Boldrin, M., Levine, D., 1999. Perfectly competitive innovation. Federal Reserve Bank of Minneapolis, Res. Dept. Staff Rep. 303.
Boldrin, M., Levine, D., 2002. The case against intellectual property. American Economic Review 92 (2), 209–212.
Boldrin, M., Levine, D., 2004. The case against intellectual monopoly. International Economic Review 45, 327–350.
Boldrin, M., Levine, D., 2005. The economics of ideas and intellectual property. PNAS 102 (4).
Crosby, M., 2000. Patents, innovation and growth. Economic Record 76, 255–262.
Culem, C.G., 1998. The locational determinants of direct investments among industrialized countries. European Economic Review 32, 885–904.
Davidson, R., Mackinnon, J.G., 2004. Econometric Theory and Methods. Oxford University Press, New York.
Devinney, T., 1994. Characterizing international patents behaviour. Working Paper 94,024, Australian Graduate School of Management.
Encaoua, D., Guellec, D., Martinez, C., 2006. Patents systems for encouraging innovation: Lessons from economic analysis. Research Policy 35, 1423–1440.
Fawcett, J.J., Torremans, P., 2001. Intellectual Property and Private International Law. Oxford University Press, Oxford.
Fullerton, R., McAfee, R., 1999. Auctioning entry into tournaments. Journal of Political Economy 107 (3), 573–605.
Ginarte, J., Park, W., 1997. Determinants of Patent Rights: A cross-national study. Research Policy 26 (3), 283–301.
Glaeser, E., La Porta, R., Lopez-de-Silanes, F., 2004. Do Institutions cause growth. Journal of Economic Growth 9 (3), 271–303.
Green, W., 2003. Econometric Analysis. Prentice Hall, Englewood Cliffs.
Griliches, Z., 1990. Patent statistics as economic indicators: A survey. Journal of Economic Literature, American Economic Association 28 (4), 1661–1707.
Grosse, R., Trevino, L.J., 1996. Foreign direct investment in the United States: an analysis by country of origin. Journal of International Business Studies 27 (1), 139–155.
Grossman, G.M., Helpman, E., 1993. Innovation and Growth in the Global Economy. ISBN-10:0-262-57097-1.
Grubaugh, S.G., 1987. Determinants of foreign direct investment. Review of Economics and Statistics 691, 149–152.
Guell, R., Fischbaum, M., 1995. Toward allocative efficiency in the prescription drug industry. The Milbank Quarterly 63, 213–299.
Hall, B., Ziedonis, R., 2001. The determinants of patenting in the US Semiconductor industry, 1980-94. Rand Journal of Economics 32 (1), 101–128.
Hardin, G., 1968. The tragedy of commons. Science 161, 1243–1248.
Heller, M., Eisenberg, R., 1998. Can patent deter innovation? The anticommons in biomedical research. Science 280, 698–701.
Hellwig, M., Irmen, A., 2000. Endogenous technological change in a competitive economy. Journal of Economic Theory 101, 1–39.
Herrera, H., Schroth, E., 2000. Profitable innovation without patents protection: the case of credit derivatives. Working Paper at the Berkeley Center, Stern NYU.
Hollis, A., 2007. Incetive mechanisms for innovation. IAPR Tehcnical Paper Series No. TP-07005.
Hopenhayn, H., Llobet, G., Mitchell, M., 2006. Rewarding sequential innovators: Prizes, patents, and buyouts. Journal of Political Economy 115 (6).
Hsiao, C., 1986. Analysis of Panel Data. Cambridge University Press.
Jaffe, A., 1999. The US patent system in transition: policy innovation and the innovation process. NBER Working Paper 7280.
Jaffe, A., Lerner, J., 2004. Innovation and its Discontents: How Our Broken Patents System is Endangering Innovation and Progress and What to do about it. Princeton University Press.
Jones, C., 1995. R&D-based models of economic growth. Journal of Political Economy 103 (3), 759–784.
Kaufmann, D., Kray, A., Mastruzzi, M., 2009. Governance Matters VIII: Aggregate and Individual Governance Indicators, 1996–2008. World Bank Policy Research Working Paper No. 4978.
Knack, S., Keefer, P., 1995. Institutions and economic performance: cross country testing using alternative institutional measures. Economics and Politics 7 (3), 207–227.
Kremer, M., 1998. Patent buyouts: a mechanism for encoraging innovation. Quarterly Journal of Economics 113, 1137–1167.
Kurtossy, J., 2004. Innovation indicators derived from patent data. Periodica Polytechnica - Social and Management Sciences 40 (1), 91–101.
Lerner, J., 2002. 150 years of patent protection. American Economic Review 92, 221–225.
Mansfield, E., Schwartz, M., Wagner, S., 1981. Imitation costs and patents: an empirical study. Economic Journal 91, 907–918.
Mauro, P., 1995. Corruption and growth. Quarterly Journal of Economics 110, 681–712.
Nadiri, M., 1993. Innovations and Technological Spillovers. NBER Working Paper Series 4423.
Nordhaus, W., 1969. Invention Growth and Welfare. MIT Press, Cambridge, MA.
Park, W., 1999. Impact of the international patent system on productivity and technology diffusion. In: Owen Lippert (Ed.) Competitive Strategies for Intellectual Property Protection, Frasier Institute, Vancouver.
Pavitt, K., 1988. Uses and abuses of patent statistics. In: van Raan, A.F.J. (Ed.), Handbook of Quantitative Studies of Science and Technology. Elsevier, Amsterdam, pp. 509–536.
Quah, D., 2002. 24/7 competitive innovation. Working Papers Series, LSE.
Ramello, G., 2005. Intellectual property and the markets of ideas. Review of Network Economics 4 (2).

Romer, P., 1990. Endogenous technological change. Journal of Political Economy 98, S71–S-102.
Romer, P., 1993. Implementing a national technology strategy with self-organizing industry investment boards. NBER Working Paper Series 1870.
Sachs, J., Warner, A., 1997. Sources of slow growth in African economies. Journal of African Economies 6 (3), 335–376.
Scherer, M, 1998. The propensity to patent. International Journal of Industrial Organisation 1, 107–128.
Scotchmer, S., 1999. On the optimality of the patent renewal system. Rand Journal of Economics 30 (2), 181–196.
Shapiro, C., 2002. Competition Policy and Innovation, OECD Science, Technology and Industry Working Papers 2002/11, OECD, Directorate for Science, Technology and Industry.
Shavell, S., Ypserle, T., 2001. Rewards versus intellectual property rights. Journal of Law and Economics 44, 525–547.
Spence, M., 1984. Cost reduction, competition and industry performance. Econometrica 52, 101–121.
Ulmer, E., 1987. Copyright and Industrial Property. Martinus Nijhoff, Dordrecht-Boston.
Wooldridge, J., 2001. Econometric Analysis of Cross Section and Panel Data. MIT Press.
Wright, B., 1983. The economics of invention incentives: Patents, prizes, and research contracts. American Economic Review 73 (4).
Yusuf, S., 2007. From creativity to innovation. World Bank Policy Research Working Paper 4262.