

A multilevel analysis of innovation in developing countries

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Abstract

Innovation is a multilevel phenomenon. Not only individual characteristics and capabilities of firms, but also the environment within which the innovation process occurs is important. Although this has been always recognized in the literature on innovation and more recently conceptualized in the innovation systems approach, a quantitative test that explicitly concerns the hypothesis that national innovation systems matter for innovativeness of firms is lacking. Using data for about 15,000 firms in 30 developing countries from the Productivity and Investment Climate Survey organized by the World Bank, we estimate a multilevel model of innovation that integrates factors at different levels of the analysis. The results indicate that various aspects of the national innovation system directly influence the likelihood of firms to innovate and also affect the firm-level relationships between size and innovativeness of firms.

Keywords: Innovation in firms, national innovation system, multilevel modeling, developing countries.

1. Introduction

Social scientists have long recognized a need to integrate analysis of individual behaviour and the social, technological and other environments within which that behaviour occurs. A classic case is suicide, which is often triggered by the interplay between individual characteristics and the social context (Durkheim, 1897). Another less morbid example is school performance of children that is not only associated to their capabilities and efforts, but also to characteristics of the class, school and the educational system (Burstein, 1980). Everyday experience tells us that people from the same communities, countries and cultures tend to have more similar preferences than those chosen at random from the population, although their gender, age or personal income also matter. Many other socio-economic phenomena concern a hierarchical structure, where individual entities tend to be related at different levels of the analysis.

Innovation research often refers to the relationship between firms and the environment. Already Schumpeter was well aware of the role played by the social context (Schumpeter, 1934). A key element of the entrepreneurial function put forward by him is the ability to overcome resistance to radical innovations in the society. At the most abstract level the idea about survival of firms propelled by innovation, but determined by the environment, is central to theorizing (and simulations) in the evolutionary economics (Nelson and Winter, 1982; Andersen, 1994). Although Schumpeter focused on social impediments to innovation, the recent literature concentrates more on search for factors in the environment that enable firms to innovate. An explicitly multilevel perspective along these lines is the concept of firms embedded in national innovation systems (Lundvall, 1992; Nelson, 1993 and Edquist, 1997). Still empirical research on innovation continues to use single-level methods that are seriously restricted to test hypotheses on relations identified at different levels.

A multilevel problem is a hypothesis that concerns relationships between variables that are measured at different hierarchical levels (Hox, 2002). Single-level models rest heavily on the assumption on independence of the observations from each other. If a nested structure of data exists, however, estimates of standard errors in the conventional statistical tests tend to be biased downwards and can indicate spuriously significant results. By relaxing this assumption, multilevel modeling provides statistically more accurate estimates (Goldstein, 2003). Another problem is conceptual. Single-level models may suffer from the fallacy of the wrong level, if results derived from data at one level are interpreted at another level (for examples see Luke, 2004). Even more importantly, a proper recognition of data hierarchies allows us to examine new lines of questions. Multilevel modeling enables us to directly examine the extent to which specific differences between countries are accountable for outcomes at the firm-level. It is also possible to investigate whether these effects differ for firms with certain characteristics.

The aim of this paper is to show how empirical research on innovation can benefit from multilevel modeling. Novelty of this paper is twofold; both in the methodological and empirical domains. First, we assess quantitatively the hypothesis that national innovation systems influence the firm's likelihood to innovate. Second,

we bring evidence on innovation in developing countries from a unique dataset that has been rarely utilized for this purpose so far. The paper proceeds as follows. Section 2 puts forward arguments for multilevel analysis of innovation. Section 3 explains the dataset and construction of the variables. Section 4 specifies the bivariate logit multilevel model of innovation. Section 5 presents results of the estimates. And the last section concludes and outlines agenda for multilevel modeling of innovation in the future.

2. A need for multilevel modeling of innovation

A hierarchical (or nested) structure of many kinds of data has been recognized in the literature. Multilevel modeling has been used in sociology (Van den Eeden, Hüttner, 1982; Blalock, 1984; DiPrete, Forristal, 1994; Hox, Kreft, 1994; Jones, 1995), in educational research (Burstein, 1980; Aitkin, Longford, 1986; de Leeuw, Kreft, 1986; Keeves and Cheung, 1990; de Leeuw and Kreft, 1995; Goldstein, Spiegelhalter, 1996); in psychology (Bryk, Raudenbush, 1987; Krull, MacKinnon, 2001; Van den Noortgate, et al., 2003) and in health science (Goldstein, et al., 1994). Other multilevel analyses can be cited from demography, epidemiology and biology (Hox, 2002). So far multilevel models have been sparsely used to study economic phenomena (typically by sociologists). A rare example is the analysis of gender inequality in earnings by Kreft and de Leeuw (1994). Similarly the potential of multilevel modeling has not been realized in research on innovation; except the recent analysis of firms embedded in regional innovation systems by Srholec (2007).¹

The idea is that individual entities interact with the contexts to which they belong, implying that these individuals are influenced by the properties of their surroundings. As far as innovation is concerned, the multilevel metaphor suggests that firms in environments conducive to generation and absorption of new knowledge should be more likely to innovate. Innovation requires new combination of productive means (Schumpeter, 1934). Some of them are inside of the firm, while others need to be obtained externally. A purely “off-the shelf” purchase of some of these external resources is not efficient, because transfer of knowledge often requires interactive learning between users and producers (Lundvall, 1988) and therefore learning in economies with advanced division of labour is socially embedded activity (Lundvall, Johnson, 1994).

A central argument underlying the literature on innovation systems is that innovation is determined by factors operating at different levels. Spatial concentration of the relevant actors, resources and other environmental factors conducive to learning influences firms’ innovative performance (Lundvall, 1992; Nelson, 1993 and Edquist, 1997). A firm embedded in a vibrant innovation system may therefore become a successful innovator, while the very same firm in a considerably less favourable environment may fail to innovate. Also the effect of structural characteristics and

¹ Note that the “multilevel” metaphor has been occasionally used in the literature on innovation over the years (see for example Drazin and Schoonhoven, 1996; van Driel, Schot, 2005; Constantinides, Barrett, 2006), but exclusively at the conceptual level without any formal modeling of the proposed relationships.

internal capabilities of a firm on its innovative performance may depend on synergies with resources of other innovative organizations located in the same area and on support from institutions conducive to collective learning.

It cannot be emphasized enough that the firm is at the core of this conceptual framework. Although we need to think about firms embedded in the social context, the firm remains the basic unit of the analysis. And we should use quantitative analytical tools to examine hypotheses derived from the literature on national innovation systems. However, in order to quantitatively test predictions of the “contextual” theories of innovation in firms, we need to use data and employ methods that are appropriate for that purpose. One of the appealing aspects of multilevel modeling is that it facilitates the introduction of these contextual concepts into formal modeling of innovation in an econometric framework.

Most of the existing literature has used macro data to analyse differences in innovation performance between the frontier and late-comer countries. Indicators of USPTO patents, scientific articles, R&D expenditure, ICT infrastructure or educational attainment have been used to measure different aspects of national innovation systems, which are often analysed under the rubric of national innovation, technological or social capabilities in cross-country comparative research (Furman, et al., 2002; Archibugi, Coco, 2005; Fagerberg, Srholec, 2006; Fagerberg, et al., 2007). Although important aggregate evidence has been put forward, a relatively little can be concluded from these studies how the technological, economic and social environment influences the innovation process in firms. A complex phenomenon, such as the innovation process, cannot be fully understood at any single level of analysis.

An important bottleneck for future deepening of research in this tradition is that the empirical analysis is far behind our theoretical understanding of innovation. Abundance of theoretical reasoning on innovation systems is in sharp contrast with the general lack of quantitative work aimed at validating these hypotheses. At this front multilevel modeling has much to offer. We need to transcend the dichotomy between the firm and higher levels of the analysis in the empirical research on innovation. Such a perspective is particularly crucial for our understanding of how firms in developing countries can technologically catch-up, because there is considerable variety in the higher-level factors among developing countries. To show how this can be done is the main purpose of the following analysis.

3. Dataset

We use micro data from the World Bank's Productivity and Investment Climate Survey (PICS). Firms were asked about various aspects of their business activities, including a set of questions on innovation and learning, in a questionnaire harmonized across many developing countries. For more details on methodology of the PICS see World Bank (2003).

Our main focus is on innovativeness of firms. The survey includes two direct questions on innovation. Firms were asked whether they developed a major new product line and whether they introduced new technology that has substantially changed the way the main product is produced. These questions broadly refer to the concepts of product and process innovation. INNPDT is a dummy with value 1 for firms that answered positively on the former and INNPCS is a dummy with value 1 for firms that answered positively on the latter. A general measure of innovativeness is INNOV, which is a dummy with value 1 if the firm answered positively to at least one of these questions. Similarly to the data from CIS, these innovations are new to the firm, but not necessarily new to the market or to the world. As shown below, this is essential to bear in mind for proper interpretation of the results in the context of developing countries.

