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Risk capital, private credit, and innovative production

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Abstract. Although ideas production plays a critical role for growth, there has been only a modicum of research on the role played by financial forces in fostering new inventions. Drawing on Schumpeterian growth theory, this paper tests the roles of risk capital and private credit in stimulating knowledge production. Using panel data for 77 countries over the period 1965–2009, we find that countries with more developed financial systems are more innovative. A stronger patent protection framework, on the other hand, curbs innovative production. JEL classification: O30, O40

Capital de risque, crédit privé et production innovante. Même si la production d'idées joue un rôle critique dans la croissance, il y a eu peu de recherche sur le rôle joué par les forces financières dans la promotion de nouvelles inventions. En se basant sur la théorie schumpéterienne de la croissance, ce texte calibre les rôles du capital de risque et du crédit privé dan s la stimulation de la production de connaissance. Utilisant des données de panel pour 77 pays pour la période 1965–2009, on découvre que les pays qui ont des systèmes financiers plus développés sont plus innovateurs. Un cadre plus robuste de protection des brevets, d'autre part, ralentit la production innovante.

1. Introduction

In the R&D-based growth models of Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992) and Aghion and Howitt (2009), innovative efforts are the key driver of growth. Despite its critical role for growth, there has been very little research examining the factors that are responsible for new inventions and, particularly, the role played by financial forces in fostering them.

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Innovation of products and adoption of new technology are costly, requiring an efficient financial system that facilitates the provision of capital to finance ground-breaking projects and pioneering firms. Moreover, although studies have demonstrated that financial development is beneficial for economic growth, little is known about how innovative production responds to it.

In their seminal study, Rajan and Zingales (1998) show that industries that are more reliant on external funds tend to grow faster in economies with more developed financial systems. Building on this research, a number of recent studies have shown that financial development has a disproportionately positive effect on innovation by small firms and their larger counterparts (see Guiso, Sapienza, and Zingales 2004; Aghion, Fally, and Scarpetta 2007; Beck et al. 2008, among others). In particular, Aghion et al. (2007) show that greater access to external finance promotes the entry of new firms and their post-entry growth. A key implication of their results is that a well-developed financial system is crucial to support their early-stage growth and facilitates the 'creative destruction' process. Given that smaller or newer firms tend to be more innovative and less risk averse than the incumbents, the results of these studies suggest that financial development has great potential in promoting innovations. As Schumpeter (1911) contends, financial intermediaries stimulate the rate of technological innovation by identifying potential entrepreneurs with a higher probability of success in inventing new goods and production processes. Moreover, Hicks (1969) notes that financial market improvements that enhanced capital market liquidity were the primary cause of the British Industrial Revolution.

The above discussion indicates that financial development plays a potentially important role in stimulating ideas production. However, although a sizable literature has shown that financial development is a significant determinant of economic growth (see Levine 2005 for a survey), there is little empirical analysis exploring the impact of financial development, including the development of venture capital markets, on the production of new ideas – a key channel through which financial forces can have an impact on economic growth. Using data for 44 countries over the period 1973–2005, Ang (2011) highlights that financial development facilitates the accumulation of knowledge creation in the steady state. The present paper builds on this research. However, rather than focusing on analysing the long-run relationship between financial development and ideas accumulation where the stock of ideas is assumed to converge to a stochastic balanced growth path, we examine a broader cross-section of countries and test whether financial development influences the production of new ideas. Furthermore, we also examine the influence of venture capital and initial public offerings (IPOs) on ideas production, given that risk capital is targeted at young and innovative firms, thus providing a test on whether ideas production is stimulated by the provision of funding for risky projects conducted by innovative firms. Our research complements the microeconomic evidence of Dabla-Norris, Kersting, and Verdier (2010), who find that the effect of innovation on firms' productivity is significantly larger in countries with more developed financial systems.

In sum, we ask the question: what is the role of financial development in facilitating technological innovation? Since innovative activity is often risky and capital intensive and therefore requires financial systems with mechanisms for reducing financial market imperfections, it can be expected that countries with more developed financial systems tend to be technologically more advanced. Accordingly, we use aggregate data for 77 countries over the period 1965–2009. The empirical analysis is based upon a Schumpeterian ideas production function, which is extended to allow for the effect of financial development, including development of venture capital markets and IPOs, on innovative output. We control for intellectual property protection, educational attainment, the capital-output ratio, the world stock of knowledge, the technology gap, and international knowledge spillovers in the regressions. On the whole, our main results strongly support the view that financial development plays a positive and significant role in stimulating ideas production or knowledge creation. Furthermore, we find that the depth of risk capital markets, along with the overall development of financial systems, promotes ideas production.

The rest of the paper is organized as follows. The next section discusses the theories of financial development and innovations and suggests possible channels through which financial development may influence innovative activity. It also sets out the analytical framework underlying our empirical modelling strategy discussed in section 3. Data and construction of variables are described in section 4. Section 5 presents and discusses the results. Section 6 examines the roles of venture capital and initial public offerings and tests whether they have an independent effect on innovations. Section 7 concludes.

2. Financial development and innovations

There are several channels through which financial development can potentially influence innovative activity. Aghion, Howitt, and Mayer-Foulkes (2005) highlight the fact that a developed financial system facilitates the adoption of new products or processes and leads to an improvement in productive efficiency, which allows firms or countries to catch up to the frontier more quickly. In their model, an innovator can avoid repaying his creditors by hiding the outcomes of successful innovations. The hiding costs, however, are positively related to the level of financial development. Hence, innovative activity will be constrained if a country is underdeveloped financially. Similarly, in the Schumpeterian growth models with credit constraints developed by Aghion and Howitt (2009), financial development results in lower screening and monitoring costs, thus mitigating agency problems and increasing the frequency of innovations.

In the model developed by Aghion et al. (2009), catching up to the technology frontier by the laggards depends on technical collaboration between foreign investors, who are familiar with frontier technology, and domestic entrepreneurs, who are familiar with the local conditions to which the technology must be adapted. Domestic savings are influential for the adaption of frontier technology because it allows the domestic entrepreneur to take a stake in the joint project, thus mitigating the agency problems that would otherwise discourage the foreign investor. It follows that innovative growth depends on domestic savings, given that the provision of domestic funds encourages this cooperative joint venture through reducing agency problems. Thus, financial development also has the potential of indirectly stimulating innovative production or knowledge creation by affecting domestic savings (see Mavrotas and Son 2008).

The important role of financial development in the process of innovation has also been highlighted in the product innovation model of de la Fuente and Marín (1996). Risk aversion and private information in R&D activity lead to a moral hazard problem, and this makes innovative activity unattractive to risk-averse entrepreneurs. This problem, however, can be mitigated through improved monitoring by financial systems, which allows intermediaries to offer better insurance terms. In a similar vein, the product variety model of Blackburn and Hung (1998) proposes that firms have incentives to hide successful R&D projects to avoid repaying their loans. Moral hazard gives rise to the enforcement of incentive-compatible loan contracts through costly monitoring systems. In their model, the development of financial systems allows financial intermediaries to diversify among a large number of projects, thus significantly reducing delegation costs. The lower costs of monitoring spur technological development and ideas production. Similarly, in the financial endogenous growth model developed by Morales (2003), financial intermediation is growth enhancing, because it promotes innovative production through the introduction of contracts that are designed to reduce moral hazard problems. Such a monitoring technology induces researchers to exert a higher level of effort and increases the probability of success for the research project.

In a recent paper, Buera, Kaboski, and Shin (2011) argue that financial underdevelopment distorts the allocation of capital among incumbents and potential innovative entrants. They show that an underdeveloped financial system misallocates patenting activity by delaying the entry of productive but poor individuals, whereas incompetent but rich entrepreneurs remain in business. As a result, incompetent but wealthy entrepreneurs stay in business, whereas talented but poor individuals are prevented from participating until they are able to self-finance the needed capital. Furthermore, they show that financial frictions lead to higher relative prices of manufactured goods and lower capital rental rates and wages in equilibrium. Consequently, this results in too few entrepreneurs and oversized establishments in manufacturing and in too many entrepreneurs and undersized establishments in services. Their model calibrations show that misallocation of capital due to financial distortions is responsible for 90% of the effect of financial frictions on the service sector TFP.