Besides the variable on innovation, we have information on size, age, ownership and selected aspects of firm's capabilities. SIZE is natural logarithm of the number permanent employees in the initial period. Besides advantages from scale economies of various kinds, size is important to control for due to definition of the dependent variable. Since INNOV is a dummy for introducing at least one innovation, larger firms should be by principle more likely to report a positive answer because they comprise more activities or even multiple product lines and plants under a single roof.

AGE in natural logarithm of the number of years since the firm has begun operations in the country. On one hand older firms tend to have more accumulated knowledge and other resources to capitalize on, but on the other hand newly established firms (and therefore younger firms) should appear to be more innovative because they by principle need to introduce a new (to the firm) product and process when they launch the new business. The information on ownership structure allows us to distinguish between foreign- and domestic-owned firms. FA is a dummy with value 1 for foreign affiliates (more than 50% of foreign ownership).

Not only structural features influence innovativeness of firms. Internal capabilities and resources devoted to learning are essential for success in the innovation process. The dataset provides information on training of employees, adherence to ISO norms and use of Internet in the business. SKILL is a dummy with value 1 if the firm offers formal (beyond "on the job") training to its permanent employees. ISO is a dummy with value 1 if the firm has received ISO (e.g. 9000, 9002 or 14,000) certification. And WWW is a dummy with value 1 if the firm regularly uses a website in its interactions with clients and suppliers.

About 15,000 manufacturing firms in 30 developing countries are included in the analysis.² Only firms with 10 and more employees have been included in the sample due to large differences in coverage of smaller firms between countries. Also the Oslo Manual recommends using only firms with more than 10 employees (OECD, 1997), so that the dataset is consistent with Community Innovation Surveys (CIS) in this respect. Service sector has not been covered by the survey in many countries and therefore could not be included in the analysis. The dataset is based on surveys organized over the period from 2002 to 2006. If the survey was conducted more than once in a country, we use the latest year available in the PICS 2006 Dataset.

A basic overview of the data is given in Table 1. Let us focus on INNOV, which is our main dependent variable. About 65% of firms in the sample introduced product or process innovation. The propensity of firms to innovate differs largely between countries. Only 20% of firms innovated in Egypt, but about 90% of firms claimed to introduce innovation in Peru. A number of other countries in Latin America together with South Africa came out with more than 80% innovative firms. Although one can argue that these innovate rates may not be representative due to limited number of observations in some countries, this can only partly explain these differences. For example, there are 1,548 firms from Brazil of which 85% reported innovation, 1,512 firms from India of which only 47% innovated and 946 firms from Egypt with as little as 20% innovators. If so many firms tend to report innovation (or not) in a country, there must be some real-world explanation behind it. And as has been already emphasized above, coverage by industry seems to be representative in countries that have been allowed to enter the analysis. Also coverage of different size and age categories has been investigated before the analysis and as the table confirms there should not be a serious bias along these lines either.³

At the first glance, it may seem counterintuitive that so many firms could have innovated in developing countries; especially in Latin America, which is usually not put forward as the most “innovative” part of the developing world. Before diving more deeply into explaining the propensity of firms to innovate in the econometric framework below, let us elaborate on two major issues that may help to understand these numbers. First we need to consider in a more detail the definition of INNPDT and INNPCS in the PICS survey and second we need to take into account specificity of the innovative process in the developing countries.

² Only countries with information on the key variables and a relatively large/representative sample of firms (with regards to coverage by industries, etc.) are included in the analysis. China was not included because of missing data on some of the explanatory variables and highly unbalanced sectoral coverage. More on the selection of countries and industrial composition of the sample is available from the author upon request.

³ Apart perhaps from the fact that large firms are overrepresented in the samples from Thailand and Vietnam and to a lesser extent in a few other countries, but this does not seem to drive the results.

Table 1: Overview of the sample

County	Year	Observations	INNOV	INNPDT	INNPCS	SIZE	AGE	FA	SKILL	ISO	WWW
Argentina	2006	507	0.84	0.77	0.69	3.96	3.24	0.09	0.53	0.28	0.77
Bolivia	2006	261	0.88	0.77	0.75	3.55	2.94	0.10	0.64	0.19	0.44
Brazil	2003	1,548	0.85	0.68	0.67	4.00	2.70	0.05	0.66	0.19	0.73
Chile	2004	544	0.58	0.48	0.28	4.23	3.22	0.13	0.73	0.37	0.74
Colombia	2006	446	0.84	0.71	0.72	3.54	2.77	0.02	0.58	0.14	0.44
Ecuador	2003	376	0.76	0.55	0.54	3.77	2.90	0.10	0.74	0.19	0.60
Egypt	2004	946	0.20	0.14	0.11	3.48	2.82	0.02	0.11	0.09	0.18
El Salvador	2003	363	0.80	0.64	0.56	3.86	2.82	0.07	0.50	0.06	0.37
Guatemala	2003	333	0.74	0.55	0.48	3.93	2.77	0.10	0.59	0.04	0.34
Honduras	2003	311	0.67	0.49	0.48	3.99	2.44	0.18	0.61	0.07	0.30
Hungary	2005	246	0.45	0.38	0.20	4.01	2.68	0.17	0.48	0.31	0.91
India	2005	1,512	0.47	0.43	0.18	3.66	2.68	0.01	0.18	0.27	0.39
Kazakhstan	2005	252	0.53	0.35	0.39	3.86	2.27	0.05	0.35	0.13	0.60
Lebanon	2006	132	0.73	0.55	0.46	3.62	3.27	0.02	0.64	0.21	0.52
Madagascar	2005	259	0.54	0.38	0.35	3.77	2.56	0.31	0.46	0.07	0.33
Mexico	2006	734	0.46	0.40	0.40	3.85	2.86	0.07	0.40	0.29	0.37
Nicaragua	2003	269	0.74	0.52	0.55	3.41	2.77	0.12	0.45	0.04	0.22
Panama	2006	166	0.75	0.62	0.60	3.55	3.15	0.08	0.49	0.13	0.42
Paraguay	2006	299	0.79	0.72	0.68	3.44	3.02	0.07	0.51	0.09	0.37
Peru	2006	274	0.90	0.79	0.78	3.91	2.82	0.11	0.65	0.23	0.49
Philippines	2003	538	0.59	0.48	0.41	4.19	2.79	0.19	0.23	0.18	0.25
Poland	2005	259	0.65	0.49	0.52	3.74	2.87	0.08	0.71	0.28	0.88
Romania	2005	292	0.62	0.38	0.52	4.01	2.61	0.12	0.36	0.22	0.72
South Africa	2003	554	0.82	0.69	0.61	4.70	2.92	0.16	0.66	0.43	0.71
Tanzania	2003	157	0.51	0.34	0.36	3.60	2.59	0.20	0.52	0.15	0.31
Thailand	2004	1,179	0.77	0.59	0.60	5.08	2.66	0.15	0.81	0.45	0.37
Turkey	2005	1,056	0.59	0.36	0.44	4.39	2.77	0.03	0.59	0.48	0.73
Uruguay	2006	271	0.80	0.69	0.65	3.49	3.14	0.10	0.41	0.14	0.41
Vietnam	2005	862	0.62	0.43	0.45	4.78	2.20	0.10	0.59	0.39	0.30
Zambia	2002	167	0.72	0.50	0.51	4.24	2.63	0.23	0.32	0.05	0.25
Total	..	15,113	0.65	0.51	0.47	4.04	2.76	0.09	0.51	0.25	0.49

As already explained above, INNPDT refers to the question whether the firm has “developed a major new product line” (World Bank, 2003, pg. 46), so that there is no explicit reference to “technologically” new product. Let’s us compare this to the definition of product innovation in the CIS3 questionnaire (Eurostat, 1997, pg. 4): “Product innovation is a good or service which is either new or significantly improved with respect to its fundamental characteristics, technical specifications, incorporated software or other immaterial components, intended uses, or user friendliness... Changes of a solely aesthetically nature, and purely selling of innovations wholly produced and developed by other enterprises, shall not be included.” Obviously the definition in CIS3 is longer, more precise and most importantly much more

restrictive.⁴ It is likely that a firm that answered negatively in CIS3 would provide a positive answer in PICS.⁵ So strictly speaking we should not compare the propensity to introduce product innovation detected in PICS with numbers that we are accustomed to observe in the CIS data and we therefore should not be surprised to find a higher frequency of product innovators in our sample.⁶

INNPCS refers to a somewhat longer question whether the firm has “introduced new technology that has substantially changed the way that the main product is produced” (World Bank, 2003, pg. 46), which refers to an explicit “technological” content of the change. Again we compare this to the CIS3 question on process innovation (Eurostat, 1997, pg. 5): “Process innovation includes new and significantly improved production technology, new and significantly improved methods of supplying services and of delivering products... Purely organisational or managerial changes shall not be included.” Although these definitions seem to be much closer in the emphasis on “new technology”, there is still the restriction in the latter part of the CIS definition that is not mentioned in PICS. It might be that some firms consider organizational and other related changes in their answers to the PICS questionnaire, which they would not include in CIS. And therefore similar concerns about comparability of these two surveys apply for the frequency of process innovation too.⁷

Second important reason for relatively high frequency of innovation in the sample, and perhaps even more relevant for our analysis, is that these new products and processes are new to the firm, but not necessarily to others. Along these lines the definition of innovation is PICS and CIS does not differ, however, what matters here is the different context, because PICS are focused on developing countries, while CIS is a European venture. Since firms in developing countries can benefit from imitation of technologies introduced by firms in the frontier countries, all else equal they are more likely to introduce the “new to the firm” innovation than their counterparts in Europe or elsewhere in the developed world. From this “technology gap” perspective we should actually expect to find more “new to the firm” innovation in developing countries, which is exactly what comes out from the data. Most innovation captured in our dataset arguably reflects diffusion of advanced technology from abroad and therefore “innovation through imitation” rather than introduction of radically new technology based on indigenous research and development.

⁴ One may argue if such a relatively complicated question would be feasible to ask in developing countries, including some of the least developed nations, where awareness about technological innovation (and general literacy) is relatively limited. Simpler may be actually better in this context, at least as far as the response rate and comparability of the answers is concerned.

⁵ It should be noted that it may not be entirely clear what “major” means in the PICS definition, so that this aspect of the question can be understood differently across firms (as well as in different countries). Also in the CIS data we have experienced that firms in some countries seem to be more “optimistic” about their technological innovations and therefore tend to answer positively more often. No doubt that the assessment of what is “major” may differ even more across countries (and cultures).

⁶ In addition, one should bear in mind that our sample includes only firms in manufacturing that tend to have much higher frequency of innovation than in most other sectors, so that one should not tend to compare our results with the overall frequency of innovation detected in CIS for all sectors, but only to the CIS numbers specific to manufacturing firms. It should not be necessary to emphasize that in this comparison the difference appears to be smaller.

⁷ It is interesting to note that the 2nd revision of the Oslo Manual concentrates on technological nature of innovation, whereas the 3rd revision of the Oslo Manual extends the definition by new marketing and organizational methods, which makes it somewhat closer to the more “open” definition in PICS.

A major advantage of data from PICS is that information on all variables, including SKILL, ISO and WWW, is available for both innovators and non-innovators, whereas most (and the most interesting) information from CIS, such as details on different types of expenditure on innovation, sources of information or cooperation, is available only for the innovators (non-innovating firms are allowed to skip most of the CIS questionnaire). Such design of the CIS survey severely limits any inferences that can be made about the factors behind success in introducing innovation, since we simply do not know much about the non-innovators. Another consequence of this split is that every model that requires this more detailed information from CIS data must control for a potential sample selection bias. Needless to say, identification of the selection equation is problematic due to the lack of information for both groups of firms, which typically becomes “swept under the carpet” in the literature based on the CIS data (although results of the second equation are often sensitive to specification of the exclusion restriction).⁸ Any of these concerns are fortunately not relevant for analysis of the PICS data.

Since we are going to use a multilevel model, we also need data for specific country-level variables that can capture salient aspects of the national innovation system and therefore explain innovativeness of firms. We use these indicators in the form of three-year averages (if not specified differently below) to limit influence of shocks and measurement errors occurring in specific years and because definition of the innovation variables in PICS refers to the period over the last three years. As can be seen from Table 4, the survey was conducted in different years across countries over the period 2002-2006 and we keep this in mind when constructing the country-level variables, so that we average different three-year periods depending of timing of the survey in the particular country.

From the previous discussion clearly follows that some measure of the technology gap is going to be the central characteristics of the national environment. It is customary in the literature on catching-up (and convergence) to assume that labour productivity reflects technological level of a country and therefore difference in GDP per capita with regards to the leading nation is used as a general proxy for the catching up potential (Fagerberg, 1987; Barro, 1991). Although GDP per capita represents technological level of a country to a great extent, there are also other factors that spill into this measure. GDP per capita reflects endowments by natural resources, such as oil and gas, which is particularly relevant in the context of developing countries. Not many would probably tend to suggest that Kuwait, United Arab Emirates, Bahrain, Saudi Arabia or Trinidad and Tobago have attained the same technological level as Korea or Slovenia; despite they appear in the same category in terms of GDP per capita (World Bank, 2007). Also variety of other non-technological factors related to geography, climate, disease ecology, natural disasters or even ethnic fractionalization have been shown to matter a lot (Masters, MacMillan, 2001; Easterly and Levine, 2001; Bloom, et al., 2003; Sachs, et al., 2004), particularly at the early stages of economic development.

⁸ Note that it is not common to provide sensitivity tests on specification of the selection equation in the empirical research based on the CIS data and therefore we actually know very little how are some of the widely received results sensitive to this problem. For example, it would be interesting to see how are these results sensitive to using of obstacles to innovation to identify the selection restriction, despite the variables of obstacles measure perceptions of firms on them above anything else (Srholec, 2007).

Since we need a measure that specifically represents the gap in technology, and not a joint impact of various factors behind economic development, we use information on international PCT (Patent Co-operation Treaty) patents for this purpose. Although patents reflect inventions, but not necessarily innovations, the basic condition of patentability that the invention must be novel (and internationally for the PCT patent) serves quite well the purpose of detecting the distance from the technology frontier. Another advantage of PCT patents is that the information is readily available for all countries in our sample, because they have signed the PCT treaty and this source of patent statistics does not suffer from home (or regional/language, etc.) advantages for some countries. A well-known weakness of patents is that “patentability” of knowledge differs across sectors, which tends to be reflected in the aggregated figures, but the sectoral bias is to a certain extent a problem for every indicator of technology. For simplicity we assume that the United States can represent the technology frontier. Our measure of the technology gap (GAP) is then the difference in PCT patent applications per capita between the United States and the particular country (higher value implies large gap) over the relevant three-year period.⁹

Advantages of backwardness are important, but arguably not the only relevant country-level factor. As has been well-understood in the literature on economic growth, the technology gap represents a great “promise” for development, but there are various conditions (technological, absorptive, social and other capabilities) that are required to learn from the more advanced countries and therefore for the ability of a country to actually realize this potential. For this purpose we use a battery of indicators that proxy for quality of the research infrastructure, overall educational level, availability of finance, income inequality and various aspects of governance, which are often cited as the important “conditional factors” in the literature on catching up (see Fagerberg, Godinho, 2004 and Fagerberg, Srholec, 2006 for overviews).

Availability of research infrastructure, like universities, R&D labs and a pool of researchers in the labour force reduce costs and uncertainties associated with firm’s innovative activities. The quality of research infrastructure conforms to the narrow view of national innovation systems by Nelson (1992). Although some part of these resources is devoted to basic research, most of R&D in developing countries is arguably geared toward fostering absorptive capacity rather than the ability to generate new knowledge at the world frontier. Note that Kim (1997) was well aware of this fact, because he used technological capability and absorptive capability interchangeably in the Korean context. As a measure of the national research infrastructure, we use the number of researchers in R&D per million people over the relevant five-year period. Despite we collected data from a variety of sources including the World Development Indicators (World Bank, 2007), UNESCO Science & Technology Statistics and RICYT (The Ibero-American Network of Science and Technology Indicators), missing data for four countries must have been filled by sample-average imputation.

⁹ Since non-linearity in the effect of GAP is commonly assumed in the literature, we have also tested this indicator in natural logarithm, but results of the estimates were the same due to almost perfect correlation between both versions of the indicator in our sample and therefore for the sake of parsimony we do not apply the logarithmic transformation.

However, agglomeration of researchers does not necessarily imply a vibrant innovation system. The best example is the context of post-socialist countries, where commercialization of research has been traditionally weak. Such objections are well-taken, so that we consider factors that capture various aspects of what Abramovitz (1986) would refer to as social capabilities and therefore extend our view on the national innovation system closer to the broader perspective of Lundvall (1993). A central aspect of social capabilities is the general level of education (EDU), which we measure by the literacy rate in adult population (% of people ages 15 and above) based on educational data from the UNESCO Institute for Statistics (complemented by estimates from the UN Human Development Reports in a few cases). Availability of finance is often identified as the critical condition for innovation. Our variable on accessibility of credit (FIN) refers to the extent of domestic credit to private sector in % of GDP, which has been acquired from the World Development Indicators (World Bank, 2007). Both the EDU and FIN variables are averages over the relevant three-year periods with no missing data.

Another relevant aspect of the national environment (and policies) is the extent of income inequality, which is traditionally measured by the GINI coefficient. For this indicator we have used the latest year available in the WIDER World Income Inequality Database 2.0a that provided data for all countries in the sample; except Lebanon for which it has been estimated by the sample-average imputation. Inequality of income reflects the extent of profit taxation that has a direct influence on net (after-tax) rewards from innovation for firms. And the detrimental effect should increase with more progressive taxation and therefore redistribution of income. On the other hand, taxes are collected to provide resources for public expenditures, which may indirectly improve environment for innovation by providing education, security, justice and other public goods (as well as government subsidies to certain kind of business). So not only the extent of income redistribution, but also quality of governance may matter in this context. Also a large number of middle-class people – in other words relatively even income distribution – might provide better environment for innovative start-ups, so that our expectation on the effect of the income inequality on innovation is ambiguous.