Thus far we have referred to an 'underdeveloped' financial system without detailing its characteristics – what it actually means in practical terms and how it impacts materially on innovation. An underdeveloped financial market operates under a legal system that is generally shallow, is characterized by overregulation of financial transactions, and where financial contracts are poorly enforced (Valderrama 2008). Poor enforcement of financial contracts raises the cost of borrowing, renders it difficult to access loans, increases the spreads between borrowing and lending rates, and depresses the domestic rate of return to savers. New and innovative firms with restricted capital bases find it particularly difficult, if not impossible, to obtain loans in underdeveloped financial markets (Lingelbach, Vina, and Asel 2005). Furthermore, large, time consuming and expensive legal procedures are required for lenders to recoup their investment when debtors default (Acemoglu, Johnson, and Robinson 2005). Other examples of poor contract enforcement also occur when governments grant blanket debt amnesties for large groups, such as farmers and large manufacturing producers in times of difficulties. Emerging-market firms also find it hard to borrow internationally to finance domestic investment because lenders may fear that their loan contracts will not be enforced, much as happened during the Russian crisis of 1996, the Asian crises of 1997, and the Argentinean default of 2001, when individuals and firms in those countries were not allowed access to their savings (Valderrama 2008).

Countries with underdeveloped financial systems generally have shallow capital markets, meaning that the domestic capital market is not sufficiently liquid to raise capital for investment in R&D, residential buildings, structures, machinery, and non-residential buildings. An underdeveloped financial system does not have sophisticated financial contracts, rendering the diversification of risks difficult and, ultimately, depressing banks' willingness to lend. In many developing countries the funding supply curve is often so inelastic that even governments cannot rely on bond issuances in the domestic market to raise capital but, instead, have to rely on foreign donors and lenders (Lee 1997). Furthermore, savers in countries with underdeveloped financial markets do not have access to good investment opportunities such as pension schemes, investment in domestic and foreign stocks, and so on, but rather have to rely on bank deposits or deposits with small-holding money lenders with low or no interest. A further implication of this is that these markets tend to be inadequate in channelling savings to profitable opportunities. Often, lending is channelled to large corporations with established relationships with banks, while small innovative and productive firms are often denied access to formal finance (Valderrama 2008).

3. Empirical framework

The previous section suggests that financial underdevelopment can be detrimental for innovative activity because of the moral hazard problems in fulfilling contractual obligations, the absence of a liquid capital market to raise capital, high costs of capital, the preferential treatment of mature and established firms, and cumbersome and lengthy bureaucratic procedures associated with borrowing. To explore the relationship between financial forces and innovative production, we incorporate the role of financial development into the ideas production process and obtain the following econometric specification:

$$\ln \dot{A}_{i,t} = \beta_{0i} + \beta_{1i} \ln \dot{A}_{i,t-1} + \beta_{RI} \ln RI_{i,t} + \beta_{A} \ln A_{i,t} + \beta_{FD} \ln FD_{i,t} + \gamma' C_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t}, \tag{1}$$

where $\dot{A}_{i,t}$ is the amount of new knowledge or ideas produced (i.e., the inventive output), $RI_{i,t}$ is research intensity, $A_{i,t}$ is the domestic stock of knowledge or ideas, $FD_{i,t}$ is a financial development indicator, $C_{i,t}$ is a vector of control variables described below, which are all expressed in logs, μ_i is an unobserved country-specific effect, δ_t is a time-specific effect, $\varepsilon_{i,t}$ is a stochastic error term, and i and t represent country and annual periods, respectively. The signs of β_{RI}, β_A, and β_{FD} are expected to be positive. We are interested mainly in testing whether the coefficient of financial development, β_{FD}, on growth is statistically and economically significant. Equation (1) is estimated using unbalanced panel data for 77 countries over the period 1965–2009. Definitions and sources of data are detailed in the data appendix.

Equation (1) underscores the importance of finance in determining the rate of development of new technology and scientific knowledge. However, the production of ideas is a complicated process that can also be influenced by other external factors. Moreover, ideas production and financial development may be driven simultaneously by a third factor. To address these concerns, we control for the effects of the degree of patent protection, educational attainment among the adult population, the capital-output ratio, the world stock of knowledge, distance to the frontier, international knowledge spillovers through geographic proximity, venture capital, and IPOs.

Patent protection may provide adequate incentives for the creators of new technology to innovate, through protecting their future profits, thereby stimulating technological inventions. O'Donoghue and Zweimüller (2005) argue that greater patent protection facilitates the accumulation of knowledge, given that the information in patent claims is available to future innovators or that patent policy is also useful in counteracting entrepreneurs' inclination to pursue suboptimal innovations. However, patent protection may also hamper innovations. Helpman (1993), for example, shows that stronger protection lowers the rate of innovation in the long run, as firms tend to produce old-technology products that remove resources from innovative activity. Furthermore, Boldrin and Levine (2008) argue that patent protection can be used as a tool to hurt competitors, as the granting of a monopoly over a new invention may block the development of another equally useful innovation, thereby retarding technological development. Since innovators' property rights can still be protected even without patents and copyrights, they argue that intellectual monopoly is an unnecessary evil.

The world knowledge stock, distance to the frontier, and international knowledge spillovers through geographic proximity are also included as control variables to account for the fact that these external influences may affect domestic ideas production. The world stock of knowledge is included as a control variable, since international knowledge may transmit freely across borders (see Bottazzi and Peri 2007). To the extent that ideas already discovered elsewhere can be used to generate further knowledge, the production of new ideas is proportional to the world stock of knowledge. Distance to the frontier is included, as Bernard and Jones (1996) argue that changes in innovative activity may also depend on technological catch-up. Countries that are relatively backward can grow faster by utilizing technologies developed in the leading country. Thus, the further away a country is from the frontier, the greater potential it has to grow faster through higher production of new ideas.

Finally, international transmission of knowledge through geographic proximity is allowed for because the exchange of ideas may be eased by greater proximity and knowledge spillovers tend to cluster geographically, according to Keller (2002). He argues that with greater proximity people are more able to create knowledge through interaction (e.g., conferences, speeches, visits, and seminars) and adopt and assimilate knowledge that has been developed elsewhere. Moreover, countries with similar growth and income experiences tend to cluster geographically and often have close trade links, similar cultures, and frequent movement of labour across borders.

Special attention is given to venture capital and IPOs in promoting innovations. Although development of capital markets maybe captured, to some extent, by the measures we use for financial development, there are reasons to believe that they are particularly influential for innovations, since venture capitalists target only new and innovative companies. It is well established that the incumbents are often less innovative than new companies (Hobijn and Jovanovic 2001). The key characteristics of technological revolutions include a surge in innovative activity, a marked increase in the inflow of new and innovative firms, and a higher exit rate (Hobijn and Jovanovic 2001). However, the entry rate of these new companies is likely to be contingent on the access to risk capital. The exit rate is high among young and innovative companies, which often have little or no credit history and have difficulty in borrowing from the traditional banking system. The venture capital market, which specializes in risky but potentially promising capital investments, provides a useful alternative to obtain funds.

The relationship between financial development and ideas production may, to some extent, be driven by reverse causality since an innovative economy may induce, through needs, the creation of a deeper financial system to ensure efficient allocation of resources. In other words, an innovative environment may induce financial intermediaries to create financial instruments to accommodate the need for finances among new and established innovative firms. In the literature, it is common to use legal origins and creditor rights as instruments for financial development (see, e.g., La Porta et al. 1997; Beck, Levine, and Loayza 2000). In a panel framework, however, the drawback of using these instruments is that they are time invariant. Given that it is incredibly difficult to find good time-varying instruments, external instruments are rarely used in the literature on growth and financial development. Instead, equation (1) is estimated using the one-step system GMM estimator of Arellano and Bover (1995). Bond, Hoeffler, and Temple (2001) and Durlauf, Johnson, and Temple (2005) argue that the system GMM estimator is the preferred approach for estimation of empirical growth models because of its superior ability in exploiting stationarity restrictions. This technique has been widely used to deal with unobserved heterogeneity and endogeneity bias in estimation.

The system GMM estimator is designed for dynamic panel analysis, which embodies the assumption that some regressors may be endogenous in the data-generating process (Arellano and Bover 1995; Roodman 2009). Hence, the use of this dynamic panel estimator has an added advantage in that it does not just control for endogeneity of financial development but also for all other regressors. In particular, Bond, Hoeffler, and Temple (2001) note that a major strength of the system GMM estimator is its ability to yield consistent parameter estimates even in the presence of endogenous regressors. Specifically, internal instruments based on previous realizations of the endogenous regressors are used. This follows from the assumption in the data-generating process that all regressors are weakly exogenous, implying that unanticipated shocks to the production of new ideas do not affect current regressors, including, in particular, financial system development (see Beck, Levine, and Loayza 2000).