As already anticipated above, we need to take into account the quality of governance in the country. Some aspects of governance, such as the stability of government and its effectiveness in defining and enforcing rules, have been put forward in the literature on social capabilities (see Fagerberg, Srholec, 2006 for a discussion). Other aspects related to the extent of corruption, adherence to civil liberties, political and human rights or the effectiveness of government and regulation have been also widely discussed in the literature. It is obvious that governance is a multifaceted concept and there is hardly any single measure that could capture complexity of this phenomenon. By combining data from a large number of sources, the World Bank has constructed variables for six different aspects of governance: i) Voice and Accountability, ii) Political Stability, iii) Government Effectiveness, iv) Regulatory Quality, v) Rule of Law, and vi) Control of Corruption (for details on the methodology see Kaufmann, et al., 2005), which we will use in our analysis. Following Fagerberg and Srholec (2006), we use factor analysis to construct a composite measure of governance (GOV), because all of these variables appear to be highly correlated to each other (and

therefore it is not feasible to include them in the regression analysis along each other due to concerns of multicollinearity).¹⁰

4. A bivariate logit 2-level model of innovation

A multilevel model also known as hierarchical, random coefficient, variance component or mixed-effects model is a statistical model that relates a dependent variable to explanatory variables at more than one level (Luke, 2004). Assume 2-level structure with firms at level-1 nested in countries at level-2. A standard 1-level model is the following:

$$(1) \quad y_{ij} = \beta_{0j} + \beta_{1j} x_{ij} + e_{ij}$$

where y_{ij} is the dependent variable, x_{ij} is the firm level explanatory variable, β_{0j} is the standard intercept, β_{1j} is the standard slope coefficient, e_{ij} is the standard residual error term, i is the firm ($i = 1 \dots n$) and j is the country ($j = 1 \dots m$). Although we allow for more than one country in the analysis, the equation is formulated separately for each of them. If we were interested only in this relationship, we can estimate the m models separately, assuming different parameters for each country and a common intra-country residual variance. A linear 2-level model with explanatory variables at both firm and country levels emerges, if we let the intercept β_{0j} and slope β_{1j} to become random variables (and therefore relax the assumption on independence of the observations on each other):

(2) Level-1 linear model:

$$y_{ij} = \beta_{0j} + \beta_{1j} x_{ij} + e_{ij}$$

Level-2 model:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} z_j + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} z_j + u_{1j}$$

where z_j is the level-2 predictor and u_{0j} and u_{1j} are normally distributed residual terms for each level-2 equation, which are independent from the level-1 residual e_{ij} . Since the level-2 effects are identified by the subscript j , we have a hierarchical system of regression equations, where we are allowing each country to have a different average outcome (β_{0j}) and a different effect of the level-1 predictor on the outcome (β_{1j}). Although a different level-1 model is estimated for each country, the level-2 equation is defined for all of them.

¹⁰ Only one factor score with eigenvalue higher than one has been detected (other eigenvalues < 0.20), which explains 72.5% of the total variance (principal factors extraction method): i) Voice and Accountability (0.76), ii) Political Stability (0.62), iii) Government Effectiveness (0.92), iv) Regulatory Quality (0.88), v) Rule of Law (0.94), and vi) Control of Corruption (0.95); factor loadings in brackets.

By substituting β_{0j} and β_{1j} into the level-1 model and rearranging we can write the entire model in a single equation:

$$(3) \quad y_{ij} = \gamma_{00} + \gamma_{01}Z_j + \gamma_{10} x_{ij} + \gamma_{11}Z_jx_{ij} + (u_{0j} + u_{1j}x_{ij} + e_{ij})$$

where in brackets is the random part and the rest contains the fixed part of the model. The main differences of the 2-level model from the standard 1-level model are the inclusion of the higher-level predictor, the cross-level interaction term ($\gamma_{11} z_j x_{ij}$) and most importantly the random part of the model. As discussed by Goldstein (2003), the presence of more than one residual term makes the traditional estimation procedures such as ordinary least squares inapplicable and therefore specialized maximum likelihood procedures must be used to estimate these models.¹¹ For more details on these estimators see Raudenbush, et al. (2004).¹²

So far we have assumed that the dependent variable is continuously distributed. If the dependent variable is binary, we need to specify a non-linear multilevel model. For this purpose, we assume a binomial sampling model (the Bernoulli distribution) and use a logit link function to transform the level-1 predicted values. Only the level-1 part of the model differs from the linear case and the multilevel model can be delineated as follows:

$$(4) \quad \text{Level-1 logit model:}$$

$$E(y_{ij} = 1 | \beta_j) = \varphi_{ij}$$

$$\text{Log} [\varphi_{ij} / (1 - \varphi_{ij})] = \eta_{ij}$$

$$\eta_{ij} = \beta_{0j} + \beta_{1j}x_{ij}$$

Level-2 model:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}Z_j + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}Z_j + u_{1j}$$

where η_{ij} is the log of the odds of success, such as the propensity of a firm to introduce innovation. Although φ_{ij} is constrained to be in the interval (0,1), the logit transformation allows η_{ij} to take any value and therefore can be substituted to the structural model. From this follows that the predicted log-odds can be reversed to an odds by $\exp(\eta_{ij})$ and to the predicted probability φ_{ij} by $\exp\{\eta_{ij}\}/(1+\exp\{\eta_{ij}\})$. Moreover, there is no term for the level-1 residual in the model because for binary dependent variables the variance is completely determined by the mean and thus a separate error term is not estimated (for details see Luke 2004, pg. 55).

¹¹ Another reason why analysis of multilevel data with the ordinary multiple regression techniques does not work well is that the interaction term $u_{1j}x_{ij}$ indicates that the error differs with the predictor, which refers to heteroscedasticity in the standard level-1 regression model (Hox, 2002, pg 14).

¹² A common approach to control for the compositional effects is to ignore the random variability associated with the higher-level factors and include sectoral, regional or national dummies into the estimate. However, a dummy is a “catch-all” variable for which we can only speculate what it really represents, which is of a little help if the prime interest is in effects of the higher-level factors. After all, if these dummies significantly improve predictive power of the model, a multilevel analysis should be given priority.

Our aim is to explain firm's likelihood to innovate by factors operating at the firm and country levels. INNOV is the main dependent variable. Structural characteristics of firms SIZE, AGE, FA and the variables on firm's capabilities SKILL, ISO and WWW are the level-1 predictors, while the distance of the country where the firm is nested from the technological frontier GAP and the variables on various aspects of the national innovation system R&D, EDU, FIN, GINI and GOV are the level-2 predictors. Full specification of the model with a complete set of fixed and random effects is the following:

(5) Level-1 logit model:

$$E(\text{INNOV}_{ij} = 1 \mid \beta_j) = \varphi_{ij}$$

$$\text{Log} [\varphi_{ij} / (1 - \varphi_{ij})] = \beta_{0j} + \beta_{1j}\text{SIZE}_{ij} + \beta_{2j}\text{AGE}_{ij} + \beta_{3j}\text{FA}_{ij} + \beta_{4j}\text{SKILL}_{ij} + \beta_{5j}\text{ISO}_{ij} + \beta_{6j}\text{WWW}_{ij}$$

Level-2 model:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\text{GAP}_j + \gamma_{02}\text{R\&D}_j + \gamma_{03}\text{EDU}_j + \gamma_{04}\text{FIN}_j + \gamma_{05}\text{GINI}_j + \gamma_{06}\text{GOV}_j + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}\text{GAP}_j + \gamma_{12}\text{R\&D}_j + \gamma_{13}\text{EDU}_j + \gamma_{14}\text{FIN}_j + \gamma_{15}\text{GINI}_j + \gamma_{16}\text{GOV}_j + u_{1j}$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21}\text{GAP}_j + \gamma_{22}\text{R\&D}_j + \gamma_{23}\text{EDU}_j + \gamma_{24}\text{FIN}_j + \gamma_{25}\text{GINI}_j + \gamma_{26}\text{GOV}_j + u_{2j}$$

$$\beta_{3j} = \gamma_{30} + \gamma_{31}\text{GAP}_j + \gamma_{32}\text{R\&D}_j + \gamma_{33}\text{EDU}_j + \gamma_{34}\text{FIN}_j + \gamma_{35}\text{GINI}_j + \gamma_{36}\text{GOV}_j + u_{3j}$$

$$\beta_{4j} = \gamma_{40} + \gamma_{41}\text{GAP}_j + \gamma_{42}\text{R\&D}_j + \gamma_{43}\text{EDU}_j + \gamma_{44}\text{FIN}_j + \gamma_{45}\text{GINI}_j + \gamma_{46}\text{GOV}_j + u_{4j}$$

$$\beta_{5j} = \gamma_{50} + \gamma_{51}\text{GAP}_j + \gamma_{52}\text{R\&D}_j + \gamma_{53}\text{EDU}_j + \gamma_{54}\text{FIN}_j + \gamma_{55}\text{GINI}_j + \gamma_{56}\text{GOV}_j + u_{5j}$$

$$\beta_{6j} = \gamma_{60} + \gamma_{61}\text{GAP}_j + \gamma_{62}\text{R\&D}_j + \gamma_{63}\text{EDU}_j + \gamma_{64}\text{FIN}_j + \gamma_{65}\text{GINI}_j + \gamma_{66}\text{GOV}_j + u_{6j}$$

where there are seven level-1 fixed effects ($\gamma_{00} \dots \gamma_{60}$), six level-2 fixed effects for the intercept ($\gamma_{01} \dots \gamma_{06}$), thirty-six cross-level fixed effects ($\gamma_{11} \dots \gamma_{66}$) and seven random effects ($u_{0j} \dots u_{6j}$); of which γ_{00} is the estimated grand average of the log-odds of firms to innovate across countries, $\gamma_{10} \dots \gamma_{60}$ are the estimated averages of the firm-level slopes across countries, $\gamma_{01} \dots \gamma_{06}$ refer to the estimated effects of the country-level predictors on the log-odds of innovation, $\gamma_{11} \dots \gamma_{66}$ capture the cross-level interactions between the country-level predictors and the firm-level relationships, u_{0j} tells us that the intercept vary around the grand average between countries, and $u_{1j} \dots u_{6j}$ indicate that the slopes vary not only as a function of the predictors, but also as a function of a unique country effect.

As much as forty-eight fixed effects are outlined in the full specification of the model. For concerns about reduced parsimony, degrees of freedom, problems of multicollinearity and difficult interpretation of the parameters, it is not viable to estimate the full model, at least not in a sample with only thirty countries at level-2 of the model. Fortunately, there is a variety of specifications that can be estimated depending on the research question. For example, models with only the intercept as a function of level-2 predictors or models with only selected cross-level interaction terms can be estimated. Also models with random effects only for selected level-2 equations can be specified, although this might be difficult to justify conceptually. Admittedly the cross-level effects terms should be included only if there is a strong theoretical argument for the respective interaction effect to be significant (Hox, 2002). And we shall follow this advice in the following.

5. Econometric estimates

We analyse the bivariate logit 2-level model of innovation from bottom up. First, we consider only the level-1 predictors and let the level-2 effects to be random variables. Second, we examine the so-called “intercept-as-outcome” model, which includes the level-2 predictors only for the intercept. And finally, we estimate the so-called “slopes-as-outcomes” model, which relates the level-2 predictors to the intercept and slopes. For reasons outlined above, we refrain from estimating the full specification of the model and examine only selected cross-level interaction effects. Since the questions on product and process innovation have been asked separately and phrasing of the latter seems to be more intimately related to technological change, we run the estimates for INNOV as well as INNPDT and INNPCS dependent variables.¹³

To improve interpretability of the results, we standardize the firm-level predictors SIZE and AGE as well as all of the country-level predictors by deducting mean and dividing by standard deviation, so that these variables enter the estimation with mean of zero and standard deviation equal to one. Only the dummy explanatory variables are not standardized. Standardization of the variables implies that all of the predictors have meaningful zero-points, which greatly simplify meaning of the estimated parameters, as shall be seen below. Also the standardization procedure transforms the variables to a common scale of units of standard deviation, which allows us to directly compare magnitude of the estimated coefficients.

Table 2 provides the first set of results. We start by estimating the basic specification with only the firm-level predictors included in the model. Although there are no country-level predictors, the multilevel nature of the model is delineated by the fact that we allow the estimated firm-level intercept and slopes to vary across countries by including the random effects. Only six firm-level fixed effects ($\gamma_{00} \dots \gamma_{60}$) and six random effects ($u_{0j} \dots u_{6j}$) outlined in equation (5) are therefore estimated.

Let us first consider the estimate for INNOV. Size comes out as important explanatory factor for the likelihood of the firm to introduce product or process innovation, while age and foreign ownership does not seem to matter. SKILL, ISO and WWW are highly significant and with expected signs, which underlines the role of firm’s internal capabilities for innovation in developing countries (and confirms that the data provides reasonable information on these variables). A comparison of the estimated coefficients suggests that formal training has the highest effect.¹⁴

¹³ A specialized statistical software Hierarchical Linear and Non-linear Modeling (HLM) version 6.04 was used to estimate the equations. See Raudenbush, et al. (2004) for details on the estimation procedure.

¹⁴ Although one may suspect problems with multicollinearity between the firm-level predictors, Appendix 1 shows that this is not the case.

Table 2: Results of the basic model

	Dependent variable:		
	INNOV	INNPDT	INNPCS
<u>Level-1 fixed effects:</u>			
Intercept _{ij} (γ_{00})	0.244 (0.143)*	-0.392 (0.128)***	-0.540 (0.142)***
SIZE _{ij} slope (γ_{10})	0.190 (0.041)***	0.140 (0.035)***	0.205 (0.032)***
AGE _{ij} slope (γ_{20})	-0.027 (0.032)	-0.021 (0.034)	-0.054 (0.022)**
FA _{ij} slope (γ_{30})	-0.123 (0.077)	-0.120 (0.084)	-0.178 (0.083)**
SKILL _{ij} slope (γ_{40})	0.652 (0.070)***	0.506 (0.075)***	0.589 (0.071)***
ISO _{ij} slope (γ_{50})	0.300 (0.063)***	0.314 (0.081)***	0.230 (0.048)***
WWW _{ij} slope (γ_{60})	0.497 (0.051)***	0.472 (0.060)***	0.410 (0.047)***
<u>Level-2 random effects:</u>			
Intercept _{ij} (u_{0j})	0.591 (574.0)***	0.465 (411.1)***	0.577 (530.0)***
SIZE _{ij} slope (u_{1j})	0.030 (78.1)***	0.021 (78.3)***	0.014 (53.7)***
AGE _{ij} slope (u_{2j})	0.016 (62.6)***	0.022 (86.6)***	0.003 (35.6)
FA _{ij} slope (u_{3j})	0.038 (29.6)	0.092 (40.6)*	0.091 (49.9)***
SKILL _{ij} slope (u_{4j})	0.083 (68.2)***	0.115 (96.4)***	0.096 (83.8)***
ISO _{ij} slope (u_{5j})	0.050 (41.3)*	0.120 (75.2)***	0.008 (38.1)
WWW _{ij} slope (u_{6j})	0.025 (38.8)	0.051 (49.5)***	0.029 (38.6)
Index of dispersion	0.9824	0.9863	0.9819
Level-1 firms	15,113	15,155	15,127
Level-2 countries	30	30	30

Note: Non-linear unit-specific model with the logit link function; restricted maximum likelihood estimate; coefficients and robust standard errors in brackets reported for the fixed effects; variance components and chi-square in brackets reported for the random effects; *, **, *** denote significance at the 10, 5 and 1 percent levels.

To further interpret the results, as noted above, we need to transform the estimated coefficients from the log-odds back into their original units by using inverse of the logit function, which is the exponential function. For SKILL, ISO and WWW the conditional log-odds to innovate product or process is estimated at 0.652, 0.300 and 0.497 respectively. Since these are dummy variables, the estimate predicts that the probability to innovate is by 13.5 percentage points higher for a firm that provides formal (beyond “on the job”) training to its permanent employees, by 6.2 percentage points higher for a firm that follows the quality standards and by 10.3 percentage points higher for a firm that regularly uses Internet in its interactions with clients and suppliers; holding all other variables constant (hence marginal effects). If we combine these aspects of firm’s capabilities together, for a typical domestic-owned firm located in an “average” country (SIZE, AGE, FA and the random effects equal to zero) that jointly provides formal training, received ISO certification and uses Internet the predicted probability to innovate is 84.4%, while for the same firm without any of these capabilities the expected probability to innovate is only 56.0%. Firm’s capabilities appear to be therefore important for innovation.

Let us compare the results for INNOV with the estimates for INNPDT and INNPCS as the dependent variables. Not much has changed in the effect of the capability variables. The main difference is in the impact of age and foreign ownership on the likelihood of firms to introduce process innovation, which both came out with significantly negative coefficients. For age this result indicates that the advantage of newness prevails over the potential benefits from knowledge accumulated over time through learning by doing and other effects. Younger firms come out relatively more innovative because they must introduce new production when they actually launch the business. Also it well might be that the older firms developed routines and path-dependent trajectories that tend to hamper process innovation.

Using micro dataset from CIS-3 in the Czech Republic, Srholec (2005) showed that foreign affiliates tend to engage less in internal R&D compared to domestic-owned firms and Knell and Srholec (2004) found out that foreign affiliates are less likely to cooperate on innovation with partners in the Czech economy; all highly significant results even when controlling for a number of other factors. Our results based on a sample of other thirty countries behind the technology frontier suggest that foreign affiliates are by 2.5 percentage points less likely to introduce process innovation (marginal effect of the FA dummy). Despite the above cited outcomes from the Czech Republic, this is surprising, because foreign affiliates should be able to capitalize on technology accumulated by their foreign parents and other firms in the group (including their R&D spending abroad), which should make it easier for them to innovate. However, evidence from PICS dataset tells us the opposite at least as far as the country random effects are accounted for in a multilevel framework.¹⁵ It should be mentioned, moreover, that the coefficient for FA is also negative in the estimates for INNOV and INNPDT, although it is significant only at 15% and 20% respectively.