Furthermore, educational attainment and the capital-output ratio are included as additional control variables to alleviate potential endogeneity problems, as they may simultaneously impact ideas production and financial development. Educated individuals who are not accounted for among R&D researchers may jointly enhance innovations and facilitate development of the financial system. Sophistication of the financial system often requires an educated labour force with a deep understanding of finance to develop new and more sophisticated financial instruments. Similarly, a more capital-dependent economy, as measured by the capital-output ratio, is likely to produce more ideas, because capital is often required to generate new ideas through experiments outside and inside labouratories. Experimental equipment requires a well-developed financial system to fund its acquisition.

4. Data and construction of variables

The inventive output is measured by patents applied for by domestic residents, following the literature on ideas production (see, e.g., Kortum 1993; Madsen 2008; Ang 2011; Ang and Madsen 2011). Given that the most valuable and commercially viable ideas are patented, patent counts provide a reasonable measure of the number of innovations. However, patent data also suffer from some shortcomings in the sense that not all ideas are patented and individual patent counts do not reflect the economic value of patents. The number of patents applications rather than patents granted is chosen as our preferred indicator of innovative output, since the granting frequency and the time lag between filing and approval or rejection varies substantially over time and between countries (Griliches 1990). However, to ensure that the results are not driven by the use of patent applications, patents granted to residents are also used in the robustness checks below. The case for using patents granted is that they have passed the review process and, as such, are better able than patent applications to capture original inventions.

The stock of inventive output or knowledge (A_t) is constructed based on the number of domestic patents applied for ($\dot{A}_t$). Data of the first available year for each country are used to get as precise a measure as possible of the knowledge stock in 1965. The initial knowledge stock is estimated to be $A_{i0} = \dot{A}_{i0}/(\delta + g)$, where the depreciation rate is assumed to be 15% and g is the average growth in number of patents filed by domestic residents over the period considered. This gives the steady-state stock of ideas in the standard neoclassical growth models. Patent stock is then computed using the perpetual inventory method with the same depreciation rate.

R&D intensity, RI_{it}, is measured as the ratio of R&D expenditures to GDP. Although R&D activity can also be entered in levels according to semi-endogenous growth theories (see, e.g., Jones 1995), a new strand of literature has consistently found support for the Schumpeterian growth models of Peretto and Smulders (2002), Aghion, Howitt, and Mayer-Foulkes (2005), and Aghion and Howitt (2005), where growth can be better explained by research intensity rather than the levels or growth rates of R&D (see Ha and Howitt 2007; Madsen, Ang, and Banerjee 2010a, b; Ang and Madsen 2011). Some of the countries in the sample have only a few observations of R&D data over the sample period, especially the low-income countries. We have therefore included only countries for which R&D data are sufficiently available.

Financial development (FD_{it}) is measured using the ratio of private credit to GDP (see, e.g., Demetriades and Hussein 1996; Arestis and Demetriades 1997; Levine 2005; Ang and McKibbin 2007; Beck, Demargüç-Kunt, and Levine 2007; Baltagi, Demetriades, and Law 2009). Private credit includes total lending extended by financial intermediaries to the private sector. It excludes credit issued to the public sector or state-owned enterprises and issued by central banks and development banks. Beck, Demargüç-Kunt, and Levine (2007), among others, argue that this is a more precise measure of financial development compared with alternative indicators such as the ratio of monetary aggregates to GDP or the ratio of commercial bank assets to commercial bank plus central bank assets, which are often used in the literature on financial development. Alternative indicators are considered in the robustness checks, including M3/GDP, stock market shares traded / GDP, stock market capitalization / GDP and stock market turnover ratio (i.e., the value of total shares traded over stock market capitalization).

The patent rights index compiled by Ginarte and Park (1997) and Park (2008) is used as a measure of patent rights protection. The index covers five dimensions:

(1) patentability of various kinds of inventions, (2) membership in international patent arrangements, (3) provisions for loss protection, (4) enforcement mechanisms, and (5) duration of the patent term. Each dimension is assigned a value ranging from zero to one. The unweighted sum of these five values provides an indication of the overall level of intellectual property rights protection, with higher values reflecting greater levels of protection. Annual series are obtained by interpolation and extrapolation, since the data are available only for every five years to 2005. Distance to the frontier is measured by the ratio of the technology leader's patent stock to the patent stock of the country under consideration. The technology frontier is determined by the country having the highest accumulated patents in the world at a particular time, which in most cases turns out to be the U.S. The world stock of knowledge is measured as the sum of all patent stocks across the world, excluding the country in question.

Knowledge spillovers through the channel of geographical proximity between trade partners (IKS_{it}^{prox}) are captured by equation (2), following the approach of Ang and Madsen (2012), in which knowledge spillovers are proportional to the square root of the *inverse* relative geographical distance

$$IKS_{it}^{prox} = \sum_{j=1}^{77} \sqrt{\frac{TD_i}{D_{ij}}} DS_{jt}, \quad i \neq j, \tag{2}$$

where D_{ij} is the geographical distance in kilometres between the capital city of country i and the capital city of country j and TD_i is the sum of geographical distance between the capital city of county i and the capital cities of all other countries. Thus, the ratio $\frac{TD_i}{D_{ij}}$ reflects the geographical proximity between country i and country j. A higher value of the ratio is expected to carry a larger weight of knowledge spillovers to country i from country j. Knowledge spillovers are proportional to the square root of the geographical proximity measure under the assumption that distance becomes proportionally less important as an impediment to knowledge transmission the further away a country is from the knowledge center. DS_j is country j's R&D stock.

Finally, following Eaton and Kortum (1999), the Japanese patent applications are scaled down by a factor of 4.9. Okada (1992) and Tong and Frame (1994) find that the number of inventive claims per patent is approximately the same across countries, other than Japan, where Okada (1992) finds that the patents granted to foreigners hold, on average, 4.9 times as many inventive claims as patents granted to Japanese inventors.

Figure 1 shows the relationship between the initial level of financial development and the average number of ideas produced over the sample period. The scatter plots show a clear positive relationship between these variables, suggesting that financial development may play a positive role in spurring ideas production. Table 1 presents the summary statistics of the main regression variables. The large variation in the number of patent applications and financial development

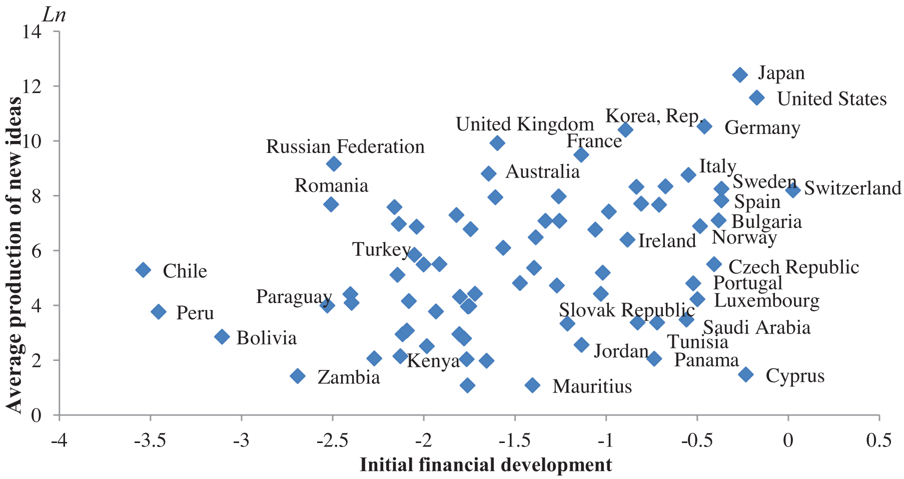

FIGURE 1 Ideas production and financial development
NOTES: Financial development is measured as credit to the private sector divided by GDP. The initial financial development period refers to 1965, and the average production of new ideas covers the period 1965–2009.