So far we have focused only on the fixed effects. Country-level random effects are reported in the lower part of the table.¹⁶ As outlined in the model, the error term is split into seven components. By far the largest random effect has been detected for the intercept, which refers to the unexplained variability of firm's innovativeness across countries. Also differences in the effect of SIZE and SKILL between countries have been found significant at conventional levels in all of the three estimates, while the other random effects are highly statistically significant at least in one of them. Overall the random part of the model confirms that there is a great deal of variability in the firm-level effects across countries, which shall be explained by the country-level predictors. National capabilities, institutions and/or policies seem to matter for the ability of firms to innovate and also for the effect of firm's own resources devoted to upgrading of their internal capabilities. Is it possible to explain these differences by specific aspects of the national system of production and innovation?

Since the residual term for the intercept turns out to be the most important, in the next step we aim to explain the intercept by the country-level predictors, but let the firm-level effects remain "unconditional". By adding into the model the six level-2 fixed effects for the intercept ($\gamma_{01} \dots \gamma_{06}$) outlined in equation (5), we test the hypothesis that

¹⁵ Note that the variable on foreign ownership does not come out significant at the conventional levels if the country-level residual terms are not included in the model.

¹⁶ Since the HLM (version 6.04) package assumes that the variances may not be normally distributed, a chi-square test of the residuals is performed (Raudenbush, et al. 2004).

the national characteristics influence the likelihood of firms to innovate. Results of the intercept-as-outcome model are presented in Table 3.

Table 3: Results of the intercept-as-outcome model

	Dependent variable:		
	INNOV	INNPDT	INNPCS
<u>Level-1 fixed effects:</u>			
Intercept _{ij} (γ_{00})	0.252 (0.107)**	-0.384 (0.101)***	-0.532 (0.096)***
SIZE _{ij} slope (γ_{10})	0.200 (0.042)***	0.146 (0.037)***	0.208 (0.033)***
AGE _{ij} slope (γ_{20})	-0.024 (0.032)	-0.023 (0.035)	-0.058 (0.022)**
FA _{ij} slope (γ_{30})	-0.101 (0.078)	-0.104 (0.088)	-0.181 (0.081)**
SKILL _{ij} slope (γ_{40})	0.636 (0.069)***	0.499 (0.075)***	0.581 (0.070)***
ISO _{ij} slope (γ_{50})	0.359 (0.062)***	0.325 (0.080)***	0.245 (0.048)***
WWW _{ij} slope (γ_{60})	0.490 (0.050)***	0.466 (0.059)***	0.414 (0.048)***
<u>Level-2 fixed effects:</u>			
GAP _j (γ_{01})	0.381 (0.109)***	0.360 (0.139)**	0.315 (0.101)***
R&D _j (γ_{02})	0.398 (0.102)***	0.335 (0.141)**	0.273 (0.136)*
EDU _j (γ_{03})	-0.056 (0.078)	-0.021 (0.102)	0.275 (0.095)***
FIN _j (γ_{04})	0.199 (0.073)**	0.208 (0.104)*	0.181 (0.072)**
GINI _j (γ_{05})	0.537 (0.064)***	0.544 (0.089)***	0.410 (0.074)***
GOVERN _j (γ_{06})	-0.255 (0.134)*	-0.154 (0.172)	-0.280 (0.144)*
<u>Level-2 random effects:</u>			
Intercept _{ij} (u_{0j})	0.346 (330.28)***	0.312 (320.39)***	0.280 (208.07)***
SIZE _{ij} slope (u_{1j})	0.033 (76.57)***	0.024 (77.41)***	0.015 (53.81)***
AGE _{ij} slope (u_{2j})	0.016 (62.34)***	0.024 (87.00)***	0.004 (35.47)
FA _{ij} slope (u_{3j})	0.028 (30.16)	0.081 (40.28)*	0.081 (50.10)***
SKILL _{ij} slope (u_{4j})	0.077 (67.71)***	0.111 (96.12)***	0.093 (83.36)***
ISO _{ij} slope (u_{5j})	0.032 (41.78)*	0.102 (75.28)***	0.006 (38.21)
WWW _{ij} slope (u_{6j})	0.020 (38.63)	0.047 (49.43)***	0.033 (38.76)
Index of dispersion	0.9865	0.9873	0.9836
Level-1 firms	15,113	15,155	15,127
Level-2 countries	30	30	30

Note: Non-linear unit-specific model with the logit link function; restricted maximum likelihood estimate; coefficients and robust standard errors in brackets reported for the fixed effects; variance components and chi-square in brackets reported for the random effects; *, **, *** denote significance at the 10, 5 and 1 percent levels.

Most of the country-level variables are significant explanatory factors of differences in the propensity of firms to innovate across countries; even if the firm-level effects

are taken into account in the multilevel framework.¹⁷ Opportunities of firms in late-comer countries for “innovation through imitation” by absorbing technologies from the technology frontier appear to be considerable.¹⁸ All else equal (to average) a firm in Peru, which is a country with the largest GAP in technology measured by the difference in PCT international patents per capita vis-à-vis the United States, has the estimated potential to innovate by 41.7 percentage points higher than the same firm located in Hungary, which is the most technologically advanced country in the sample. Needless to say, this great promise can be fully exploited only in environment that is conducive to technology diffusion.

A vital aspect of the national innovation system that is put forward by essentially every proponent of the concept is quality of the research infrastructure, which is represented in the estimate by the number of researchers in R&D per million people. As discussed above, professionals with research training who are able to understand, assimilate (and possibly generate new) technology are also in the centre of interest in the literature on national technological and absorptive capabilities. A key supporting role of the research infrastructure for innovativeness of firms is firmly backed by the facts. Firms nested in countries with most researchers per capita in the sample, such as Poland and Hungary, are estimated to be about 25 percentage points more likely to innovate than firms located in areas with the least developed research infrastructure; holding all other factors equal to average. And magnitude of the coefficients suggests that provision of indigenous researcher in the national innovation system is as much important for innovation as the opportunities for diffusion given by the technology gap.

Somewhat related aspect of the national innovation system is the general level of education in the population. However, the literacy rate does not come out significant in the estimates on INNOV and INNPDT, which suggests that this very broad proxy for human capital does not matter for the likelihood of firms to introduce product innovation. On the other hand, the EDU variable appears to be highly significant in the estimate on INNPCS. It seems that literate workforce to a considerable extent facilitates process innovation in firms. All else equal to average, a firm is estimated to introduce process innovation at around 60% in countries with almost full literacy, but only at 35% in India with the lowest levels of literacy (about 61% of the adult population). It is also interesting to note that the R&D variable is only weakly significant in the latter estimate, if the literacy rate is controlled for, which confirms that these two aspects of the national innovation system have very different effects on product as compared to process innovation.

Another aspect of the national environment that has been taken into account is the financial system. The FIN variable refers to domestic credit to private sector as % of GDP. It is supposed to reflect the extent to which financial institutions and markets are capable of mobilizing capital on a large scale (and for the private sector), which has been put forward as one of the central aspects of social capability by Abramovitz (see Fagerberg and Srholec, 2006 for more discussion). Although this variable may be

¹⁷ It should be noted that there does not seem to be a serious problem with multicollinearity between the country-level predictors (see Appendix 2).

¹⁸ As already noted above, the advantages of backwardness are likely to decrease non-linearly as the country approach the technology frontier, so that we have tested the GAP variables in logs, but the results were the same, so that for the sake of simplicity we keep the variable in the original scale.

rightly seen as a crude measure of access to finance because it reflects the extent rather than quality of the financial infrastructure (unfortunately only a very limited data is available for venture funding in developing countries that is arguably more relevant for innovation), it comes out significant in across the board. It might be also pointed out that easiness of access to credit may very much differ between large and small firms, but this is actually a kind of question that can be best investigated in the multilevel slope-as-outcome framework as shows below.

Social system, large public sector and therefore extensive redistribution of income is often put forward as the key ingredient of the Danish (or in general Scandinavian) system of innovation that facilitates learning in the society, particularly through labour market mobility, widely accessible and high-quality public education, life-long learning, etc. (Lundvall, 2002). Although this observation has been confirmed in a number of developed countries, our results show that this virtuous circle may not be easily applicable in the context of less advanced countries. The GINI index comes out with the most significant, the largest and positive coefficient among the country-level explanatory variables in all of the three estimates. In other words, inequality of income in the economy tends to be strongly positively associated with firms' propensity to innovate, which seems to confirm the prediction that extensive redistribution decreases private income from business and therefore reduces incentives for firms to innovate.

Obviously, one reason why relatively low income inequality seems to hamper innovativeness of firms in our sample is that there is no guarantee that money derived from taxes on the rich part of the population are spend wisely for provision of public goods that would facilitate innovation. All that matters is how money derived from high taxes is spent. A brief look at the data reveals that five countries in the sample with the lowest GINI are four transition countries (Hungary, Poland, Kazakhstan and Romania) and India, while on the other side of the spectrum are clustered countries from Latin America and Sub-Saharan Africa, which is telling. Scandinavia shows that well-functioning innovation systems are feasible in countries with extensive redistribution of income, but one needs a bunch of complementary (formal and perhaps even more importantly informal) institutions in place for this structure to work, which for example transition countries have not developed yet. Social capital and the quality of governance are the prime example of these complementary institutions. Since we do not have a robust measure of social capital in hand (at least not for this sample of countries), we investigate the role of governance.