TABLE 1
Descriptive statistics, 1965–2009, 77 countries

Variable	Mean	Std. Dev.	Min	Max
Knowledge/Ideas production (*Ln*)	5.386	2.900	−2.303	12.859
Research intensity (*Ln*)	−5.014	1.237	−12.366	−3.017
Domestic stock of knowledge (*Ln*)	7.274	2.840	1.223	14.670
Financial development (*Ln*)	−0.937	0.790	−3.818	0.992
Years of schooling (*Ln*)	1.761	0.582	−1.317	2.572
Patent protection index (*Ln*)	0.839	0.511	−1.278	1.626
World stock of knowledge (*Ln*)	6.230	0.104	5.978	6.383
Distance to the frontier (*Ln*)	−0.074	0.952	−6.985	2.285
International knowledge spillovers (*Ln*)	23.029	1.065	20.725	25.077

NOTES: See the data appendix for the descriptions of variables and data sources.

across the sample is remarkable. For example, the U.S. had an average of 166,000 patent applications filed by domestic residents in 1990–2009, whereas Peru had only 39 applications. While the U.S. banks lent an average of 169% of GDP to the private sector over the period 1990–2009, Peru's banks lent only 19% of GDP over the same period.

5. Estimation results

5.1. Dynamic panel estimates

The estimated results for equation (1) are presented in table 2. All regressions satisfy the AR(1) and AR(2) tests for first- and second-order serial correlations, respectively. To conserve space, results for the AR(1) test are not presented. The regressions also pass Hansen's test of instrument validity. Column (1) reports a regression model that includes only research intensity, domestic stock of knowledge, patent protection, and financial development as explanatory variables. The coefficient of research intensity is statistically significant and has the expected sign. Although the coefficient of domestic stock of knowledge also has the right sign, its significance level is slightly less than the 5% decision rule used here. The coefficient of patent protection is negative and significant and is consistently so in all the other regressions, thus giving support to the predictions of the models of Helpman (1993) and Boldrin and Levine (2008), in which patent protection has a negative impact on ideas production because firms tend to produce old-technology products that take away resources from innovative activity and because the grant of a monopoly over a new invention may deter the development of innovations in the same family.

The coefficient of financial development is highly significant and has a short-run elasticity of 0.38 and a long-run elasticity of 0.96 (column (1)). Thus, the number of patent applications increases by almost 1% if the financial development indicator increases by the same amount. Suppose that the 20% of countries with the lowest degree of financial development, of 0.17, increases to the level of 0.99 that prevails in the 20% financially most sophisticated countries. This advance increases the number of patent applications by almost 559% in the long run, which is a massive increase and has important implications for those poor countries that seek to increase growth through innovations.

Adding educational attainment and the *K*-*Y* ratio to the model does not alter the key finding of financial development being important for innovations (columns (2)–(8)). The coefficient of educational attainment is insignificant in all regressions, suggesting that educated people do not further enhance innovative activity beyond those who are already employed in the R&D sector. The *K*-*Y* ratio is significant in the regression in the second column, but its level of significance is curtailed when other control variables are included in the regressions (columns (3)–(8)). From these results it can be concluded that the positive relationship between ideas production and financial development found in the first column is not due to the omission of educational attainment among the adult population and the *K*-*Y* ratio from the regressions.

The world stock of knowledge, international knowledge spillovers, and distance to the frontier are included jointly to capture external influences (columns (3)–(8)). Again the principal finding that financial development stimulates the production of new ideas remains unchanged. In most cases, these variables are insignificant, pointing towards knowledge transmission across borders as being

TABLE 2
System GMM (one- and two-step) estimates of extended ideas production function

	(1) Basic model	(2) Add control variables	(3) Add external variables [benchmark model]	(4) Alternative sample period: 1975–2009	(5) Alternative sample period: 1985–2009	(6) 5-year estimates	(7) Measure knowledge by patents granted	(8) Two-step system GMMs
Financial development	0.375***	0.534***	0.384***	0.320***	0.256**	0.327***	0.583***	0.375***
	(0.003)	(0.000)	(0.000)	(0.000)	(0.006)	(0.002)	(0.000)	(0.000)
Research intensity	0.297*	0.213***	0.175*	0.210***	0.309***	0.181**	0.278*	0.177*
	(0.048)	(0.005)	(0.025)	(0.002)	(0.000)	(0.009)	(0.044)	(0.029)
Stock of knowledge	0.237	0.326*	0.445**	0.356*	0.386**	0.760*	0.693***	0.438**
	(0.060)	(0.012)	(0.007)	(0.014)	(0.010)	(0.045)	(0.000)	(0.007)
Patent protection index	−0.357*	−0.271	−0.810***	−1.109***	−0.982***	−0.314	−1.021*	−0.797***
	(0.012)	(0.068)	(0.000)	(0.000)	(0.000)	(0.082)	(0.017)	(0.001)
Years of schooling		−0.261	−0.163	−0.057	−0.349	−0.010	0.619	−0.164
		(0.101)	(0.241)	(0.782)	(0.136)	(0.951)	(0.084)	(0.251)
Capital-output ratio		0.478***	0.240*	−0.016	−0.036	0.009	0.309	0.255*
		(0.003)	(0.042)	(0.879)	(0.849)	(0.952)	(0.222)	(0.027)
World stock of knowledge			2.264*	2.731*	2.210	0.231	0.409	2.012*
			(0.013)	(0.018)	(0.066)	(0.433)	(0.175)	(0.017)
Distance to the frontier			0.037	−0.212	0.209	−0.471*	0.188	0.036
			(0.086)	(0.424)	(0.420)	(0.043)	(0.141)	(0.120)
International R&D spillovers			−0.040	0.052	0.163	0.238	−0.208*	−0.027
			(0.625)	(0.589)	(0.227)	(0.073)	(0.036)	(0.713)
Lagged dependent variable	0.610***	0.567***	0.575***	0.620***	0.663***	−0.336	0.244*	0.576***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.198)	(0.015)	(0.000)
Countries	77	77	77	77	77	77	77	77
Observations	1556	1497	1497	1343	1069	432	1479	1497
AR(2) (*p*-value)	0.898	0.917	0.896	0.654	0.708	0.155	0.724	0.893
Hansen (*p*-value)	0.299	0.260	0.575	0.419	0.320	0.129	0.673	0.575

NOTES: Financial development is measured as the ratio of private credit to GDP. The dependent variable is the number of patent applications filed by domestic residents in columns (1) to (6) and (8), but is the number of patents granted to domestic residents in column (7). An intercept is included in the estimations but not reported. All estimations include time dummies. Robust standard errors are used. Except for column (8), which reports the two-step estimates, all estimates are based on the one-step approach. Figures in parentheses indicate *p*-values. ∗∗∗, ∗∗, and ∗ denote significance at the 0.5%, 1%, and 5% levels, respectively.

unimportant for ideas production. The possibility that the variables included in the estimations here are not adequately capturing the effects of spillovers cannot be ruled out. Nevertheless, the result is consistent with the fact that ideas production in the poorest countries in our sample has not significantly increased their patenting activity over the sample period despite the fact that the world knowledge stock has increased substantially during this period. However, we find some evidence of international knowledge spillovers in the cross-section regressions in section 5.2.2.

The estimates reported in column (3) are used as the baseline where all subsequent analyses are benchmarked against the results obtained therein. The regressions in columns (4) and (5) present estimates based on alternative sample periods to investigate whether there has been a structural break in the relationship between financial development and ideas production. It is essential to allow for different estimation periods, given that innovative activity has grown over time. Restricting the estimation time frame to more recent periods is also important, given the fact that R&D and patent data in these years are more reliable than those recorded in the more distant past. The estimation results using post-1975 (column (4)) and post-1985 (column (5)) data are very similar to the estimates covering the entire estimation period (column (3)). The only difference between these estimates is that the coefficient of financial development is slightly more economically and statistically significant in the regression over the whole sample period. The similarity of the results shows that a stable relationship prevails over time between innovations and their determinants, as stated in equation (1).

The regression in column (6) shows estimates in five-year intervals to smooth out the large fluctuations in patent applications over time. The results remain quite similar to the previous ones and the coefficient of financial development remains highly significant, suggesting that the degree of time aggregation is not a major issue for the estimates of ideas production functions. Furthermore, measuring innovations using patents granted to residents in the regression in column (7) yields qualitatively very similar results to the regressions in which patents applied for are used (note that patent stock in this regression is based on patents granted). The coefficient of financial development remains highly economically and statistically significant, thus demonstrating that financial development is equally influential for patents applied for and patents granted.

Thus far the system GMM estimates are obtained based on the one-step procedure. Column (8) reports the alternative two-step procedure in which a consistent estimate of the weighting matrix is used based on residuals obtained from the one-step estimate. Although modest efficiency improvements can be gained using the two-step method, the one-step procedure is preferred, since it yields more reliable estimates (Bond 2002). It is apparent that our results remain robust to this consideration. The sizes of the coefficients are remarkably similar to those obtained in the baseline model (column (3)).

An important implication of the results in table 2 is that financial development and R&D have permanent growth effects. Since the long-run coefficients of patent stock are close to one, subtraction of $\ln A$ from both sides of equation (1) yields the growth rate in knowledge stock as the dependent variable. From this it can be inferred that the growth of knowledge stock, and thus the productivity growth rate in the economy, depends positively on the level of financial development. Similarly, knowledge growth is found to be proportional to R&D intensity, noting that R&D is divided by income to allow for the fact that the effectiveness of R&D is diluted as the number of products proliferates (see Peretto and Smulders 2002; Ha and Howitt 2007). Thus, R&D has permanent growth effects and the economy will grow at a steady rate as long as R&D is kept to a fixed proportion of GDP.

5.2. Robustness checks

In this section, we perform several robustness checks by considering a few alternative indicators of financial development and whether the effects of financial development on innovation are influenced by non-linearity, technological convergence, financial crisis, the extent of patent protection and R&D intensity. Furthermore, we present estimates using external instruments for financial development.

5.2.1. Using different indicators of financial development

While the ratio of private credit to GDP is the most widely used indicator of financial development in the literature, it is useful to check whether the results are robust to alternative measures of financial development. To this end, several alternative measures of financial development are considered, including M3 / GDP, stock market shares traded / GDP, stock market capitalization / GDP, and stock market turnover ratio, where the latter is measured as stock market shares traded / stock market capitalization.

The results reported in table 3 do not reveal any significant changes to the principal results. Financial development remains an economically significant determinant for innovative activity. The coefficients of the stock market-based measures are lower than those that are related to banks' balance sheets because stock market activity has been increasing much more than credit and deposits over the period considered. Increasing activity in the stock markets has been particularly evident in the newly industrialized countries, where it was often almost impossible to raise capital in the stock markets before the 1980s. Stock markets in these countries have become much more liquid, thereby enabling more entrepreneurs to initiate innovative projects.

5.2.2. Legal origins as instruments for financial development

In this section, we present the IV-2SLS estimates as an alternative approach to deal with endogeneity. Cross-sectional estimations conducted using time-invariant instruments such as legal origins, regulatory quality, and social infrastructure are now well-established practice in the literature on financial development and growth. The areas are as follows: legal origins, regulatory quality,

TABLE 3
System GMM (one-step) estimates for alternative measures of financial development

	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
	(1) Financial development = liquid liabilities / GDP		(2) Financial development = stock market shares traded / GDP		(3) Financial development = stock market capitalization / GDP		(4) Financial development = stock market turnover ratio	
Financial development	0.541***	0.250*	0.148***	0.098***	0.244***	0.164*	0.146***	0.093***
	(0.001)	(0.046)	(0.000)	(0.000)	(0.001)	(0.011)	(0.000)	(0.000)
Research intensity	0.260***	0.245***	0.217*	0.201***	0.307***	0.273***	0.241***	0.224***
	(0.004)	(0.000)	(0.017)	(0.004)	(0.005)	(0.005)	(0.001)	(0.000)
Stock of knowledge	0.159	0.284*	0.265**	0.267*	0.182	0.313*	0.156	0.196*
	(0.246)	(0.024)	(0.007)	(0.014)	(0.139)	(0.034)	(0.079)	(0.044)
Patent protection index	−0.305*	−0.656***	−0.600***	−0.468*	−0.802***	−1.340***	−0.310***	−0.267
	(0.015)	(0.000)	(0.000)	(0.045)	(0.002)	(0.000)	(0.000)	(0.137)
Years of schooling		−0.052		−0.132		0.219		−0.221
		(0.651)		(0.484)		(0.377)		(0.202)
Capital-output ratio		0.143		−0.012		−0.229		0.002
		(0.218)		(0.931)		(0.267)		(0.985)
World stock of knowledge		2.036*		−0.602		3.379*		−0.849
		(0.023)		(0.547)		(0.031)		(0.313)
Distance to the frontier		0.038*		0.070		0.448		−0.004
		(0.033)		(0.690)		(0.164)		(0.974)
International R&D spillovers		−0.043		0.150		−0.041		0.213***
		(0.591)		(0.080)		(0.738)		(0.003)
Lagged dependent variable	0.699***	0.710***	0.638***	0.703***	0.711***	0.808***	0.753***	0.755***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Countries	77	77	77	77	77	77	77	77
Observations	1506	1450	1030	1030	1029	1029	1031	1031
AR(2) (p-value)	0.565	0.511	0.302	0.280	0.157	0.120	0.818	0.763
Hansen (p-value)	0.349	0.901	0.154	0.324	0.335	0.117	0.202	0.381

NOTES: The dependent variable is the number of patent applications by domestic residents. An intercept is included in the estimations but not reported. All estimations include time dummies. Robust standard errors are used. Figures in parentheses indicate p-values. $***$, $**$, and $*$ denote significance at the 0.5%, 1%, and 5% levels, respectively.

and social infrastructure. La Porta et al. (1997, 1998), Rajan and Zingales (1998), and Beck and Levine (2002) argue that the legal origin of a country (English, French, German, or Scandinavian) is influential for the legal and regulatory environment in financial transactions and use it as an instrument in their IV regressions to extract the exogenous component of financial development.[1]

The results are reported in the first column in table 4. The first-stage diagnostic checks (i.e., F-tests and R-squared values) of the two-stage least squares regressions suggest that the instruments are significantly related to the financial development indicator, therefore satisfying the requirement that the excluded exogenous variables are highly relevant. Moreover, tests of over-identification (i.e., Sargan's tests) suggest that the instruments are valid in all cases. In the second-stage regressions, our main results continue to hold in the sense that coefficients of research intensity, knowledge stock, and, particularly, financial development are all significant determinants of innovative activity. This finding suggests that the results are robust to the use of external instruments. It also implies that the relationship between finance and innovation is not sensitive to whether the identifying variation is in the time or cross-sectional dimension.

The results remain almost unaltered when the rule of law is used as an additional instrument in the regression in the second column in table 4, where the rule of law measures the perceptions of the degree to which people have confidence in and abide by the rules of society (see Kaufmann, Kraay, and Mastruzzi 2010). The results are also robust to the use of the legal origins and regulatory quality as instruments (column (3)), where regulatory quality captures perceptions of the ability of the government to formulate appropriate policies to promote private sector development (see Kaufmann et al. 2010). Similarly, results hold when the legal origins and overall institutional quality are used as instruments (column (4)), where the overall institutional quality reflects the simple average of all six worldwide governance indicators of Kaufmann et al. (2010), including voice and accountability, political stability, control for corruption and government effectiveness, in addition to the rule of law and regulatory quality used above.

The results are also robust to the use of social infrastructure along with legal origins as instruments (column (5)), where social infrastructure, as suggested by Hall and Jones (1999), is measured as the average of Sachs and Warner's (1995) trade openness index during the period 1950–1994 and Knack and Keefer's (1995) index of country risk to international investors over the period 1986–1995. Finally, the results remain intact when legal origins and proportion of English-speaking population are used as instruments (column (6)). Importantly, the coefficients of financial development are remarkably stable across equations, suggesting that our results are not driven by the use of alternative sets of external instruments.

1 Rajan and Zingales (1998) and Beck and Levine (2002) also use religious composition of countries as instruments for financial development in their growth regressions. Following their lead, we included religious variables in our first-round regressions; however, we omitted them, since they were insignificant.