Somewhat surprisingly, however, some aspects of what is generally perceived as "good governance" seems to have adverse effects on the frequency of innovation in developing countries, although the negative coefficient of the factor score based on the "Governance Matters" indicators from the World Bank comes out only weakly significant. Since this may seem to be a contra-intuitive result at the first sight, we have delved more deeply into this issue by testing explanatory power of various measures of governance proposed in the literature. It is not advisable to include the different indices of the Governance Matters indicators in the estimate along each other, because serious problems of multicollinearity would arise, but we can replace the GOV factor score by each of the sub-indices separately to test whether some of them are more significant than others. As already Schumpeter realized (1934, pp. 86-87): "...the reaction of the social environment against one who wishes to do

something new... manifests itself first of all in the existence of legal or political impediments...” It well might be that these forces manifest in some aspect of “governance” that impediments innovation. After all, a salient element of governance is given by the legal framework.

It comes out from this exercise that the only significant and negative coefficients are for the indexes of Government Effectiveness (-0.315**) and Rule of Law (-0.333***). If we look more closely at indicators that lie behind these variables, we find out that synonym of Government Effectiveness is “small government” for the World Bank. Hence a particular (neo-liberal) idea about what is “good” governance seems to be important for interpretation of the negative coefficient. As for the latter and even more significant negative coefficient, this result seems to conform to the observation by Schumpeter on the possibility of legal impediments to innovation, because strict enforcement of property rights seems to hinder diffusion of technology and therefore innovation, particularly as far as the “innovation through imitation” in developing countries is concerned.¹⁹

After the country-level predictors have been included in the estimates, the random effects for the intercept have almost halved (and more than halved in the estimate on INNPCS), which confirms that a sizeable part of the unexplained variance across countries has been accounted for; however these residual terms remain statistically significant at 1% level. Even more country-level explanatory variables can be thrown in the estimate to further reduce the error, but this leads into problems with multicollinearity (and do not decrease statistical significance of the error term), because the other relevant factors tend to be correlated to the incumbent explanatory variables. It actually proved to be difficult to find a variable discussed in the literature on innovation that would not be theoretically, conceptually and/or empirically correlated with research, education, finance, governance, inequality or even more to the technological gap.²⁰

At least partly the reason why the random effects for the intercept remain significant could be the relatively small number of countries in the sample, which constrains precision of the estimate. It is important to mention this reservation, even though we use the restricted maximum likelihood procedure, which is more robust to reduced degrees of freedom than the full maximum likelihood estimate and is therefore advisable to use in samples with small number of level-2 units (Goldstein, 2004). Apart from including data for more countries, which is not possible given the dataset in hand, there is little we can do about this. Furthermore, the chi-square square test of

¹⁹ Note that the “property rights” interpretation of the negative coefficient is supported by the fact that the “Property Rights” sub-index of the Heritage Foundation’s Index of Economic Freedom (-0.218**) comes out with similarly negative coefficient in this exercise (scale of this indicator has been reversed into increasing order, so that higher value implies more protection, while keeping its original range).

²⁰ Following the approach by Fagerberg and Srholec (2006), we attempted to use factor analysis on a larger set of the country-level variables (not just on the “Governance Matters” indicators) with the aim to detect several factors that would represent most of the underlying variance in the data. However, the number of variables that could be taken into account in this exercise is constrained by having only thirty countries in the sample. Note that the ratio between number of observations and variables in factor analysis should not be less than two to one and it is generally not advisable to use the method on a dataset with less than fifty observations. Although we have managed to extract several meaningful principal factors, these latent variables did not prove to reduce the error term more than the original variables, so that these results are not reported.

the residuals should be interpreted with caution because the variances are bounded at zero, so that their distributions are not normal and we also generally expect the residuals to be non-zero, so that the meaning of their statistical significance is not the same as for an ordinary variable (Luke, 2004, pg. 32). It is therefore more sensible to interpret (and compare between estimates) their sizes rather than their significance.²¹

Innovation may be less (or more) elastic to firm's size in countries with environment more conducive to innovation, or in other words the quality of the national innovation system may influence differently innovativeness of small and large firms. For example, internal R&D department may be too costly for many small firms. More opportunities to tap into external sources of knowledge in not too far distance may help to overcome this disadvantage of smallness in innovation. To further dive into these issues, we allow the country-level predictors to influence the slope of SIZE. By adding the corresponding interaction effects ($\gamma_{11} \dots \gamma_{16}$) outlined in equation (5), this "slopes-as-outcomes" model allows us to find out not only whether the country-level variables influence the likelihood of firm's to innovate, but also whether these higher-level factors affect the firm-level relationships between firm's size and innovativeness.

Our hypothesis is therefore that firms are differentially influenced by certain aspects of the environment depending on their size. A look at Table 4 reveals that these expectations are supported by the facts, because a number of significant interaction effects between SIZE and the country-level predictors have been detected. However, interpretation of the cross-level interaction terms is complex. It is useful to recall that the interaction refers to multiplying the variable, so that a negative value of the estimated coefficient means that with higher score on the country-level variables, the advantage of being large is smaller than predicted from the direct effects only.

A weakly significant interaction term has been detected between SIZE and GAP in the estimate for INNOV, so that there is some evidence that large firms are better positioned to exploit the opportunities for "innovation through imitation". It is not surprising, however, because what becomes imitated in this context comes from abroad and size should arguably matter for the ability of a firm to screen, understand and assimilate foreign technologies.

Another modestly significant cross-level effect appears between SIZE and EDU, which are also intertwined in the same direction, but only if the model is estimated separately for INNPDT and INNPCS. Large firms seem to benefit more from widespread literacy in the population. It is arguably easier to organize and manage innovation projects in large enterprises in countries with high literacy in the population, which facilitates communication through memos, written rules and routines and therefore allows for bureaucracy that is inevitable for organization of large firms. If we flip the argument, transaction costs to manage large firms with illiterate employees may be too high for efficient operation of the business. Although small firms may escape these limits by frequent face-to-face interaction between their employees, tacit rules, etc., this is not a viable mode of organization in a large business.

²¹ For this reason some statistical packages, such as R or S-plus, do not even report any significance tests for the random part of the model.

Table 4: Results of the SIZE slope-as-outcome model

	Dependent variable:		
	INNOV	INNPDT	INNPCS
<u>Level-1 fixed effects:</u>			
Intercept _{ij} (γ_{00})	0.246 (0.109)**	-0.392 (0.101)***	-0.541 (0.098)***
SIZE _{ij} slope (γ_{10})	0.183 (0.038)***	0.129 (0.032)***	0.196 (0.025)***
AGE _{ij} slope (γ_{20})	-0.026 (0.032)	-0.020 (0.034)	-0.057 (0.021)**
FA _{ij} slope (γ_{30})	-0.081 (0.077)	-0.097 (0.086)	-0.160 (0.086)*
SKILL _{ij} slope (γ_{40})	0.637 (0.068)***	0.503 (0.075)***	0.586 (0.069)***
ISO _{ij} slope (γ_{50})	0.318 (0.058)***	0.293 (0.081)***	0.237 (0.048)***
WWW _{ij} slope (γ_{60})	0.502 (0.049)***	0.475 (0.057)***	0.417 (0.048)***
<u>Level-2 fixed effects:</u>			
For Intercept _{ij} (β_{0j})			
GAP _j (γ_{01})	0.359 (0.107)***	0.375 (0.140)**	0.291 (0.118)**
R&D _j (γ_{02})	0.425 (0.101)***	0.313 (0.141)**	0.322 (0.135)**
EDU _j (γ_{03})	-0.071 (0.076)	-0.007 (0.105)	0.178 (0.091)*
FIN _j (γ_{04})	0.159 (0.070)**	0.194 (0.102)*	0.026 (0.093)
GINI _j (γ_{05})	0.608 (0.064)***	0.472 (0.091)***	0.538 (0.072)***
GOVERN _j (γ_{06})	-0.274 (0.149)*	-0.086 (0.166)	-0.278 (0.170)
For SIZE _{ij} slope (β_{1j})			
GAP _j (γ_{11})	0.065 (0.034)*	0.024 (0.026)	0.030 (0.041)
R&D _j (γ_{12})	0.015 (0.052)	-0.043 (0.039)	-0.023 (0.045)
EDU _j (γ_{13})	-0.001 (0.019)	0.043 (0.017)**	0.051 (0.024)**
FIN _j (γ_{14})	0.111 (0.020)***	0.012 (0.019)	0.103 (0.031)***
GINI _j (γ_{15})	-0.129 (0.024)***	-0.115 (0.017)***	-0.090 (0.019)***
GOVERN _j (γ_{16})	0.033 (0.037)	0.114 (0.019)***	0.014 (0.025)
<u>Level-2 random effects:</u>			
Intercept _{ij} (u_{0j})	0.359 (336.17)***	0.315 (310.75)***	0.295 (221.24)***
SIZE _{ij} slope (u_{1j})	0.022 (47.48)***	0.017 (56.84)***	0.008 (30.77)
AGE _{ij} slope (u_{2j})	0.016 (62.30)***	0.023 (86.73)***	0.003 (35.44)
FA _{ij} slope (u_{3j})	0.025 (30.19)	0.092 (40.03)*	0.099 (50.10)***
SKILL _{ij} slope (u_{4j})	0.076 (67.68)***	0.112 (96.07)***	0.090 (83.33)***
ISO _{ij} slope (u_{5j})	0.035 (41.50)*	0.103 (74.87)***	0.007 (38.05)
WWW _{ij} slope (u_{6j})	0.021 (38.66)	0.043 (49.43)**	0.036 (38.83)
Index of dispersion	0.9866	0.9879	0.9879
Level-1 firms	15,113	15,155	15,127
Level-2 countries	30	30	30

Note: Non-linear unit-specific model with the logit link function; restricted maximum likelihood estimate; coefficients and robust standard errors in brackets reported for the fixed effects; variance components and chi-square in brackets reported for the random effects; *, **, *** denote significance at the 10, 5 and 1 percent levels.