TABLE 4
Cross-sectional estimates

	(1)	(2)	(3)	(4)	(5)	(6)
	IV-2LS (IV = legal origins)	IV-2LS (IV = legal origins + rule of law)	IV-2LS (IV = legal origins + regulatory quality)	IV-2LS (IV = legal origins + overall institutional quality)	IV-2LS (IV = legal origins + social infrastructure)	IV-2LS (IV = legal origins + English speaking populations)
Initial financial development	0.541++ (0.034)	0.556++ (0.027)	0.449+ (0.050)	0.433++ (0.048)	0.580++ (0.022)	0.540++ (0.035)
Research intensity	0.609++ (0.019)	0.606++ (0.021)	0.622++ (0.011)	0.625+++ (0.009)	0.603++ (0.024)	0.609++ (0.019)
Initial stock of knowledge	0.538+++ (0.000)	0.536+++ (0.000)	0.548+++ (0.000)	0.550+++ (0.000)	0.533+++ (0.000)	0.538+++ (0.000)
Initial patent protection index	0.144 (0.723)	0.140 (0.733)	0.171 (0.653)	0.176 (0.641)	0.133 (0.750)	0.145 (0.722)
Initial years of schooling	0.402 (0.173)	0.406 (0.172)	0.374 (0.175)	0.369 (0.175)	0.413 (0.171)	0.401 (0.173)
Initial capital-output ratio	−0.134 (0.361)	−0.134 (0.365)	−0.131 (0.340)	−0.131 (0.337)	−0.135 (0.370)	−0.134 (0.361)
Initial international R&D spillovers	1.593++ (0.011)	1.614+++ (0.010)	1.456++ (0.011)	1.432++ (0.011)	1.649+++ (0.009)	1.591++ (0.011)
Constant	−28.041++ (0.029)	−28.460++ (0.027)	−25.329++ (0.033)	−24.864++ (0.032)	−29.163++ (0.026)	−27.996++ (0.029)
Observations	77	77	77	77	77	77
R-squared	0.727	0.721	0.760	0.765	0.711	0.727
First-stage F-test (*p*-val)	0.015	0.027	0.022	0.014	0.024	0.034
First-stage R-squared	0.377	0.383	0.388	0.397	0.385	0.377
Sargan's test (*p*-val)	0.433	0.638	0.307	0.341	0.588	0.469

NOTES: The dependent variable is the average number of patent applications filed by domestic residents over the sample period 1965–2009. Except for research intensity, which is averaged over the entire sample period 1965–2009, all other regressors are measured in their first available years, which turn out to be 1965 in most cases. Climate classification, landlockedness, and island dummies are included as additional control variables in the estimations. 'Legal origins' are dummies reflecting whether a country has English, French, German, or Scandinavian legal origin. Figures in parentheses are *p*-values. +++, ++, and + denote significance at the 1%, 5%, and 10% levels, respectively.

Overall, the results in this section provide further support to the evidence obtained in the previous section. Our findings are consistent with the microeconomic study of Gorodnichenko and Schnitzer (2012). Using direct measures of innovation and financial constraints from Business Environment and Enterprise Performance Surveys, which cover a broad array of sectors and countries in Eastern Europe and the Commonwealth of Independent States, and shocks to firms' cash flows and internal funds as instruments for financial constraints, they demonstrate that financial underdevelopment constrains firms' ability to innovate. Hence, their results imply that financial development has a causal positive effect on innovative production. The results in this sub-section are also consistent with the results in table 2, where educational attainment and the K-Y ratio were included in the estimates to allow for the possibility that these two variables simultaneously impact innovations and financial development.

5.2.3. Non-linearity and interaction terms

In this sub-section we consider the following factors that may have potential implications for how ideas production responds to changes in financial development: (1) non-linearity, (2) technological convergence facilitated by financial development, and (3) the interaction between financial development, on the one hand, and financial crisis, patent protection, and research intensity on the other hand.

Several authors argue that the relationship between finance and growth may be non-linear (Greenwood and Jovanovic 1990; Rioja and Valev 2004). This suggests that the relationship between financial development and ideas production may also resemble an inverted U-curve; that is, the production of new ideas initially rises with the level of financial development, and then falls after a certain threshold level of financial development is reached. To test this hypothesis, a quadratic term for financial development is included in the specification (first column in table 5). However, the quadratic term is not significant. Thus, the null hypothesis of a monotonic relationship between financial development and ideas production cannot be rejected.

Financial development may facilitate the adoption of technologies developed at the frontier through providing mechanisms to mitigate risks associated with the use of these technologies. Thus, financial underdevelopment may prevent non-frontier countries benefiting from technology transfer. In the model developed by Aghion, Howitt, and Mayer-Foulkes (2005), it is shown that, after the level of financial development crosses a certain threshold, a country will converge to the growth rate of the global technology leader. This hypothesis is tested by adding an interaction term between financial development and distance to the frontier (second column in table 5). The coefficient of the interaction term is found to be statistically significant, providing no support for the above thesis.

An implication of financial crisis is that rapid credit expansion can be harmful for growth because it brings instability to the financial system and, as a result, may also adversely affect ideas production. Thus, a highly developed financial system may be harmful for ideas production during financial crises. To deal with this possibility, an interaction term between financial crisis and financial development and a financial crisis variable are added to the regression in the third column of table 5, where the financial crisis dummies of Reinhart and Rogoff (2009) are used. These dummy variables take the value of one when a financial crisis has taken place and zero otherwise. The coefficient of the interaction term is insignificant. However, this does not necessarily imply that innovative activity is immune to

TABLE 5
Non-linear and interactive effects of financial development (one-step system GMM estimates)

	(1)	(2)	(3)	(4)	(5)
	Var. X = financial develop-ment	*Var. X* = distance to the frontier	*Var. X* = financial crisis	*Var. X* = Patent protection index	*Var. X* = research intensity
Financial development	0.364**	0.401***	0.378***	0.344*	0.514*
	(0.008)	(0.000)	(0.000)	(0.042)	(0.040)
Research intensity	0.192*	0.145*	0.157*	0.167*	0.222**
	(0.011)	(0.046)	(0.035)	(0.030)	(0.005)
Stock of knowledge	0.373***	0.429***	0.439**	0.458**	0.338***
	(0.002)	(0.002)	(0.007)	(0.005)	(0.004)
Patent protection index	−0.824***	−0.789***	−0.810***	−0.983***	−0.389*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.019)
Years of schooling	−0.027	−0.142	−0.144	−0.145	−0.263*
	(0.789)	(0.227)	(0.288)	(0.313)	(0.040)
Capital-output ratio	0.247*	0.239*	0.235*	0.191	0.312*
	(0.014)	(0.044)	(0.038)	(0.079)	(0.034)
World stock of knowledge	1.894*	1.989*	2.219*	2.226*	0.984
	(0.026)	(0.021)	(0.014)	(0.014)	(0.235)
Distance to the frontier	0.032	−0.074	0.040	0.017	0.082
	(0.162)	(0.476)	(0.066)	(0.471)	(0.140)
International R&D spillovers	−0.020	−0.010	−0.035	0.015	−0.001
	(0.740)	(0.870)	(0.662)	(0.856)	(0.993)
Financial development × *Var. X*	0.104	0.102	0.011	−0.074	0.083
	(0.097)	(0.316)	(0.843)	(0.593)	(0.269)
Financial crisis			−0.069		
			(0.317)		
Lagged dependent variable	0.634***	0.581***	0.588***	0.604***	0.625***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Countries	77	77	77	77	77
Observations	1497	1497	1497	1497	1497
AR(2) (*p*-value)	0.947	0.910	0.901	0.913	0.851
Hansen (*p*-value)	0.595	0.974	0.814	0.645	0.431

NOTES: Financial development is measured as the ratio of private credit to GDP. The dependent variable is the number of patent applications by domestic residents. An intercept is included in the estimations but not reported. All estimations include time dummies. Robust standard errors are used. Figures in the parentheses indicate *p*-values. ***, ** and * denote significance at the 0.5%, 1% and 5% levels, respectively.

financial crises, but rather that the contraction of credit in the wake of a financial crisis reduces ideas production through the reduction in the availability of credit.

Finally, consider the regression in column (4), in which financial development is allowed to interact with intellectual property right protection, as it is conceivable that the innovation effects of financial system sophistication is stronger in the presence of a strong intellectual property rights protection framework. However, there is no evidence to suggest that the strength of the effect of financial development on inventions is contingent on intellectual property rights. Finally, the results in column (5) show that the interaction between financial development and R&D intensity does not promote innovation.

6. Venture capital and IPOs

Venture capital investment and venture capital-backed IPOs[2] play potentially important roles for innovation, since they fund predominantly new and young but innovative firms. Rajan (1992), for example, argues that powerful banks frequently stifle innovations by protecting incumbents and extracting informational rents. By acquiring inside information about the firm, banks can extract informational rents and a large share of the profits from the firm, which reduces its incentives to invest in long-run innovative projects. Risk capital, consequently, becomes an important alternative source of capital for funding risky and innovative projects.

However, there are also reasons to believe that the relationship between risk capital and a bank's core lending activity is complementary. Hellmann (2002) shows in a theoretical model that banks can act strategically by seeking complementarities between their venture capital investments and other core lending activities. Such a theoretical proposition is supported by the empirical evidence of Hellmann, Lindsey, and Puri (2008), who find that a bank which provides venture capital funds to a startup firm is more likely to make loans to that firm subsequently, thus effectively using venture capital investments as a means to build lending relationships. Hence, venture capital captures a different dimension of financial development, which may have a separate influence on innovative production.

Development of a risk capital market, however, crucially depends on the availability of an effective exit mechanism since venture capitalists face substantial risks of losing their investments. IPOs provide an attractive option to liquidate a portfolio investment, since a firm that eventually goes public typically yields a much higher return that those that do not (Jeng and Wells 2000). In fact, Cockburn and MacGarvie (2009) and Puri and Zarutskie (2012) find that venture capital-backed firms are more likely to succeed in innovations and to go public than those not financed by venture capital investments.

Given that venture capital-backed IPOs are closely associated with venture capital investment, the ratio of IPOs to GDP is used as a proxy for the depth of the risk capital market in the regressions in addition to the ratio of venture capital and GDP. Venture capital investment includes seeds, start-up and expansion funding, whereas IPOs capture the proceeds raised from the offerings. In the regressions we also include the ratio of venture capital stock to GDP as a regressor instead of venture capital flow, as it is more consistent with the other indicators of financial

2 We are grateful to Werner Antweiler for suggesting venture capital and IPOs as potentially important factors in ideas production.

development such as the private credit / GDP ratio and M3 / GDP ratio, in which the numerators are stock variables. Venture capital stock is computed using the perpetual inventory method with a depreciation rate of 15% and the initial value is computed using a method similar to that used for patent stock. The data are available over a shorter period and for fewer countries than the earlier regressions. The number of countries is 35 for venture capital and 61 for IPOs. Overall the number of observations is 498 in the venture capital regressions and 698 for the IPO regressions.

The results reported in columns (1) to (3) in table 6 provide support to the notion that the availability of risk capital is pivotal for ideas production. In particular, the coefficients of both venture capital and IPOs are statistically highly significant and remain so even when the ratio of private credit to GDP is controlled for in the regressions (columns (4) to (6)). This finding remains unchanged when M3 / GPP or any other stock market-based measure of financial development considered previously is used instead (the results are not shown).

When we compare the economic significance of venture capital, IPOs, and financial development, the interpretation depends on the question asked. Using the regression results in column (4), we find that the long-run elasticities of the depth of venture capital markets and financial systems are 0.159 and 1.225, respectively. This suggests that, while risk capital complements traditional bank lending, consistent with the argument of Hellmann (2002) and Hellmann, Lindsey, and Mastruzzi (2008), the results point to the more important role of banks in supplying credit to fund innovative projects where a 1% increase in credit results in a more than 1% increase in innovative production. However, this does not necessarily imply that, in practice, bank credit is more influential than venture capital for ideas production, because the relative magnitudes of the coefficients of venture capital and bank credit reflect the fact that the volume of bank credit is much higher than that of venture capital. Specifically, since the credit-GDP ratio is on average 71% in the sample used in the regressions in table 6, while the venture capital-GDP ratio is only 0.24%, the coefficient of the credit-GDP ratio will correspondingly be higher than the coefficient of venture capital-GDP ratio. This raises the question of whether it is appropriate to compare the relative changes in venture capital and bank credit in general. Comparing absolute changes may provide better insights into their relative importance.

Suppose venture capital and bank credit are increased by the same dollar amount. For simplicity, we assume that the ratio of venture capital to GDP is doubled. In this case, ideas production will increase by 15.9% in the long run using the results in column (4). A corresponding 0.24% increase in the credit-GDP ratio, which corresponds to the same absolute increase in the value of venture capital, will increase the number of innovations only by approximately 0.41%, again using the results in column (4). Stated differently, the impact on innovative activity of a similar absolute increase in venture capital has 39 times as strong an impact on innovations as a corresponding increase in credit to the private sector! This result is not only intuitive, but is also consistent with the finding of

TABLE 6
Venture capital, initial public offerings and ideas production (one-step system GMM estimates)

	(1) [*VC* = venture capital investment/ GDP]	(2) [*VC* = venture capital stock/ GDP]	(3) [*IPO* = initial public offerings/ GDP]	(4) [*VC* = venture capital investment/ GDP]	(5) [*VC* = venture capital stock/ GDP]	(6) [*IPO* = initial public offerings/ GDP]
VC or *IPO*	0.020++	0.075+++	0.026+++	0.031+++	0.059+++	0.029+++
	(0.048)	(0.000)	(0.001)	(0.002)	(0.001)	(0.002)
Financial development				0.239+++	0.216+++	0.303+++
				(0.000)	(0.000)	(0.004)
Research intensity	0.142+++	0.144+++	0.338+++	0.079++	0.078++	0.277+++
	(0.000)	(0.000)	(0.002)	(0.039)	(0.014)	(0.010)
Stock of knowledge	0.106+++	0.113+++	0.560+++	0.164+++	0.173+++	0.319++
	(0.001)	(0.001)	(0.002)	(0.000)	(0.000)	(0.021)
Patent protection index	−0.256+	0.040	−0.109	−0.141+	−0.145+	−0.365
	(0.083)	(0.578)	(0.647)	(0.058)	(0.054)	(0.163)
Years of schooling	−0.331+++	−0.524+++	−0.673++	−0.358+++	−0.383+++	−0.661++
	(0.000)	(0.000)	(0.011)	(0.000)	(0.000)	(0.017)
Capital-output ratio	−0.114	−0.173	0.109	−0.036	−0.011	0.085
	(0.374)	(0.103)	(0.157)	(0.793)	(0.914)	(0.718)
World stock of knowledge	−0.598	−0.624	−1.051	−0.626	−0.374	−0.419
	(0.174)	(0.108)	(0.217)	(0.101)	(0.338)	(0.650)
Distance to the frontier	−0.013	0.042+	−0.050	−0.011	0.008	−0.071
	(0.575)	(0.086)	(0.298)	(0.667)	(0.745)	(0.111)
International R&D spillovers	0.159+++	0.023	0.179++	0.066	−0.006	0.116
	(0.000)	(0.672)	(0.033)	(0.143)	(0.907)	(0.227)
Lagged dependent variable	0.878+++	0.871+++	0.379++	0.805+++	0.803+++	0.608+++
	(0.000)	(0.000)	(0.036)	(0.000)	(0.000)	(0.000)
Countries	35	35	61	35	35	61
Observations	498	498	698	488	488	687
AR(2) (*p*-value)	0.119	0.132	0.831	0.113	0.115	0.851

NOTES: Financial development is measured as the ratio of private credit to GDP. The dependent variable is the number of patent applications by domestic residents. An intercept is included in the estimations but is not reported. All estimations include time dummies. Figures in parentheses indicate *p*-values. +++, ++, and + denote significance at the 1%, 5%, and 10% levels, respectively.

Colombo and Grill (2007), who discover that high-tech start-up companies are severely credit constrained and, therefore, that venture capital is vital for their innovative activity.

Thus, these results suggest that the inclusion of venture capital and IPOs captures an additional dimension of financial development that is not already captured by the credit-GDP ratio – a dimension that has probably not been considered before in the literature on financial development and growth. Furthermore, in results not shown, the finding that financial development has a positive effect on innovation is not very sensitive to the exclusion of IPOs or venture capital variables. Surprisingly, these results suggest that the venture capital or IPO measures and the financial development variables contain little overlapping information. Finally, using the venture capital stock based on a 50% depreciation rate, as opposed to a 15% depreciation rate in the regressions, gives results that are as statistically significant, although the coefficients of venture capital stock ratios are slightly larger.

Overall the results in this section show that venture capital and IPOs enhance innovations significantly more than private credit, supporting the view that banks have a conservative bias in their lending policies. The results that venture capital is influential for innovative activity are consistent with the micro evidence of Kortum and Lerner (2000), who examine the impact of venture capital on technological innovation. Using data across industries over a three-decade period, they find that venture capital is associated with a substantial increase in patenting activity, where it funded about 14% of the U.S.'s innovative activity in 1998. Our findings are also in line with Popov and Roosenboom (2012), who find that venture capital increases patenting activity in the European manufacturing industries.