As could be expected also the significant interaction term between SIZE and FIN has a positive sign, which indicates that large firms are in a better position to benefit from more developed financial systems. It is well-known that large firms have generally better access to finance from banks and therefore tend to benefit more from availability of credit. Unfortunately, we do not have any variable in hand that would capture the extent of programs for provision of loans directed to small and medium enterprises that is often established in countries with the most developed financial systems, and which should interact negatively with the size of firms.

Again the GINI coefficient appears to be highly significant across the board, in contrast to the positive direct effect on the intercept, however, the interaction term with SIZE comes out negative. At the first glance, it might seem surprising that it is easier to innovate for smaller firms in countries with less equal distribution of income, or in other words that inequality of income tends to hinder innovation in large firms. A common sense suggests that since the richest people tend to be the owners of large enterprises, their innovative efforts should be adversely affected by progressive tax system. However, this seems to be only one (and the less important) side of the story.

First, more equalitarian societies have larger public sector and tend to maintain more government subsidies/intervention in the economy. Large firms are predicted to be more innovative in this environment because they typically find themselves in a better position to lobby for state subsidies. A flipside is that large firms may need to substitute their own resources for public services that are tend to be provided in countries with higher taxation (and redistribution of income), but may not be available in countries with limited public sector. Moreover, social systems are more developed in equalitarian societies, but social support typically do not flow into hands of owners of small and medium size enterprises, at least not those who are innovative and therefore profitable. Hence in countries with extensive redistribution these entrepreneurs tend to be taxed more but do not gain equally much from the social system.

Second, it is likely that countries with less equal distribution of income suffer more from poverty and the plethora of social problems attached to it tend to more severely hinder innovation in large firms. For example, extreme inequality of income (and/or poverty) propels social unrest, strikes, etc. and logically those with larger stakes, suffer more losses, which implies adverse effects on innovative efforts of large firms. Also consider that extreme inequality of income in many developing countries reflects underdeveloped middle class, which tend to grow from a prosperous sector of small and medium enterprises. A relatively low tax on high personal income motivates people to start their own business and/or motivates owners of small firms to engage in risky innovative projects with prospects of high payoff and therefore limited redistribution of personal income makes innovation in small firms more likely. Again this negative interaction term shows how complex is the link between inequality of income and innovation in developing countries and that it should be interpreted in a broader context (and preferably in a dynamic framework if data permits).

Another important insight from estimate of the slopes-as-outcome model is that the GOV factor score on the “Governance Matters” indicators comes out with highly significant and positive interaction with SIZE in the estimate for INNPDT. A small

firm in country with relatively weak governance, such as for instance more “flexible” adherence to the existing property rights, is predicted to be more likely to introduce product innovation compared to a firm of the same size located in a country with strong governance. Large firms are the winners of the past, which capitalize on institutions that cement their strong position. A flipside is that a strict adherence to property rights may hinder structural changes driven by innovation in small firms, which is actually reassuring for our previous “Schumpeterian” interpretation of the GOV coefficient for the intercept.

Not much has changed in the country-level effects for the intercept part of the model, except in the last estimate for INNPCS. After the cross-level interaction terms with SIZE have been included, the effect of EDU on the intercept became much less significant and smaller and the effect of FIN on the intercept even turned out to be insignificant at the conventional levels, which confirms that the interaction with size of the firm is essential to understand nature of these effects. Similarly to the intercept-as-outcome model, not much has also changed in the effects of the level-1 predictors, which are highly robust to inclusion of the country-level predictors.

A look at the random part of the model reveals that these cross-level effects had mixed success in improving explanatory power of the model. In the estimates for INNOV and INNPDT the random effects for SIZE decreased a bit but remained significant. Only in the estimate for INNPCS this random effect decreased substantially to values very close to zero and ceased to be statistically significant, which confirms that the cross-level interaction terms explained most of the unmodeled cross-country variability in the effect of scale on process innovation.

Another diagnostic measure of multilevel models that has not been discussed yet is the so-called index of dispersion. Although logit multilevel models do not have a separate term for the level-1 error, we can calculate a level-1 error variance scaling factor that measures the extent to which the observed errors follow the theoretical binomial error distribution (Luke 2004, pg. 57). Index of dispersion equal to 1 indicates perfect fit between the observed errors and the theoretical assumptions. A significant over- or under-dispersion indicates model misspecification, the presence of outliers or the exclusion of an important level in the model. Less than 5% dispersion is usually seen as satisfactory. The index of dispersion is very close to unity, which confirms that the estimates do not suffer from a major problem.

6. Conclusions

The purpose of this paper was to illustrate how empirical research on innovation can benefit from multilevel modeling. Much research has been directed towards developing conceptual basis for analysis of innovation recently; however methodology of empirical analysis on innovation does not match advanced at this front. Multilevel modeling allows us to investigate research question about innovation in a proper and concise way that could not be examined otherwise. Using the multilevel approach we have shown that it is possible to use quantitative econometric methods to test various hypotheses on the effects of the national environment, such as various aspects of the national innovation systems, on the likelihood of firms to innovate. Multilevel modeling therefore appears to be promising new element in the

tool box of research on innovation systems, which allows us to formally test the complex predictions of the contextual theories of innovation.

A typical approach is to ignore hierarchical data clustering is using only the micro data (and control for sectoral and spatial dummies) or either to conduct the analysis with data only at a higher hierarchical level, such as cross-country regressions. Although there are many relevant hypotheses that are within any of the levels of analysis, there is a host of issues that require a look at relations between the various levels. Arguably this “unit of analysis” problem might be elegantly resolved, at least in empirical research, by explicit multilevel modeling that would use micro data to study the interaction between firms and their surroundings, such as sectoral, regional and national innovation systems.

It should be noted that there is a variety of specifications of multilevel models that can be estimated depending on the research question. A straightforward extension of the 2-level model is to consider a more complicated hierarchical structure. It is possible to specify models with more than 2 levels (for example 3-level models with firms in regions within countries) or so-called cross-classified models with 2 dimensions at level-2 (such as firms cross-classified in industries and countries). As more extensive micro datasets become available for research on innovation, these more complicated models should become viable to estimate in a not too distant future.

At last but not least, policy makers should understand and utilize the multilevel perspective if they are to be successful at promoting innovativeness of firms. It comes out from the analysis that smaller firms are affected differently by various aspects of national innovation systems as compared to large firms. A reasonable strategy to catalyze innovation in small and medium-size firms therefore seems to be to improve the framework conditions that are particularly relevant for them. No doubt we need to improve our understanding of the interdependence among different levels of analysis to design more complex and comprehensive innovation policies.

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Appendix 1: Correlation matrix between the firm-level variables (15,113 observations)

	INNOV	INNPDT	INNPCS	SIZE	AGE	FA	SKILL	ISO	WWW
INNOV	1.00								
INNPDT	0.75	1.00							
INNPCS	0.69	0.37	1.00						
SIZE	0.19	0.15	0.18	1.00					
AGE	0.05	0.07	0.04	0.18	1.00				
FA	0.06	0.05	0.05	0.26	-0.05	1.00			
SKILL	0.28	0.22	0.26	0.36	0.08	0.14	1.00		
ISO	0.14	0.13	0.12	0.42	0.13	0.17	0.30	1.00	
WWW	0.20	0.18	0.18	0.30	0.14	0.10	0.26	0.28	1.00

Appendix 2: Correlation matrix between the country-level variables (30 observations)

	GAP	R&D	EDU	FIN	GINI	GOV
GAP	1.00					
R&D	-0.51	1.00				
EDU	-0.04	0.52	1.00			
FIN	-0.37	-0.07	0.11	1.00		
GINI	0.31	-0.52	-0.09	0.13	1.00	
GOV	-0.54	0.51	0.32	0.39	-0.11	1.00