7. Concluding remarks

Although the literature has almost consistently shown that financial development plays a positive role for economic growth, its effect on innovations is less well known. Recent developments in the theories of endogenous growth have highlighted its importance in the process of knowledge creation. The models of de la Fuente and Marín (1996), Blackburn and Hung (1998), Morales (2003), Aghion, Howitt, and Foulkes (2005), Aghion and Howitt (2009) and Buera, Kaboski, and Shin (2011) consistently point to the important functions of financial system development in spurring innovative activity.

Using panel data for 77 countries over the period 1965–2009, this paper has estimated an extended ideas production function to allow for the influence of private credit and risk capital on innovations. Both variables are found to be economically and statistically highly influential for innovations. The results also indicate that ideas production is significantly and positively influenced by research intensity and the stock of knowledge. Furthermore, the long-run coefficient of the stock of knowledge is close to one, implying that both financial development and research intensity have persistent or even permanent growth effects. Strengthening the patent protection framework, however, tends to impede the discovery of new knowledge. These results are robust to alternative sample periods, different measures of financial development, the allowance of non-linearity, a country's ability to absorb foreign technology through risk pooling, financial crisis, and the interactive effect of financial development and research intensity as well as patent protection.

Special attention has been given to venture capital and IPOs as additional indicators of financial development because risk capital is predominantly allocated to new and innovative firms. From this perspective venture capital and the associated IPOs should potentially be more influential for innovative activity than conventional measures of financial development such as the ratio of private credit to GDP. The results show that venture capital and IPOs as a proportion of GDP are highly significant determinants of innovations, and their economic and statistical significance is not significantly affected by the inclusion of financial development in the regressions. These results suggest that venture capital and credit to the private sector contain non-overlapping information on the influence of financial development on innovations.

Credit to the private sector as well as venture capital and IPOs were also found to be economically highly significant determinants of innovations. We found that the number of patent applications increases by almost 559% in the long run if the 20% financially least developed countries achieved the same level of financial development as the 20% financially most sophisticated countries. Venture capital was found to be even more influential for innovative activity. If venture capital and credit to the private sector were increased by the same amount, the impact on innovative activity would be 39 times more for venture capital than for private credit, reinforcing the importance of venture capital for innovative activity.

The results of the paper have important economic implications. First, financial development fosters growth through ideas production and, therefore, innovative activity is an important channel through which financial development affects growth. Second, our findings indicate that financial development permanently increases patenting activity because of scale effects in ideas production, thus giving a theoretical rationale as to why empirical studies generally find that there are permanent growth effects associated with financial development. This finding is important, since most of the literature on financial development has focused on its effect on capital deepening, which does not create permanent growth effects under the standard assumption of diminishing returns to capital. Beyond some point the marginal return of adding new capital will be smaller than its marginal cost and growth would stop at this point without further productivity advances. Third, the finding that venture capital, as a spin-off of financial development, enhances innovative activity suggests that the provision of capital to risky, but innovative, projects has high social returns. Since we found venture capital to be markedly more important for innovative activity than the provision of credit in general, it is not only the quantity of financial development that is important for innovative activity but also its composition and the changes in its composition.

The policy implications of the results of this paper are that many developing countries could promote innovative activity, and thus growth, through deepening the financial system, particularly through the promotion of the venture capital market. In many poor countries, the financial system is so underdeveloped that even small steps such as the formation of a capital market for bonds and even risk capital would be a major step forward in the creation of an innovative environment. The results in this paper also show that, even if they have a quite well developed financial system, the most advanced countries can improve the composition of their financial system through incentives that promote venture capital investment. These incentives could include, for example, tax brackets, government guarantees, subsidies, and assistance to new firms.

Data appendix

TABLE A1
Descriptions of variables and data sources

Variable	Definition	Source
Knowledge / ideas production	This variable is measured as the number of patents filed by domestic residents. The number of patents granted to domestic residents is also used to check the sensitivity of the results. The stock knowledge (A_t) is constructed using the perpetual inventory method with a decay rate (δ) of 15%. The initial level of knowledge stock in 1965 is estimated as $A_0 = \dot{A}_0/(\delta + g)$, where $\dot{A}_0$ is the first available observation on the number of patents filed by domestic residents and g is the average growth in $\dot{A}$ over the period considered.	World Intellectual Property Organization (http://www.wipo.int/ipstats/en/statistics/patents/)
Research intensity	Total R&D expenditure divided by GDP.	China Statistical Yearbook (for China), S&T Statistics Data Book (for India), and Main Science and Technology Indicators (for OECD countries), and UNESCO Statistical Yearbook (for other countries)
Domestic stock of knowledge	The initial knowledge stock is estimated as the ratio of initial number of patents applied for by domestic residents divided by the sum of the depreciation rate (assumed to be 15%) and the average growth in the number of patents filed by domestic residents over the entire period considered.	World Intellectual Property Organization (http://www.wipo.int/ipstats/en/statistics/patents/)
Financial development	This variable is equal to the ratio of private credit to GDP. The following alternative measures are also considered as robustness checks for the results: M3 / GDP, stock market shares traded / GDP, stock market capitalization / GDP and stock market turnover ratio.	Financial Structure Dataset, World Bank (revised in November 2010)

(*Continued*)

TABLE A1
(*Continued*)

Variable	Definition	Source
Years of schooling	Average years of schooling among adults above 25 years old.	Barro and Lee (2010)
Patent protection index	The index covers these dimensions: (1) patentability of various kinds of inventions; (2) membership in international patent arrangements; (3) provisions for loss protection; (4) enforcement mechanisms; and (5) duration of the patent term. Each dimension is assigned a value ranging from zero to one. The unweighted sum of these five values provides an indication of the overall level of intellectual property rights protection, with higher values reflecting greater levels of protection.	Park (2008)
World stock of knowledge	This variable reflects the sum of all patent stocks across the world, excluding the country of interest.	World Intellectual Property Organization (http://www.wipo.int/ipstats/en/statistics/patents/) and authors' own calculations.
Distance to the frontier	Distance to the frontier is measured by the ratio of the technology leader's patent stock to the patent stock of the country under consideration. The frontier is determined by the country having the highest accumulated patents in the world at a particular time.	World Intellectual Property Organization (http://www.wipo.int/ipstats/en/statistics/patents/).
International knowledge spillovers	Knowledge spillovers through the channel of geographical proximity between trade partners are measured using an algorithm similar to that of Coe and Helpman (1995), except that the weights are captured by the square root of the inverse relative geographical distance.	R&D data are obtained using the above sources. Distances between cities are constructed using the *Haversine* formula.
Financial crisis	A dummy variable reflecting the occurrence of banking crises (1 = crisis; 0 = none).	Reinhart and Rogoff (2009, 2011)
Legal origin	The legal origin (English, French, Socialist, German or Scandinavian) of the company law or commercial code in each country.	La Porta, Lopez-de-Silanes, and Shleifer (2008)
Rule of law	An index that measures the perceptions of the degree to which people have confidence in and abide by the rules of society.	Kaufmann, Kraay, and Mastruzzi (2010)
Regulatory quality	A measure that captures perceptions of the ability of the government to formulate appropriate policies to promote private sector development.	Kaufmann, Kraay, and Mastruzzi (2010)

(*Continued*)

TABLE A1
(*Continued*)

Variable	Definition	Source
Overall quality of institutions	This is the simple average of six key dimensions of institutional development, which is constructed using the World Bank's Worldwide Governance Indicators. The indicators include voice and accountability, political stability, control for corruption, government effectiveness, rule of law, and regulatory quality.	Kaufmann, Kraay, and Mastruzzi (2010)
Social infrastructure	This is computed as the average of Sachs and Warner's (1995) trade openness index during the period 1950–1994 and Knack and Keefer's (1995) index of country risk to international investors over the period 1986–1995.	Hall and Jones (1999)
English-speaking population	This is the fraction of the population speaking English.	Hall and Jones (1999)
Venture capital	Total venture capital investment is defined as the sum of seed, start-up, and expansion investment. Venture capital stock is computed using the perpetual inventory method with a depreciation rate of 15% and the initial value is computed using a method similar to that used for knowledge stock described above.	Asian Venture Capital Journal (for Asian countries), Canada's Venture Capital and Private Equity Association (for Canada), European Private Equity and Venture Capital Association (for European countries) and National Venture Capital Association (for the U.S.).
IPO	This variable captures the proceeds or the total amount raised from an initial public offering relative to GDP.	Thomson Financial SDC Platinum Global New Issues database

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